

Avaluació i mitigació de les captures accidentals d'ocells marins en la pesca artesanal de palangre del Mediterrani

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TESI DOCTORAL

2017

Les captures accidentals d'ocells marins que ocorren en els palangrers de l'oest del Mediterrani estan tenint un greu impacte sobre les poblacions de les tres baldrigues endèmiques de la conca: cendrosa (*Calonectris diomedea*), balear (*Puffinus mauretanicus*) i mediterrània (*P. yelkouan*). El seu comportament gregari i gran capacitat de busseig fa que aquestes espècies siguin més susceptibles a ser capturades pels palangres, podent implicar fins i tot la mort de desenes o centenars d'exemplars en una única calada. Encara que es tracta d'esdeveniments que ocorren ocasionalment, el nivell de mortalitat provocat pel conjunt de la flota pot arribar a ser insostenible per a la viabilitat d'aquestes espècies, especialment per a la críticament amenaçada baldriga balear. Tot i així, els ocells no són els únics que es veuen perjudicats, ja que aquestes captures involuntàries també poden suposar molèsties i pèrdues importants per als pescadors. Per evitar la mortalitat d'ocells als palangres, en alguns indrets del món ja s'han implementat amb èxit diversos mètodes de mitigació, els quals estan beneficiant tant als ocells com als pescadors. En canvi, al Mediterrani, la informació disponible sobre aquesta problemàtica és escassa i fragmentada, i encara no es fa servir cap tipus de mesura per reduir les captures d'ocells. La present tesi aporta informació sobre les característiques dels palangrers demersals que operen a l'oest del Mediterrani, així com la magnitud, l'extensió i els factors que modulen les captures accidentals. Aquest coneixement ha servit no solament per entendre el fenomen i el seu impacte, sinó també per seleccionar i dissenyar els mètodes de mitigació més adients per a la flota. A més, aquesta tesi inclou l'assai de diversos mètodes per reduir les captures d'ocells, el qual ha servit per identificar l'estratègia de mitigació més efectiva per minimitzar aquest impacte.

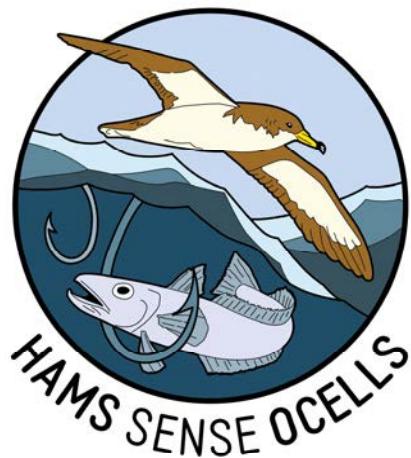


Tesi Doctoral · Verònica Cortés Serra

2017

AVALUACIÓ I MITIGACIÓ DE LES CAPTURES
ACCIDENTALS D'OCELLS MARINS EN LA PESCA
ARTESANAL DE PALANGRE DEL
MEDITERRANI

Verònica Cortés Serra



Tesi doctoral
Llançà, Novembre 2017

Il·lustració portada: Pep Cantó
Il·lustracions: Toni Mulet , Martí Franch
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Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals
Programa de Doctorat en Biodiversitat

Avaluació i mitigació de les captures accidentals d'ocells marins en la pesca artesanal de palangre del Mediterrani

Assessing and mitigating seabird bycatch in the artisanal longline fisheries of the Mediterranean

*Memòria presentada per
VERÒNICA CORTÉS SERRA
per optar al grau de doctora per la Universitat de Barcelona*

Barcelona, 2017

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*A la meua família,
pel seu suport incondicional.*

*Als pescadors,
per tot el que he après de vosaltres.*

“Ave del mar, espuma migratoria, ala del Sur, del Norte, ala de ola, racimo desplegado por el vuelo, multiplicado corazón hambriento, llegarás, ave grande, a desgranar el collar de los huevos delicados que empolla el viento y nutren las arenas hasta que un nuevo vuelo multiplica otra vez vida, muerte, desarrollo, gritos mojados, caluroso estiércol, y otra vez a nacer, a partir, lejos del páramo y hacia otro páramo”

Arte de pájaros, PABLO NERUDA

AGRAÏMENTS

Han sigut un grapat d'anys de dedicació intensa i quasi exclusiva a la tesi, i és per això que el final d'este llarg camí em fa sentir una gran emoció i satisfacció. Fent una retrospectiva dels darrers anys, m'adone de tot el que he aconseguit i m'ha aportat l'experiència d'esta tesi, tant a nivell professional com personal, i tot això gràcies a un muntó de gent que ho ha fet possible!

Primer de tot, vull agrair al **Jacob**, per donar-me l'oportunitat d'introduir-me en esta aventura de palangres i ocells marins, també per la supervisió d'esta tesi i pel que he que après de la teua part. Després, a tots els pescadors de Catalunya, Balears i País Valencià que han col·laborat al nostre projecte i/o ens han permès pujar a les seues barques de manera totalment desinteressada; moltes gràcies als patrons i mariners de les barques **Adan y Eva**, **Cayetano Ruso**, **Cona C.B.**, **Costa Brava Nord**, **Cruyff**, **Curniola**, **Deianec**, **Na Foguera**, **Guilanova**, **Llebex**, **Helsa**, **Joana**, **Kranki**, **Larry**, **Es Llamp**, **La Maca**, **Mari Montse**, **Mar Endins**, **La Mina**, **Moro**, **El Niño**, **Panollo II**, **La Palandriu**, **Pare Joan**, **Peret**, **Projillo**, **Ramón**, **Saoro**, **Skipi II**, **El Sopalmero**, **Vigilante** i **Zaramar**. La contribució de tots ells ha sigut fonamental per realitzar esta tesi, però no puc evitar fer una menció especial als que han sigut els meus mestres; amb els que he compartit moltes hores de mar i m'han transmès els seus coneixements, a més de fer-me partícip de la seu forma de vida. Especialment vull agrair al **Jaume i Josep** (Cona C.B), amb els que em vaig iniciar; jo i la majoria dels estudiants i col·laboradors que han participat recollint dades. Des de fa una desena d'anys que col·laboren amb la Universitat, i en el meu cas particular, sempre he comptat amb el seu suport i han sigut els meus assessors en les proves de mitigació. La seu ajuda i paciència, ha estat essencial, també el bon humor i els ranxos dels divendres! En aquest sentit, també he d'agrair la contribució a la meua formació pesquera i els bons moments viscuts a la mar al **Fermín** de la barca **Kranki**, als germans **Quim**, **Jordi**, **Carlos** i el seu pare **Quim** de la **Mari Montse**, **Jordi** de la **Salfer**, **Antonio** de la **Mar Endins** (especialment els seus consells per a les proves de la línia espantaocells), **Jaume** de la **Costa Brava Nord**, **Guillermo** de la **Zaramar** i **Marc** de la **Cruyff**.

Per altra banda, he de mencionar també als estudiants de grau i col·laboradors que van acceptar el repte d'alçar-se a hores intempestives i aguantar les dures i llargues jornades de mar; alguns d'ells inclús es van atrevir a obrir alguns cadàvers de baldrigues! Moltes gràcies a **David**, **Lluïsa**, **Pau**, **Manel**, **Neus**, **Adriana**, **Èric**, **Oriol**, **Toni** i **Blanca**, sense la vostra participació haguera sigut impossible aconseguir el gran volum de dades que he disposat per a esta tesi! A més de la seu motivació per embarcar-se, vull agrair-li també al Toni Mulet els dibuixets tan xulos que ens ha fet per als projectes i articles. No puc oblidar-me, a més, dels disseccionadors de les baldrigues: **Jessica**, **Andrea** (Rodríguez) i **Jordi**, gràcies per tota la feina feta!

Però, no tot el treball de camp va ocórrer dins de les barques....també em va tocar trepar pels penya-segats marins on es trobaven els caus de les baldrigues cendroses. La primera persona que em va ensenyar com caminar amb estil pels penya-segats volcànics, i em va demostrar que les baldrigues no s'agarren com els passeriformes (com jo estava acostumada...), va ser la **Teresa**. Te estoy muy agradecida, no solo porque evité muchas caídas y picadas, sino también por estar siempre dispuesta a ayudarme, escucharme, darme consejos, compartir momentos, preocuparte por mi...la lista de motivos sería bien larga! Eres una gran persona, i t'estime moltíssim! Per al treball en les colònies, també va ser indispensable l'ajuda i experiència del **Jose** (de los Reyes), que em va ensenyar com col·locar GPSs a les baldrigues i prendre mostres. Pero no solo eso, como compañero de batallas veterano, agradezco haber contado con tu opinión y apoyo. Continuant amb la resta de "minions", he d'agrair també el suport que he rebut de totes elles: la **Zuzana**, por escucharme cuando lo he necesitado, y los viajes/congresos que compartim; la **Laura** (Stefan), por alegrarnos el despacho con tu risa contagiosa; la **Fernanda**, por tu naturalidad y buena fe, los momentos compartidos han sido muy agradables; la **Vir**, pel teu enginy i sentit de l'humor, que ha generat un bon ambient al despatx; la **Marta**, empezamos viviendo situaciones arriesgadas (gracias por tu apoyo en ese momento), aunque para ti, eso fue solo un entrenamiento de lo que te iba a venir...has sido muy valiente!; i la **Laura** (Zango), sempre ocupada amb moltes responsabilitats i campanyes, però encara així disposta a ajudar!

No puc oblidar-me de les persones amb les que vaig compartir algunes de les campanyes en les colònies; van ser dies intensos i durs, però també vam poder gaudir de moments molt especials. Vull mencionar especialment a la **Andrea** (Soriano), **Robert**, **Elisa** i la **Loli**.

També vull agrair als col·laboradors externs, els quals han contribuït de manera notable a la millora d'aquesta tesi. Primer de tot, als membres de la meua comissió de seguiment: **Lluís Cardona**, **Pep Arcos** i **Pere Abelló**, gràcies per la vostra supervisió i consells! Però en especial, vull donar les gràcies al Pep, la teua experiència en pesqueries ha sigut essencial, però també la teua predisposició a ajudar-me al llarg de totes les fases de la tesi (inclus fins l'últim moment per revisar una part!), els teus comentaris i suggeriments sempre han sigut molt útils. També mencionar al **Salva García**, siempre has estado dispuesto a colaborar y compartir datos con nosotros, pero sobretodo agradezco tu motivación en participar y ayudar cuando ha sido necesario, ha sido todo un placer trabajar contigo!. A **Oli Yates**, por tu ayuda en mi estancia en Chile y tus sabios consejos, fue todo un gusto conversar y compartir un embarque con alguien con tanta experiencia y que comparte tu misma pasión, espero que lo volvamos a repetir! A **Marguerite Tarzia**, thanks for the trust you placed in me and for appreciating my work, it has been a really pleasure to work with you!

“Pajarear” durant el treball de camp de la tesi era tot un privilegi, però ho va ser també fer-ho amb l’“Avuteam”, fundat per **Manolo, Irene, Francesc** i jo mateixa. Vam tenir una època d’esplendor, en la que les eixides de pajareo acabaven perillósament en el bar, festes de poble o fent botellón. A pesar d’algunes llacunes, tinc molts bons records d’aquells dies! Menció especial es mereix el Francesc, que a més de company de departament i de pajareo, també ha sigut un gran amic, gràcies pel teu suport quan ho he necessitat!

L’anellament també va servir per fer teràpia, especialment quan ho comparteixes amb uns frikis dels ocells molt motivaos. Ací he de destacar als *padawans* de l’alcoià-comtat (**Pep, Jesús, els Javis, Pablo, Rubén i Jana**). Anellavem molts pardals i flipàvem amb les mudes, però també eren “eventos” de rises i de poc trellat, que ens servia a tots per oblidar, per un moment, les nostres històries. També van ser especials les eixides d’anellament/pajareo amb el **Sergio i Emilio**, ademàs he de agradar vuestro apoyo, a todos los niveles, durante los inicios de esta tesis.

Vull també agrair a tots aquells que, d’alguna manera o altra, m’han ajudat a poder afrontar esta etapa de la millor forma, ja siga amb consells, suport moral o bé simplement fent unes cerveses per disconnectar i arreglar el món....Espere no oblidar-me de ningú perquè sou molts! Als meus companys de la facultat: **Eli, Oriol** (Canals), **Raül, Olatz, Eloy, Jaime, Mario, Nico, Oriol** (Cano), **Carol, Alberto, Joan, Blanca, Gaia, Helena, Débora, Gemma, Morgana, Karla i Carolina**. En aquest sentit, ha sigut també imprescindible la meua compi **Pili**, les nostres xerrades al sofà amb una copa de vi sempre ho tornava tot més lleuger. Van ser clau també la meua família de Barcelona, el gueto valencià i els seus aliats: **Andy, Alex, Sara, Xavi, Edu, Gabi, Vicent i Mònica**. A Andy, gracias por estar siempre dispuesto a ayudarme, en especial con el inglés, pero también por acogerme en tu casa todas las veces que he vuelto a Barcelona! No puc oblidar-me de la **Rocío**, la nostra convivència a l’hostal de Wellington va ser un punt d’inflexió, després d’això els nostres retrobaments són sempre, per a mi, memorables...eres molt gran! I would also like to thank **Bob**, for your joy and always positive attitude; our long discussions helped me a lot to keep a good mood during the most challenge period of this thesis. In addition, I’m also very grateful that you have been my checker of English!

Has aparegut quasi en l’etapa final, però encara aixina no t’has lliurat de viure els meus moments d’estrès i nerviosisme. Moltes gràcies **Jose** per la paciència, pel teu suport, per com em cudes i m’estimes, amb tu tot té altre color!

Per últim, però no menys important, vull donar el més profund dels meus agraïments a la meua família. Tot el que he aconseguit fins ara ha sigut, en gran part, gràcies a vosaltres, per tota l’estima que m’heu donat i el vostre suport

incondicional, sempre que ho he necessitat. Heu tingut que tindre molt d'aguant, especialment els darrers anys, i és per això que esta tesi vos la dedique a vosaltres: als **meus pares** i la **meua germana Sònia**.

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RESUM

Els ocells marins es troben entre els ocells més amenaçats del planeta, especialment a causa de les pressions induïdes per les activitats humanes. En particular, la mortalitat per captura accidental en la pesca comercial representa una de les seves principals amenaces a nivell global. Els ocells marins són altament sensibles a la mortalitat addicional atès les característiques del seu cicle vital. És per això que les captures accidentals estan posant en risc a nombroses espècies. En el Mediterrani, la pesca amb palangre és la principal causa de mortalitat dels ocells marins, i possiblement el factor que més contribueix al seriós declivi observat en les baldrigues endèmiques de la conca. No obstant això, la informació disponible sobre la intensitat i extensió del seu impacte és escassa i fragmentada. Així mateix, encara no s'ha implementat cap tipus d'estratègia en la flota per evitar aquesta mortalitat accidental.

La present tesis pretén avaluar i contribuir al coneixement sobre la problemàtica de les captures accidentals d'ocells marins en la pesca amb palangre de l'oest del Mediterrani, així com identificar l'estratègia de mitigació més adient per a la flota. En particular, l'estudi s'ha focalitzat en els palangrers de fons ja que fan servir arts més perillosos per als ocells i, a més, existeix una menor informació sobre el seu impacte.

En primer lloc, les observacions a bord dels palangrers demersals de l'oest del Mediterrani ha demostrat una elevada mortalitat d'ocells marins, en particular de les 3 espècies endèmiques i amenaçades de baldrigues: cendrosa (*Calonectris diomedea*), balear (*Puffinus mauretanicus*) i mediterrània (*P. yelkouan*), la qual cosa posa de manifest la necessitat urgent de desenvolupar accions efectives per reduir les captures accidentals d'aquestes espècies. La major susceptibilitat de les baldrigues és causat pel seu comportament gregari i gran capacitat de busseig. És per això que, ocasionalment, es troben involucrades en captures massives de desenes o centenars d'individus, provocant aquests esdeveniments grans molèsties per als pescadors. A més, s'ha pogut identificar diversos factors temporals, operacionals, espacials i meteorològics que influeixen en el risc de captura accidental, encara que destaca particularment l'estació de l'any i el moment del dia que es realitza la calada. Altres factors influents són el tipus d'esquer, les condicions de vent, la configuració del palangre (distància entre pesos), el nombre d'hams calats i la distància a les colònies de cria.

En segon lloc, l'ús de diferents aproximacions (anàlisis simultani de les dades GPS dels ocells i els VMS dels vaixells, comptatges d'ocells en les observacions a bord i mortalitat reportada pels pescadors) ha permès explorar en detall els efectes de la pesca d'arrossegament sobre el risc de captura accidental en els palangres. S'ha observat que la falta de disponibilitat dels descarts proveïts per la pesca

d'arrossegament incita a que les baldrigues cendroses acudeixin amb major intensitat als palangrers, incrementant així el risc de captura accidental. Conseqüentment, la imminent normativa adoptada per la Unió Europea, la qual pretén prohibir els descarts mitjançant l'obligació de desembarcar totes les captures, podria agreujar el problema de les captures accidentals.

En tercer lloc, l'examen dels cadàvers de baldrigues, obtinguts als palangrers que operen en l'àrea d'estudi, ha demostrat l'existència d'una mortalitat desigual a nivell poblacional. Els adults són la classe d'edat més afectada, sent particularment vulnerables en les proximitats de les colònies de cria per al cas de la baldriga cendrosa. Així mateix, existeix un biaix cap als mascles a l'inici del període de cria. No obstant, en les baldrigues del gènere *Puffinus*, existeix una mortalitat esbiaixada cap a les femelles durant el període d'alimentació dels polls. També s'ha trobat que la mortalitat als palangres en l'àrea d'estudi està afectant fonamentalment a les poblacions locals (Illes Balears), encara que també són capturades baldrigues provinents d'altres colònies, especialment durant l'època de migració.

Per últim, l'assaig de diversos mètodes de mitigació adaptats als palangrers demersals, ha servit per formular l'estratègia més apropiada per reduir les captures accidentals d'ocells en la flota estudiada. Fins al moment, la calada nocturna seria el mètode més eficaç per evitar la mortalitat accidental d'ocells sense afectar les captures objectiu o altres espècies no comercials quan la pesca va dirigida al lluç europeu. Tanmateix, seria necessari confirmar els seus efectes sobre altres espècies objectiu de la flota. A més, una restricció temporal de l'activitat durant els mesos més conflictius podria també reduir considerablement aquesta problemàtica, encara que hauria d'anar acompanyat d'altres mesures i seria necessari avaluar els possibles efectes sobre el rendiment pesquer. Altres mètodes que podrien reduir les captures d'ocells serien l'increment de la taxa d'enfonsament del palangre o evitar l'ús d'esquers attractius per als ocells. Malgrat tot, la alta diversitat d'estrategies i arts de pesca que existeix en l'àrea dificulta la identificació de mètodes que puguin ser aplicables al conjunt de la flota. Conseqüentment, per tal d'atendre aquesta complexitat, es recomana constituir un joc de diferents mesures de mitigació que puguin ser adaptades a la major part de mètodes de pesca.

ABSTRACT

Seabirds are amongst the most threatened group of birds in the world, especially due to the pressures caused by human activities. In particular, bycatch mortality by commercial fisheries represents one of the major threats to many seabirds worldwide. Seabirds are highly sensitive to additional mortality due to the characteristics of their life cycle. For this reason, incidental catches by fisheries are putting many seabird species at risk. In the Mediterranean, the longline fishery is the main cause of seabird mortality and possibly the most important factor contributing to the decline of endemic shearwater populations. However, the information available on the level and extent of its impact is scarce and fragmented. Moreover, no mitigation strategy to prevent this bycatch mortality has yet been implemented in the fleet.

The present thesis aims to assess and contribute to the knowledge about seabird bycatch by longline fisheries of the western Mediterranean, as well as to identify the most appropriate mitigation strategy for the fleet. In particular, the study has focused on demersal longliners since they use the most dangerous gear for seabirds and also because there is little information available.

First of all, observations on board demersal longliners in the western Mediterranean have revealed a high mortality of seabirds, in particular of the three endemic and threatened species of shearwaters: Scopoli's (*Calonectris diomedea*), Balearic (*Puffinus mauretanicus*) and Mediterranean (*P. yelkouan*), calling for urgent and effective action to reduce their bycatch rates. This greater susceptibility of shearwaters is due to their highly aggregative behaviour and deep diving capability, which together lead to occasional massive catches of dozens and even hundreds of individuals, and also significant economic losses for fishermen. There are several temporal, operational, spatial and meteorological factors influencing on the bycatch risk, but the most dominant factors are the season and the setting time. Other influential factors are the bait type, wind conditions, longline configuration (distance between the weights), proximity to the breeding colonies and the number of hooks set.

Secondly, the use of different approaches (concurrent analysis of GPS data from seabirds and VMS from vessels, seabird counts from onboard observations and the mortality reported by fishermen) has allowed more detailed exploration of the effects of trawl fishing on the bycatch risk by longliners. In Scopoli's shearwater, the reduction of discards by trawlers led to increased interaction between these seabirds and longliners, thus increasing the bycatch risk. Consequently, the incoming legislation adopted by the European Union, which intends to ban discards through landing obligation, will likely aggravate the bycatch problem.

Thirdly, examination of the carcasses collected from the longline fisheries operating in the study area has demonstrated unequal bycatch mortality at population level. Adults are the age class most affected, being particularly vulnerable in the vicinity of breeding colonies for the case of Scopoli's shearwater, which also show a male-biased mortality at the beginning of the breeding season. However, in *Puffinus* shearwaters, mortality is female-biased during the chick-rearing period. Furthermore, the mortality on longlines in the study area is more pronounced but not limited to Spanish breeding colonies, as birds from other Western Mediterranean colonies are bycaught while using the area as a stopover site during the migration period.

Finally, the trials of different mitigation methods adapted to demersal longliners has helped to identify the most appropriate strategies to reduce the seabird bycatch by the fleet studied. It appears that night setting would be the most effective method to prevent seabird mortality without compromising target catches or other non-commercial species. However, these results should be confirmed for longliners targeting species other than European hake. Likewise, a temporal closure of the fishery during the most conflictive months is also a promising strategy to reduce the impact of bycatch. Nevertheless, this limitation should be implemented together with other measures and its potential effects on fishing activity should be carefully evaluated. Others methods that may reduce seabird bycatch include increasing the sink rate of the longlines and avoiding the use of baits attractive to seabirds. However, the high diversity of fishing strategies and gears used in the area hampers the identification of suitable solutions applicable to the whole fleet. Consequently, to deal with this complexity it would be necessary to establish a set of different mitigation measures that can be adapted to the majority of fishing methods.

INTRODUCCIÓ GENERAL



Interacció de l'activitat pesquera amb els ocells marins

Els ocells marins es consideren el grup d'ocells més amenaçat del planeta a causa del crític deteriorament que han experimentat en les últimes dècades (Croxall et al. 2012). Tant és així que, a nivell global, s'estima que les poblacions d'ocells marins s'han reduït un 70% entre 1950 i 2010 (Paleczny et al. 2015). Aquest declivi és especialment agut en les espècies pelàgiques, el qual és impulsat tant per les seves característiques demogràfiques, que fa que tinguin un creixement lent i una capacitat de recuperació limitada, així com pel seu ampli rang de distribució, que els exposa a una major diversitat d'impactes (Croxall et al. 2012, Paleczny et al. 2015). El creixement i expansió de les activitat humanes és la principal causa d'aquesta tendència negativa observada en les poblacions (Paleczny et al. 2015), sent especialment important l'impacte generat per la pesca comercial (Tuck et al. 2001, Lewison & Crowder 2003, Barbraud et al. 2012). No obstant això, els efectes de l'activitat pesquera sobre les poblacions d'ocells marins són múltiples i complexos (Tasker et al. 2000, Montevecchi 2002, Furness 2003).

Les millores tecnològiques que han experimentat les flotes pesqueres en les últimes dècades del segle XX ha conduït a una major capacitat pesquera i una notable expansió geogràfica (Pauly 2008, Watson et al. 2013). Com a conseqüència d'aquest creixement desmesurat, la major part dels recursos pesquers es troben sotmesos a una forta explotació (Pauly et al. 2003, Watson et al. 2013, Tsikliras et al. 2015). Aquesta pressió és difícilment suportable per les poblacions i, en molts casos, ha conduït a una sobreexplotació o col·lapse dels estocks pesquers, amb la conseqüent alteració de l'estructura i funcionalitat de l'ecosistema marí (Pauly et al. 1998, Jackson et al. 2001, Coll et al. 2008, Utne-Palm et al. 2010).

Els ocells marins, al ser depredadors apicals en la cadena tròfica, són informadors de l'estat del medi marí i poden alertar de possibles canvis i pertorbacions que esdevenen en l'ecosistema (Piatt et al. 2007, Einoder 2009). Tant és així que, en certes àrees on la pressió pesquera ha produït una davallada dramàtica de la biomassa dels estocks, de manera indirecta, s'ha traduït amb una disminució substancial de les poblacions d'ocells (Furness & Tasker 2000, Oro et al. 2002, Jahncke et al. 2004, Furness 2007, Cohen et al. 2014), especialment d'aquelles espècies més sensibles a la disponibilitat de les seves principals preses naturals, com els petits peixos epipelàgics (Alder et al. 2008).

Malgrat la possible competència per la disponibilitat d'aliment que pot donar-se en certes regions (Karpouzi et al. 2007, Bertrand et al. 2012), algunes espècies carronyeres, com els procel·lariformes, làrids, mascarells i paràsits, es beneficien de l'activitat pesquera mitjançant l'explotació del rebuig que es genera en la pesca (Wagner & Boersma 2011, Bicknell et al. 2013). Generalment, aquest rebuig inclou esquers que es retornen al mar, vísceres o bé peixos que han sigut descartats pel

seu baix interès comercial, per tenir una mida inferior a la legal, perquè estan malmesos o perquè s'ha assolit la quota de captura de l'espècie.

A escala global, s'estima que la indústria pesquera descarta gairebé 7,3 milions de tones de peix cada any, el que representa un 8% del total de les captures mundials, sent la pesca d'arrossegament el principal productor d'aquest rebuig (Kelleher 2005). D'aquesta manera, les pesqueries posen a l'abast per als ocells carronyers una ampla gamma de peixos demersals que de manera natural els hi seria impossible d'aconseguir. A més, al ser un recurs abundant i predictable, tant en el temps com en l'espai, pot representar per als ocells una font d'aliment de més fàcil accés que les pròpies preses naturals (Bartumeus et al. 2010, Patrick et al. 2015), especialment si aquestes últimes són escasses (Pichegru et al. 2007, Tew Kai et al. 2013).

No obstant, el grau d'explotació dels descarts pesquers varia no solament entre espècies d'ocells (Wagner & Boersma 2011), sinó també entre colònies de cria (Pichegru et al. 2007, Granadeiro et al. 2014) i entre individus (Votier et al. 2010, Torres et al. 2011, Patrick et al. 2015). Malgrat això, en alguns casos, els descarts representen una part important de la dieta (Oro et al. 1997, Arcos & Oro 2002, Bugoni et al. 2010), tenint aquest particular oportunitisme efectes profunds en la seva biologia reproductora, distribució i dinàmica poblacional (Oro 1995, Arcos & Oro 1996, Oro et al. 2004b, Bartumeus et al. 2010, Cama et al. 2013, Oro et al. 2013, Bécares et al. 2015).

En general, l'ús extensiu d'aquest recurs addicional té associat diversos guanys per als ocells, ja sigui mitjançant una reducció en les àrees i el temps d'alimentació (Grémillet et al. 2008, Bartumeus et al. 2010), o bé per un augment en l'eficàcia biològica a través d'una major fecunditat (Oro 1996, Louzao et al. 2006) i/o resiliència a les pertorbacions ambientals i catàstrofes (Oro et al. 2013). Tot i així, atès que aquest recurs està constituït fonamentalment per espècies demersals, sol contenir un major nivell de contaminants (Arcos et al. 2002) i menor contingut energètic en comparació amb les preses naturals i, per alguns ocells, aquest últim fet pot suposar una disminució en l'èxit reproductor (Grémillet et al. 2008).

Així mateix, cal destacar que una forta dependència als descarts pot tenir conseqüències negatives a llarg termini, especialment en el moment en que aquesta font d'aliment supplementària deixa d'estar disponible per als ocells (Furness 2003, Furness et al. 2007, Oro et al. 2013). Per exemple, per tal de reduir l'impacte que suposa la generació de descarts per als recursos pesquers i a l'ecosistema marí en general, en la última reforma de la Política Pesquera Comú (PPC) de la Unió Europea s'ha incorporat una nova regulació que pretén eliminar gradualment la producció de descarts mitjançant l'obligació de desembarcar totes les captures a port (Quadre I, https://ec.europa.eu/fisheries/reform_en). La implementació

d'aquesta normativa es realitzarà des de 2015 fins 2019 en totes les embarcacions comercials europees que operen en aigües comunitàries o en alta mar, encara que les barques d'arrossegament seran les més afectades a causa de la seva alta taxa de descarts. Per tant, la previsible disminució d'aquest recurs addicional per als ocells marins podria tenir importants efectes sobre les seves comunitats (Reeves & Furness 2002, Bicknell et al. 2013).

QUADRE I. DESCARTS I L'OBLIGATORIETAT DE DESEMBARCAR

El **Reglament (UE) nº 1380/2013** del Parlament Europeu i del Consell, estableix com un dels seus objectius l'eliminació gradual de la pràctica del descart mitjançant *l'obligació de desembarcar les captures de les espècies subjectes a límits de captura o a mides mínimes per al cas del Mediterrani* (article 15). Aquesta mesura pretén millorar el comportament pesquer a través d'una millora en la selectivitat.

La fase d'implementació d'aquesta normativa s'inicià al 2015, i s'espera que al 2019 estigui implementada en la totalitat de vaixells comercials que operen en aigües europees o en vaixells europeus que pesquen en alta mar. No obstant, existeixen casos en els que la obligatorietat de desembarcar no s'aplica:

- espècies sotmeses a prohibició de pesca
- espècies amb una elevada taxa de supervivència
- peixos malmesos (per depredació, malalties o contaminació)
- exempció de *minimis* (es permet descartar fins a un 5% del total anual de captures).

En el cas del **Mediterrani**, el 20 d'Octubre de 2014 s'establí el primer pla de descarts que afectava als petits peixos pelàgics (**Reglament -UE- nº 1392/2014**), en particular la sardina, seitó, verat i sorell. La seua aplicació s'inicià a l'1 de gener del 2015 per a les pesqueries que utilitzen xarxes d'arrossegament o xarxes d'encerclament. Posteriorment, a través del **Reglament (UE) 2017/86** de la Comissió, s'estableix el pla de descarts per determinades pesqueries dirigides a la captura d'espècies demersals, com el lluç i el moll de fang, sempre i quan representen més del 25% de les captures. La seva aplicació s'inicià a l'1 de gener del 2017 en les pesqueries que utilitzen xarxes d'arrossegament, palangres i tresmalls. Per a tots els casos, s'estableix una exempció de *minimis*, atès que la prohibició suposaria elevats costos en relació a la manipulació de les captures no desitjades. Per tant es permet descartar un percentatge del total anual capturat.

Algunes poblacions d'espècies carronyeres, especialment les de gavines de gran mida, actualment es troben inflades de manera artificial principalment per la gran quantitat de rebuig que proveeix l'activitat pesquera (Oro et al. 2013). La prohibició de descarts podria implicar, doncs, una reducció notable de les seves poblacions i canvis comportamentals relacionats amb l'explotació del seu aliment (Reeves & Furness 2002, Bicknell et al. 2013). En conseqüència, per contrarestar aquesta carència de descarts, els ocells omnívors com les gavines i paràsits, podrien augmentar la taxa de depredació sobre altres espècies més petites (p.ex. els ocells de tempesta), les quals podrien veure's seriosament perjudicades (Votier et al. 2004, Sanz-Aguilar et al. 2009).

Per altra banda, els ocells que habitualment són atrets per les barques de pesca, a curt termini, podrien seguir amb més intensitat altres pesquerdes que prèviament eren menys utilitzades a causa de la seva baixa taxa de descarts, com els palangrers i arts menors (García-Barcelona et al. 2010a, Laneri et al. 2010, Báez et al. 2014). No obstant, aquestes pesquerdes normalment utilitzen arts de pesca més perillosos per als ocells, atès el seu alt risc de captura accidental, cosa que podria fer augmentar la seva mortalitat.

La captura accidental d'ocells marins en els arts de pesca

La captura accidental en els arts de pesca es considera un dels impactes més greus que sorgeix de la interacció entre ocells i pesquerdes (Tasker et al. 2000). A vegades, els arts poden actuar com a parany mortals quan els ocells segueixen les barques de pesca per alimentar-se dels esquers col·locats als hams, dels descarts o bé de les captures comercials. La mortalitat d'ocells marins causada per aquestes captures involuntàries genera greus problemes de conservació, ja que afecta principalment al paràmetre més sensible del seu cicle vital: la supervivència adulta. La major part dels ocells marins són espècies de vida llarga i creixement lent, com a resultat d'una baixa mortalitat adulta, una maduresa retardada i una baixa fecunditat (Weimerskirch 2002). Per tant, qualsevol increment no natural de la mortalitat adulta és difícilment contrarestat i té greus conseqüències sobre la viabilitat de les seves poblacions (Tasker et al. 2000, Arnold et al. 2006).

A banda d'això, en algunes espècies s'ha detectat una mortalitat diferencial entre sexes a causa d'una segregació espacial en les àrees d'alimentació, cosa que condiciona el seu solapament amb les pesquerdes i el consegüent risc de ser capturat accidentalment (Bugoni et al. 2011, Jiménez et al. 2016a, Gianuca et al. 2017). Aquest fet pot conduir a un biaix en la relació entre sexes en la població i, per tant, tenir un sever impacte sobre la fecunditat i viabilitat poblacional (Mills & Ryan 2005). És per això que la captura accidental en els arts de pesca està posant en alt risc a nombroses espècies d'ocells marins, conduint a un gran nombre de

poblacions i espècies prop de l'extinció (Inchausti & Weimerskirch 2001, Lewison & Crowder 2003, Wanless et al. 2009).

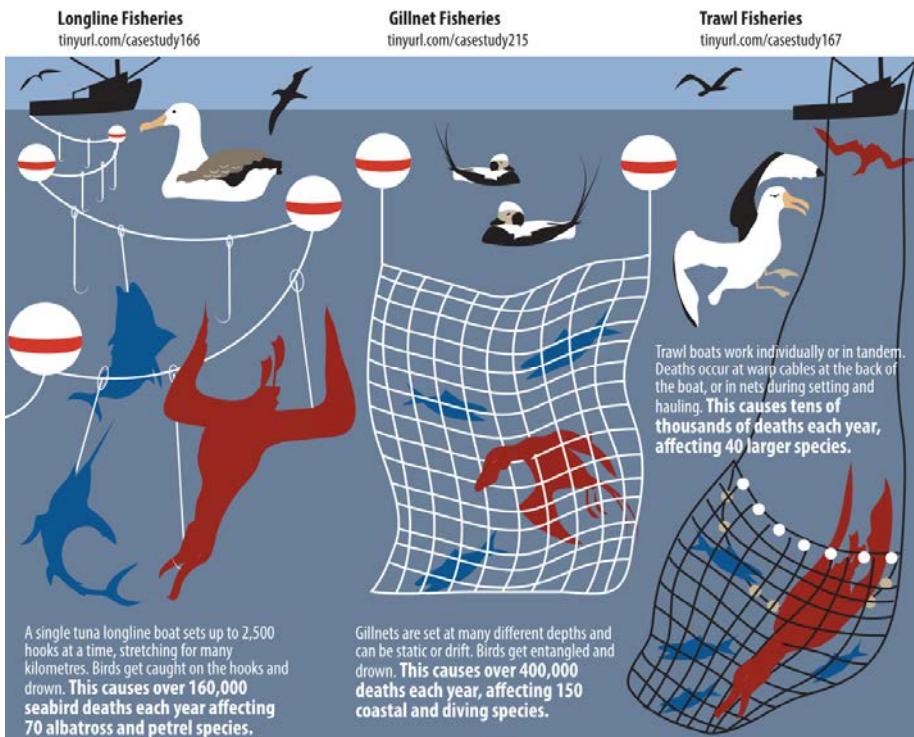


Figura 1. Descripció de com ocorren les captures accidentals d'ocells marins en les pesqueres de palangre (longline fisheries), xarxes fixes (gillnet fisheries) i d'arrossegament (trawl fisheries). Il·lustració de Birdlife International.

Les captures accidentals ocorren a nivell global i poden donar-se en diferents modalitats de pesca (Lewison et al. 2014, Pott & Wiedenfeld 2017), particularment en el palangre, les xarxes fixes i l'arrossegament (Figura 1). En la pesca amb palangre, els incidents ocorren quan els ocells s'aventuren a robar els esquers col·locats als hams i queden embolicats en la línia o enganxats a l'ham, i en la majoria dels casos, quan són capturats, acaben morint ofegats al enfonsar-se amb l'art (Brothers et al. 1999a). En el cas de les xarxes fixes, les captures són causades per emmallament quan els ocells intenten alimentar-se de les captures atrapades, ja que no són capaços de detectar les xarxes baix de l'aigua (Žydelis et al. 2013). En canvi, en la pesca d'arrossegament, la mortalitat d'ocells pot ocurrir bé com a resultat de col·lisions amb els cables quan intenten alimentar-se dels descarts, o bé

per embolicaments amb la xarxa quan bussegen per robar el peix capturat (Weimerskirch et al. 2000, Løkkeborg 2008).

A nivell global, els majors nivells de captura accidental d'ocells marins es troben en la pesca de palangre i les xarxes fixes. S'estima que almenys 160.000 ocells, fins a un màxim de 320.000 ocells, podrien estar morint anualment en els palangres, particularment de les espècies d'albatros, petrells i baldrigues (Anderson et al. 2011). En el cas de les xarxes, la taxa anual de mortalitat podria arribar fins a 400.000 ocells, principalment d'espècies costaneres i bussejadors de diversos grups d'ocells, com els àlcids, baldrigues, corb marins, pingüins i els ànecs marins (Žydelis et al. 2013). Per altra banda, en el cas de la pesca d'arrosseigament, tot i que no s'ha realitzat una revisió global sobre la magnitud del seu impacte, alguns estudis han demostrat una alta mortalitat d'ocells en determinades regions de l'hemicèl sud (Weimerskirch et al. 2000, Sullivan et al. 2006, Maree et al. 2014), especialment d'albatros i petrells.

No obstant, la magnitud i gravetat d'aquestes captures en les diferents flotes de pesca varia a nivell geogràfic i temporal, d'acord amb el grau de solapament entre la distribució d'ocells i les pesquerries, així com la densitat d'ocells, intensitat de l'esforç pesquer, característiques dels arts i l'aplicació amb èxit de mesures de mitigació per reduir aquestes captures (Lewison et al. 2014).

Diagnòstic i primeres actuacions per reduir les captures accidentals

Les primeres evidències que demostraren el problema de la captura accidental d'ocells marins provenen de les pesquerries de xarxa fixa que operen a l'oceà Pacífic, Atlàntic i el mar Bàltic (Tull et al. 1972, Ainley et al. 1981, United & Geological 1987). En el cas de la pesca amb palangre, els primers incidents foren detectats a partir de les anelles recuperades d'albatros capturats en vaixells pesquers que feinejaven a l'hemicèl sud (Morant 1983, Croxall 1984). No obstant, les captures accidentals en els palangres reberen inicialment una major atenció a nivell global, mentre que la magnitud i importància de les captures en les xarxes fixes romangué desconegut durant molt de temps (Žydelis et al. 2009).

A finals dels 80 i principis dels 90 començaren a sorgir treballs que alertaren de l'important impacte que estava tenint la pesca amb palangre sobre els ocells marins, especialment en les espècies d'albatros que criaven a l'hemicèl sud (Weimerskirch & Jouventin 1987, Croxall et al. 1990, Prince et al. 1994). En particular, s'estimaren xifres alarmants de 44,000 albatros capturats anualment per els tonyinaires japonesos que operaven en l'oceà austral (Brothers 1991), no obstant es tracta d'una estima poc acurada ja que es basa en l'extrapolació obtinguda de 45 individus capturats en una única regió i estació (Løkkeborg 2008).

Les captures accidentals en el palangre es presentava, per tant, com una de les principals causes del declivi de les poblacions d'albatros de l'oceà sud a causa de l'elevada mortalitat que generava. Més endavant es demostrà que aquestes captures no es restringien únicament a l'oceà sud (Murray et al. 1993, Gales et al. 1998, Brothers et al. 1999a, Dunn & Steel 2001, Cooper et al. 2003) i, a més, començaren a ser aparents en altres pesqueres, com la pesca d'arrossegament i les xarxes d'encerclament (Bartle 1991, Weimerskirch et al. 2000, Sullivan et al. 2006).

La creixent preocupació d'aquesta amenaça sobre els ocells marins i les grans pèrdues econòmiques que representaven aquestes captures per a l'activitat pesquera, incità a que científics, comunitats pesqueres, organitzacions governamentals i ONGs proclamaren la necessitat urgent d'aplicar mesures per reduir aquestes captures involuntàries (Brothers et al. 1999a). La comissió internacional per a la Conservació dels Recursos Vius Marins Antàrtics fou pionera en la proposta i regulació de les mesures de mitigació en el 1992 (ccamlr.org/en/system/files/e-cons-meas-92-93_1.pdf), en particular promogué l'ús de les línies espantaocells. Posteriorment, el Comitè de Pesca (COFI) de l'Organització de les Nacions Unides per a la Agricultura i Alimentació (FAO) adoptà en 1999 un Pla d'Acció Internacional (FAO 1999) per reduir les captures accidentals d'ocells marins (IPOA-seabirds) per tal d'acomplir amb el Codi de Conducta per a la Pesca Responsable (FAO 1995). Aquest document servia com instrument voluntari i recomanava als països que presentaven problemes de captures accidentals a desenvolupar Plans d'Acció Nacionals (NPOA-seabirds) per minimitzar aquestes captures. Des d'aleshores, s'han redactat nombrosos NPOAs en diferent països, com Xile, Argentina, Brasil, Uruguai, illes Geòrgia del Sud, Sud-àfrica, Canadà, Nova Zelanda, Namíbia, Austràlia, Malvines, Estats Units i Japó (acap.aq/en/resources/management-plans/1690-npoa-seabirds).

En el cas d'Europa, les actuacions per reduir les captures d'ocells en la pesca estan arribant amb massa retard. El Consell Internacional per a l'Explotació del Mar (CIEM o ICES en anglès) aporta estimes conservatives de més de 200,000 ocells que podrien estar morint per la flota europea que opera en aigües comunitàries o internacionals. Entre els ocells més afectats, es troben espècies greument amenaçades, com la baldriga balear (*Puffinus mauretanicus*), la qual presenta un sever declivi causat principalment per la mortalitat en la pesca (Genovart et al. 2016).

En Novembre de 2012 s'aprova en la Comissió Europea el Pla d'Acció Europeu per reduir les captures d'ocells gràcies als esforços de Birdlife International (eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0665:FIN:ES:PDF). Aquest document representa un marc d'ordenació per reduir les captures d'ocells en els vaixells europeus que feinegen en aigües europees o exteriors. Es destaca especialment l'escassa informació disponible sobre l'extensió d'aquesta

problemàtica i el seu impacte sobre els ocells marins, a més de la necessitat d'aplicar mesures de mitigació en les regions on s'ha detectat un sever impacte. Actualment es troba en fase de negociació a les institucions de la Unió Europea.

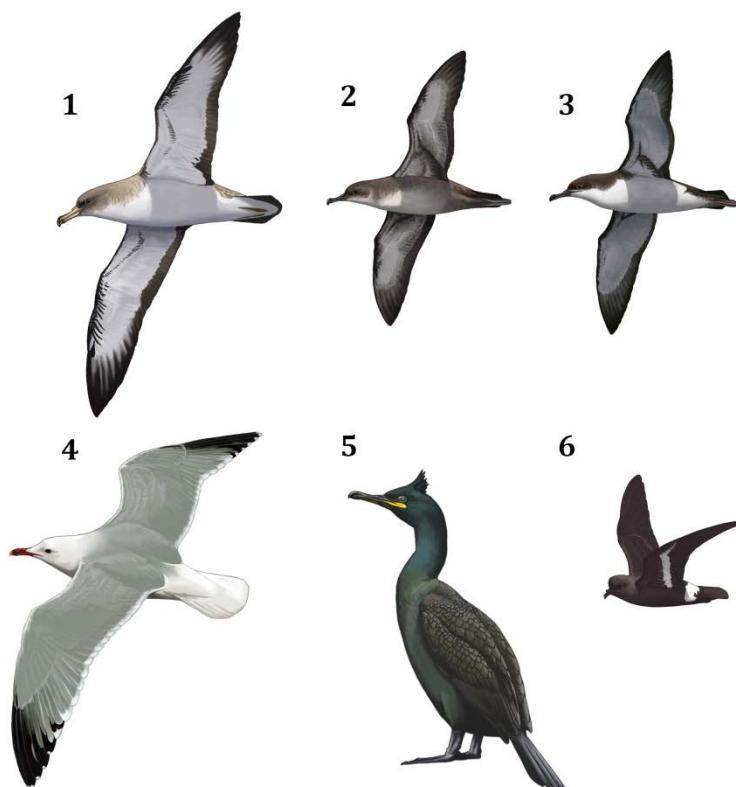


Figura 2. Ocells marins endèmics del Mediterrani: Baldriga cendrosa (1), balear (2), mediterrània (3), gavina corsa (4), corb marí emplomallat (5) i ocell de tempesta (6). Il·lustrador Martí Franch.

La captura accidental d'ocells marins en el Mediterrani

La flota pesquera del Mediterrani es composa principalment per embarcacions polivalents d'arts menors (80%), seguit per les barques d'arrosegament (8%), d'encerclament (5%) i de palangre (2%) (FAO 2016). Així mateix, en aquesta regió habita una relativament reduïda comunitat d'ocells marins però amb un gran nivell d'endemismes (Zotier et al. 1999), com la baldriga balear (*Puffinus mauretanicus*), mediterrània (*P. yelkouan*) i cendrosa (*Calonectris diomedea*), la gavina corsa (*Larus audouinii*), el corb marí emplomallat (*Phalacrocorax aristotelis desmarestii*) i l'ocell de tempesta (*Hydrobates pelagicus melitensis*) (Figura 2).

Algunes d'aquestes espècies endèmiques es troben amenaçades i incloses en les categories de la llista vermel·la de la UICN, com la Críticament Amenaçada baldriga balear i la Vulnerable baldriga mediterrània. En canvi, la baldriga cendrosa, a pesar de no estar inclosa en aquestes categories d'amaña, s'ha detectat un significant declivi en algunes de les seves poblacions (Genovart et al. 2017b).

Pel que fa a les captures accidentals, al Mediterrani ocorren principalment en el palangre i les xarxes fixes (arts menors). No obstant això, també s'ha documentat captures d'ocells en altres modalitats de pesca; com l'arrossegament, encerclament i les nances (Taula 1), encara que es consideren infreqüents i no semblen tenir un impacte significatiu sobre les poblacions d'ocells marins.

Taula 1. Espècies d'ocells marins capturats en diferents arts de pesca emprats en les pesqueres d'aquells països on hi ha informació disponible.

Arts de pesca	País	Espècies d'ocells	Referències
Xarxa d'arrossegament	Espanya	Baldriga balear	1
Xarxa fixa	Espanya Grècia	Corb marí gros i empomallat	2, 5, 6, 7
Xarxa d'encerclament o de teranyina	Espanya	Baldrigues i àlcids	7
Palangre demersal	Espanya Grècia Malta França Itàlia	Baldriga cendrosa, mediterrània i balear, gavià argentat, mascarell, gavina corsa, capnegra i riallera, paràsit gros i cuaample, gavineta de tres dits, corb marí empomallat	2, 3, 5, 7
Palangre pelàgic	Espanya Grècia Malta Itàlia Tunísia	Baldriga cendrosa, mediterrània i balear, gavià argentat, mascarell, gavina corsa, paràsit gros i cuaample, gavineta de tres dits, corb marins	2, 3, 4, 5, 7, 8
Nances	Espanya	Corb marí gros i empomallat	2

1. Abelló & Esteban 2012, 2. Cortés & González-Solís (no publicat), 3. Dimech et al. 2008, 4. García - Barcelona et al. 2010b, 5. Karris et al. 2012, 6. Louzao & Oro 2002, 7. SEO/Birdlife 2014, 8. Valeiras & Camiñas 2003

Xarxa d'arrossegament

A pesar de que la pesca d'arrossegament atrau a un gran nombre d'ocells, atesa la seu elevada taxa de descarts, no s'han detectat captures accidentals en un gran nombre d'operacions monitoritzades a l'oest del Mediterrani (1994 - 2003, Oro & Ruiz 1997, Arcos & Oro 2002, Abelló et al. 2003, Louzao et al. 2011). Encara que al

2011 es registraren dos incidents d'exemplars de baldriga balear a l'oest del Mediterrani (Abelló & Esteban 2012). Les dades col·lectades en qüestionaris dirigits a pescadors d'Espanya i Malta suporten també aquesta baixa incidència (Dimech et al. 2009, SEO/Birdlife 2014).

Malgrat això, l'activitat d'arrossegament pot influir en les captures accidentals que ocorren en altres pesqueres, particularment en el palangre. Alguns d'estudis duts a terme en el oest del Mediterrani han detectat un increment del nombre d'ocells següent les barques de palangre i/o un major risc de captura accidental durant els dies no laborables de la pesca d'arrossegament (p.ex. en dies festius, caps de setmana o períodes de vedat) (García-Barcelona et al. 2010a, Laneri et al. 2010, Báez et al. 2013). Quan les embarcacions d'arrossegament no operen, els ocells marins podrien compensar aquesta manca de descarts acudint a altres flotes, com els palangrers o barques d'arts menors, fet que pot incrementar el risc de ser capturats accidentalment.

Xarxes fixes

La informació disponible en el Mediterrani sobre l'impacte de les embarcacions que fan servir xarxes fixes, com el tresmall i la solta, és escassa i fragmentada. No obstant això, els estudis desenvolupats en aquesta regió indiquen que les captures accidentals podrien ocórrer a nivells més baixos que en qualsevol altre lloc del món (Žydelis et al. 2013). Encara que es necessiten més dades per avaluar l'impacte real d'aquesta modalitat de pesca sobre les diferents espècies d'ocells marins afectades.

En general, les espècies més susceptibles a ser capturades en les xarxes fixes solen tenir una gran capacitat de busseig, com els àlcids, anàtids marins i les baldrigues (Žydelis et al. 2013). En el Mediterrani, les xarxes semblen afectar fonamentalment al corb marí emplomallat (Louzao & Oro 2004, Karris et al. 2013a, Cortés & González-Solís, dades no publicades). Encara que també les baldrigues i gavines podrien ser capturades en aquest art de pesca (SEO/Birdlife 2014).

El primer treball que aportà evidències sobre l'ocurrència d'aquestes captures prové dels anys 70 i es basa en enquestes a pescadors realitzats al llarg de la costa Mediterrània francesa (Besson 1973). L'estudi trobà una alta incidència sobre la baldriga balear/mediterrània en el qual, tenint en compte l'esforç pesquer de l'època, s'estimà que podrien estar morint anualment 800 baldrigues en aquesta pesquera. Contràriament, els estudis més actuals basats en qüestionaris a pescadors (Espanya i Grècia: Louzao & Oro 2004, Karris et al. 2013a, SEO/Birdlife 2014), troben que les captures d'ocells ocorren de manera infreqüent i que rarament impliquen un gran nombre d'ocells (SEO/Birdlife 2014).

Palangres

En el Mediterrani, la captura accidental en la pesca de palangre es considera la major font de mortalitat per als ocells marins (Tudela 2004, ICES 2008, Quadre II). No obstant això, la informació disponible sobre l'impacte que suposa per als ocells marins encara és escassa i restringida a determinats països (Cooper et al. 2003), com França, Grècia, Itàlia, Malta, Espanya i Tunísia (Taula 1).

A partir d'aquesta informació, s'ha pogut determinar que almenys 12 espècies són susceptibles a les captures en les flotes palangreres del Mediterrani (Taula 1), incloent la Críticament Amenaçada baldriga balear (Birdlife International 2016). Aquesta última espècie mostra un tendència negativa severa a causa de la seva inusual baixa taxa de supervivència adulta, sent la mortalitat per captura accidental la principal sospitosa del seu declivi (Genovart et al. 2016). Aquesta tendència negativa associada amb una baixa supervivència adulta ha sigut també detectada en les poblacions de Malta i França de la baldriga Mediterrània (Oppel et al. 2011). Els autors proposen que la mortalitat en les pesqueres és el principal responsable del seu declivi.

D'acord amb aquests resultats, és molt probable que els accidents mortals d'ambdues espècies estiguin succeint fonamentalment a la pesca amb palangre. De fet, en el cas de la baldriga cendrosa, un estudi demogràfic realitzat a l'oest del Mediterrani suggereix que la captura accidental en el palangre està tenint un fort impacte sobre la seva viabilitat poblacional, especialment causat per l'elevada mortalitat generada i una major incidència sobre els adults (Genovart et al. 2017b).

La major part dels estudis realitzats al Mediterrani sobre la magnitud de les captures accidentals provenen de la flota espanyola que opera a l'oest de la conca. Per aquesta regió, s'ha estimat una taxa de captura accidental de 0,01 – 0,05 ocells per 1000 hams calats en el palangre pelàgic, el qual significa que podrien ser capturats al voltant de 500 ocells a l'any en la flota pelàgica espanyola (Valeiras & Camiñas 2003, García-Barcelona et al. 2010b). No obstant, s'obtingueren taxes de captura més elevades en la flota palangrera que opera a les Illes Columbretes (Castelló, País Valencià), especialment en la demersal (0.69 vs. 0.25 ocells/1000 hams). S'estima, per tant, per aquesta única regió una mortalitat anual de 650 – 2830 ocells (Belda & Sánchez 2001).

D'altra banda, aquests estudis han demostrat que les espècies més afectades per la pesca amb palangre són la baldriga cendrosa i el gavià argentat (*Larus michahellis*), i en menor mesura la baldriga balear (Belda & Sánchez 2001, Valeiras & Camiñas 2003, García-Barcelona et al. 2010b). Encara que es sospita que ocasionalment ocorren captures massives de desenes o centenars d'exemplars, on es veuen especialment involucrades la baldriga balear i mediterrània (Arcos et al. 2008, ICES 2013). A més, Belda i Sánchez (2003) trobaren que el 60% de les baldrigues

cendroses capturades a les Illes Columbretes eren adults, fet que agreuja l'impacte de les captures accidentals sobre les poblacions afectades (Arnold et al. 2006).

QUADRE II. MORTALITAT ANUAL D'OCELLS MARINS EN LA PESCA DE PALANGRE DEL MEDITERRANI

Combinant la informació recopilada per la Comissió General de Pesca del Mediterrani sobre l'esforç pesquer de les diferents flotes que operen al Mediterrani (GFCM Task 1, Recommendation GFCM/33/2009/3) amb les taxes de captura obtingudes a l'oest del Mediterrani (palangre demersal: Cortés & González-Solís, dades preliminars no publicades; palangre pelàgic: García-Barcelona et al 2010b), s'ha obtingut una estima conservadora de almenys 5100 ocells que podrien morir anualment en els palangrers que operen a la conca del Mediterrani: 3200 ocells en el palangre demersal i 2008 en el pelàgic. Cal tenir en compte però que aquestes xifres es troben infraestimades atès que no s'inclou la mortalitat produïda en els palangres de les embarcacions polivalents d'arts menors, ja que no es disposa informació sobre l'esforç pesquer, ni la possible existència d'embarcacions no registrades.

País	Nombre vaixells	Mortalitat anual palangre demersal	Mortalitat anual palangre pelàgic
Bulgària	50	53	43
Croàcia	216	535	-
França	73	741	75
Grècia	-	355	42
Itàlia	170	658	1487
Malta	53	99	190
Espanya	389	1094	213

En Malta, les entrevistes realitzades als pescadors de palangre mostraren un alt nivell de captures de baldrigues (Dimech et al. 2009), especialment en el palangre de fons. En aquesta regió, l'espècie més afectada és la baldriga cendrosa, mentre que la baldriga mediterrània es capturada ocasionalment. S'estima que al voltat de 1.200 baldrigues cendroses podrien ser capturades anualment en el palangrers de Malta, la majoria en la pesca demersal.

Karris et al (2012) també féu servir enquestes per tal d'avaluar les captures accidentals d'ocells en Grècia, en particular de la flota local que opera en el mar Jònic. Els autors han trobat que l'espècie més susceptible a la captura accidental és

també la baldriga cendrosa, tant en el palangre demersal com el pelàgic. No obstant, el palangre demersal és el responsable d'un major nombre de captures. A partir de la informació recopilada, estimaren una mortalitat anual de 400 individus de baldriga cendrosa que podrien ser capturats en la flota estudiada, dels quals el 90% serien capturats en els palangrers demersals.

En Itàlia, França i Tunísia també s'han registrat captures d'ocells marins en la flota palangrera, especialment de baldriga cendrosa (Cooper et al. 2003). Encara que la informació disponible continua sent anecdòtica i no permet quantificar o avaluar l'impacte causat per les pesqueres de palangre sobre les poblacions d'ocells marins. Aquests països alberguen importants colònies reproductores de baldriga cendrosa i mediterrània, per tant, és probable que les captures d'ocells siguin significatives en els palangrers que operen en aquestes àrees.

Convé destacar que, a pesar d'aquesta alta mortalitat d'ocells i el greu impacte que està tenint sobre les poblacions de baldrigues del Mediterrani, actualment encara no es fa servir o s'ha implementat cap tipus de mesura per reduir les captures accidentals en els palangres que operen al Mediterrani.

Mesures de mitigació per a la pesca amb palangre

Existeix una gran diversitat de mètodes per reduir la captura accidental d'ocells en els palangres, els quals poden comportar una modificació de les pràctiques pesqueres i/o dels equipaments (Bull 2007, Løkkeborg 2011).

En general, les mesures de mitigació es poden classificar en quatre categories principals (Brothers et al. 1999a, Løkkeborg 2011):

- **Evitar la pesca en les àrees i períodes on la interacció entre palangrers i ocells és més probable i intensa** (limitacions temporals, calat nocturn, etc.)
- **Limitar l'accés dels ocells als hams amb esquers** (modificar les barques per permetre el calat sota l'aigua, augmentar el pes del palangre per a que s'enfonsi més ràpid, utilitzar palangres més curts, etc.)
- **Dissuadir als ocells d'atacar els esquers** (ús de línies espantaocells, repel·lents olfactius o acústics, canons d'aigua, etc.)
- **Reduir l'atractiu o visibilitat dels esquers** (evitar el rebuig de peix o despulles abans o durant el calat, utilitzar esquers artificial o poc atractius per als ocells, tenyir els esquers de color fosc per a que siguin menys conspicus, etc.)

Actualment, en certes regions del món ja s'apliquen mesures per minimitzar les captures accidentals d'ocells. Aquestes mesures han resultat ser molt eficaces, ja que han permès reduir més del 80% o inclús quasi la totalitat de les captures d'ocells, com és el cas de les línies espantaocells (Melvin et al. 2001, Løkkeborg 2003), la calada nocturna (Cherel & Weimerskirch 1996, Weimerskirch et al. 2000) o l'addició de pes a la línia (Agnew et al. 2000, Robertson et al. 2006). No obstant, l'efectivitat i viabilitat dels mètodes de mitigació depèn del comportament de les espècies d'ocells que interaccionen (capacitat de busseig, alimentació nocturna), del tipus de palangre (demersal o pelàgic), així com d'altres característiques operacionals pròpies de cada flota (p.ex. velocitat de calada, horaris de pesca, tècnica per calar el palangre).

En conseqüència, per poder identificar correctament les mesures de mitigació més adients per a una flota en particular, cal tenir un coneixement detallat, no solament de les espècies d'ocells que interaccionen, sinó també de les característiques operacionals, dels components i estructures dels diferents tipus d'arts, així com determinar quins són els factors que incrementen el risc d'aquests accidents (Bull 2007, Løkkeborg 2011). Tanmateix, és essencial que l'aplicació d'aquests mètodes sigui compatible amb l'activitat pesquera. Es a dir, que s'utilitzin tècniques fàcils d'implementar, segures i que no disminueixin l'eficiència pesquera. També és recomanable que vagin acompañades d'incentius per als pescadors, no només pel fet de reduir els robatoris dels esquers per part dels ocells, sinó que també els proporcioni beneficis operacionals i/o socials (Gilman 2001, Gilman et al. 2005, Boyd 2014).

OBJECTIUS



L'**objectiu general** de la present tesi és avaluar i contribuir al coneixement sobre la problemàtica de les captures accidentals d'ocells marins en el palangrers artesanals que operen a l'oest del Mediterrani i identificar les possibles solucions per minimitzar-les. En particular, l'estudi s'ha centrat principalment en la flota de palangre demersal, atès que utilitza configuracions de palangre més perillosos per als ocells i existeix poca informació sobre el seu impacte.

Així doncs, els **objectius específics** de la tesi són:

- Caracteritzar la flota de palangre demersal espanyola que opera a l'oest del Mediterrani
- Determinar el grau d'interacció amb els palangrers de les diferents espècies d'ocells marins susceptibles a les captures accidentals
- Estimar la taxa de captura accidental i la mortalitat anual en els palangrers demersals de l'oest del Mediterrani, concretament en la conca nord-occidental
- Identificar els factors que tenen una influència rellevant sobre els intents d'atacar els esquers (com aproximació del risc de captura accidental)
- Examinar l'efecte de la pesca d'arrossegament sobre el grau d'interacció dels ocells amb els palangrers i el risc de captura accidental, utilitzant la baldriga cendrosa com a model d'estudi
- Determinar l'edat, sexe i origen dels ocells capturats accidentalment per la flota palangrera espanyola (pelàgica i demersal) i el seu patró espacial-temporal.
- Avaluar l'eficiència i aplicabilitat pràctica de diferents mesures de mitigació adaptades als palangrers artesanals demersals del Mediterrani: la calada nocturna, les línies espantaocells, l'addició de pesos i els esquers artificials.
- Proposar una estratègia per mitigar les captures accidentals en els palangrers demersals de l'oest del Mediterrani.

INFORME DEL DIRECTOR



El Dr. **Jacob González-Solís**, professor de la Universitat de Barcelona i supervisor de la tesi doctoral titulada “*Avaluació i mitigació de les captures accidentals d’ocells marins en la pesca artesanal de palangre del Mediterrani*”, informa que l'estudi realitzat per **Verònica Cortés Serra** per a la present tesi doctoral compren 4 articles científics; 2 publicats, 1 acceptat i 1 sotmès a revistes científiques d'elevat impacte i incloses en el Science Citation Index (SCI).

A continuació s'especifica la contribució científica del doctorand i el factor d'impacte (segons “Thomson Institute for the Scientific Information”) de les revistes científiques on s'ha publicat o han sigut sotmesos els manuscrits:

- **Capítol 1. Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates**

Verónica Cortés, Jose Manuel Arcos & Jacob González-Solís

Marine Ecology Progress Series 565: 1- 16 (Publicat)

Factor d'impacte (2017): 2.292

V.C. ha contribuït en el disseny de l'estudi, recollida i anàlisi de les dades i la redacció científica.

- **Capítol 2. Relative abundance and distribution of fisheries influence risk of seabird bycatch**

Andrea Soriano-Redondo, Verónica Cortés, José Manuel Reyes-González, Santi Guallar, Juan Bécares, Beneharo Rodríguez, José Manuel Arcos & Jacob González-Solís

Scientific Reports 6:37373 (Publicat)

Factor d'impacte (2016): 4.847

V.C. ha contribuït en la recollida i anàlisi de les dades i ha realitzat comentaris en el manuscrit.

- **Capítol 3. Sex and age-biased mortality of three shearwater species in longline fisheries of the Mediterranean**

Verónica Cortés, Salvador García-Barcelona & Jacob González-Solís

Marine Ecology Progress Series (En premsa)

Factor d'impacte (2017): 2.292

V.C. ha contribuït en la recollida i anàlisi de les dades i la redacció científica.

- **Capítol 4. Seabird bycatch mitigation trials in artisanal demersal longliners of the Western Mediterranean**

Verónica Cortés & Jacob González-Solís

PLOS ONE (En revisió)

Factor d'impacte (2015-2016): 3.54

V.C. ha contribuït en el disseny de l'estudi, recollida i anàlisi de les dades i la redacció científica.

A més a més, el director certifica que els coautors citats en els articles científics que conformen la present tesi doctoral, no han utilitzat, implícitament o explícitament, aquests treballs per a l'elaboració d'altres tesis doctorals.

Barcelona, 30 de novembre de 2017

Dr. Jacob González-Solís

SECCIÓ I

COMPRENSIÓ I AVALUACIÓ DE LES CAPTURES ACCIDENTALS D'OCELLS MARINS ALS PALANGRERS DE L'OEST DEL MEDITERRANI



CAPÍTOL 1

Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates

Ocells marins i palangrers demersals en el nord-oest del Mediterrani: factors que modulen les seves interaccions i les taxes de captura accidental

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Juan Bécares

RESUM

La mortalitat per captura accidental en les pesqueres de palangre es considera la principal amenaça que troben al mar nombroses espècies d'ocells marins. Aquestes captures accidentals ocorren a nivell global, encara que els nivells de mortalitat estan principalment determinats pels trets específics de la pesquera que opera en cada àrea, i el comportament d'alimentació i l'abundància local dels ocells marins. En el Mediterrani es sap que els palangrers artesanals demersals capturen diversos ocells marins, no obstant, existeix escassa informació sobre les taxes de captura i els principals factors que influeixen sobre la probabilitat i el nivell de les captures accidentals. Des de 2011 fins 2015 realitzarem 220 sortides a bord de palangrers demersals del mar Balear amb el propòsit d'estudiar la seva interacció amb els ocells marins, així com entendre els procediments detallats de la pesquera i els factors que poden influir sobre les captures accidentals dels ocells marins. Addicionalment, registrarem els ocells capturats que foren reportats pels pescadors. Trobem una mitjana general de la taxa de captura accidental de 0,58 ocells per 1000 hams (0,13-1,37, 95% IC), el qual implicaria una estima conservativa de 274 fins 2.198 ocells marins capturats anualment en els palangrers demersals de l'àrea d'estudi. Les espècies més afectades foren les 3 endèmiques i amenaçades baldrigues del Mediterrani (baldriga cendrosa *Calonectris diomedea*, balear *Puffinus mauretanicus* i mediterrània *P. yelkouan*), probablement a causa del seu comportament gregari i les seves capacitats de busseig. En general, els principals factors que influïren sobre el risc de captura accidental foren l'estació i el moment del dia. Altres factors influents foren el tipus d'esquer, les condicions de vent, la configuració de l'art (en particular la distància entre els pesos), la proximitat a les colònies de cria i el nombre d'hams. Aquest estudi demostra que la mortalitat causada pels palangrers demersals és alta i podria posar en perill la viabilitat de les poblacions de les baldrigues. Per tant, la identificació i implementació de mesures de mitigació es requereix de manera urgent.

ABSTRACT

Bycatch mortality in longline fisheries is considered the main threat at sea for numerous seabird species. These incidental catches occur worldwide, but mortality levels are mainly determined by the specific traits of the fishery operating in each area and the feeding behaviour and local abundance of seabirds. In the Mediterranean, demersal artisanal longliners are known to catch several seabirds, but bycatch rates and the main factors influencing both the probability and the level of seabird bycatch are poorly known. From 2011 to 2015 we conducted 220 trips onboard demersal longline vessels of the Balearic Sea, aiming to study their interaction with seabirds, as well as to understand the detailed procedures of the fishery and the factors that might influence seabird bycatch. Additionally, we

recorded bird catches reported by fishermen. We found an average overall bycatch rate of 0.58 birds per 1000 hooks (0.13–1.37, 95% CI), which would imply a conservative estimate ranging from 274 to 2198 seabirds caught annually on demersal longliners in the study area. The most affected species were the 3 endemic and threatened Scopoli's, Balearic and Mediterranean shearwaters of the Mediterranean (*Calonectris diomedea*, *Puffinus mauretanicus* and *P. yelkouan*, respectively), likely due to their highly aggregative behaviour and diving capabilities. Overall, the main factors influencing bycatch risk were season and time of day. Other influential factors were bait type, wind conditions, gear configuration (specifically, distance between weights), proximity to the breeding colony and the number of hooks. This study shows that mortality caused by demersal longliners is high and may be jeopardizing the viability of the shearwater populations. Therefore, the identification and implementation of mitigation measures is urgently required.

Keywords: Artisanal fisheries, On-board observations, Mortality, Mitigation measures, Susceptibility to capture, Shearwaters

INTRODUCTION

Fishing is considered one of the most serious threats to seabirds worldwide, both through bycatch and the over-exploitation of fish prey (Tasker et al. 2000, Croxall et al. 2012). Bycatch in longline fisheries mainly occurs when birds try to steal bait from the hooks while the line is being set. During these attempts, seabirds can become entangled or hooked, and die by drowning when the gear sinks (Brothers et al. 1999a). Globally, at least 160 000 seabirds are killed annually in longline fisheries, most of them albatrosses (Diomedeidae), petrels and shearwaters (Procellariidae) (Anderson et al. 2011). Many of these species are threatened, and bycatch has significantly contributed to dramatic declines of their populations (Weimerskirch et al. 1997, Inchausti & Weimerskirch 2001, Lewison & Crowder 2003, Wanless et al. 2009). This is especially so since bycatch influences adult survival, the most sensitive demographic parameter for long-lived organisms with low fecundity and delayed maturity, such as seabirds (Weimerskirch 2002). Collecting data through on-board observations is the first step to quantifying bycatch and identifying the main drivers affecting bycatch rates. Many factors potentially influence the degree of seabird interactions with longline vessels, such as operational characteristics, type and configuration of the fishing gear, weather conditions at setting and the seabird species present in a given area (Brothers et al. 1999b, Weimerskirch et al. 2000, Gilman 2001, Dietrich et al. 2009). Understanding the relative importance of these factors is crucial to managing and implementing

best practices to reduce bycatch for a specific longline fleet and area (Brothers et al. 1999a).

Seabird bycatch is well documented in some regions, such as the Southern Oceans and North Pacific, where industrial longline vessels operate (Brothers 1991, Gales et al. 1998, Weimerskirch et al. 2000). Observer programmes conducted in these regions have allowed the development of mitigation measures adapted to the regional fleets to minimize the incidence of bycatch (Brothers et al. 1999a, Gilman et al. 2003, Løkkeborg 2011). Nonetheless, seabird bycatch rates in many longline fleets are still largely unknown, especially in semi-industrial and artisanal fleets (Anderson et al. 2011). One of the major gaps of knowledge is in the Mediterranean Sea, where longline fishing is arguably the main cause of seabird mortality and possibly the most important factor contributing to the decline of some seabird populations(Cooper et al. 2003, Arcos et al. 2008, Laneri et al. 2010, Genovart et al. 2016). Despite this, fishermen in this area still do not use any mitigation measures to reduce seabird catches. Previous studies in Spain estimated bycatch rates at ca. 0.013–0.049 birds per 1000 hooks in the semi-industrial pelagic longliners (Valeiras & Camiñas 2003, García-Barcelona et al. 2010b). These figures can be considered relatively low, but several characteristics of this fleet make it less problematic compared to artisanal demersal longliners, which use smaller hooks baited with the most common seabird prey in the area, such as sardine *Sardina pilchardus*. Information from these artisanal fisheries is scarce, but supports the view that they can have a higher impact on seabirds than semi-industrial pelagic longliners. Indeed, a previous study on artisanal demersal longliners operating around the Columbretes Islands showed high mortality rates, reaching up to 0.16–0.69 birds per 1000 hooks (Belda & Sánchez 2001). However, mortality estimates assessed in a small area cannot be extrapolated to other areas because bycatch rates are highly variable locally, due to differences in bird abundances and longline fleet characteristics (Valeiras & Camiñas 2003, Lewison et al. 2014). Therefore, reasonably broad spatial and temporal coverage of on-board observer programmes is required to obtain accurate and reliable bycatch estimates (Gilman et al. 2005, Anderson et al. 2011).

This study provides the first comprehensive data on seabird bycatch by the artisanal demersal longliners operating throughout the entire Balearic Sea (northwestern Mediterranean) based on on-board observations. Our main objectives were to (1) characterize the Spanish Mediterranean demersal longline fishery; (2) determine the degree of interaction with longliners for the different species of seabirds; (3) assess the factors influencing seabird attempts to take bait (taken as a proxy of bycatch risk); and (4) estimate the bycatch mortality of this fleet for the study area.

MATERIALS AND METHODS

Study area

The study was performed in the Balearic Sea (Fig. 1), which includes the Balearic Islands and the northeastern Iberian waters (Catalonia and north of Valencian region), and marginally extends southwards across the south of Valencian region. The area holds important seabird breeding colonies, including the entire global population of the Balearic shearwater *Puffinus mauretanicus* and the bulk of that of Audouin's gull *Larus audouinii*, as well as important populations of Scopoli's shearwater *Calonectris diomedea* (Martí & Del Moral 2003). Other breeding species of relevance include the European storm petrel *Hydrobates pelagicus*, the Mediterranean shag *Phalacrocorax aristotelis desmarestii* and the yellow-legged gull *L. michahellis*. All of these species have important foraging grounds in the region, particularly over the Iberian shelf, which also attracts breeding birds from colonies beyond the study area, particularly Mediterranean and Scopoli's shearwaters (Arcos, et al. 2012b, Péron & Grémillet 2013, Péron et al. 2013).

The demersal longline fleet in the region consists of artisanal boats ranging from 7 to 15 m in length and 1 to 4 crew members. This artisanal fleet is very heterogeneous and dynamic, with high variability regarding longline configuration and fishing practices, mainly linked to the species targeted and the specific fishing habits. Overall, the fleet can be divided into 2 major groups: medium-scale longliners and small-scale vessels. Basic differences between these groups are the distance from the coast where they fish, the type and size of hook and bait, the number of hooks that are set and the longline length. Moreover, small-scale vessels are polyvalent, so they can alternate among different gears throughout the year, such as longline, gillnets, trammel nets or traps. Medium-scale longliners are mainly concentrated on the Catalan coast (11 boats in 2015; Generalitat de Catalunya pers. comm.), with another 6 boats in Valencia (in 2015; www.agroambient.gva.es) and only 3 in the Balearic Islands (in 2014; Govern de les Illes Balears pers. comm.). Their activity is reported to the administration, so it was possible to estimate the dimension and effort of the fleet. On the other hand, small-scale vessels are not bound to report on the type of gear used, so their effort is little known. They represent the most important fleet in the Balearic Sea, reaching a few hundreds of boats operating in each sub-region.

Data collection

Observations onboard demersal longliners were carried out across the Balearic Sea during 220 fishing days (103 in medium-scale and 117 in small-scale vessels), from January 2011 to January 2015. These comprised 35 artisanal vessels (11 medium-scale and 24 small-scale vessels) from 26 fishing ports. Observation trips were

organized attempting to cover the main fishing grounds of the longline vessels in the study area year-round. Detailed descriptions of the fishing gear and practices (e.g. operational characteristics, fishing grounds, target species), were documented for each fishing trip. Specifically for each setting operation, the position, time of day, meteorological data and diverse fishing characteristics were recorded. In addition, observers registered at 10 min intervals all seabirds that followed the vessels during line setting. For each time interval, the number and distance astern of all attacks on bait performed by each seabird species were also registered and were ranked in 6 intervals: <5, 5–10, 11–20, 21–50, 51–100 and >100 m. In the night settings, counts of birds and attacks were limited by the distance from the stern at which they could be detected, given the illumination provided by the boat. All seabirds bycaught were recorded specifying the species, location and time of catch, when it was possible to recover the bird hooked.

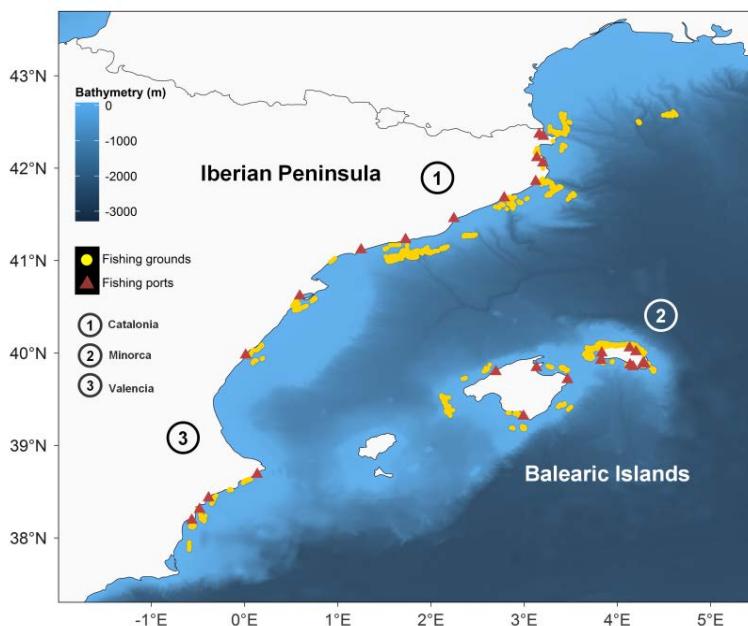


Figure 1. Fishing grounds in the northwestern Mediterranean in which on-board observations were performed during the study period

During the 4 yr of study, fishermen also provided information on seabird catches that occurred when no observers were onboard. In some cases, they collected seabird carcasses which allowed us to confirm the species identification. Although these observations were collected irregularly and opportunistically, this

information helped us to understand the occurrence, species involved and the main periods of multiple-catch events; an understanding that would have been difficult to obtain solely from the on-board programmes due to the scarcity of the events.

Data analysis

Factors affecting seabird attack rates. During this study, we did not register sufficient bird catches to properly assess what factors have an important influence on bycatch. Instead, we used the number of attacks on baited hooks as a proxy of bycatch risk, since it reflects the direct interaction with the longline gear. This assumption was supported by the positive and significant correlation between bycatch and attack numbers, both when we considered all settings monitored ($r_s = 0.42$, $p < 0.001$, $N = 309$ settings) and only those in which there were seabird catches ($r_s = 0.71$, $p < 0.001$, $N = 24$).

Generalized linear mixed models (GLMMs) were used to identify the main factors affecting seabird attack rates. Analyses were conducted considering 2 groups: (1) all seabird species together and (2) only Scopoli's shearwaters, one of the species most commonly caught by the demersal longline fleet. In the latter case, we only considered those fishing trips performed during the period in which the species is present in the Mediterranean (March to October).

Count data are characterized by skewed distributions, as a result of a high proportion of zero values and a few events of large counts (flocking behaviour) (Fletcher et al. 2005). Hurdle models are a suitable method for modelling this type of distribution (Welsh et al. 1996, Fletcher et al. 2005, Zuur et al. 2009); these models are characterized by treating the data in 2 parts: (1) presence versus absence (Zero part); and (2) presence observations (Count part).

We analysed the relationship between the occurrence and number of attacks with temporal, spatial and operational variables (Table 1). To assess its influence on seabird attraction to longliners, trawling activity was also considered, as previous studies found an important effect on seabird catches (Laneri et al. 2010, Báez et al. 2014, Soriano-Redondo et al. 2016). Consecutive settings with the same fishing gear characteristics were grouped to avoid pseudoreplication. Vessel identity was included in all models as a random effect to control for the non-independence between sets within the same vessel. The number of birds following the boat was used as an offset in the count data. We only considered the line settings targeting demersal fish. Moreover, settings performed at night and with hooks baited with species of crustaceans and molluscs were not considered in the count data or in either 2 parts of the model due to the low number of events of attacks on bait. Likewise, trawler activity was not considered in the count data due to the low number of observations when trawlers were not operating.

We applied the 'glmmadmb' function from the 'glmmADMB' package (R 3.0.1.). The Zero hurdle part was modelled assuming a binomial (BI) error structure (logit link function = cloglog), while the Count part was analysed considering a truncated version of the Negative Binomial distribution (HNB). We explored the factors selected to check collinearity between them and to remove non-explanatory categories. We then used the variance inflation factor (VIF) to verify the independence of each variable in the estimate of the regression coefficients of the model (Zuur et al. 2010).

Finally, we constructed the following models (see detailed information about the factors considered in Table 1):

All species:

Number of attacks (HNB) ~ season + wind + bait type + bait size + time + hooks + distance weights

Occurrence of attacks (BI) ~ season + wind + bait type + bait size + time + hooks + distance weights + trawler activity

Scopoli's shearwater:

Number of attacks (HNB) ~ period + distance to colony + wind + bait size + time + distance weights

Occurrence of attacks (BI) ~ period + distance to colony + wind + bait type + bait size + time + hooks + distance weights + trawler activity

Model selection was made using the model-averaging process. This approach is useful when there is uncertainty about which is the best model (Burnham & Anderson 2002). In this way we obtained model-averaged parameter estimates, taking into account the unconditional variation linked to the uncertainty of the model selection (Burnham & Anderson 2002). We estimated the parameters using the 95% confidence set of the models where the sum of Akaike weights reached >0.95.

Seabird bycatch and mortality. Bycatch rate was expressed as the number of birds caught per 1000 hooks set. We calculated the average rate for each group of demersal longliners (medium and small-scale vessels), area (Iberia and Balearic Islands) and longline type. Confidence intervals (95%) were determined using bootstrap re-sampling (10000 iterations) from observed data.

Table 1. Explanatory variables used in the analyses of the factors influencing seabird interaction with longliners in the northwestern Mediterranean Sea

Factor	Type	Description
<u>Temporal</u>		
Season (all species)	Categorical	Winter (Dec–Feb), Spring (Mar–May), Summer (Jun–Sep), Autumn (Oct–Nov)
Period (Scopoli's shearwater)	Categorical	Prelaying (March–1 st week June), incubation (until mid-July), chick-rearing (until mid-October)
<u>Spatial</u>		
Distance to colony	Continuous	Kilometres from the nearest breeding colony (scaled)
<u>Meteorological</u>		
Wind	Categorical	Presence of wind: Beaufort force scale > 1
<u>Operational</u>		
Bait type	Categorical	Fish, cephalopods, mixed (fish + cephalopods)
Bait size	Categorical	Shorter or longer than 10 cm (max. = 20 cm)
Setting time (time)	Categorical	Night, within ±1 h of dawn, daytime
Hooks set (hooks)	Continuous	Number of hooks set (scaled)
Distance between weights	Continuous	Distance between the weights attached to the snoods (scaled)
<u>Trawler activity</u>		
Trawler working days (trawler activity)	Categorical	Overlapping with trawling activity according to their spatial and temporal closures

To estimate the mortality caused by the demersal longliners in the Balearic sea, we only considered the data collected in vessels from Catalonia (Iberia) and Minorca (NE Balearic Islands), as these areas had better spatial and temporal effort coverage allowing reliable estimates. For the medium-scale longliners, we only considered the bycatch rate obtained on the Catalan coast. Fishing effort was estimated using the data of annual fish landings from 2015 provided by the local administration (Generalitat de Catalunya). From this, we estimated the number of vessels operating in the area and the average number of fishing days per year (11 boats: 143 fishing days for each vessel and 3 141 281 hooks set by the entire fleet). For the small-scale longliners, we were only able to estimate mortality for Minorca. There we could collect data on the boats with sufficient detail to estimate fishing effort through surveys of fishermen (18 boats: 78 fishing days and 1 534 572 hooks). In the Iberian area, we did not have enough information to estimate the effort of these vessels; therefore it was not possible to evaluate the mortality

caused by this fishery. In all cases, mortality estimates were only based on dead birds and did not include birds released alive.

To evaluate differences in bycatch susceptibility among species and longline type, we used the chi squared (χ^2) test to compare the proportion of birds caught during the observations onboard with the expected proportion of birds that could potentially be caught (Y), as indicated by (1) the number of birds observed following the vessels and (2) the observed number of attacks on baited hooks. The proportions were calculated as:

$$Y_{ij} = \frac{n_{ij}}{N_j} \quad (1)$$

where n_i is the individual number of i species for each j source of data considered (attendance, attacks), while N is the total number of all species vulnerable to bycatch.

RESULTS

Characteristics of the demersal longline fishery

The fishing grounds of the medium-scale demersal vessels stretched from 1.5 to 36 nautical miles (n miles) offshore (mean \pm SD = 8.7 ± 3.4), at depths between 22 and 549 m (mean \pm SD = 271.7 ± 112.9). They manually set from 338 to 4800 hooks (1888 ± 731) per fishing day at 1.2 to 10.5 knots (5.04 ± 1.58). The size of the hooks was 3.57 ± 0.30 and 1.64 ± 0.26 cm of total length and of gape, respectively. In the case of the small-scale vessels, several boats used demersal longlines seasonally, mainly in accordance with the temporal pattern of fish abundance, market conditions and time closures of specific target species. However, a few vessels used longlines year round. Their fishing grounds were usually close to the coast, ranging from 0.3 to 19 n miles (2.3 ± 1.7), at depths between 7 and 609 m (mean \pm SD = 81.8 ± 71.7). They set from 147 to 2610 hooks (957 ± 538) each fishing day at 0.9 to 7 knots (2.93 ± 0.95). Hook sizes were 2.97 ± 0.48 cm for overall length and 1.42 ± 0.41 cm for the gape.

For both vessel types, hooks were commonly baited with fish, usually sardine, European anchovy *Engraulis encrasicolus* and round sardinella *Sardinella aurita*, but sometimes with cephalopod species. Fishermen from the small-scale longliners frequently used smaller-sized bait, either because they cut fish into small pieces or baited with other small species of crustaceans and molluscs. Longlines were mainly set during daylight (84% of the settings observed, $N = 316$), either at dawn (48%) or during daytime (36%), while setting at night was less frequent (16%). The soak time (the time lapse between the setting and the hauling) of the longlines varied

among vessels and target species. Most often longlines were hauled 1 to 2 h after setting, although some fishermen left longlines in the water for ca. 15 h.

Irrespective of the type of vessel, longline configurations can be classified into 2 types according to the distribution of the hooks relative to the seabed: (1) the Piedra-Bola (PB) system (Fig. 2a, b), which is characterized by using a combination of weights and floats, so that hooks are kept at different depths, and (2) the bottom longline (Fig. 2c) which keeps the hooks level over the seafloor by only attaching weights to the snoods at regular intervals. The PB system may also be divided in 2 different sub-groups: the zigzag (Fig. 2a) and the pyramidal structure (Fig. 2b). The main differences between these structures are the distance between weights and the distance from the float to the nearest weight (Table 2), these being shorter in the zigzag structure. The zigzag structure was most commonly used by the medium-scale vessels (78% of the fishing trips conducted), mainly employed for fishing European hake *Merluccius merluccius* and blackbelly rosefish *Helicolenus dactylopterus*. Pyramidal structures were less frequent (8%) and were used to target blackspot seabream *Pagellus bogaraveo*. In addition, some fishermen occasionally used this structure for fishing pelagic species (7%), such as Ray's bream *Brama brama*. In this case, they used larger floats and more weights attached to the branch lines (5.4 ± 2.4 kg) placed at greater distances (556.0 ± 72.7 m). Bottom longlines (Fig. 2c) were typically used in small-scale vessels (86%) for fishing a wide diversity of demersal fish, such as common pandora *Pagellus erythrinus*, toothed bream *Dentex dentex* and gilt-head seabream *Sparus aurata*. In this type of fishing gear, we could distinguish 2 different longline configurations based on whether fishermen did or did not use weights attached along the mainline (Table 2; 50%, bottom-weights; 36%, bottom-no weights).

Seabird species and abundance

Seabirds were present in 67% of 316 settings monitored, totalling 1969 individuals from 16 species (Table 3). The most frequent species behind the vessels were Scopoli's shearwater (37% of the sets), yellow-legged gull (27%), Audouin's gull (11%), Balearic shearwater (7%) and Mediterranean gull *Larus melanocephalus* (6%).

Attempts to take baits occurred in 38% of the settings monitored, totalling 2180 events (Table 3). The main species involved in these attacks were Scopoli's shearwater (58%), Balearic shearwater (17%), yellow-legged gull (10%) and Audouin's gull (8%) (Table 3). Considering only the settings performed during daytime (N = 265), we found that most attacks occurred within 5 to 20 m behind the stern of the boat (89%). For the small-scale vessels, attacks mainly occurred at 5 to 10 m from the stern (53%), while for medium-scale boats, the attacks were most frequent from 10 to 20 m (74%).

Regarding the gear configuration used (Fig. 3), for PB-zigzag, most attacks occurred from 10 to 20 m astern (85%), while for bottom-weights attacks occurred more often at 5 to 10 m (61%). For the bottom-no weights, attacks also occurred in the first 10 m (40%), but were more frequent from 10 to 20 m (52%).

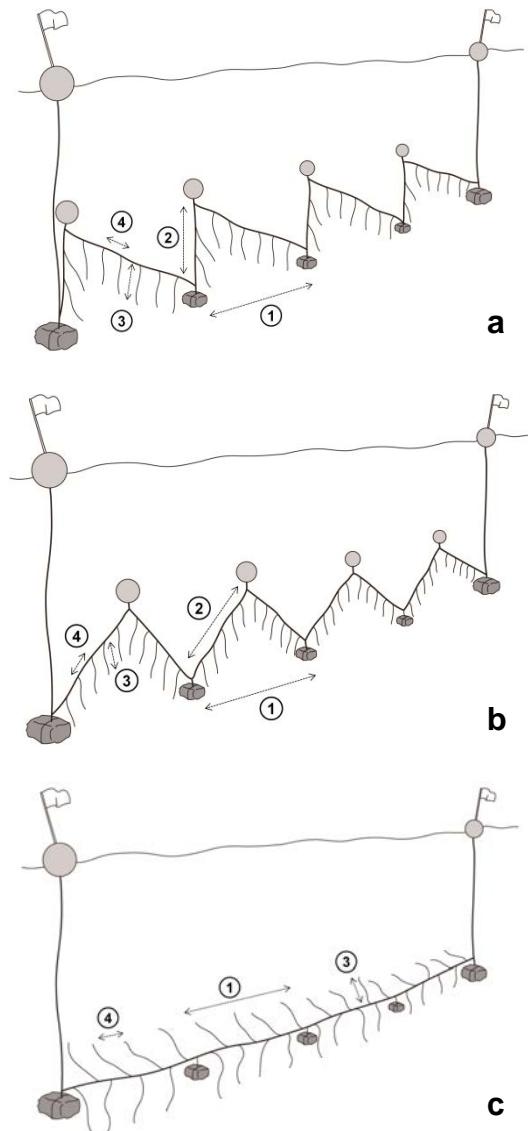


Figure 2. Longline configurations used by the demersal fleet: (a, b) the “Piedra – Bola” system (a = PB – zigzag, b = PB – pyramidal) and (c) the bottom longlines (bottom-weights). 1 = distance between weights, 2 = minimum distance between the weight and the float, 3 = length of branch lines, 4 = distance between hooks. Drawing by Toni Mulet

Table 2. Fishing gear characteristics of the most commonly used longline types by demersal longliners of the Balearic Sea. PB = "Piedra-Bola" configuration. Distance values and lengths are expressed in meters. Values correspond to mean \pm SD. Numbers inside brackets refers to the number of fishing trips in which the fishing gear was used. Medium = medium-scale vessels (N = 96 fishing trips), Small = small-scale vessels (N = 114)

Gear:	PB- zigzag		PB- pyramidal		Bottom-weights		Bottom-no weights
Type of vessel:	Medium	Small	Medium	Small	Medium	Small	Small
% usage and (n)	78 (80)	10 (11)	8 (8)	4 (5)	14 (15)	50 (58)	36 (42)
Weight (kg)	2.1 \pm 0.4	1.2 \pm 1	3.61 \pm 1.1	0.5 \pm 0.1	1.10 \pm 0.47	0.8 \pm 0.8	-
Distance between weights	97.3 \pm 28.4	113.6 \pm 32.0	120.8 \pm 27.7	201.4 \pm 242.8	887.1 \pm 539.7	411.3 \pm 364.0	-
Min distance weight to float	17.9 \pm 9.6	30.6 \pm 12.2	96.7 \pm 87.4	101.4 \pm 122.8	-	-	-
Length of branch lines	1.92 \pm 0.1	2.1 \pm 0.2	2.0 \pm 0.0	2.0 \pm 0.0	1.3 \pm 0.7	2.4 \pm 0.6	2.2 \pm 0.29
Distance between hooks	3.9 \pm 0.9	5.0 \pm 1.1	3.5 \pm 0.6	5.6 \pm 0.7	6.0 \pm 1	6.8 \pm 1.9	6.2 \pm 0.44

Table 3. Number of birds (mean \pm SD, total birds within brackets, N = 316 settings) of each species observed following vessels (attendance), species occurrence (% total occurrence days within brackets), number of bait attacks (mean \pm SD, total attacks within parenthesis, N = 298) and occurrence of attack events 8%, in parenthesis number of days on which attacks observed) from the sets

Common name	Taxon	No. attending	% bird occurrence	No. of attacks	% attack occurrence
Scopoli's shearwater	<i>Calonectris diomedea</i>	8.3 \pm 13.5 (730)	27.8 (88)	22.1 \pm 57.1 (1280)	19.13 (57)
Balearic shearwater	<i>Puffinus mauretanicus</i>	5.7 \pm 16.0 (142)	7.9 (25)	19.2 \pm 56.6 (365)	6.4 (19)
Yellow-legged gull	<i>Larus michahellis</i>	4.7 \pm 6.5 (536)	35.8 (113)	6.2 \pm 9.9 (212)	11.4 (34)
Audouin's gull	<i>Larus audouinii</i>	3.2 \pm 3.5 (232)	22.8 (72)	5.7 \pm 6.7 (183)	10.7 (32)
Mediterranean shearwater	<i>Puffinus yelkouan</i>	3.5 \pm 2.7 (35)	3.2 (10)	7.5 \pm 8.3 (30)	1.3 (4)
Mediterranean gull	<i>Larus melanocephalus</i>	3.1 \pm 3.1 (107)	11.1 (35)	1.6 \pm 1.4 (13)	2.7 (8)
Small shearwaters	<i>Puffinus spp.</i>	2.7 \pm 2.6 (30)	3.5 (11)	6.8 \pm 6.7 (27)	1.3 (4)
Black – legged kittiwake	<i>Rissa tridactyla</i>	2.7 \pm 2.4 (38)	4.4 (14)	4.9 \pm 5.2 (44)	3.0 (8)
Sandwich tern	<i>Sterna sandvicensis</i>	2.6 \pm 2.01 (13)	1.6 (5)	4.7 \pm 2.2 (14)	1.0 (3)
European storm-petrel	<i>Hydrobates pelagicus</i>	2.3 \pm 1.4 (75)	10.1 (32)	0	0
Black-headed gull	<i>Chroicocephalus ridibundus</i>	1.5 \pm 1.0 (6)	1.3 (4)	9 \pm 0.00 (9)	0.3 (1)
Common tern	<i>Sterna hirundo</i>	2 (4)	0.6 (2)	0	0
Northern gannet	<i>Morus bassanus</i>	1.2 \pm 0.5 (6)	1.6 (5)	1.3 \pm 0.6 (4)	1.0 (3)
Great skua	<i>Catharacta skua</i>	1 (1)	0.3 (1)	0	0
Lesser black-backed gull	<i>Larus fuscus</i>	1 (3)	1.0 (2)	0	0
Pomarine skua	<i>Stercorarius pomarinus</i>	1 (1)	0.3 (1)	0	0
Great cormorant	<i>Phalacrocorax carbo</i>	5 (5)	0.3 (1)	0	0

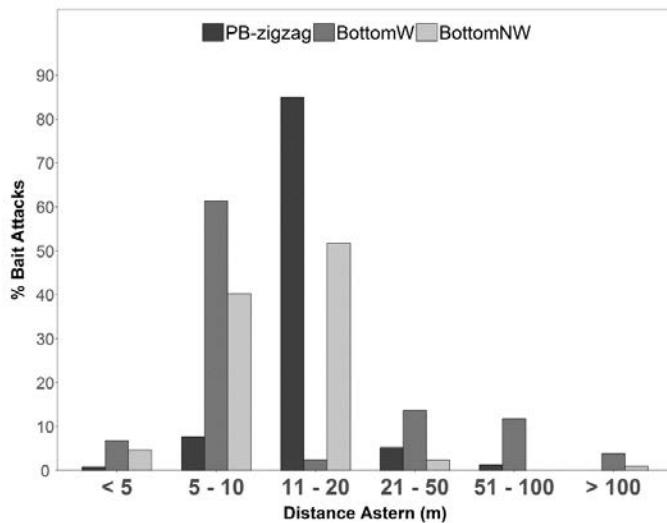


Figure 3. Proportion of bait attacks (%) performed by seabirds at different distance-intervals from the vessel stern considering separately the gear configurations most commonly used by demersal longliners of the study area. PB-zigzag = Piedra – Bola (zigzag configuration). BottomW = longline with only weights attached along the mainline (bottom-weights). BottomNW = longline without either weights or floats (bottom-no weights). Piedra-bola and bottom longline configurations correspond to gear of the medium and small-scale vessels, respectively. The PB-pyramidal configuration was not considered here due to low sample size

Factors influencing seabird attacks

All species. Season and the bait used were the most important factors influencing the number of attacks (Table 4). The number of attacks was greater in spring and when fishermen used bait larger than 10 cm, but it decreased when only fish bait was used. Moreover, the number of attacks was higher on windy days and with an increased number of hooks set. The occurrence probability of attacks was mainly influenced by the setting time, the season and the bait type used; it increased in settings at dawn, during spring and when fishermen used fish bait. In addition, occurrence probability was greater on windy days and at larger weight to weight distances.

Scopoli's shearwater. The number of attacks was greater in the pre-laying and incubation periods than during chick-rearing (Table 4), and also when larger bait was used. In addition, the number of attacks increased on windy days and with the distance between weights. The occurrence probability of attacks was mainly influenced by the setting time and the season; it increased during dawn settings and during the incubation period. Moreover, the occurrence probability was higher on windy days, but decreased with the increased distance to breeding colonies.

Table 4. Parameters estimated in the model averaging selection (coefficients values and unconditional standard errors) for each variable included in the two hurdle processes: Abundance (number of attacks) and Occurrence (presence probability of attacks), considering all seabird species and only Scopoli's shearwaters. RI = Relative variable importance (sum of the Akaike weights from all models in the set where the factor occurs). Coefficient values denote the direction and the effect size. Parameters of the categorical factors were calculated relative to the reference categories (coefficient takes the value 0): Autumn (Season), Prelaying (Period), Calm (Wind), Cephalopods (Bait species), bait size lower than 10 cm (Bait size), dawn/night (time), weekend or trawling moratorium (Trawler activity). Abundance of attacks in night settings was not considered in the analysis.

Fixed Factors	Categories	All species				Scopoli's shearwater			
		Abundance	RI	Occurrence	RI	Abundance	RI	Occurrence	RI
(Intercept)		-1.00 ± 0.48		-2.86 ± 0.69		-0.03 ± 0.63		-3.24 ± 0.78	
Season/Period	Spring/Incubation	1.43 ± 0.36	1	0.93 ± 0.35	1	-0.09 ± 0.49	1	1.03 ± 0.48	0.89
	Summer/Chick-rearing	0.44 ± 0.35		0.18 ± 0.38		-2.52 ± 0.81		0.04 ± 0.61	
	Winter	0.16 ± 0.46		-0.01 ± 0.41		-		-	
Distance to colony	Number	-	-	-	-	-0.43 ± 0.31	0.41	-0.71 ± 0.35	0.82
Wind	Occurrence	0.27 ± 0.12	0.62	0.60 ± 0.20	0.99	0.53 ± 0.20	0.79	0.83 ± 0.34	0.91
Bait type	Fish	-0.75 ± 0.30	0.97	0.96 ± 0.32	0.96	-	-	0.66 ± 0.52	0.25
	Mixed	0.21 ± 0.26		0.77 ± 0.35		-		0.51 ± 0.46	
Bait size	> 10 cm	0.85 ± 0.25	1	0.15 ± 0.30	0.28	1.59 ± 0.48	1	0.44 ± 0.42	0.37
Time	Dawn	-	0.51	1.38 ± 0.46	1	-	0.25	1.50 ± 0.69	1
	Day	-0.35 ± 0.22		0.75 ± 0.49		0.27 ± 0.24		-0.24 ± 0.79	
Hooks	Number	0.27 ± 0.12	0.79	0.17 ± 0.12	0.51	-	-	-0.13 ± 0.23	0.29
Distance weights	Number	0.22 ± 0.16	0.44	0.44 ± 0.13	1	0.39 ± 0.22	0.59	0.19 ± 0.17	0.38
Trawler activity	Occurrence	-	-	-0.44 ± 0.30	0.52	-	-	-0.17 ± 0.51	0.25

Seabird bycatch and mortality

Bycatch occurred in 9% of the settings observed (12% of the fishing days), totalling 109 birds out of 342 022 hooks observed (Table 5). In addition, 1 bird was caught during the hauling operations. Most birds were caught by the small-scale vessels (81%) when comparing type of vessels, and in the bottom-weight configuration (55%) when considering the gear type. However, most of these catches occurred in a single setting that caught 48 *Puffinus* spp. The remaining catches occurred in the bottom longlines without weights (25%), PB-zigzag configuration (17%) and in the PB-pyramidal configuration targeting pelagic fish (2%). Overall average bycatch rate obtained in the study area was 0.58 birds per 1000 hooks (0.13–1.37, 95% CI; N = 211 fishing trips). The highest bycatch rate was found in the small-scale vessels (Fig. 4), especially those from peninsular ports: 1.56 birds per 1000 hooks (0–4.67; N = 48). However, this rate was obtained from only 1 mass catch event (Table 5). Small-scale vessels from the Balearic Islands also showed a high bycatch rate: 0.59 birds per 1000 hooks (0.18–1.15; N = 65), with Scopoli's shearwater being the main species affected (Table 3). Concerning the longline configuration used, we found the highest bycatch rates in both types of bottom gear, especially in the longlines without weights (Fig. 4).

Table 5. Number of seabirds caught during the on-board observations by species, area and vessel type (2011 – 2015). Number of individuals recovered alive is indicated in brackets. No birds were caught in medium - scale vessels from Balearic Is. (10350 hooks). Bycatch rate = num. birds per 1000 hooks setting (mean + CI 95%). Mortality = number of birds that would be killed annually estimated from the bycatch rate obtained

Species	Peninsula		Balearic Is.	Total (342,022 hooks)
	Medium – scale (218,453 hooks)	Small – scale (44,809 hooks)	Small – scale (68,410 hooks)	
Balearic shearwater	5	-	8 (8)	13
Mediterranean shearwater	2	1 ^a (1)	-	3
Scopoli's shearwater	5	-	27 (5)	32
<i>Puffinus</i> spp.	1	45 ^b (3)	2 (2)	48
Audouin's gull	2	-	2 (1)	4
Yellow-legged gull	3	-	4 (1)	7
Black-legged kittiwake	2	-	-	2
Northern gannet	1	-	-	1
Total	21	46	43	110
Bycatch rate	0.12 (0.05 – 0.21)	1.56 (0 – 4.67)	0.59 (0.18 -1.15)	0.58 (0.13 - 1.37)
Mortality	357 (126 - 642)	-	675 (148 – 1,556)	1,032 (274 -2,198)

^aBycaught during the hauling; ^bbycatch occurred in only 1 setting, and most were *Puffinus yelkouan*, however, it was not possible to check the ratio between both *Puffinus* species.

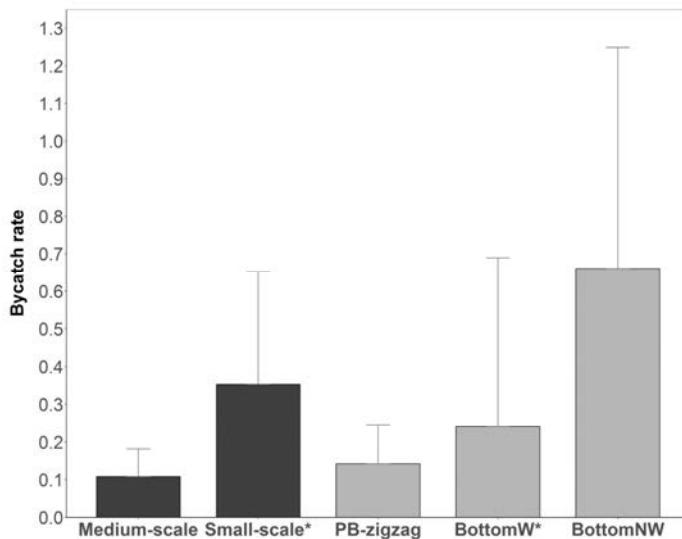


Figure 4. Bycatch rate (birds caught per 1000 hooks, mean \pm 95% CI) according to both vessels type (left) and the most common gear configuration (right) in the study area. Vessel type includes medium-scale ($N = 103$ fishing trips) and small-scale vessels ($N = 117$) of the study area. Gear configuration includes PB-zigzag (Piedra – Bola in zigzag, $N = 73$), BottomW (bottom-weights, longline with only weights attached along the mainline, $N = 73$), and BottomNW (bottom-no weights, longline without either weights or floats, $N = 42$). The PB-pyramidal configuration was not considered here due to low sample size. *The massive catch of small shearwaters is not included in the data

Most birds caught were recovered dead (81%). Only in the small-scale vessels, due to their lower setting speed, was it possible for fishermen to stop and release hooked birds alive. On the other hand, these longliners normally set in shallower waters and their branch lines are long enough for birds to reach the surface and survive until hauling.

Fishermen reported 739 birds caught when we were not onboard, during the 4 yr study period (Table 6). Most of these birds were shearwaters (96%), which were frequently captured in multi-catch events (up to 200 birds in a single event).

According to onboard observations, bycatch primarily occurred from March to July (Fig. 5a), being especially high in May. This seasonal pattern was roughly consistent with the fishermen's reports, which also showed low levels of bycatch in summer and early autumn, and a small peak in winter (Fig. 5b).

Table 6. Number of birds reported by fishermen (maximum birds registered per event is indicated in brackets) in each year of study period (N = 739 birds, 15 boats). Total events = number of fishing days in which bird catches were reported. Total bycatch = number of birds bycaught including those events registered in the on-board observations. Some species could not be identified at species level, so those are grouped by genus or in a general group. (*) indicates small – scale vessels. 2015 is compromised of January only. Species binomials are given in Table 3

Species	2011	2012	2013	2014	2015	Total events	Total bycatch
Balearic shearwater	-	3	5	11 (3)	-	19	97
Mediterranean shearwater	-	-	-	14 (4)	-	6	49
Scopoli's shearwater	1	30 (12)	1 + 30* (30)	49 (20) + 12* (9)	-	20	166
Unidentified shearwaters:							
<i>Puffinus</i> spp.	-	18 (8)	20 (10)	130* (130) + 33 (30)	20 (20)	12	269
<i>Puffinus</i> and <i>Calonectris</i>	200 ^a (200)	38 (38)	-	8 (4) + 80* (80)	-	3	215
<i>Puffinus</i> or <i>Calonectris</i>	-	-	-	8 (4)	-	4	8
Northern gannet	-	3	5 (2)	-	-	8	10
Audouin's gull	-	3 (2)	10 (4)	-	-	8	18
Mediterranean gull	-	-	4 (4)	1	-	2	5
Sandwich tern	-	-	-	1	-	1	1
Unidentified gulls	-	-	2	-	-	1	2
Yellow-legged gull	-	-	-	-	-	-	7
Black-legged kittiwake	-	-	-	-	-	-	2
						Total	849

^aWe could check 109 individuals provided by the fisherman. The birds identified were: 65 Balearic shearwater, 32 Mediterranean shearwaters and 12 Scopoli's shearwaters.

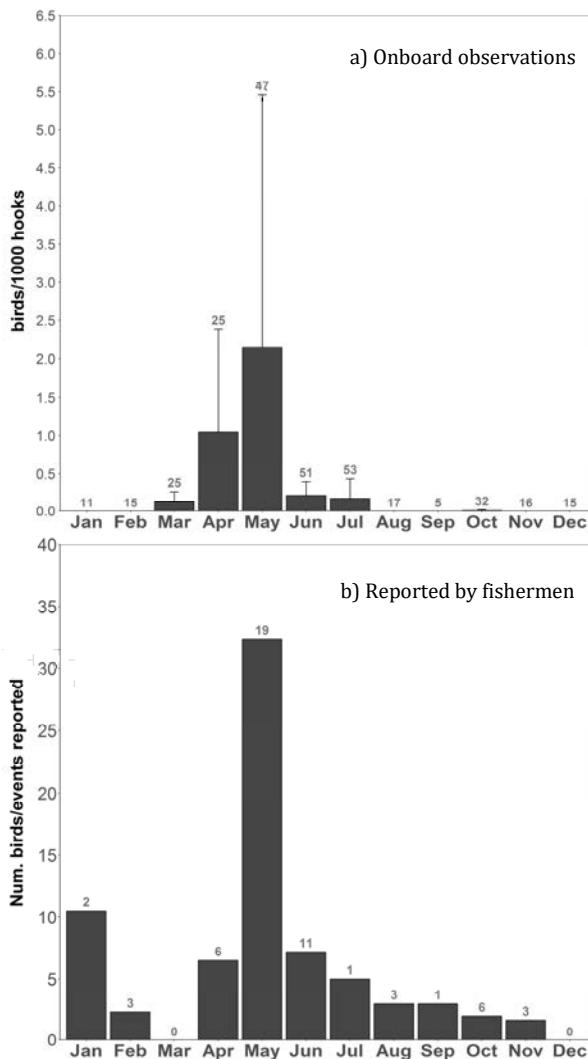


Figure 5. Monthly occurrence of bycatch according to (a) on-board observations data (mean bycatch rate + 95% CI) and (b) birds reported by fishermen (raw number). Numbers above bars specify (a) the number of settings observed and (b) the number of events reported

Seabird bycatch was greater in the daytime ($N = 53$ birds, Fig. 6), mainly influenced by a massive catch registered at midday (45 *Puffinus* spp. in 1 setting). Settings during the night resulted in fewer catches ($N = 7$) that mainly occurred during full moon (71%). In this case, the species most affected were nocturnal feeders, such as Scopoli's shearwaters ($N = 2$) and Audouin's gulls ($N = 2$). However, Balearic shearwaters were also caught at night ($N = 3$). Additionally, a higher bycatch rate of shearwaters and gulls was found when a mix of cephalopods and fish were used as bait (Fig. 7).

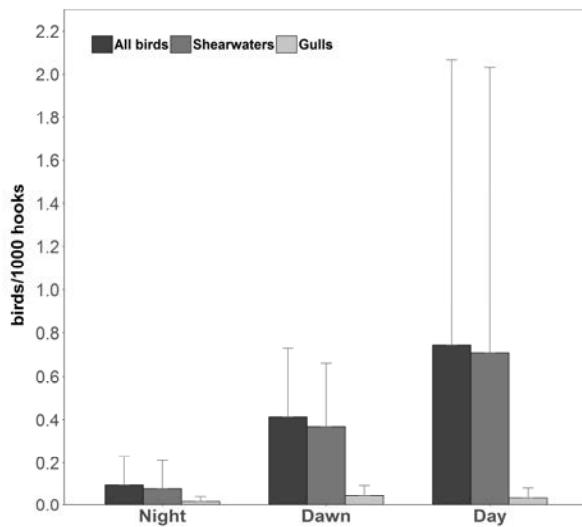


Figure 6. Bycatch rates (+ 95% CI) in demersal longliners in relation to the 3 different setting time intervals considered: night ($N = 51$ settings), dawn ($N = 150, \pm 1$ h from sunrise) and daytime ($N = 115$). Data are grouped by all bird species, shearwaters only (*Calonectris diomedea* + *Puffinus* spp.) and gulls only (*Larus michahellis*, *L. audouinii*, *Rissa tridactyla*).

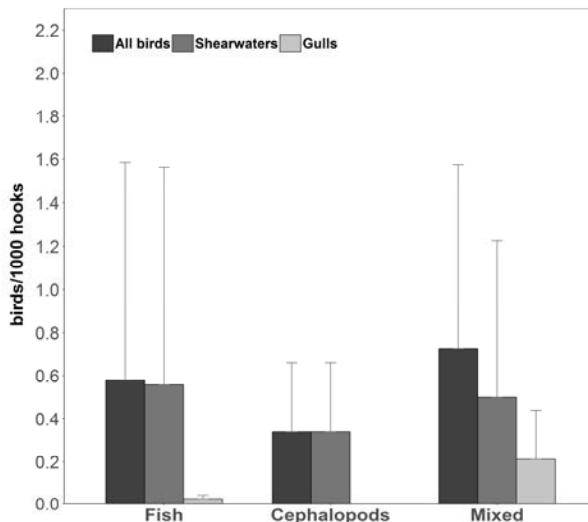


Figure 7. Mean numbers of birds bycaught (+ 95% CI) in demersal longliners in relation to bait category: Fish ($N = 150$), Mixed ($N = 39$, Fish + Cephalopods) and Cephalopods ($N = 106$). Data are grouped by (1) all bird species, (2) shearwaters (*Calonectris diomedea* + *Puffinus* spp.) and (3) gulls (*Larus michahellis*, *Larus audouinii*, *Rissa tridactyla*).

The annual mortality estimated for the medium-scale vessels from Catalonia was 357 (126–642) birds, while for Minorca's small-scale vessels it was 675 (148–1556) birds. Therefore, considering both areas together, we obtained a minimum annual mortality for the Balearic Sea of 1032 (274–2198) birds in the setting operations, including 683 (46–1818) Scopoli's shearwaters, 123 (0–278) Balearic shearwaters and 35 (0–85) Mediterranean shearwaters.

Susceptibility to bycatch

The proportions of species of birds observed following the vessels differed from the proportion of birds caught (Table 7, $\chi^2 = 53.47$, df = 7, p < 0.001). That is, shearwater species (Scopoli's shearwater: $\chi^2 = 4.62$, df = 1, p < 0.05; and *Puffinus* spp.: $\chi^2 = 29.48$, df = 1, p < 0.001) and gannets *Morus bassanus* ($\chi^2 = 4.72$, df = 1, p < 0.05) were substantially more frequently caught than expected. In contrast, yellow-legged gulls were less often caught than expected from their attendance ($\chi^2 = 14.53$, df = 1, p < 0.001). Likewise, the proportion of attacks on baited hooks obtained for each species also differed from the proportion of birds caught ($\chi^2 = 18.12$, df = 7, p < 0.05). Catches of *Puffinus* spp. ($\chi^2 = 4.61$, df = 1, p < 0.05) and gannets ($\chi^2 = 10.07$, df = 1, p < 0.01) occurred more often than expected from their proportion of attacks. However, the proportion of catches of Scopoli's shearwater was lower compared to the relative frequency of their attacks ($\chi^2 = 4.21$, df = 1, p < 0.05).

On the other hand, there was no difference in the proportion of birds caught in each longline type from their attendance ($\chi^2 = 0.06$, df = 3, p = 0.99) and the attacks observed ($\chi^2 = 0.01$, df = 3, p = 0.99).

DISCUSSION

Our study confirms that artisanal demersal longliners in the Balearic Sea cause high seabird mortality. This is particularly so for Scopoli's shearwater around the Balearic Islands and, most importantly, for small (*Puffinus*) shearwaters off the Iberian Peninsula, often involving multi-catch events. We also provide detailed information on the fishery, which is diverse in specific gear configurations and fishing strategies, and assess which are the main factors influencing seabird bycatch. This is a first step towards understanding seabird bycatch and developing appropriate mitigation measures. However, the high diversity of configurations and strategies makes it difficult to accurately estimate bycatch or to identify easy mitigation solutions applicable to the whole fleet.

Table 7. Bycatch susceptibility of the different seabird species (expressed as the % of birds potentially bycaught) and in different longline configuration by considering the proportion of birds caught ($N = 64$ birds) in relation to the birds attending vessels and to the birds attacking bait. Proportions are based on numbers registered during on-board observations. The massive catch event of small shearwaters (Table 5) and the data from the Piedra-bola (PB)-pyramidal gear to target pelagic fish are not included in the analysis.* p -value < 0.05, ** p -value < 0.01. Species binomials are given in Table 3.

Species/gear	% of birds potentially bycaught		% of birds caught
	By attendance	By attacks	
Scopoli's shearwater	39.50*	60.05*	50.00
<i>Puffinus spp.</i>	11.21**	19.83*	28.19
Yellow-legged gull	28.06**	8.46	10.94
Audouin's gull	12.57	8.13	6.25
Black – legged kittiwake	2.06	2.07	3.13
Northern gannet	0.33*	0.19**	1.56
Mediterranean gull	5.58	0.61	0
Sandwich tern	0.70	0.66	0
<i>PB-zigzag</i>	0.35	0.31	0.30
<i>PB-pyramidal</i>	0.02	0.00	0
<i>Bottom-weights</i>	0.18	0.27	0.26
<i>Bottom-no weights</i>	0.44	0.40	0.42

The overall average bycatch rate obtained in this study was 0.58 (0.13–1.37) birds per 1000 hooks. This rate is within the range of previous studies on demersal longliners from the Columbretes Islands (0.16–0.69 birds per 1000 hooks, Belda & Sánchez 2001), and higher than that found in previous studies in the pelagic longliners from the western Mediterranean (0.01–0.05 birds per 1000 hooks, Valeiras & Camiñas 2003, García-Barcelona et al. 2010b; 0.25 birds per 1000 hooks, Belda & Sánchez 2001). In previous studies, the most caught species were Scopoli's shearwater and yellow-legged gull, while catches of small shearwaters (*Puffinus spp.*) were comparatively low (Belda & Sánchez 2001, Valeiras & Camiñas 2003, García-Barcelona et al. 2010b, Laneri et al. 2010). In contrast, our study reports for the first time high bycatch rates of the Critically Endangered Balearic shearwaters (BirdLife International 2017a) and the Vulnerable Mediterranean shearwaters (BirdLife International 2017b), confirming previous suspicions (Arcos et al. 2008, ICES 2013). Along with Scopoli's shearwater, these small shearwaters were the most commonly caught by demersal longliners in the Balearic Sea, particularly on the Catalan continental shelf, where important foraging grounds are located (Arcos et al. 2012b, Péron et al. 2013, Meier et al. 2015). This high incidence of capture is subject to irregular catches, often involving dozens to even hundreds of individuals,

thus complicating the detection and quantification of the problem. Demographic studies carried out on these 2 *Puffinus* species, Balearic and Mediterranean shearwaters, showed a severe decline in their populations related to high mortality at sea (Oppel et al. 2011, Genovart et al. 2016), altogether indicating that incidental catches likely represent the most relevant cause of their decline.

We estimated that at least 274 to 2198 birds are killed annually by the demersal longliners in the Balearic Sea. However, this number should be considered a gross underestimation because (1) not all birds caught during settings are retrieved during gear hauling due to carcasses falling off the hooks, becoming untangled from the line or being removed by scavenger marine species, which may result in an underestimation by more than half (Gales et al. 1998, Gilman et al. 2003, Brothers et al. 2010); (2) it is difficult to detect mass catch events of birds through on-board observer programmes with low coverage, due to their stochastic nature; and (3) the estimate is solely based on catches occurring on small-scale vessels from the Minorca coast and medium-scale longliners from the Catalan coast, as these were the only areas where it was possible to obtain reliable fishing effort data. Especially, there is a lack of information about the fishing effort of the small-scale vessels operating in the area, which hampers obtaining an accurate estimate of the mortality caused by this fishery.

We found that susceptibility to bycatch as indicated by the proportion of birds attending vessels and those attacking the bait, greatly differed among species; in particular, it was greater in the shearwater species and gannets, and lower in the more common yellow-legged gull. This taxon-specific risk varies with the feeding ecology and behaviour of each species (Weimerskirch et al. 2000). Indeed, the lower number of bait attacks by gull species, despite being the most common birds attending longline vessels, is likely due to their lower diving capabilities, which limits their access to the baited hooks once these sink into the water. In contrast, shearwaters are strong divers that can reach the baited hooks even when these are several meters underwater, reaching depths down to 28 m (Meier et al. 2015), thus increasing their bycatch risk. Likewise, in the case of the northern gannet, the species also showed a high susceptibility to being caught in longlines due to its high deep-diving ability (Ropert-Coudert et al. 2009), although relatively few catches were recorded due to its relatively low occurrence behind vessels.

Season was the most important factor influencing seabird attacks on baited hooks. In addition, the setting time also had a large effect on attack occurrence probability. Other factors such as type and size of the bait, wind conditions, distance between weights and number of hooks set also had a significant, albeit lower, influence on the seabird interaction with longline vessels. When considering only Scopoli's shearwater, distance to the colony became an additional factor of relevance, whereas baitype and the number of hooks had no significant effects.

Previous studies in the area reported higher seabird bycatch during the breeding period (Belda & Sánchez 2001, García-Barcelona et al. 2010b, Laneri et al. 2010). We found that the number of attacks on bait was greatest in spring (April to June), when most Mediterranean seabirds are breeding. The spring also had the highest level of seabird bycatch registered from onboard observations as well as from fishermen's reports. In the case of the *Puffinus* species, this season coincides with the chick-rearing period. In Scopoli's shearwater, it includes both the pre-laying and incubation periods. These results coincide with those by Laneri et al. (2010), but differ from other studies carried out in the western Mediterranean, which found greater catches of Scopoli's shearwaters during the chick-rearing and fledging period (October; Belda & Sánchez 2001, García-Barcelona et al. 2010a, Báez et al. 2014). These differences might be related to small to medium-scale geographical differences between these group of studies, matching different spatiotemporal distribution patterns of the shearwaters, and highlight the relevance of applying a local approach of management. We can infer from this that an appropriate seasonal regulation of the fishing effort might significantly reduce seabird bycatch in the study area, although it could also entail significant economic losses for the artisanal fishermen since this period coincides with the most productive months of the fishery.

Settings during daylight hours increased the attack occurrence probability, and it was further increased when longlines were set at dawn, agreeing with previous studies (e.g. Belda & Sánchez 2001, Laneri et al. 2010). This is because seabird species in the Mediterranean are mainly diurnal and are particularly active at dawn and dusk (Passos et al. 2010, Dias et al. 2012, Meier et al. 2015). Concordantly, incidental catches were most frequent at dawn, although catches can also be high during daytime. Several studies recommend night setting as the most suitable method for reducing seabird bycatch in multiple types of longline fisheries (Brothers et al. 1999b, Belda & Sánchez 2001, Løkkeborg 2011). However, its effectiveness may vary depending on the seabird community occurring in a particular area. Some seabirds are active feeders at night and could also be caught during this period, especially on nights with bright moonlight or a full moon (Brothers et al. 1999b, Belda & Sánchez 2001, Delord et al. 2010). In this study, we found that seabird interactions were significantly reduced at night, with only 9% of all catches reported during this time period. This result is particularly relevant for the Critically Endangered Balearic shearwater, as this species is mostly active in daylight, specifically during the crepuscular hours (Meier et al. 2015), so that catches at night are less likely. Indeed, only 3 of 64 *Puffinus* shearwaters caught during the onboard observations were Balearic shearwaters captured at night, all of them on the same boat in 2 consecutive days, coinciding with a full moon. Thus, night setting appears to be a promising mitigation measure in the Mediterranean. Moreover, it could be relatively easy to enforce effectively compared to other potential mitigation measures, although it might reduce catches of target species

and lead to economic losses for fishermen (Brothers et al. 1999a, Sanchez et al. 2003). Careful experimental approaches should assess the practical applicability of night setting and quantify its effects on target species as well as on other non-target species of fish potentially sensitive to longlining bycatch (e.g. elasmobranches), and confirm the efficacy of this mitigation method in different moonlight conditions.

Another important factor influencing attacks was the type of bait used. The number of attacks was greater when fishermen used mixed bait and cephalopods than when they used fish bait. Mixed bait also increased the bycatch rate, possibly because different species tend to select different bait types (Trebilco et al. 2010). However, this effect was largely due to a higher capture of gulls. On the other hand, the attack occurrence probability was greater for hooks baited only with fish than those baited with other types of bait. When considering only Scopoli's shearwater, however, we did not find a significant effect of the type of bait used. The number of attacks also increased when fishermen used bait larger than 10 cm, which agrees with the prey size selected by shearwaters (Arcos 2001) and Audouin's and yellow-legged gulls when feeding on trawler discards in the western Mediterranean (Arcos et al. 2001).

Wind conditions at setting also had an important influence on the attacks. In general, the abundance and the occurrence of attacks increased on windy days. Some fishermen also reported that seabird catches increased on very windy fishing days (pers. comm.). Previous studies evaluating effects of weather conditions on seabird bycatch showed contrasting results. Some also detected an increase in seabird interactions under bad weather conditions (Brothers et al. 1999b, Weimerskirch et al. 2000, Delord et al. 2010), since water turbulence may keep baited hooks near the surface and therefore available to seabirds for a longer time, thus increasing bycatch risk. Alternatively, increased interactions could also be due to a greater difficulty for birds to find and capture their natural prey under these conditions, leading to an increased interaction with fishing vessels. In contrast, other studies did not detect any effect of wind speed on seabird bycatch (Klaer & Polacheck 1998) or found that its influence varied from species to species (Dietrich et al. 2009).

Specific gear configuration, namely the distance between weights, also had an important influence on seabird bycatch; increased distances led to a greater likelihood of bait attacks and, in the case of Scopoli's shearwater, it increased the number of attacks. This makes sense, as greater distances and lighter weights slow the longline sink rate (Robertson et al. 2008) and therefore increase seabird access to the baited hooks. We found these characteristics in the bottom longliners used by small-scale vessels in the study area. Despite this, we did not find differences in bycatch susceptibility among longline types. However, bycatch rates were higher in the bottom longlines, especially those that did not have weights attached. This may

be explained by the greater exposure of the bait to seabirds, which could increase the attacks and in turn the risk of being caught. Nevertheless, to properly evaluate the accessibility of the baited hooks to seabirds it would be necessary to measure the sink rate of the different longline types used.

Setting the longlines near breeding colonies increased the probability of Scopoli's shearwaters attacking baits, an effect previously reported in several other studies (Weimerskirch et al. 2000, Dietrich et al. 2009, Trebilco et al. 2010). However, the number of shearwater attacks did not change significantly with distance. In fact, 17% of the catches recorded for this species occurred at more than 70 km from the nearest breeding colony. This result shows that the risk of mortality in this species can also be high in fishing grounds far from their breeding colonies.

The number of hooks set increased the attacks if we considered all seabird species. In general, previous studies found an increase in the incidental mortality with the number of hooks deployed per set (Delord et al. 2010, Báez et al. 2014), but its influence may differ among species (Dietrich et al. 2009). Nonetheless, other studies did not assess its effect, as they considered the number of hooks set as a simple measure of the fishing effort (Belda & Sánchez 2001, Trebilco et al. 2010).

Overall, we found that the likelihood of attacks at line setting was greater on days when trawlers were not operating, although the importance of this factor was relatively low compared to the other factors. Nevertheless, this result agrees with previous studies carried out in the western Mediterranean, which found an increase in the probability of birds attending longliners and/or greater incidental catches during non-working days of the trawlers (García-Barcelona et al. 2010a, Laneri et al. 2010, Báez et al. 2014, Soriano-Redondo et al. 2016). Trawler discards have a great influence on foraging behaviour of scavenging species (Bartumeus et al. 2010, Cama et al. 2013, Bécares et al. 2015), so the absence of trawler activity can induce birds to search for alternative food resources, such as bait used by longline vessels.

CONCLUSIONS

Our results show that demersal longline fisheries catch high numbers of the 3 endemic species of shearwater in the Mediterranean, all of them of conservation concern, calling for urgent and effective action to reduce their bycatch rates. The present study provides insight on the factors influencing bycatch in the Balearic Sea, which should be taken into account when designing the most appropriate mitigation measures for the region. It also shows that setting at night and implementing temporal closure of the fishery during the most conflictive months are the most promising strategies to reduce seabird bycatch. Nevertheless, further

studies directed towards assessing the effectiveness of these strategies to reduce seabird bycatch and their potential effects on fishing activity are desirable. Streamer lines and the increase of bait sink rate by adding weight to the line, or a combination of different mitigation measures, have also been proven to be very effective in some demersal fisheries from other regions (Brothers et al. 1999b, Dietrich et al. 2008, Løkkeborg 2011, Melvin et al. 2013), but should be carefully evaluated in the Mediterranean, since the diving capability of the 3 shearwater species may render these mitigation methods less effective.

ACKNOWLEDGEMENTS

We are grateful to the skippers and crews of fishing vessels that voluntarily collaborated in this project. We thank Cristina Aranguren, Èric Domínguez, Lluïsa Ferrer, Manel Mamano, Pau Marquès, Neus Matamala, Toni Mulet, Blanca Sarzo, Adriana Rodríguez, Oriol Torres and David Torrens for making observations on the fishing vessels, and Rosario Allué (Generalitat de Catalunya) and Francesc Roselló (Govern de les Illes Balears) for providing fishing effort data. We also thank Oliver Yates from RSPB and 2 anonymous referees for their helpful comments and recommendations, and to Andy Smith and Bob Bonn for providing language help. This study was funded by the Fundación Biodiversidad (18PCA4328, 2012-13; 2013-14; 2014-15) and the Spanish government (CGL2009-11278/BOS, CGL2013-42585-P), and also received financial support from the EC LIFE+ Project INDEMARES. V.C. was supported by a PhD grant from the Generalitat de Catalunya (FI/DGR/2011), and J.M.A. was partially supported by the Segré Fondation through the BirdLife Seabird Task Force.

CAPÍTOL 2

Relative abundance and distribution of fisheries influence risk of seabird bycatch

L'abundància relativa i distribució de les pesquerdes influeix en el risc de captura accidental d'ocells marins

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RESUM

Les pesqueres proporcionen una font abundant i previsible d'aliment per a nombrosos ocells marins pelàgics a través dels descarts, encara que també representen una gran amenaça a causa de les captures accidentals, les quals estan posant en perill les seves poblacions a nivell mundial. La reforma de la Política Pesquera Comuna de la Unió Europea (PPC), la qual té la intenció de prohibir els descarts a través de l'obligació de desembarcar totes les captures, pot obligar als ocells marins a buscar fonts d'aliment alternatives, com ara els hams escats dels palangres, incrementant així les taxes de captura accidental. Per comprovar aquesta hipòtesi, es realitzà un anàlisi combinat de les interaccions entre ocells marins i pesqueres utilitzant com a model la baldriga cendrosa *Calonectris diomedea* en el Mediterrani. Les dades de seguiment mostraren que la probabilitat de que les baldrigues segueixin als palangrers augmenta de manera exponencial amb una densitat decreixent de les embarcacions d'arrossegament. Les observacions a bord i els esdeveniments de mortalitat corroboraren aquest resultat: la probabilitat de que els ocells segueixin als palangrers augmenta un 4% per cada vaixell d'arrossegament que abandona les proximitats del palangrer, i la mortalitat dels ocells augmenta deu vegades quan els vaixells d'arrossegament no operaven. Per tant, la implementació de l'obligatorietat de desembarcar a les aigües de la UE provocarà, probablement, un augment substancial de les taxes de captures accidentals en els palangrers, almenys a curt termini, a causa de que els ocells substituiran els vaixells d'arrossegament pels palangrers. En conseqüència, l'aplicació de l'obligació de desembarcar ha de ser vigilat acuradament i contrarestat mitjançant una implementació urgent de mesures de mitigació per reduir les captures accidentals en la flota palangrera.

ABSTRACT

Fisheries provide an abundant and predictable food source for many pelagic seabirds through discards, but also pose a major threat to them through bycatch, threatening their populations worldwide. The reform of the European Common Fisheries Policy (CFP), which intends to ban discards through the landing obligation of all catches, may force seabirds to seek alternative food sources, such as baited hooks from longlines, increasing bycatch rates. To test this hypothesis we performed a combined analysis of seabird-fishery interactions using as a model Scopoli's shearwaters *Calonectris diomedea* in the Mediterranean. Tracking data showed that the probability of shearwaters attending longliners increased exponentially with a decreasing density of trawlers. On-board observations and mortality events corroborated this result: the probability of birds attending longliners increased 4% per each trawler leaving the longliner proximity and bird mortality increased tenfold when trawlers were not operating. Therefore, the

implementation of the landing obligation in EU waters will likely cause a substantial increase in bycatch rates in longliners, at least in the short-term, due to birds switching from trawlers to longliners. Thus the implementation of the landing obligation must be carefully monitored and counterbalanced with an urgent implementation of bycatch mitigation measures in the longline fleet.

INTRODUCTION

Effects of fishing on marine megafauna are widespread and diverse, mainly due to overfishing, production of discards and bycatch (Hall et al. 2000, Kelleher 2005, Worm et al. 2006). Bycatch, the incidental capture of non-target species, is of particular concern for long-lived species with low reproductive rates and delayed sexual maturity, such as seabirds (Hall et al. 2000). Baited hooks offer the opportunity for an easy meal, yet these entail a very high risk of birds being hooked and subsequently drowned. A recent global review estimated seabird bycatch by longlines in 160,000-320,000 birds per year (Anderson et al. 2011). In fact, for some species, the current rates of bycatch are unsustainable for their long-term viability (Tuck et al. 2001, Arnold et al. 2006, Rivalan et al. 2010, Genovart et al. 2016).

On the other hand, fishery discards may also have profound impacts on the breeding biology, distribution and population dynamics of seabirds, by making available demersal and benthonic species otherwise naturally inaccessible (Wagner & Boersma 2011, Bicknell et al. 2013, Oro et al. 2013). Worldwide discards are estimated to be 8% of the total catch (i.e. around 7,000,000 tonnes discarded annually, Kelleher 2005). Ultimately, discards seem to be responsible for the increases in population sizes of several scavenging species over the last decades, such as large gulls (Furness 2003, Wagner & Boersma 2011).

Seabird-fishery interactions are of particular concern in the Mediterranean (Arcos et al. 2008); an enclosed and low-productive sea with a high degree of endemism (Zotier et al. 1999). Four seabird species are endemic to the basin and commonly caught by fishing gear, particularly in longlines: the Audouin's gull *Larus audouinii*, and the Scopoli's *Calonectris diomedea*, Yelkouan *Puffinus yelkouan* and Balearic shearwaters *Puffinus mauretanicus* (ICES 2013, FAO 2016). Among these, the Yelkouan and Balearic shearwaters are globally threatened (Vulnerable and Critically Endangered, respectively, BirdLife International 2016). According to conservative estimates, at least 5,000 birds could be killed annually in the region (FAO 2016). In particular, the bycatch of Scopoli's shearwaters represents over 50% of all birds caught in longlines in some areas of the Western Mediterranean, which would imply that 4-6% of the local population breeding in the Balearic Islands is killed every year (Belda & Sánchez 2001, Cooper et al. 2003, Anderson et

al. 2011). For these species, bycatch by other gears appears to be far less relevant (ICES 2013, FAO 2016).

In the Mediterranean Sea, discards are estimated to be 18% of the catch (i.e. around 230,000 tonnes discarded annually), with trawlers being responsible for 15 to 65% of the discards (FAO 2016). Discard availability modifies the diet, foraging strategies and distribution of seabirds (Votier et al. 2004, Bartumeus et al. 2010, Cama et al. 2013, Bécares et al. 2015) , with some species obtaining up to 75% of their energy needs from this resource (Arcos & Oro 2002, Arcos et al. 2008).

To further complicate matters, interactions among different fisheries may lead to unexpected indirect effects on seabirds. Some recent studies in the Mediterranean provided evidence that the attendance of Scopoli's shearwaters to trawlers and longliners may depend on the relative activity schedules of these fleets (García-Barcelona et al. 2010a, Laneri et al. 2010, Báez et al. 2014). When trawlers do not operate, shearwaters may seek alternatives to discards, such as baits used by longline fisheries, with a consequent increase in the risk of being hooked (Laneri et al. 2010, Báez et al. 2014). This possibility needs to be fully explored, since changes in fishery schedules or discard availability can occur at any time, and a proper management may minimize their negative impacts on seabird mortality. Indeed, the reform of the Common Fisheries Policy (CFP, <http://ec.europa.eu/fisheries/cfp/>) by the European Union (EU), among other measures, is implementing the elimination of discards through the so called *landing obligation*, with the aim of reducing the impact of fisheries on marine ecosystems. Therefore, there will be a gradual reduction in discards, from now to 2019, that could severely affect the Mediterranean seabird community, including the threatened shearwater species (Arcos et al. 2008). Thus, there is an urgent need to improve our understanding about the undesirable interactions among different fishery activities on seabird mortality.

To cast light on this problem, we studied the interaction between Scopoli's shearwater and fishing boats, and how different fishery schedules and vessel distribution patterns affect bycatch on the western Mediterranean Sea. Specifically, we used three different approaches: (1) individual GPS trajectories of Scopoli's shearwaters and Vessel Monitoring System (VMS) trajectories of fishing boats to study spatiotemporal dynamics, and establish whether vessel densities determine shearwaters choice between longliners and trawlers; (2) seabirds counts on-board longliners to determine the main drivers influencing seabird attendance during longline settings, focusing particularly on the potential influence of trawler activity in the surrounding area; and (3) 13 complete years of bycatch data from longline vessel to understand whether the rate of bycatch increases on days when trawlers do not operate.

METHODS

Spatiotemporal interactions

To establish the spatiotemporal interaction between tracked birds and fisheries, we obtained data from two main sources: GPS devices for tracking shearwaters and the VMS for tracking vessels. GPS-tracking of Scopoli's shearwaters was conducted in Cala Morell (Menorca, Balearic Islands, Spain; 40° 3'N, 3° 52'E), in two different years. In 2010, birds were tracked during the incubation period, from the 18th June to the 8th July; and in 2012 during the chick rearing period, from the 25th July to the 20th September. This area holds the largest Scopoli's shearwater colony of the Balearic Islands, tentatively estimated in 1,000-6,000 pairs (Catchot 1992, Martí & Del Moral 2003). Scopoli's shearwaters were captured at night by hand or using looped poles on the nest, when they flew back to the colony to feed their offspring or for incubation shifts. We used GPS loggers (Perthold Engineering LLC, weighing 20g, Forin-Wiart et al. 2015) sealed to be waterproof and programmed to record bird position each 2.5 or 5 minutes. Loggers were attached to the back of the birds using Tesa© tape (Wilson et al. 1997). At deployment, birds were ringed, sexed (through biometric measures) and weighed. In an attempt to minimise adverse effects on the birds, total mass of the device did not exceed 3% of the birds body mass (Phillips et al. 2003). At recovery, GPS devices were detached and birds were weighed. On average, we found a 25g decrease on bird weight after tag retrieval (Paired t-test, $t = 4.4138$, $df = 83$, $p < 0.001$), that we do not expect to have relevant effects on the foraging behaviour of the birds (Passos et al. 2010). In 2010, we deployed 30 GPS tags in 25 individuals, whereas in 2012, 79 GPS loggers were deployed on 56 individuals. In order to minimise the possible impact of tagging birds on their breeding success, only one adult bird per nest was tagged. Birds carried loggers from 3 to 17 days before retrieval, recording from 1 to 9 foraging trips. These protocols were approved by *Servei de Protecció d'Espècies*, from the Balearic Islands Government. The methods were carried out in accordance with the relevant guidelines and bird handling and tagging protocols.

The Vessel Monitoring System (VMS) is a satellite-based monitoring system, implemented by the European Union, that provides data on the location, course and speed of fishing vessels over 12 m long (European Commission 2011). In the Spanish Mediterranean, 90% of trawlers and 60% of pelagic longliners use this localization system, although, only a few demersal longliners and artisanal (polyvalent) vessels use it (Bécares & Cama 2013). The default frequency of VMS locations is one fix every two hours. Consequently, the spatiotemporal combination of VMS and GPS data was obscured by the uncertainty about the position of each vessel in the two hour gap between two consecutive locations. Taking into account this limitation, to cover the potential interactions between birds and vessels throughout the entire vessel trip, we identified all bird locations within a ±1h

interval and within a 5km buffer from a vessel location (as maximum speeds of vessels are around 5km/h). Next, we applied a second filter selecting bird trajectories where the bird bearing diverged in less than $\pm 30^\circ$ from the vessel bearing (estimated from consecutive locations). This bird bearing was considered the mean bearing for all locations inside each buffer of spatiotemporal coincidence. We chose $\pm 30^\circ$ because after some trials this angle emerged as the most biologically meaningful figure. For each bird-vessel interaction location, we assessed the number of vessels within a ± 1 h interval and a 30km radius. We chose 30km as it has been shown that some procellariforms can detect food resources up to 30 km away (Warham 1990, Votier et al. 2010). We focused our research in two types of fisheries, trawling and pelagic longlining, since shearwaters tend to associate with them in search of food. Demersal longliners, including artisanal (polyvalent) vessels were excluded from this analysis, despite also attracting (and catching) seabirds, since most of them are too small to carry the VMS system (see above). Moreover, we only selected the interaction events where at least one trawler and one longliner were present in the area to control for the fisheries different regime and ensure that when birds interacted with a trawler they had also the option to interact with a longliner and vice versa.

We used a generalized lineal mixed model that included year as a random effect, number of trawlers and number of longliners as fixed effects and a binomial response, either the bird interacted with a longliner or it interacted with a trawler. We calculated the AIC values of all candidate models and selected the model with the lowest AIC value as the best model for explaining bird interaction with fisheries.

On-board censuses

At-sea surveys were carried out during 3 consecutive years (2011-2013) covering the main fishing grounds of longline fisheries in the Catalan shelf and Balearic Islands, during the period where the species was present in the Mediterranean (March - October). The counts were conducted during 102 longline settings from 20 small-scale vessels operating in the NW Mediterranean (16 demersal and 4 pelagic longliners). Here we only considered the maximum number of Scopoli's shearwaters following the vessels at the end of each 10-min counts in each setting operation, as well as the number of attacks to the bait and the number of birds incidentally captured. The number of birds hooked (26 birds in nine events) was too low to perform reliable statistical analyses. Fishing habits, detailed description of fishing gear used and meteorological data were noted in each fishing trip (Table 2). The number of trawlers in a 6km radius around the longliner was also recorded in each 10-min survey.

Bycatch events are relatively rare and patchy, thus being difficult to monitor through low-effort observer programmes. We evaluated seabird attendance to

longliners as a proxy of seabird attacks, which are more closely related to seabird bycatch and therefore mortality. Generalized lineal mixed models (GLMMs) were used to identify the main factors influencing Scopoli's shearwater interaction with longliners. Abundance data is characterized by having a high proportion of zero values and a skewed distribution of non-zero positive values caused by large counts of individuals (flocking behaviour) (Fletcher et al. 2005). Hurdle models are a suitable method for modelling this type of distributions, which is characterized by treating the data in two parts: (1) presence/absence of the species (Zero part) and (2) the abundance when the species is present (Count part) (Welsh et al. 1996, Fletcher et al. 2005, Martin et al. 2005, Zuur et al. 2009). We analysed the relationship between the number and presence of Scopoli's shearwaters and temporal, spatial and operational variables (Table 2). Trawler presence in the surrounding area was also considered to assess their influence on seabird attraction to longliners. Longliner identity was used as a random effect. We used "glmmadmb" function from the "glmmADMB" R package (R version 3.1.2). Zero hurdle part was modelled with the assumption of a binomial error structure (logit link function), while in the Count part a truncated version of the Negative Binomial distribution was considered (log link function). We checked collinearity between predictors and removed redundant ones. Then, we used the variance inflation factor (VIF) to verify the independence of each variable on the estimate of the regression coefficients of the model (Fox & Monette 1992).

Relative importance analysis was carried out with the model-averaging approach. This approach is useful when there is a large uncertainty about a set of models (Burnham & Anderson 2002). In this way, we obtained model-averaged parameter estimates that were directly comparable to each other (Burnham & Anderson 1998). We estimated the parameters from the set of all models for which the sum of Akaike weights reached > 0.95 .

Bycatch records

From 2003 to 2015 fishermen from a single demersal longline vessel fishing off the Catalan coast recorded and handed over Scopoli's shearwater carcasses accidentally caught in their longline. To establish temporal bycatch patterns, we analysed whether the number of birds hooked and the number of capture events differed among the days of the week by using a Pearson's Chi-squared Test for Count Data with Bonferroni correction.

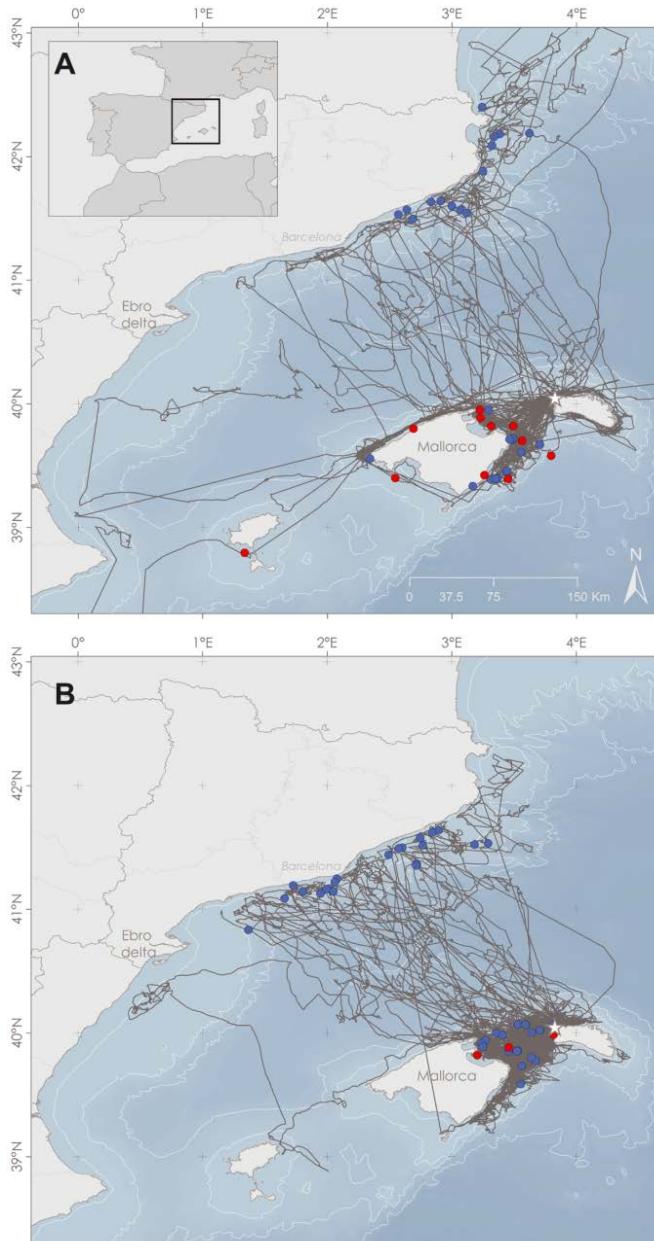


Figure 1: Shearwater GPS tracks (in grey) and concurrent interactions between shearwaters and fishing vessels (dots) inferred from the Vessel Monitoring System (VMS) in 2010 (A) and 2012 (B). Red dots correspond to interaction with longliners and blue dots to interactions with trawlers. Maps were generated with ArcGis version 10.3 (URL: <https://www.arcgis.com>).

RESULTS

Spatiotemporal interactions

Overall, we tracked 65 shearwaters in two different years, 2010 and 2012, with 4 birds being tracked both years. We obtained trajectories from 90 GPS deployments, 30 trajectories corresponding to 38 foraging trips in 2010 and 60 trajectories corresponding to 145 foraging trips in 2012 (Fig 1). Birds mainly foraged in the Catalan shelf and the Menorca channel, areas used by both trawlers and longliners (Fig 1). We obtained 267 interaction events, where a bird followed a vessel, 246 interactions occurred with trawlers and 21 with pelagic longliners. From those, only 86 events corresponded to events in which at least one longliner and one trawler were fishing simultaneously in the same area (Fig 1). From those interactions, 72 were with trawlers and 14 with longliners. Interactions with longliners mainly happened in the Menorca channel, close to the breeding areas, while interactions with trawlers happened both in the Catalan shelf and in the Menorca channel. We found no direct effect of the number of longliners in the area on the probability of interaction with either a trawler or a longliner. However, the probability of interacting with a longliner increased as the number of trawlers decreased ($P = 0.029$), from nearly 0% when 20 or more trawlers were in the area, to 40% probability of interaction when only 1 trawler was present (Fig 2).

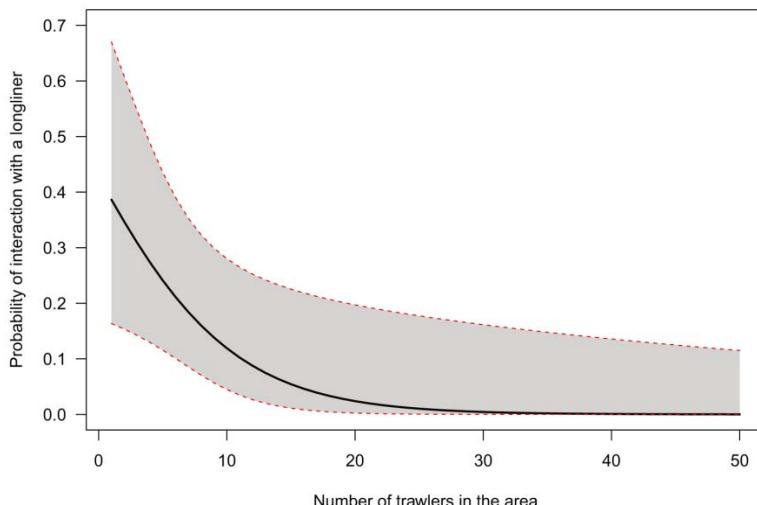


Figure 2: Probability of interaction between shearwaters and longliners as a function of the number of trawlers in the area. Black line represents the predicted values from the model and the grey area represents the 95% confidence intervals.

On-board censuses

We found that the number of attacks to the bait and the number of birds following a vessel was correlated ($r_s = 0.38$, $P = 0.004$). Since sample size for seabird attendance was greater than for bait attacks, we used seabird attendance as a proxy for bycatch risk on subsequent analyses, allowing us to study the ultimate factors that influence it. Analysis of relative importance showed that setting time was the main variable to account for shearwater presence and abundance behind longliners: shearwaters were more likely to occur in greater numbers at twilight (Tables 1 and 2). Bait type and longline type also had an important effect on bird attendance, birds being more likely to interact with longliners when they used mixed baits (fish and cephalopods, instead of only one of both) and when they targeted pelagic species (instead of demersal species) (Tables 1 and 2). The distance to the nearest breeding colony had a relatively high influence on shearwater abundance; the further away from colony areas the less likely it was to detect birds attending longliners (Tables 1 and 2). The number of hooks in each setting had a very low effect on the presence and abundance of birds attending longliners (Tables 1 and 2). The breeding stage of the birds (pre-laying, incubation or chick-rearing) and the meteorological conditions did not affect bird attendance to longliners (Tables 1 and 2). The probability of birds attending longliners increased 4% per each trawler leaving the longliner surroundings, but bird abundance was not affected by the number of trawlers (Tables 1 and 2).

Bycatch data

From 2003 to 2015, we collected all birds hooked in a longline boat from Vilanova i la Geltrú after arrival to the port. During this period, 67 Scopoli's shearwaters became entangled in the fishing gear and died. We found that the number of birds caught differed significantly among the days of the week; it was higher on Sundays and Mondays than on the remaining days ($\chi^2 = 17.63$, $p < 0.001$). In fact, 51% (34 individuals) of the birds were hooked on Sundays, when trawlers do not operate, and 28% (19 individuals) on Mondays, when longline vessels start operating before trawlers after the weekend rest. From Tuesday to Friday, only 14 birds were hooked across the 13 years covered. In addition, we found that the probability of a bycatch event (when one or several birds were hooked) followed the same pattern: events were more likely to occur on Sundays and on Mondays than on the rest of the week days (12 bycatch events occurred on a Sunday, 5 on a Monday and 6 from Tuesday to Friday; $\chi^2 = 4.9$, $p = 0.03$).

Table 1. Coefficient, standard errors and relative importance (RI) of each variable for shearwaters attendance to longliners. See Table 2 for detailed explanation of the variables

Variable	Value	Std. Error	RI
Presence - Zero part (Intercept)	-0.84	1.01	
Bait: Fish	1.75	1.11	0.93
Bait: Mixed	2.73	1.38	
LT: Pelagic	1.96	1.31	0.59
Time: Daytime	-1.39	0.79	0.90
Trawlers	-0.18	0.24	0.53
SDC	-0.27	0.45	0.42
Period: Incubation	0.11	0.47	0.35
Period: Prelaying	-0.41	0.74	
Wind: Windy	-0.07	0.34	0.24
SHS	0.02	0.16	0.24
Abundance – Count part (Intercept)	2.48	0.47	
LT: Pelagic	0.15	0.40	0.31
Time: Daytime	-0.53	0.46	0.76
Trawlers	-0.01	0.09	0.22
SDC	-0.15	0.19	0.55
Period: Incubation	0.01	0.07	0.05
Period: Prelaying	0.01	0.11	
Wind: Windy	-0.03	0.16	0.20
SHS	-0.08	0.14	0.39

Table 2. Explanatory variables used in the analyses of Scopoli's shearwaters interaction with longliners

Variable	Abbr	Type	Description
Breeding period	Period	Categorical	Pre-laying (March – 1st week June), incubation (until mid-July) or chick-rearing (until October)
Distance to colony	SDC	Continuous	Distance from the nearest colony (scaled km)
Wind	Wind	Categorical	Windy or still
Bait composition	Bait	Categorical	Fish, cephalopods or mixed (fish + cephalopods)
Setting time	Time	Categorical	1h ± of the twilight or rest of the daytime
Longline type	LT	Categorical	Demersal or pelagic
Hooks setting	SHS	Continuous	Number of hooks setting (scaled)
Number of trawlers	Trawlers	Continuous	Number of trawler within 6km from the longliner
Longliner ID		Random	Boat identifier

DISCUSSION

The concurrent analysis of GPS data from seabirds and vessels showed the importance of the spatiotemporal distribution of operating trawlers in determining the probability of seabirds interacting with longliners: the higher the density of trawlers, the less likely birds interacted with a longliner. On-board censuses of seabird attendance to longliners corroborated this result, showing that attendance, which can be taken as a proxy of bycatch risk, increased when trawlers were not operating in the longliner proximity. Finally, dead birds collected by fishermen showed that seabird catches were significantly and substantially greater on days when trawlers did not operate. Hence, results from these three different approaches point towards the same direction: seabird bycatch in longliners significantly increases when trawlers operate in low densities or do not operate.

In this regard, the reform of the CFP, which intends to substantially reduce or even eliminate fishery discards, might dramatically increase seabird bycatch risk, at least in the short term, by forcing seabirds to intensify their foraging efforts, including the search of an “easy meal”, i.e. switching from trawler discards to longline baits. Our results show that, at present, trawlers are acting as a buffer of the seabird interactions with longliners, such that the probability of shearwaters interacting with a longliner decreases from 40% when only one trawler is present in the area to almost 0% when >20 trawlers are present (Fig 2). The same pattern applies to the on-board observations and bycatch rates. For each trawler leaving the surroundings of a longliner, the probability of seabirds following the longliner increases by 4%; and the rate of bycatch experiences a tenfold increase when trawlers do not operate. The reduction of discards is therefore likely to result in a substantial increase in bycatch rates of Scopoli’s shearwaters, to a level that could be completely unsustainable for some western Mediterranean populations (Sanz-Aguilar et al. 2016). Moreover, our results can reasonably be extrapolated to other seabirds species targeting trawler discards in the Mediterranean which are also known to be caught in longlines, such as the Audouin’s gull and the Yelkouan and Balearic shearwaters (Bécares et al. 2015). The latter is of particular concern given its sensitive conservation status, since bycatch appears to account for almost half the adult mortality estimated for the species (Genovart et al. 2016).

Given the concern of bycatch for many Mediterranean seabirds, including the four endemic species, it is urgent to take into account this multi-fisheries interaction when designing fishing regulations, in order to minimise its potentially detrimental effect. As a first approach, our results suggest that precluding longline vessels (both demersal and pelagic) to set their lines when trawlers are not operating might substantially contribute to this aim. However, given that (trawling) discards will anyway be reduced in the short run, our results also call for an immediate

enforcement of effective mitigation measures in longliners to reduce seabird bycatch. Since our results also point out that the strongest influence on seabird attendance to longliners was the time of setting, operational measures regulating the setting timing should contribute to minimise the problems. Indeed, seabirds were more prone to interact with longliners during sunset and sunrise. These results have also been observed in other studies which showed that many diurnal seabirds have activity peaks at dawn and dusk (Belda & Sánchez 2001, Sanchez et al. 2003, Laneri et al. 2010). Since most seabirds affected by longliners in the Mediterranean are basically diurnal, a promising mitigation measure to be applied in this region would be night setting, as previously suggested in other studies (Belda & Sánchez 2001, Boggs 2003, Sanchez et al. 2003, Løkkeborg 2011). This measure could be easily implemented at low economic costs, and compliance could be monitored and enforced to some extent through the control of fishing schedules of longliners by harbour authorities, as it is currently done for other types of fisheries. However, fishermen could be reluctant because it would require a rearrangement of their schedules and it could also limit the number of setting operations, particularly during the relatively short summer nights. Therefore, further work is needed to assess the efficacy and viability of this measure as well as of other mitigation measures that have proven successful in other regions. Among them, the use of tori-lines, the increase of sinking rates of the line through configuration changes, or a combination of the above, might also contribute to minimise seabird bycatch in Mediterranean longliners (Brothers et al. 1999a, Løkkeborg 2003, 2011, ACAP 2014, 2016a).

In conclusion, our study highlights the importance of combining various sources of information to achieve robust and complementary results on the complex effects of fishing activities on seabird bycatch. In particular, three different approaches indicated that the risk of a seabird to be captured in longlines increases dramatically when trawlers are not present in the area where longliners operate. That is, when trawlers stop providing discards seabirds may switch from trawlers to longliners, and therefore the landing obligation being implemented by the CFP must be carefully monitored and counterbalanced with the urgent implementation of mitigation measures. In a more general sense, our results point out that to determine the best management practices of the different fishing fleets, we need to study unexpected impacts rising from the interactions among different types of fisheries. Therefore, impacts of changes on the discard availability must be carefully evaluated and monitored across the different fleets to avoid catastrophic effects on seabird populations as well as on other components of the marine ecosystem.

ACKNOWLEDGMENTS

We thank the *Conselleria d'Agricultura, Medi Ambient i Territori* of the *Govern de les Illes Balears* for permission and support in conducting fieldwork. We acknowledge the *Fundacion Biodiversidad* (18PCA4328; 20121964, FEP-FB), *Ministerio de Economía y Competitividad* and *Fondos FEDER* (CGL2009-11278/BOS, CGL2013-42585-P) for funding. SEO/Birdlife was supported by EC LIFE+ Project INDEMARES. We thank Èric Domínguez, Joan Ferrer, Lluïsa Ferrer, Pau Marquès, Blanca Pérez, Oriol Torres and David Torrens for carrying out on-board censuses and Robert Manzano, Helena Navalpotro, Marcel Gil and Santi Bateman for fieldwork assistance, and Rafel Triay for local assessment in Menorca. We also thank the *Fundación Biodiversidad* and the Secretaría General de Pesca (MAGRAMA) for providing VMS data and crews of fishing vessels that voluntarily collaborated in this project, especially La Cona C.B. crew for the bycatch data. We are grateful to Santi Álvarez-Fernández for technical support; to Jorge S. Gutiérrez and Stephen C. Votier for helpful suggestions on the drafts of the manuscript.

CAPÍTOL 3

Sex and age-biased mortality of three shearwater species in longline fisheries of the Mediterranean

Biaix en la mortalitat entre sexes i edats de les tres espècies de baldrigues en les pesqueres de palangre del Mediterrani

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Pau Marquès

RESUM

Les taxes de captura accidental en les pesqueres de palangre són insostenibles per a nombrosos ocells marins a nivell global. No obstant això, per comprendre els seus efectes a nivell poblacional, és essencial avaluar els biaixos en la mortalitat entre sexes i grups d'edat, ja que les mortalitats desiguals poden agreujar els impacts de les captures accidentals. Al Mediterrani, la captura accidental és la principal causa del declivi poblacional per a les tres espècies de baldriges endèmiques (Baldriga cendrosa *Calonectris diomedea*, balear *Puffinus mauretanicus* i mediterránea *P. yelkouan*), però poc se sap sobre els biaixos poblacionals dels ocells capturats en els palangrers. Des de 2003 fins 2015, recollirem 639 cadàvers de baldriges dels palangrers espanyols que operaven al nord-oest del Mediterrani, els dissecarem per determinar la seva edat i sexe, a més examinarem els seus patrons espacials i temporals i l'origen dels ocells anellats. La major part de les baldriges capturades en els palangrers foren adults, però la proporció d'immadurs i subadults augmentà al final del període de cria. Els adults de la baldriga cendrosa foren capturats principalment en les proximitats de les colònies de cria. En canvi, tots els ocells de les baldriges *Puffinus* foren capturats a la plataforma ibèrica. Les captures de les baldriges cendroses estaven esbiaixades cap als mascles, particularment durant la pre-posta i en les proximitats de les colònies de cria. Les captures de les baldriges *Puffinus* també estaven esbiaixades cap als mascles durant la pre-posta, no obstant, les captures dels adults es trobaven esbiaixades cap a les femelles durant l'alimentació dels pollets. Les recuperacions de les anelles revelaren que la majoria dels ocells foren anellats a les illes Balears, encara que algunes baldriges cendroses anellades a França i Itàlia també foren capturades durant la seva migració, la qual cosa demostra que els impacts dels palangres espanyols no es restringeixen a les poblacions locals. El biaix en la mortalitat cap als adults i cap a un dels sexes que s'ha trobat en aquest estudi pot agreujar els impacts de les captures incidentals en les poblacions, cosa que posa en relleu la necessitat urgent d'accions de conservació.

ABSTRACT

Bycatch rates in longline fisheries are unsustainable for many seabirds worldwide. Nevertheless, to understand its effects at population level it is essential assessing sex and age-biased mortalities, since uneven mortalities may exacerbate bycatch impacts. In the Mediterranean, bycatch is the main cause of population decline for the three endemic shearwater species (Scopoli's *Calonectris diomedea*, Balearic *Puffinus mauretanicus* and Mediterranean shearwater *P. yelkouan*), but little is known about population biases of the birds caught in longliners. From 2003 to 2015, we collected 639 shearwater carcasses from Spanish longliners operating in the north-western Mediterranean, dissected them to determine their age and sex

and examined their spatial and temporal patterns and the origin of ringed birds. Most shearwaters caught in longliners were adults, but the proportion of immatures and subadults increased in the late breeding period. Adult Scopoli's shearwaters were mostly caught around the breeding colonies. In contrast, all *Puffinus* birds were caught in the Iberian shelf. Scopoli's shearwater catches were male-biased, particularly during the prelaying and close to the breeding colonies. *Puffinus* shearwaters catches were also male-biased during the prelaying, but adult catches were female-biased during chick-rearing. Ring recoveries revealed most birds were ringed in the nearby Balearic Islands, but some Scopoli's shearwaters ringed in France and Italy were also caught during their migration period, showing impacts of the Spanish longliners are spread well beyond Spanish colonies. The adult-biased and sex-biased mortality found in this study may aggravate bycatch impacts on populations and highlights the urgent need for conservation action.

Keywords: Seabirds, Sex ratio, Bycatch, north-western Mediterranean, Colonies of origin, Differential susceptibility

INTRODUCTION

Seabirds are amongst the most threatened group of birds in the world, especially due to the pressures induced by human activities (Croxall et al. 2012). In particular, bycatch in commercial longline fisheries represent one of the major threat to many seabird species, since it causes the annual death of several hundred thousand birds worldwide (Anderson et al. 2011). The incidental mortality on longlines occurs when seabirds attempt to steal the bait from the hooks during line setting, become hooked or entangled in the fishing gear and drown. Procellariiform species (albatrosses, petrels and shearwaters) are the seabirds most frequently caught in longline fisheries (Anderson et al. 2011). These seabirds show slow life-history strategies, which make them particularly sensitive to additive mortality and therefore cannot cope with the mortality caused by fisheries (Arnold et al. 2006, Croxall et al. 2012, Genovart et al. 2017b). As a result, many seabird populations exhibit a negative trend linked to these incidental catches (Weimerskirch et al. 1997, Lewison & Crowder 2003, Poncet et al. 2017). Consequently, determining bycatch rates has been a prime issue in seabird conservation worldwide over the last two decades (e.g. Anderson et al. 2011, Cortés et al. 2017). However, not only numbers are important but a greater effect on adult birds and uneven mortality among sexes can exacerbate demographic impact of bycatch (Lewison et al. 2012, Komoroske & Lewison 2015), but despite of its potential importance these biases have been scarcely recorded.

Incidence of bycatch on different age classes can vary widely among species, regions and seasons (Phillips et al. 2010, Gianuca et al. 2017). The most common pattern found in longline fisheries is adult-biased bycatch (Nel et al. 2002, Phillips et al. 2010, Gianuca et al. 2017). However, in some species, regions and fishery types, catches of immature birds may also predominate (Murray et al. 1993, Gales et al. 1998), suggesting susceptibility to bycatch among age classes is determined by differences in their spatial and seasonal distribution and overlap with fisheries, rather than by differential ability in accessing to the bait and discards (Riotte-Lambert & Weimerskirch 2013, Gianuca et al. 2017). In long-lived species, such as seabirds, adult survival is the most important demographic parameter for the population growth rate (Lebreton & Clobert 1991). Therefore, the additional mortality on this age class in particular can have immediate and large effects on seabird population trends (Arnold et al. 2006, Barbraud et al. 2012, Genovart et al. 2016). Moreover, procellariiforms are monogamous birds with strong intra-pair cooperation (Bried & Jouventin 2002); thus, the most immediate effect of bycatch mortality of adults is the pair-bond disruption due to the loss of partner. This can lead to breeding failure when the partner dies during the breeding season (Belda & Sánchez 2001), as well as to a delay in the next breeding cycle until finding a new mate and to a reduction of the reproductive success due to a mate familiarity effect (Bradley et al. 1995, Ismar et al. 2010, Sánchez-Macouzet et al. 2014). On the other hand, a high mortality rate of immatures also may substantially influence the population viability by reducing the recruitment level necessary to maintain population stability at a medium to long-term (Arnold et al. 2006, Votier et al. 2008, Finkelstein et al. 2010, Penteriani et al. 2011).

The incidence of the sex-biased incidental mortality is also important, since the sex ratio imbalance reduces the effective population size, which has a significant impact on fecundity and population viability (Jouventin et al. 1999, Mills & Ryan 2005). In some species, bycatch mortality is most frequently skewed towards males (Phillips et al. 2010, Gianuca et al. 2017), although this bias may vary both seasonally and regionally (Gales et al. 1998, Nel et al. 2002, Gianuca et al. 2017). Many albatross and petrel species show a sexual segregation in foraging areas and diet, in particular during the prelaying period (Phillips et al. 2017a). Thus, the uneven mortality between males and females is usually driven by sex differences in their spatio-temporal distribution and the resultant variation in the relative spatial overlap with high-risk fisheries (Bugoni et al. 2011, Jiménez et al. 2016b, Gianuca et al. 2017).

In the Mediterranean Sea, a high seabird mortality in longline fisheries has been documented, particularly of the three endemic and threatened shearwaters of the Mediterranean: Scopoli's *Calonectris diomedea*, the Balearic *Puffinus mauretanicus* and the Mediterranean *P. Yelkouan* (Belda & Sánchez 2001, García-Barcelona et al. 2010b, Báez et al. 2014, Cortés et al. 2017). However, little is known on the

population biases of this mortality and their spatial and temporal patterns, as well as on the origin of the affected birds. There is only one study providing data about bycatch age-composition from 38 ringing recoveries collected in the longline fleet operating nearby Columbretes Islands (W Mediterranean) (Belda & Sánchez 2001). Authors found most birds were adults (60%) ringed in the Columbretes archipelago and other neighbouring Spanish colonies (Balearic Islands). However, this study is restricted to a specific area and season, limiting the generalizability of the results.

There is no information on age- and sex- biased mortality for any of the three species of shearwaters so far. Nevertheless, some studies pointed out during the prelaying period females usually perform longer foraging trips whereas males visit the colony more often than females (Bourgeois et al. 2008; Guilford et al. 2012, J. González-Solís, unpubl. data). These sexual differences in foraging behaviour could lead to a differential interaction with longline fisheries and result in sex-biased mortality. Population effects of this unnatural mortality have recently been illustrated in the three shearwaters of the Mediterranean (Oppel et al. 2011, Genovart et al. 2016, 2017b). Considering equal survival between sexes and parity in population sex ratios, demographic models showed that the population viability of these species is compromised by adult mortality in fisheries. Moreover, in the case of Scopoli's shearwaters, Sanz-Aguilar et al. (2016) found that this loss of breeders is being buffered by immigration, since the local recruitment is not enough to compensate this loss. Furthermore, in the Spanish breeding colonies of Scopoli's shearwater, it has been found a variation in the adult survival among colonies, which is related to the degree of spatial overlapping between the foraging areas and longline fisheries (Genovart et al. 2017a).

To understand the potential consequences of uneven mortality between sex and age classes and the geographical extent of the impacts, we analysed the age and sex of the shearwater carcasses and the provenance of the rings recovered by Spanish demersal and pelagic longline fleet operating in the north-western Mediterranean.

METHODS

Study area

The study was conducted in the north-western Mediterranean, which includes the Catalonia (Iberian Peninsula) and Balearic Island regions. This area contains important breeding colonies of endemic and sensitive seabirds (Zotier et al. 1999, Arcos et al. 2009). Most shearwater colonies are distributed along the Balearic archipelago, but birds primarily forage over the Iberian continental shelf in addition to the waters around the colony (Arcos et al. 2012b, Meier et al. 2015).

Nevertheless, the Iberian shelf also attracts Scopoli's and Mediterranean shearwaters from colonies beyond the study area, such as French and Italian colonies (Péron et al. 2012, Péron & Grémillet 2013). Concurrently, an important longline fleet operates in this region (FAO 2016), mainly composed of artisanal demersal (medium-scale and small-scale) and semi-industrial pelagic vessels (Féral 2004).

The demersal longline fleet in the region consists of artisanal boats ranging from 7 to 15 m in length and 1- 4 crew members that usually make one-day fishing trips. Main fishing grounds are located in the continental shelf or shelf-break areas close to the fishing ports of origin (Cortés et al. 2017). Generally, the medium-scale vessels employ demersal longlines all year round, but the small-scale vessels are polyvalent so several boats use demersal longline seasonally. The fishing effort of the demersal medium-scale vessels in the north-western Mediterranean is mainly concentrated in the continental shelf of Catalonia (Cortés et al. 2017). In contrast, the effort of the small-scale vessels is widely distributed along the continental shelf of the study area. In the case of pelagic longline fisheries, the fleet is composed of vessels ranging from 9.5 to 25 m in length and 3 -10 crew members, and the days spending at sea per fishing trip ranged from 1 to 9 (normally 3 or 4). The fleet operating in the study area shows a high variable spatial and temporal distribution, but the main fishing grounds are located around Balearic Islands and Levantine region waters, including both neritic and oceanic waters. For detailed information about the gear characteristics of both longline fleets see Cortés et al. (2017), García-Barcelona et al. (2010b), and Macías et al. (2012)

Seabird dissections

We collected 639 shearwaters accidentally caught between 2003 and 2015 by different longline fleets operating in the north-western Mediterranean: 1) demersal (medium-scale longliners; n = 314 birds, and small-scale vessels; n = 103) and 2) semi-industrial pelagic fleet (n = 222). The specimens were either collected during on-board observed sets or voluntarily offered by longline fishermen when there was not observer on-board.

All collected birds were labelled indicating date, fishing harbour, name of the vessel, species, and position. Seabird carcasses were frozen immediately after being landed at -20°C until dissection. All specimens were dissected to determine the age and sex by inspecting and measuring the sexual organs, following Van Franeker (2004). We also examined the moulting stage as an additional criterion for ageing birds. We classified birds into 4 age classes: juveniles (hatch-year), immatures, subadults and adults mainly based on gonadal development (see Apèndix I). To distinguish the juvenile and immature birds from adults we also used the presence and size of the Bursa of Fabricius (Broughton 1994). Subadult category indeed

includes both, immature birds close to adult age and non-breeding adults, since gonadal development of these two stages is difficult to tease apart (Hector et al. 1986). Therefore, we were only able to confirm adult age when birds were in breeding state (Van Franeker 2004). In males, testes gradually become larger and turn from blackish to greyish, reddish or pinkish with age but only the testicles of breeding males acquire a creamy colour and reach sizes larger than 30 mm². In females, the development of the ovarian follicles and the oviduct increase with age, from an ovary without developed follicles (< 0.1 mm) and very thin and straight oviduct to larger follicles and an enlarged oviduct, but only breeding females develops prominent follicles (> 2 mm) and a wider, curved oviduct.

To distinguish between the two *Puffinus* species, we considered plumage coloration and biometrics and conducted genetic analyses in 66% and isotopic analyses in 20% of the specimens (N = 390) to confirm the species (Militão et al. 2014, García-Barcelona et al. 2016).

Data analysis

We analyzed the seasonal and spatial demographics of the seabirds caught by the longline fleet operating in the study area. To evaluate the seasonal variability, we defined different time periods for each shearwater species in accordance with their phenology (see Fig. 1) (Ruiz & Martí 2004, Bourgeois & Vidal 2008, Reyes-González & González-Solís 2011, Raine et al. 2013). We examined the annual and seasonal deviation from the 1:1 expected sex ratio for each shearwater species. To calculate the sex ratio, we considered two data groups: (1) all individuals; where all age classes were included in the analysis, and (2) adult individuals. In addition, we compared the annual and seasonal age-related proportion (adults, subadults, and immature plus juveniles) for each shearwater species. Furthermore, in the case of Scopoli's shearwater, we compared the proportion of adults, males and sex ratio between areas; the Catalonia and Balearic archipelago. These differences were tested using a chi-square test with Yates's correction for continuity.

To determine the origin of the individuals caught by the longline fleet of the region, we used the recovered rings that came either from the dead birds gathered or from ring data reported by fishermen. We considered the place and time of the first capture to know the breeding colony of origin and the accurate (if it was ringed as a chick) or approximate age of the banded birds when they died.

RESULTS

Seabird dissections

Most birds were recovered from the Catalonia area (86%, N = 639, Table 1) and all the *Puffinus* shearwaters from the shelf of this region. Almost all Balearic shearwaters (93%) and a large proportion of the Mediterranean shearwaters (75%) were caught by vessels operating in the central-southern area. However, we also registered catches in areas further north, especially of the Mediterranean shearwater (25%). In the case of Scopoli's shearwaters (Table 1), the majority of the carcasses were collected in Catalonia area (65%), but they were equally distributed over the shelf off the northern and central-southern Catalonia and the Balearic Islands (32%, 33% and 36%, respectively).

Table 1. Number of dead shearwaters collected in the longline fisheries operating in the north-western Mediterranean. Data are grouped in two main areas: Catalonia and Balearic Islands. It is also showed the overall proportion for the different age classes considered in this study: adults (AD), subadults (SA), and immature plus juveniles (IM). N refers to the total number of birds collected (N_1) or those that we were able to identify the age of each species (N_2).

	Catalonia	Balearic Is.	N_1	%AD	%SA	%IM	N_2
Scopoli's shearwater	162	89	251	72	12	16	215
Balearic shearwater	188	0	188	40	31	29	182
Mediterranean shearwater	182	0	182	45	29	26	170
<i>Puffinus</i> spp.	18	0	18	31	25	44	16
Total	550	89	639	-	-	-	583

The shearwaters were mainly collected during the prelaying-incubation of Scopoli's shearwater and the chick-rearing period of the *Puffinus* shearwaters (Fig. 1). However, we also recovered a high number of carcasses of the *Puffinus* shearwaters during the prelaying and of Scopoli's shearwaters during the prelaying and post-breeding migration.

Adults were the age class most caught in the 3 species of shearwaters (Table 1), followed by subadults and immatures (both, juvenile and immature birds). Adults of Scopoli's and Mediterranean shearwater were more abundant than subadults (SS: $\chi^2_{(1)} = 150.11$, p < 0.001, MS: $\chi^2_{(1)} = 9.07$, p < 0.01) and immatures (SS: $\chi^2_{(1)} = 127.14$, p < 0.001, MS: $\chi^2_{(1)} = 13.83$, p < 0.001), while in the case of Balearic

shearwater, the proportion of adults was only significantly higher than immatures ($\chi^2_{(1)} = 4.38$, $p < 0.05$).

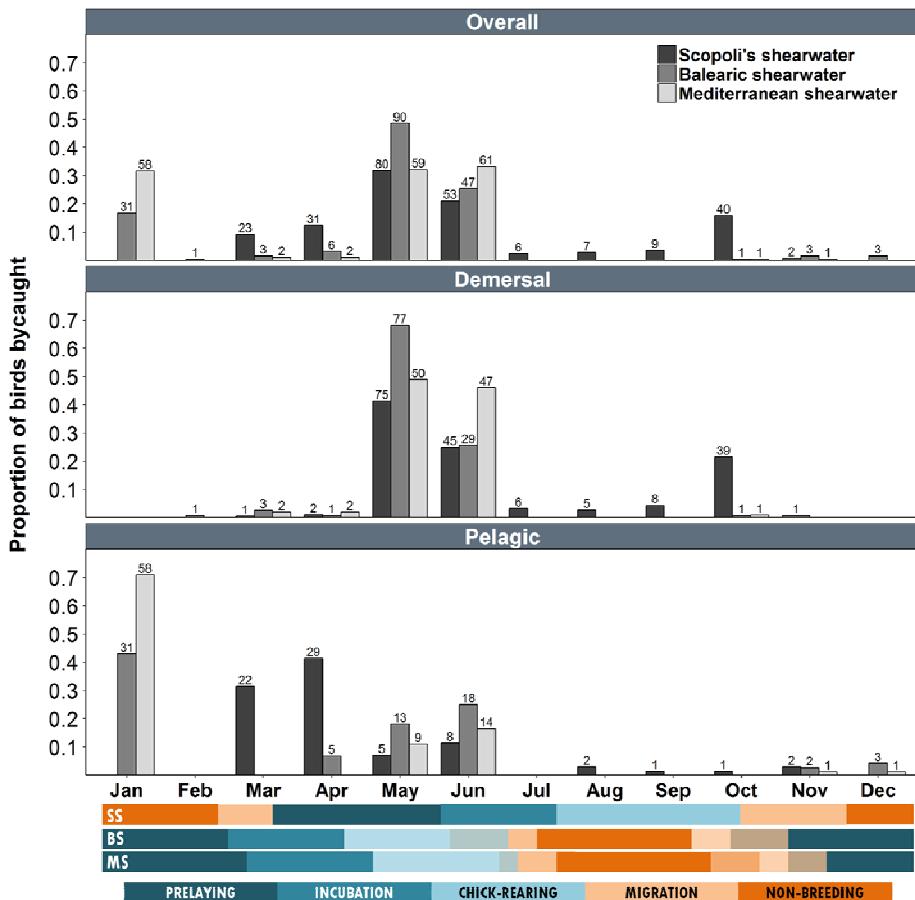


Figure 1. Proportion of Scopoli's (SS: dark, N = 251), Balearic (BS: grey, N = 185) and Mediterranean shearwaters (MS: light grey, N = 184) accidentally caught by month in longliners, considering the overall fleet (N = 620 birds) and the demersal (N = 396) and pelagic longliners (n = 224) separately.

Moreover, adults of Scopoli's shearwaters were more abundant around the Balearic Islands (Fig. 2a; $\chi^2_{(1)} = 29.42$, $p < 0.001$), while immatures were almost exclusively caught over the Iberian shelf (Fig. 2b; $\chi^2_{(1)} = 23.19$, $p < 0.001$). Adult shearwaters were predominantly caught during the prelaying, but also during the incubation for Scopoli's shearwater (Fig. 3). However, in this latter species, the proportion of

subadults and immatures increased as the breeding season progressed, reaching their maximum in the chick-rearing period (Fig. 3a, SS: $\chi^2_{(2)} = 64.93$, $p < 0.001$). Instead, in the *Puffinus* shearwaters, the immature were equally caught along the breeding period, while the proportion of subadults increased in the chick-rearing (Fig. 3b, BS: $\chi^2_{(2)} = 11.24$, $p < 0.01$; Fig. 3c, MS: $\chi^2_{(2)} = 6.62$ $p < 0.01$).

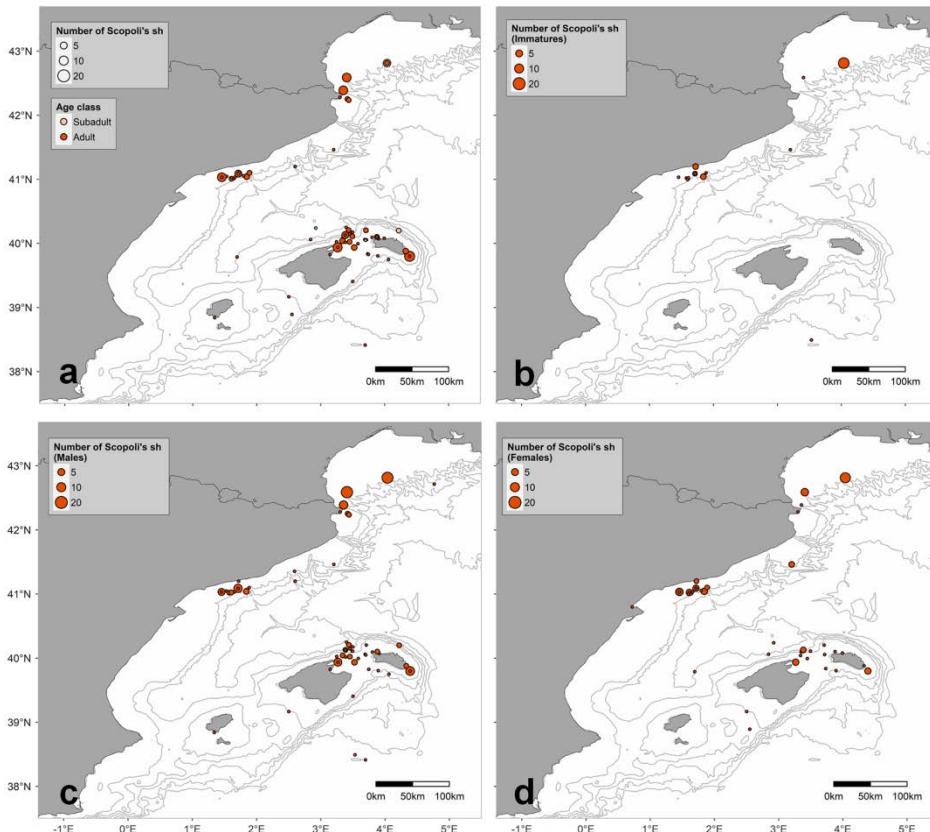


Figure 2. Spatial distribution of the different Scopoli's shearwater age and sex classes killed by longlines: (a) adults + subadults ($N = 200$ birds), (b) immature + juveniles ($N = 35$), (c) males ($N = 146$ birds) and (d) females ($N = 95$)

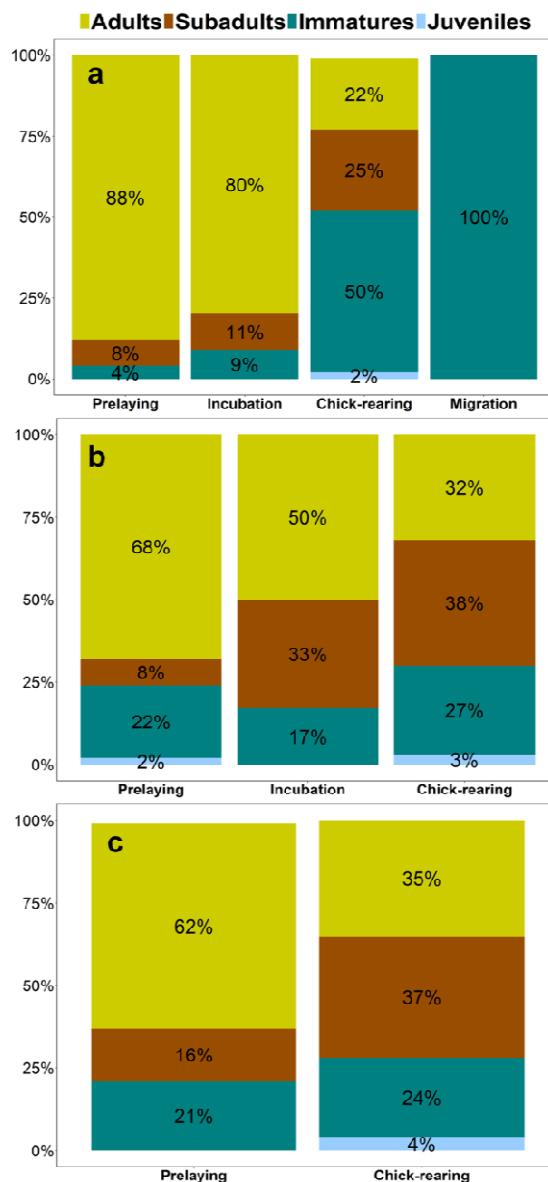


Figure 3. Percentage of each age class (adults, subadults, immatures and juveniles) accidentally caught in different time periods for each shearwater species: (a) Scopoli's (prelaying; N = 102 birds, incubation; N = 64, chick-rearing; N = 40, migration; N = 4), (b) Balearic (prelaying; N = 41, incubation; N = 6, chick-rearing; N = 132) and (c) Mediterranean (prelaying; N = 62, chick-rearing; N = 111) shearwaters.

Overall mortality showed a significant sex ratio bias only in Scopoli's shearwater towards males (Table 2). In this species, male proportion was higher in the Balearic archipelago (70%) than in the Iberian area (56%) (Fig. 2c and Table 3; $\chi^2_{(2)} = 4.12$ p < 0.05). Male-biased mortality was also found when only adults were considered (Table 2). However, when we consider breeding periods separately, male-bias was only significant in prelaying. When we examined sex ratio occurring off Catalonia and Balearic Islands independently (Table 3), we only found the male mortality deviation in the Balearic Islands in both, all-year-round and in the prelaying period.

In the case of *Puffinus* shearwaters (Table 2), we also found a male-biased during the prelaying period when all individuals and only adults were considered. On the contrary, there was a female-biased during the chick-rearing period. However, for the Balearic shearwater this bias was only significant in adult birds caught during both chick-rearing and all-year-round.

Table 2. Proportion (%) of males and sex ratio (SR), considering all age classes or only adults birds (ARS), of the shearwater species killed in north-western Mediterranean by longline fisheries annually and in each breeding period. P-values: *** < 0.001, ** < 0.01, * < 0.05

Species/Period	% Male	N	SR (M:F)	% Adult males	N	ASR (M:F)
Scopoli's shearwater						
<i>Annual</i>	61	242	1.6:1***	66	151	1.9:1***
<i>Prelaying</i>	64	105	1.8:1**	69	91	2.2:1***
<i>Incubation</i>	62	80	1.6:1	59	51	1.4:1
<i>Chick-rearing</i>	52	52	1.1:1	67	9	2.0:1
Balearic shearwater						
<i>Annual</i>	51	182	1.1:1	34	73	0.5:1*
<i>Prelaying</i>	73	41	2.7:1**	74	27	2.8:1*
<i>Incubation</i>	33	6	-	0	3	-
<i>Chick-rearing</i>	45	132	0.8:1	12	43	0.1:1***
Mediterranean shearwater						
<i>Annual</i>	48	174	0.9:1	43	77	0.8:1
<i>Prelaying</i>	71	62	2.4:1**	82	38	4.6:1**
<i>Chick-rearing</i>	35	111	0.5:1**	0.1	39	0:1***

Table 3. Proportion (%) of adults, males and adult males of the Scopoli's shearwaters caught annually and in each breeding period, considering the catches occurred off the Catalonia and Balearic Islands separately. Sex ratio (SR) is obtained considering all age classes or only adult birds (ASR). Total number of birds is indicated between brackets. P-values: *** < 0.001, ** < 0.01, * < 0.05

	Catalonia					Balearic Islands				
	% Adults	% Males	SR	% Adult males	ASR	% Adults	% Males	SR	% Adult males	ASR
Annual	62 (123)	56 (153)	1.3:1	60 (70)	1.5:1	92 (87)	70 (89)	2.3:1***	70 (81)	2.2:1***
Prelaying	64 (28)	52 (29)	1.1:1	56 (18)	1.3:1	97 (74)	70 (76)	2.3:1**	73 (73)	2.7:1***
Incubation	83 (54)	61 (70)	1.6:1	62 (45)	1.6:1	60 (10)	60 (10)	1.5:1	33 (6)	-
Chick-rearing	19 (37)	49 (49)	1:1	57 (7)	-	67 (3)	100 (3)	-	100 (2)	-

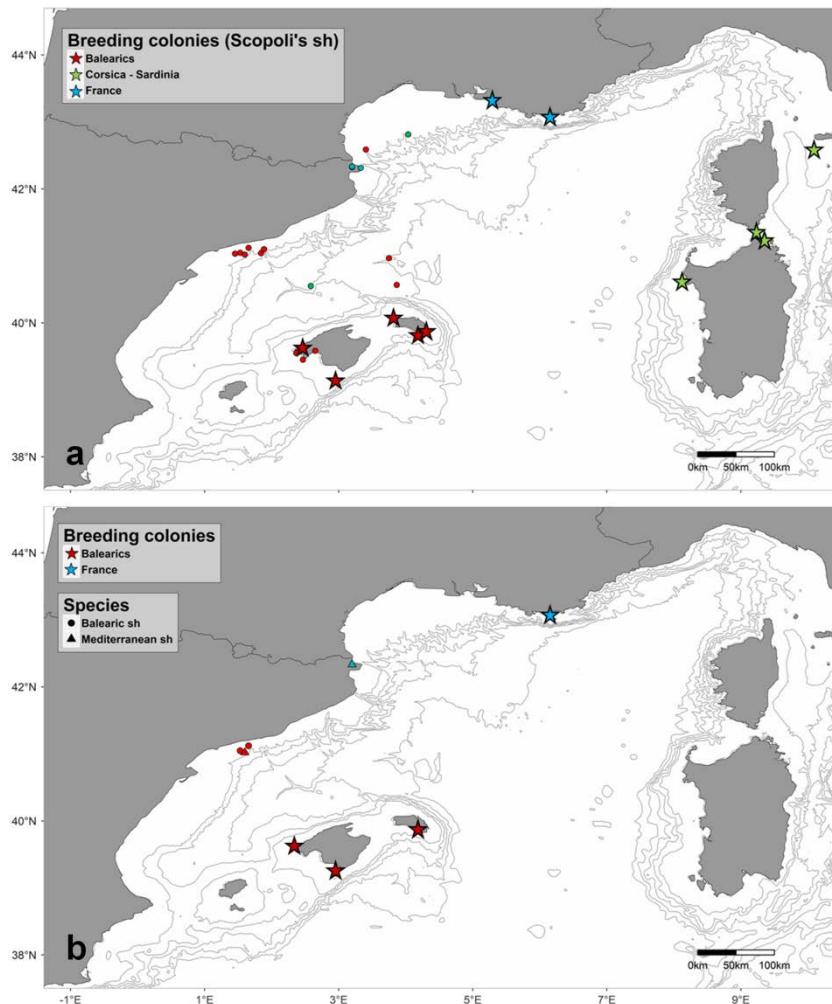


Figure 4. Spatial locations of ringed birds caught by longline fisheries operating in the north-western Mediterranean and their breeding colonies of origin for (a) Scopoli's shearwater ($N = 32$ banded birds) and (b) the *Puffinus* shearwaters (Balearic and Mediterranean shearwater, $N = 4$). The breeding colonies showed in the map correspond to the banding locations of the ringed birds collected in longline vessels. These colonies are grouped in 3 different regions: Balearic Islands (red), France (green) and Corsica - Sardinia (blue).

Ring recoveries

Ringing data obtained from birds caught in longliners operating in the study area over the same study period ($N = 34$ recoveries) showed that most ringed individuals were Scopoli's shearwaters (88%) caught throughout the breeding

period and during the migration (Apèndix II). Birds were ringed in different breeding colonies of the western Mediterranean located in the Balearic (63%), French (27%) and Italian (10%) islands but the origin differed across the Catalan coast. That is, most Scopoli's shearwaters caught in the northern Catalonia were ringed in France or Italy, while the birds caught in the central-southern area and in waters around the Balearic archipelago were mostly ringed in Balearic Islands (Fig. 4a). For those ringed birds that we could determine the age (67%, N = 30), adults were the age class most often recovered (86%, N = 20), ranging from 6 years to a maximum of 17 years. In the case of ring recoveries of the Balearic (6%, N = 34) and Mediterranean (6%) shearwaters, all ringed specimens were adults caught in the chick-rearing period. Balearic shearwaters were ringed in Majorca Island (Balearic archipelago), while one individual classified as Mediterranean shearwater was ringed in Minorca Island (Balearic archipelago) and another one in a French colony (Fig. 4b). Catches of the *Puffinus* shearwaters occurred in the central-southern Catalonia, although the Mediterranean shearwater from the French colonies was caught in the northern part of the study area.

DISCUSSION

This is the first comprehensive study on age- and sex-related variation in seabirds caught by longline fisheries in the Mediterranean. The examination of the catches from demersal and pelagic longline vessels revealed clear differences in mortality among age classes and sex, which varied across areas and seasons and among the 3 endemic shearwater species of the Mediterranean: Scopoli's, Balearic and Mediterranean shearwaters. In addition, ring recoveries showed bycatch mortality is affecting breeding populations from the Western Mediterranean, both in and out of the study area.

The incidental mortality of Scopoli's shearwater was registered in the shelf off the Iberian coast but also close to the Balearic Islands, an important foraging ground for shearwaters breeding in Western Mediterranean colonies (Louzao et al. 2009, Péron & Grémillet 2013). Conversely, all *Puffinus* shearwaters were caught on the Iberian shelf during the prelaying and chick-rearing periods. The Balearic shearwater was more frequently caught in the central-northern (93% of the catches) than in northern Catalonia, an area well known as a major foraging hotspot for the species year-round (Louzao et al. 2009, Arcos et al. 2012b). In the case of the Mediterranean shearwater, the incidental catches were important in the central-northern (75%), but also in the northern Catalonia (25%), which is considered one of the most important foraging area of species in the western Mediterranean (Arcos et al. 2012b, Péron et al. 2013).

In the three shearwater species most catches were adult birds, particularly during the prelaying period. This high prevalence of adults was also found in the ringing and recovery data collected in this study. However, the proportion of adults decreased with the progress of the season. In Scopoli's shearwater, the incidental mortality of adults peaked during the incubation period and, after that, we found an increase of catches of immatures and subadults, which possibly results from the increase in numbers of these age-classes in the area. During the pre-migration period, immatures and subadult Scopoli's shearwaters come into the area from more eastern breeding colonies (Péron & Grémillet 2013), with the consequent increase in by-catch risk. In the case of the *Puffinus* shearwaters, we only found an increase of the proportion of subadults from prelaying to chick-rearing period, while the immatures were equally caught along the breeding season. However, the number of adults in the late breeding period may have also been underestimated due to gonadal regression (Hector et al. 1986), which makes difficult to tease apart adult breeders from subadults late in the season. This bias may be particularly important in the *Puffinus* shearwaters, since most birds were collected during the chick-rearing period.

Interestingly, the spatial distribution of the age classes was not uniform. Adults Scopoli's shearwater were caught in a higher proportion in waters close to their major breeding site in the area (Balearic Islands, 92% of total individuals caught) than in the Iberian coast (57%), whereas the reverse was true for other age classes. Indeed, juvenile and immature birds were nearly exclusively caught in the Iberian coast and the proportion of subadults was also larger in this area. Our findings agree with a previous study that also found a high proportion of adults caught in the longline fleet operating nearby Columbretes Is. (Iberian Peninsula), where a small breeding colony of the species occurs (Belda & Sánchez 2001). A higher proportion of adults caught nearby the breeding colonies is possibly related to differences in distribution among age-classes derived from the constraints of central place foraging in breeding birds (Phillips et al. 2017b) and the avoidance of intraspecific competition in the vicinity of the colonies by non-breeders (Weimerskirch et al. 2006, Votier et al. 2011).

Imbalance in the sex ratio of the catches was noticeable in some periods and areas. In particular, in the three shearwater species most catches of pre-laying adults were males. This possibly results from sex-related differences in the at-sea distribution during this period. Indeed, pre-laying males forage closer to the breeding colonies than females in many procellariform species (Phillips et al. 2017a), including the Balearic, Mediterranean and Scopoli's shearwaters (Bourgeois et al., 2008; Guilford et al., 2012, J. González-Solís, unpubl. data). This is typically related to the different role of males and females in this period, since females have to form the egg and engage in long pre-laying exodus often far from the breeding colonies, whereas males are more involved in nest defence and remain

in areas closer to the breeding colony than females (Hedd et al. 2014, Phillips et al. 2017b). Similarly, the skewed mortality towards females in adult Balearic and Mediterranean shearwaters during the chick-rearing period is possibly related to sex-specific differences in food-provisioning behaviour influencing the likelihood of interaction with longlines. Indeed, in the sibling species, the Manx shearwater (*Puffinus puffinus*), females show longer trips and lower feeding rates than males during chick-rearing (Gray & Hamer 2001). Alternatively, the sex-biased mortality observed in this study may actually reflect an imbalance in adult sex ratios (ARSs) at population-level. In fact, the skewed ASR, in particular towards males, has been observed in many bird species (Bessa-Gomes et al. 2004, Donald 2007), with this tendency being more pronounced in those species that have unfavourable conservation status (Donald 2007). Previous studies carried out in two different populations of Scopoli's shearwater (Spain and Greece) did not find significant deviation of parity in sex ratios at hatching and fledging (Genovart et al. 2005, Karris et al. 2013b), although it was found a slightly male-biased in the population of Greece. Nevertheless, in monogamous birds, a skew in the ASR primarily resulting from a differential mortality between sexes rather than differences in the offspring sex ratio (Awkerman et al. 2007, Donald 2007, Székely et al. 2014). The sex-specific survival rates may occur because male and females have different behaviour, ecology and life-histories (Kokko & Jennions 2008, Székely et al. 2014), which leads to unequal exposure to mortality sources. The lack of information about population structure does not allow us to rule out the possibility of a pre-existing sex bias in the shearwater populations; however, because bycatch in longline fisheries is the main source of mortality for these species, it is to be expected that the sex-biased mortality found in this study could be having a large influence on population sex ratios (Awkerman et al. 2007).

We also examined the origin of birds caught in longliners based on 34 ring recoveries. Most recoveries of Scopoli's shearwaters (63%, N = 30 birds) corresponded to birds ringed at the closest breeding site, the Balearic islands (53% from Majorca and 10% from Minorca), similar to previous studies (Belda & Sánchez 2001). Genovart et al. (2017a) built a longline bycatch risk map for Scopoli's shearwater from three distant Spanish breeding colonies, and linked this with their adult survival. Authors found colony-specific sensitivity to bycatch, with Pantaleu (Majorca) and Columbretes Is. being the colonies most affected. Our study corroborates this high incidence on colonies of Majorca, particularly in Pantaleu (32% of total rings from Spanish breeding colonies). Nevertheless, we also found a significant proportion of birds ringed in French and Italian colonies (37%) which were mainly caught in the north of Catalonia (83%, N = 12), particularly during the migration period. This is because the Spanish western Mediterranean is an important stop-over site during the post-breeding migration for Scopoli's shearwaters from more eastern breeding colonies (Péron & Grémillet 2013). On the other hand, the four rings from *Puffinus* shearwaters were recovered on the Catalan

coast, basically corresponding to breeding colonies within or nearby the Spanish western Mediterranean. Two Balearic shearwaters were ringed as chicks in Majorca, the closest breeding site for the species. Two Mediterranean shearwaters were ringed at Porquerolles (southern France) and the Balearic/Mediterranean shearwater hybrid population of Minorca.

CONCLUSIONS

Although we would expect immature birds to be more numerous in the population (Arcos et al. 2012a, Garcia et al. 2016, Sanz-Aguilar et al. 2016), we found adult birds to be by far the most common age class among birds caught by the longliners in the 3 shearwater species. In the case of Scopoli's shearwaters, the proportion of adults was particularly high in the vicinity of their breeding colonies. These results show the longline fleet operating in the north-western Mediterranean is mainly affecting the survival of breeding birds, the most sensitive and critical demographic parameter in long-lived seabirds (e.g. Genovart et al. 2017b). We also found a number of imbalances in the sex ratio of the three shearwater species across areas and seasons due to sex-specific differential mortality in longline fisheries, which may exacerbate bycatch impacts on population dynamics (Mills & Ryan 2005, Awkerman et al. 2006), in particular on species with small populations (Bessa-Gomes et al. 2004), such as the critically endangered Balearic shearwater. Overall, our study shows population biases in bycatch, which may aggravate demographic implications for populations of the 3 endemic shearwater species. Moreover, impacts are more pronounced, but not limited, to the Spanish breeding colonies, affecting birds from other Western Mediterranean colonies while using the area as a stopover site during the migration period. On the other hand, the strong temporal pattern of the shearwater bycatch found in this study supports the recommendation of implementing a temporal closure of the longline fleet, both demersal and pelagic, to minimize the bycatch rate in the study area (García-Barcelona et al. 2010a, Báez et al. 2014, Cortés et al. 2017). Indeed, in the pelagic longline fleet this type of temporary closure have already been implemented in the past, such as in October and November in 2009 (ICCAT Recommendation 08-03), and from January to March in 2017 (ICCAT Rec. 16-05). Although these closures were primarily oriented to recover fish stocks, these could also be very beneficial for shearwaters if implemented in the more critical periods of bycatch, such as April, May to June and October. Furthermore, our findings show the importance of achieving a comprehensive spatial and temporal coverage of the fleet to properly assess the bycatch impact on seabird populations. Further detailed studies are needed on the foraging distributions of shearwaters and its overlap with fisheries to better interpret the causes of the age- and sex-related variations in the bycatch mortality by longline fisheries. Moreover, demographic models on the population

viability of the three endemic shearwaters of the Mediterranean should be improved by incorporating the population biases found in the present study.

ACKNOWLEDGEMENTS

We are grateful to the skippers and crews of fishing vessels that voluntarily collaborated in this project. We specially thank Teresa Militão for the support and help in the seabird dissections, and all the students and collaborators who collected seabirds from longline vessels and/or made the dissections: Èric Domínguez, Lluïsa Ferrer, Eleftheria Georgiou, Manel Mamano, Pau Marquès, Jordi Martínez, Neus Matamala, Adriana Rodríguez, Andrea Rodríguez, Oriol Torres, David Torrens, Isabel García, Esther Camacho and Maite Louzao. We thank “Oficina de Especies Migratorias” (MAGRAMA and SEO/Birdlife) for providing ringing data of the recoveries. We also thank Bob Bonn for providing language help. This study was funded by the *Fundación Biodiversidad* (18PCA4328, 2012-13; 2013-14; 2014-15) and Spanish government (CGL2009-11278/BOS, CGL2013-42585-P). VC was supported by a PhD grant from the Generalitat de Catalunya (FI/DGR/2011). The onboard observer program in surface longline vessels was supported by the Spanish Institute of Oceanography based in Málaga (IEO), GPM programs (IEO) and Data Collection Framework (DCF) (EU-IEO).

SECCIÓ II

MESURES DE MITIGACIÓ PER REDUIR LES CAPTURES ACCIDENTALS EN ELS PALANGRERS DEMERSALS



CAPÍTOL 4

Seabird bycatch mitigation trials in artisanal demersal longliners of the Western Mediterranean

Assajos per a la mitigació de les captures accidentals d'ocells marins en els palangrers artesans demersals de l'oest del Mediterrani

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RESUM

Gran nombre d'ocells marins moren anualment arreu del món en les pesqueres de palangre. Al Mediterrani, aquesta mortalitat afecta seriosament a la viabilitat de les poblacions dels ocells marins, en particular de les tres baldrigues endèmiques. Tot i així, actualment no s'està implementant cap mètode de mitigació específic per evitar les captures accidentals dels ocells marins. Del 2013 al 2014, evaluarem l'eficàcia i l'aplicabilitat pràctica de quatre mesures de mitigació en palangrers demersals artesanals dirigits a la pesca del lluç europeu (*Merluccius merluccius*) del Mediterrani: la calada nocturna, la línia espantaocells, les línies amb pesos i els esquers artificials. Realitzarem cinquanta-dos calades experimentals (amb la mesura de mitigació) i controls (sense cap mesura) aparellades i es compararen els seus efectes sobre la interacció dels ocells i les captures de peixos. A més, s'estimà la taxa d'enfonsament del palangre i l'àrea d'accés dels ocells marins als hams escats en diferents configuracions de palangre. La calada nocturna reduí el risc de captura accidental sense afectar les captures de peixos objectiu i no comercials. La línia espantaocells redueix el risc de captura d'ocells mitjançant el desplaçament dels atacs als esquers, però les baldrigues encara podrien accedir als esquers més enllà de la línia a través del busseig i les serpentines no dissuadiren els ocells en condicions de vent en calma. Les línies amb pesos augmentà la velocitat d'enfonsament, però només produí una reducció limitada de la finestra d'accés dels ocells marins als hams escats i provocà alguns problemes operatius durant la calada. Els esquers artificials reduïren substancialment les captures comercials. D'altra banda, l'accés de les baldrigues als hams es trobava influenciat per la configuració del palangre, la velocitat de calada i la posició relativa respecte als flotadors i pesos. Fins al moment, la calada nocturna destaca com la millor mesura de mitigació per reduir els nivells de captures accidentals sense comprometre les captures objectiu dels palangrers demersals. Encara que aquests resultats s'haurien de confirmar en els palangrers que pesquen altres espècies que no siguin el lluç europeu.

ABSTRACT

High numbers of seabirds are killed annually worldwide in longline fisheries. In the Mediterranean, this mortality is seriously affecting the viability of seabird populations, in particular of the three endemic shearwaters. Even so, no specific mitigation method is currently being implemented to avoid seabird bycatch. From 2013 to 2014, we assessed the efficiency and practical applicability of four mitigation measures on artisanal demersal longliners targeting European hake (*Merluccius merluccius*) in the western Mediterranean: night setting, tori line, weighted lines and artificial baits. We performed fifty-two pairs of experimental (with the tested mitigation measure) and control settings (without any measure),

and compared their effects on seabird interaction and fish catches. In addition, we estimated the longline sink rates and the seabird access area to baited hooks in different longline configurations. Night-setting reduced bycatch risk without affecting target and non-commercial fish catches. The tori line reduces the bycatch risk by displacing bait attacks, but shearwaters could still access baits by diving beyond the line and the streamers did not deter birds under calm wind conditions. Weighted lines increased sink rate, but it resulted in only a minor reduction of the seabird access window to baited hooks and led to some operational problems during the setting. Artificial baits substantially reduced commercial catches. On the other hand, the seabird access to the baited hooks was influenced by the longline configuration, the setting speed and the relative position to the floats and weights. So far, night setting stands out as the best mitigation measure for reducing bycatch levels without compromising target catches in demersal longliners. Ideally, these results should be confirmed in longliners targeting species other than European hake.

Keywords: Artificial bait, Bird Scaring line, Longline sink rate, Night setting, Seabird Access Window, Shearwaters, Weighted line

INTRODUCTION

Longline fisheries constitute the most serious threat faced by seabirds at sea worldwide (Croxall et al. 2012). At least 160,000 seabirds are killed through getting hooked and drowning each year when birds attack baited hooks during line setting (Anderson et al. 2011). Procellariiformes, such as albatross, petrels and shearwaters appear to be the most affected seabirds by this fishery (Brothers et al. 1999a, Anderson et al. 2011). Combined with other human-mediated disturbances, mortality induced by longline fisheries is putting numerous seabird populations at risk and has driven some to extinction (Inchausti & Weimerskirch 2001, Lewison & Crowder 2003, Wanless et al. 2009). Nevertheless, several studies have demonstrated the efficiency of different mitigation methods to reduce seabird bycatch in longline fisheries (Brothers et al. 1999a, Løkkeborg 2011). Possible measures include deterring birds from taking baits (e.g. tori lines, acoustic or olfactory deterrents), limiting access to the baited hooks by increasing the sink rate of the longline (e.g. weighted lines, Chilean method, thawing the bait), avoiding the periods or areas where seabird interactions are most intense and likely (e.g. night setting, area or seasonal closures) and making bait less attractive or visible for seabirds (e.g. artificial baits, blue-dyed baits) (Brothers et al. 1999a, Løkkeborg 2011). Nevertheless, the efficiency of the mitigation methods employed may vary depending on the seabird species assemblage at fishing grounds and the longline type used (Løkkeborg 2011). In principle, the use of mitigation methods increases

fishing efficiency and profitability, since the reduction of the bait loss by seabirds could lead to an increase of commercial catches (Løkkeborg 2003). For this reason, their effects on target species and on the fishing operations must be carefully examined.

In Western Mediterranean, bycatch by longlines is thought to be one of the main causes of population decline in shearwater species (Oppel et al. 2011, Genovart et al. 2016, 2017b). Scopoli's shearwater (*Calonectris diomedea*) is the most bycaught species in this region (Belda & Sánchez 2001, García-Barcelona et al. 2010b, Laneri et al. 2010). Nevertheless, a previous study on bycatch rates showed that Balearic and Mediterranean shearwaters (*Puffinus mauretanicus* and *P. yelkouan*) are also frequently caught by demersal longliners (Cortés et al. 2017). The current situation of the critically endangered Balearic shearwater is particularly alarming, as a recent review on its demographic trends highlighted again the unusually low adult survival, which is leading to a severe decline of its populations (Genovart et al. 2016). In fact, this study showed Balearic shearwaters could be driven to extinction in 60 years if mortality caused by fisheries continues at its current level.

Artisanal demersal longliners seem to be the major source of seabird mortality in the Mediterranean sea (FAO 2016). This fleet uses smaller bait and hooks compared to pelagic longliners thus increasing the chances of birds being hooked. Massive catches of tens to hundreds shearwaters in only one setting occur occasionally every year in this fishery suggesting that demersal longliners are having a large effect on the three endemic shearwaters of the Mediterranean basin (Cortés et al. 2017). The Balearic and the Mediterranean shearwaters are the most affected species in these large scale mortalities, mainly due to their gregarious behaviour and diving abilities, allowing them to seize baited hooks at greater depths than other seabirds such as gulls (Cortés et al. 2017). Despite the potential impact that demersal longliners are having on shearwater populations, no specific mitigation method is currently recommended by fishery management authorities, or used to prevent or minimize seabird bycatch. Therefore, there is an urgent need to find (and implement) effective mitigation techniques adapted to the Mediterranean demersal longline fleet.

Seabird bycatch by the demersal longliners operating in the study area increases during the breeding period and when longlines are set at sunrise. In addition, some operational characteristics of the vessels also have a significant influence, such as the bait type used, gear configuration (in particular, the distance between the weights) and the number of hooks set (Cortés et al. 2017). In accordance with these findings, we selected four mitigation methods, which have proved to be effective in other region, and adapted to the artisanal demersal longliners from the Western Mediterranean: 1) night setting, 2) tori lines (bird scaring lines or streamer lines), 3) weighted lines, and 4) artificial baits. Then, we tested their efficacy and practical

applicability. For each method, we assessed their effects on seabird attraction, on seabird bait attacks, on fish catches and on fishing activity by comparing paired longline settings with and without each mitigation method (Løkkeborg 2011). In addition, we determined the effects on sink rates of the longline configurations most commonly used in demersal longliners of the study area.

METHODS

Ethics Statement

The trials were conducted in two commercial vessels so all fishing activities were performed by the fishermen. We had the approval of the captains to carry out the experiments in their vessels and complied with the relevant requirements to go onboard commercial fishing vessels as occasional crewmember. This study did not require special permissions since fishing operations were conducted in conformity with the local rules and regulations.

Mitigation measure trials

The experiments were mainly carried out on a medium-scale artisanal demersal longliner (*Cona C.B.*, 11.10 m length) from north-western Mediterranean between May to July 2013 and 2014 (41°08'N, 1°53'E, Vilanova i la Geltrú, Catalonia, Spain). In addition, one of the trials (tori line) was also tested on another medium-scale demersal longliner in May 2014 (*Mar endins*, 14.5 m length) that operates in the Gulf of Lion area (42°20'N, 31°30'E, Llançà, Catalonia, Spain).

The areas and period were chosen to be among those with the highest risk of bycatch within the study area (Cortés et al. 2017). The fishing grounds are located within important foraging areas of the most susceptible species (the three endemic shearwaters) (Arcos et al. 2012b, Péron et al. 2013, Meier et al. 2015), while the study period overlapped with the prelaying and incubation stage of Scopoli's shearwaters and the chick-rearing and post-nuptial migration stage of the *Puffinus* shearwaters. In addition, trials performed with one of the longliners (*Cona C.B.*) coincided with a trawling moratorium period, which should exacerbate bycatch probability (Soriano-Redondo et al. 2016). Both vessels used a fishing gear configuration called the "Piedra - Bola" system (WFL), which is composed of a series of floats and weights to keep hooks at different heights from seabed (Fig 1), following a zigzag structure (see Cortés et al. 2017).

Hooks were baited with European pilchard (*Sardina pilchardus*) or European anchovy (*Engraulis encrasicolus*) to target European hake, although other species with less commercial value were also caught, such as blackmouth catshark (*Galeus*

melandromus), European conger (*Conger conger*), blackbelly resefish (*Helicolenus dactylopterus*) and small-spotted catshark (*Scyliorhinus canicula*).

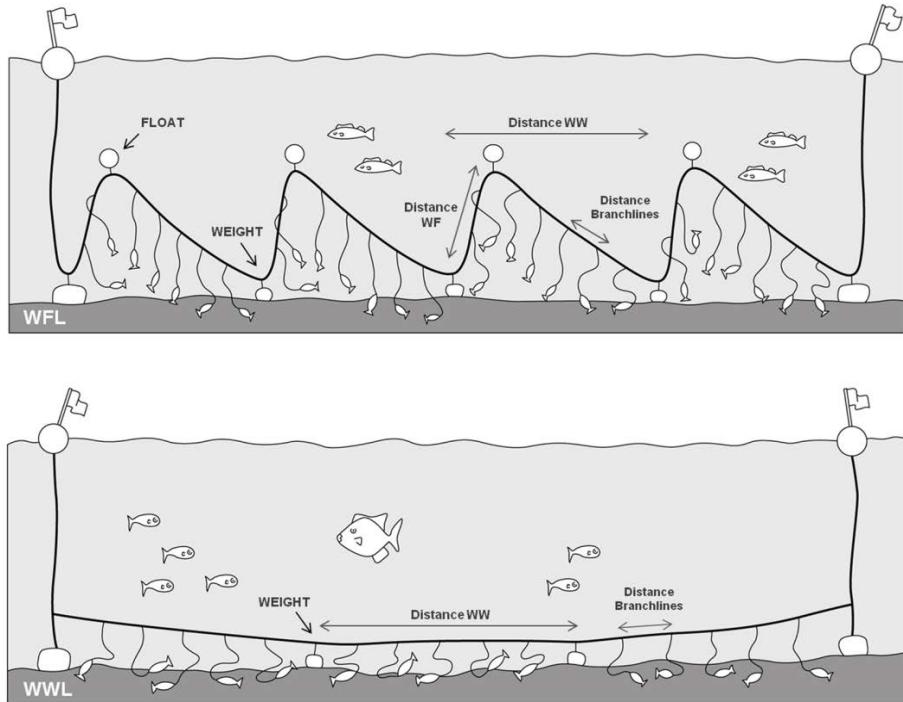


Figure 1. Longline types used by the artisanal demersal fleet. WFL: “Piedra – Bola” configuration composed by a sequence of floats and weights. WWL: fishing gear typically used by small-scale vessel where only weights are attached to the mainline. Drawing by Toni Mulet

There were some differences in the fishing gear configuration linked to the particular practices of the fishermen on the different boats (Table 1). The main differences were the distance between consecutive weights, as well as the distance from the weight to the float.

Trials were performed under typical fishing conditions to test different mitigation strategies. A description of the methods used is detailed in the Supplementary material (Apèndix II). For each mitigation measure, paired longline settings were performed: one line was normally set without any mitigation measure (control setting) and the other one using the tested mitigation measure (experimental setting). The duration of each setting (control or experimental) was about 30 minutes. In case of the *Cona C.B.*, longlines were left in the water until the night of

the following day (around 15 hours), starting with the first line set the previous day. On the *Mar endins*, the soak time of the longlines was 2-3 hours and the order of the hauling operations was the same as for the settings. The artificial baits used in the trials were manufactured by the Spanish company Arom Bait®, and consisted of brown, triangular pieces composed of a mix of products derived from fish.

Table 1. Characteristics of the fishing gears used in demersal longliners in which the sink rates were recorded. Longline types: "Piedra - Bola" configuration used by the medium-scale vessels *Cona C.B.* (WFL1) and *Mar endins* (WFL2), and the small-scale vessel *Vigilant* (WWL). Distance WW = distance between consecutive weights. Distance WF = minimum distance between the weight and the float. Distance and length are in meter units.

	Weights (kg)	Distance WW	Distance WF	Distance Branchlines	Branchline length
WFL1	2.32	70	11	3.7	1.8
WFL2	2.26	90	7	3.33	1.8
WWL	1.5	500	-	8	3

During setting operations, the number and species of seabirds attending the vessel and the attacks on bait performed by each species every 10-min period were recorded. For each time interval, the number and distance astern of overall attacks on bait were also registered and were ranked in six intervals: < 5, 5-10, 11-20, 21-50, 51-100 and > 100 m. During the night, counts of birds and attacks were limited by the distance from the stern at which these could be detected given the illumination provided by the boat. Position, depth and setting speed were also recorded at every count interval. A detailed description of the fishing gear used and the meteorological data were registered for each fishing trip. Seabird catches were recorded during the hauling, together with the number of the fish commercial catches, their size (from the tip of the snout to the tip of the longer lobe of the caudal fin), condition and the discards (fish catches returned to the sea). Seabird catches observed during the setting but not retrieved during the hauling were also considered. Discards were classified into four different causes: (1) bad condition of the specimens, (2) low commercial value, (3) small size and (4) non-commercial or protected species (fish bycatch). Moreover, the body mass of a sample of 470 European hakes were measured to obtain the relationship between the weight and the size, and then estimate the body mass from those individuals that were not weighed. Potential function showed a best fit of these data ($R^2 = 0.958$; $p < 0.005$):

$$\text{Body mass} = 0.012 * \text{Total length}^{2.899}$$

The effectiveness of each mitigation method in reducing seabird attraction and bait attacks was assessed comparing results between the control and experimental lines. The practical applicability was also evaluated for all mitigation measures tested, while the effects on fish catches was only assessed in those measures that involved a change in the longline configuration and fishing habits (night setting, weighted lines and artificial baits). Given that seabird incidental catches only occur occasionally (Cortés et al. 2017), it was not possible to obtain enough data to compare bycatch rates between control and experimental settings. Instead, the number of birds following vessels and the bait attacks were used to infer seabird bycatch risk (Soriano-Redondo et al. 2016, Cortés et al. 2017).

Determining longline sink rate

Sink rates were measured to 10 m depth with Time-Depth Recorders (TDRs, long-life G5 data storage tags, CEFAS technology limited, UK). This reference depth was based on the dive ability of the Balearic shearwater (Meier et al. 2015). Each TDR measured 35.5 mm length and weighed 2.5 g in seawater. TDRs were programmed to record depth within 0.5 m every second. Devices were attached onto the monofilament of the branchline at 5 - 10 cm from the hook.

Sink rates were estimated for the three different longline configurations used in demersal longline vessels of the study area (Table 1 and Fig 1). Most data were collected from the control longlines (WFL configurations) of the mitigation trials conducted on the *Cona C.B.* (WFL1) and *Mar endins* (WFL2). TDRs were also deployed on a small-scale vessel called *Vigilante* (6.81 m length) from Mallorca that used a different longline configuration (WWL). In this case, the longline only had weights attached at regular intervals, which keeps the hooks level over the seafloor (Fig 1). Moreover, in contrast to other configurations studied, the weights used by this vessel were less heavy and more widely spaced (Table 1). This longline type is typical in the polyvalent small-scale vessels from the western Mediterranean to target a wide variety of demersal fishes, such as common pandora (*Pagellus erythrinus*), toothed bream (*Dentex dentex*) or gilt-head bream (*Sparus aurata*) (see Cortés et al. 2017).

TDRs were placed in different sections of the longline: initial (first 50 hooks), middle and final (last 50 hooks). Within each section, TDRs were placed at different hooks inside the float-weight sequence: near to the float (NF), between the float and the weight (BW) and near to the weight (NW). During the trials of the additional lead weights, TDRs were deployed in the two-paired longlines of each sample (control and experimental). To check if the lead weights increased the sink rate of the hooks, the devices were placed at the same section of the longline and position inside the float-weight sequence.

From the sink rate data and the setting speed of the vessel, it was possible to determine the distance behind the vessel at which shearwaters are most vulnerable to becoming hooked, namely the seabird access window (vessel speed x seconds to 10 m depth). This allowed the greatest bycatch risk area behind the stern during the setting for each longline type to be defined.

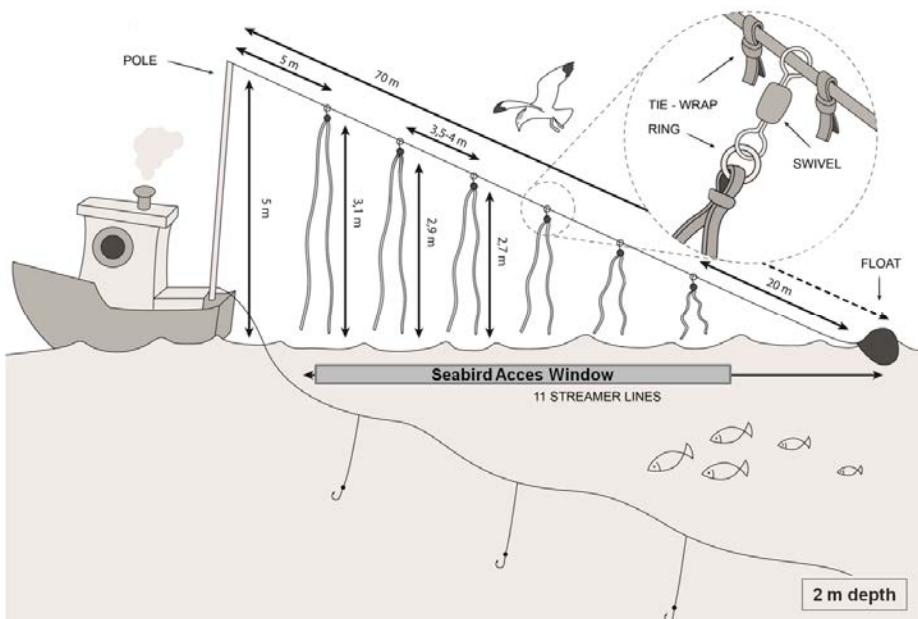


Figure 2. Design of the tori line used in the trials. Drawing by Toni Mulet.

Tori line

The tori line was designed and built jointly with fishermen according to the traits and size of each vessel. Before the experiments, the height of the tori line, length and distance between streamers were modified until adequate protection of the baited hooks was achieved. The aerial extent of the streamers determines the efficiency in deterring birds from the sinking baited hooks (Melvin et al. 2001), so the tori line was set as high as possible to reach sufficient aerial extent to cover as much as possible of the seabird access window. The final configuration of the tori line (Fig 2) was composed of 11 paired branch streamers distributed along a 6 mm-wide twisted rope of 70 m length. Rope was fixed on a pole located at the stern 5 m above the water surface. Each streamer was 12.5 mm thermoplastic red tubing, decreasing in length with increasing distance from the vessel (3 m to 1 m long) and attached to the rope at intervals of 4 m. A float was added at the end to create drag

and tension of the rope. This kept the line off the water for some distance and, consequently, increased the aerial extent of the streamers. The main purpose was to cover a minimum of 20 m behind the vessel, as most seabird attacks (89%) in demersal longliners operating in the area occur within 5 – 20 m behind the vessel (Cortés et al. 2017). In each sample, consecutive settings with or without the tori lines deployed were conducted to compare its effect on seabird interaction. Moreover, during the trials, additional tori line settings were also performed to better assess its adaptation to the vessels.

Statistical analysis

Generalized linear mixed models (GLMMs) were used to test the effect of the mitigation measure on the number of birds following the vessel, the bait attacks, the number and total kilograms caught of hake, the number of the most common commercial non-target species (catsharks and congers) and the proportion of fish discarded. The seabird species not vulnerable to bycatch, such as the Mediterranean storm-petrel (*Hydrobates pelagicus melitensis*), individuals discarded of target species and the samples of the fish catches data in which the paired lines differed more than 20 m depth were not considered in the analyses.

Each model included the use of the mitigation measure as a binary fixed effect. “Trip” was included as a random term to correlate the observations of paired longline settings. When the number of hooks differed between paired longline settings, this variable was considered as an additional factor (seabird observations in tori line trials) or offset (fish catches in weighted lines). The number of birds following the boat was used as an offset when bait attacks were analysed.

For GLMMs, significance tests for fixed effects were performed using Wald Z-tests (Bolker et al. 2009). Models were fitted with the laplace approximation using the package “glmmADMB”. A negative binomial distribution was assumed for the response variable of the seabird observations, given that count data typically show a skewed distribution and overdispersion (Zuur et al. 2009, Lindén & Mäntyniemi 2011). For the fish catches, the distribution of the response variable of each dataset was previously checked for normality using Shapiro-Wilk test. In case of no deviation from normality, linear mixed models (LMMs) were applied by using the “lmer” function from the “lme4” package. Then, a likelihood-ratio test (LT) was performed to obtain the p-values. Otherwise, negative binomial GLMMs were used in accordance with the type of mean-variance relationship found in the response variable (Zuur et al. 2009). On the other hand, a gamma distribution was used for the kilograms of hake and a binomial distribution for the proportion of fish discarded (Zuur et al. 2009). In case of the congers, due to their relative lower abundance, the probability of catching the species was modelled using binary data with a Bernoulli distribution.

The effect of the measure on the type of fish discarded was also assessed by dividing the discards into different reasons (fish damaged, low value, small size, bycatch) and comparing their proportion between control and experimental settings. Besides, the effect of the tori line on the distance astern where the bait attacks occurred was evaluated comparing the proportion of attacks inside (< 50 m) and outside (> 50 m) the area covered by the streamers. These two last analyses were assessed using a chi-square test.

Sink rate differences among (1) longline configurations, (2) the positions along the float-weight sequence, (3) the differences in the extent of the seabird access window between longline vessels, and (4) the lines with and without additional lead weights were compared using an analysis of variance (ANOVA) and a post-hoc analysis (Tukey's test). P-values were corrected by Bonferroni method. To compare sink rates between sections a Welch's *t*-test was used. Differences between longline configurations were evaluated by considering the values obtained in the middle sections and between the weights. However, only the sink rates obtained in the WFL1 configuration were used to assess the differences between the sections and the positions along the mainline. Values obtained in the position BW were used to compare sections, while in the case of the comparison between hook positions in the float-weight sequence the data from the initial section was used. The data from the final section and NW sink speed values from the middle section were not considered because of their small sample size. On the other hand, to assess the effects of lead weights on hook sinking speed, the sink rates recorded on hooks located in the middle section and near to the floats were considered. All statistical analyses were conducted using R version 3.2.4.

RESULTS

Seabird numbers and bait attacks

Setting at night was the only measure that significantly reduced the number of birds and bait attacks (see Table 2 and Fig 3, GLMM birds: coefficient = -1.95, SE = 0.38, Z = -5.08, $p < 0.001$; GLMM attacks: coefficient = -3.02, Z = -2.90, SE = 1.04, $p < 0.005$). Unfortunately, only small numbers of birds were attending longliners in the trials of the additional lead weights and artificial baits, so it was not possible to assess their effects on seabird interaction. During night settings, seabirds following the vessels were those that are known to have nocturnal foraging habits (Table 2), such as Scopoli's shearwaters and Audouin's gulls (*Larus audouinii*). Nevertheless, only Scopoli's shearwater was seen to attack bait in only one of the samples performed during the new moon.

Table 2. Seabird numbers and bait attacks registered by species (those most susceptible to bycatch) and mitigation measure. Number of birds attending vessels (a, mean \pm SD) and number of bait attacks (b, mean \pm SD) per 1000 hooks of the most common seabirds interacting with longline vessels for each mitigation measure: night setting ($N = 20$ paired sets) and tori line ($N = 12$). "Control" refers to settings without mitigation measure, while "Experimental" refers to the night or tori line settings. Number of samples in which an interaction event occurred is specified in brackets by each species. "Total" refers to the frequency of birds following vessels and attacks for all species interacting with vessels. *** $p < 0.001$, ** $p < 0.005$, * $p < 0.05$

Species	Night Setting		Tori Line	
	Control	Experimental	Control	Experimental
<i>Calonectris diomedea</i>	A 5.03 ± 6.48 (7)	1.90 ± 1.35 (2)	3.59 ± 2.61 (8)	6.87 ± 8.24 (6)
	B 24.44 ± 23.16 (6)	31.42 (1)	9.52 ± 19.73 (7)	39.47 ± 40.78 (4)
<i>Puffinus mauretanicus</i>	A 0.95 ± 0.00 (7)	0	0.95 ± 0.00 (2)	2.86 ± 1.35 (2)
	B 4.76 ± 7.00 (4)	0	4.76 ± 5.39 (2)	11.43 (1)
<i>Puffinus yelkouan</i>	A 0.95 (1)	0	1.59 ± 1.19 (4)	1.50 ± 0.94 (5)
	B 0.95 (1)	0	1.64 ± 0.69 (2)	3.29 ± 1.72 (2)
<i>Larus michahellis</i>	A 0.95 ± 0.00 (3)	0	3.61 ± 2.66 (8)	8.32 (1)
	B 0	0	4.61 (1)	3.65 ± 2.87 (1)
<i>Larus audouinii</i>	A 5.97 ± 5.41 (11)	1.48 ± 0.84 (9)	6.96 ± 4.47 (4)	3.10 ± 2.11 (4)
	B 6.55 ± 4.62 (8)	0	3.81 ± 1.34 (2)	0
Total	A 120	17.14***	100.06	106.57
	B 220	31.43**	91.65	184.20

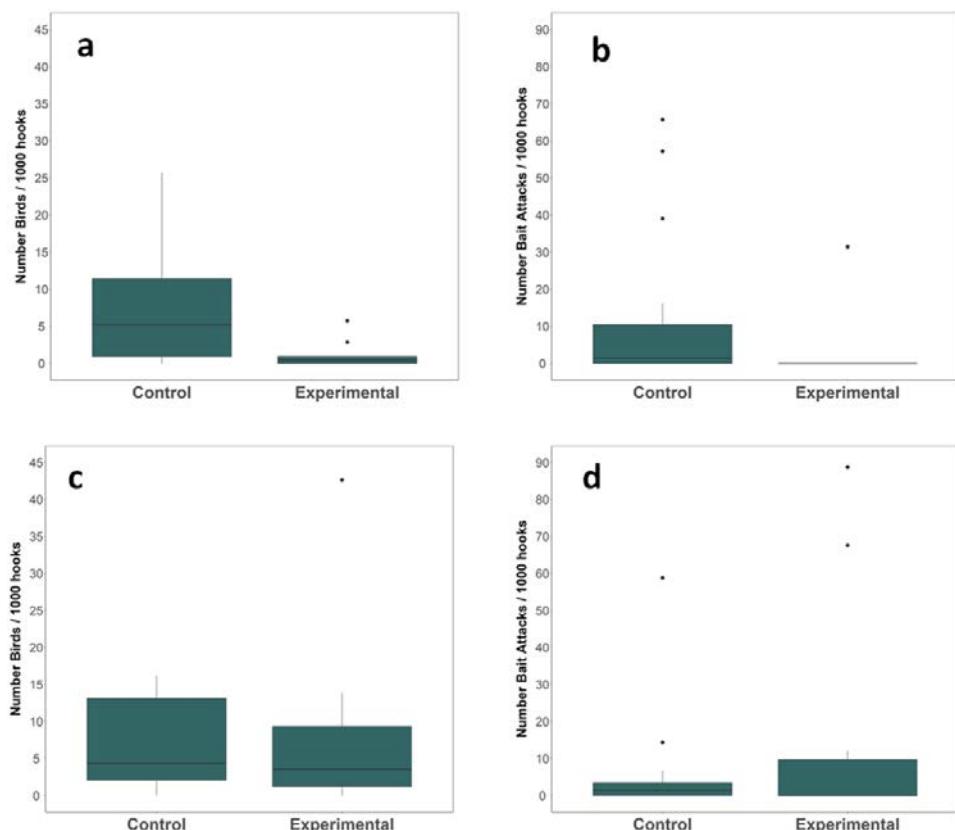


Figure 3. Number of birds following the vessel and bait attacks in the night setting (a and b) and tori lines trials (c and d). Birds (a and c) and attacks (b and d) are shown per 1000 hooks set. In each trial, paired longlines were set; “Control” denotes the settings without mitigation measure, while “Treatment” corresponds to settings at night or with tori line deployed. The middle line of boxes shows the median and the filled circles represent outliers.

The number of birds and bait attacks did not differ between control and tori line settings (Fig 3, GLMM birds: coefficient = 0.00, SE = 0.00, Z = 0.48, p = 0.63; GLMM attacks: coefficient = 0.52, SE = 0.47, Z = 1.10, p = 0.27). Nonetheless, the tori line increased the distance at which bait attacks occurred (Fig 4), scaring seabirds away from the area covered by the streamers lines (> 50 m; $\chi^2 = 39.37$, $df = 1$, $p < 0.005$). This was particularly true for shearwaters (Fig 5), which continued to attack baits when the tori line was deployed but just further away from the stern. However, the attacks on bait also occurred inside the tori line area (< 50 m), albeit less frequently on windy days (40% in calm conditions and 28% in windy days).

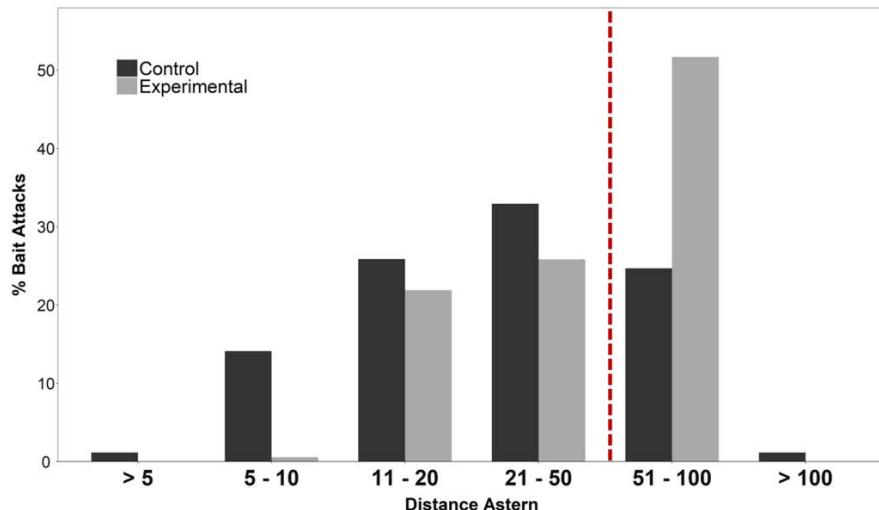


Figure 4. Proportion of bait attacks (%) performed by seabirds at different intervals from the vessel stern. In dark control settings without tori lines ($n = 12$ settings), while in grey experimental settings with the tori line installed ($n = 12$). Dashed line denotes the limit of the area covered by the streamers.

On calm days, the effectiveness of the tori line was reduced because the streamers did not move and birds ventured to attack bait at shorter distances. During the trials, three Mediterranean shearwaters were caught in one of the samples; one of them in a control setting and the other two in a tori line setting, and one Scopoli's shearwater was caught in another sample during the tori line setting. On the same day, three birds were caught (one Scopoli's shearwater, one Mediterranean shearwaters and one Balearic shearwater) during an additional tori line setting performed out with the paired comparison settings. All seabird catches occurred on a calm day. We observed that the aerial coverage of the streamer lines varied with weather conditions and setting speed, but it usually covered 30 – 45 m astern, in addition to the 20 m until the drag object. Taking into account the mean setting speed and sink rate, the streamers covered the sinking hooks until they reached 2 m depth below the surface.

Commercial catches

Target catches did not differ between control setting and night settings or lead weight settings (Table 3). However, we found a significant increase of the Blackmouth catshark in longlines with additional weights (Negative binomial GLMM: coefficient = 0.75, SE = 0.34, Z = 2.19, $p < 0.05$) and higher likelihood of catching European congers when longlines were set at night (Bernoulli GLMM: coefficient = 18.75, SE = 5.52, Z = 3.40, $p < 0.001$). On the contrary, we found a

significant reduction in the number (Negative Binomial GLMM: coefficient = -1.49, SE = 0.19, Z = -7.83, p < 0.001) and total weight caught (Gamma GLMM: coefficient = -1.54, SE = 0.20, Z = -7.69, p < 0.001) of the European hake (target species) during the artificial bait setting. Therefore, the catches obtained in artificial baits represented only a quarter of the total hake caught when fishermen used sardine or anchovy bait.

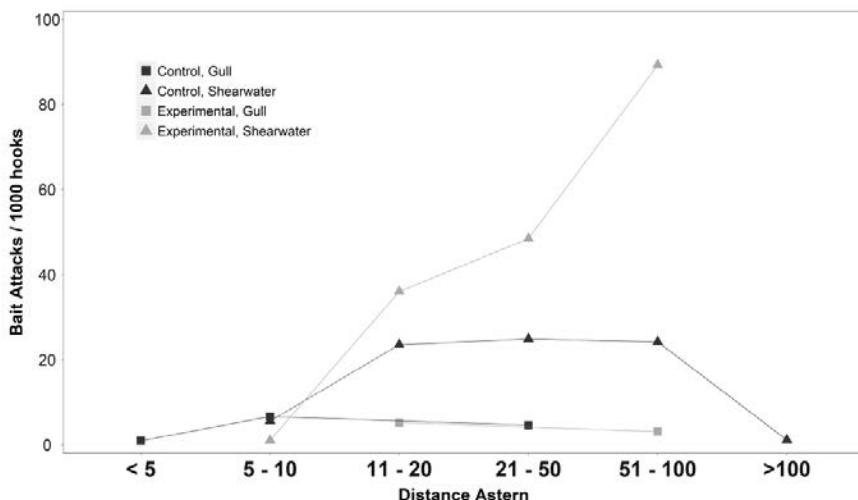


Figure 5. Total number of attacks registered at different distance intervals from the vessel stern. Shearwaters (triangle; Scopoli's, Balearic and Mediterranean shearwater) and gulls (square; Audouin's and yellow-legged gulls) were considered separately. Dark refers to the control settings without tori line (n = 12 settings), while grey refers to experimental settings with the tori line installed (n = 12).

The proportion of catch discarded was similar between the control and experimental settings of the mitigation measures tested. However, we found a significant lower proportion of discards due to fish bycatch when longlines were set at night ($\chi^2 = 7.97$, $df = 1$, $p < 0.005$) and in lines with additional weights ($\chi^2 = 8.13$, $df = 1$, $p < 0.005$). In night setting trials, these catches were mostly registered in the control lines (N = 13 individuals, 39% common stingray *Dasyatis pastinaca*, 31% the ocean sunfish *Mola mola*, 15% swordfish *Xiphias gladius*, 8% Blue shark *Prionace glauca* and 8% Atlantic bluefin tuna *Thunnus thynnus*), while only one ocean sunfish was bycaught during the settings at night. Conversely, in the weighted line trials, all fish bycatch occurred in the control lines (N = 12, 50% swordfish, 25% common stingray and 25% the ocean sunfish).

Table 3. Fish catches registered for those mitigation measures that involved a change in the longline configuration and fishing practices. Number of fish catches per 1000 hooks (mean \pm SD) for the most common commercial species and those discarded during the trials of night setting ($N = 18$ paired sets), weighted lines ($N = 11$) and artificial baits ($N = 5$). In case of European hake *Merluccius merluccius* (target species), only not discarded individuals are considered: “a” refers to the number of individuals while “b” denotes the kilograms of fish. Discards refer to the fish that was returned to the sea because: 1) specimens were in bad condition (Fish damaged), 2) did not have commercial value, 3) were too small (Small size) or 4) were non-commercial or protected species (Fish bycatch). Percentages refer to the proportion of each reason of discarding. ***
 $p < 0.001$, ** $p < 0.005$, * $p < 0.05$

	Night setting		Weighted lines		Artificial baits	
	Control	Experimental	Control	Experimental	Control	Experimental
<i>Merluccius merluccius</i>	a 35.77 \pm 25.32	33.44 \pm 25.45	28.89 \pm 12.72	31.88 \pm 12.68	57.14 \pm 12.84	12.95 \pm 7.21***
	b 20.26 \pm 14.30	18.41 \pm 15.21	14.56 \pm 7.78	16.62 \pm 7.44	35.49 \pm 18.21	7.67 \pm 3.83***
<i>Galeus melastomus</i>	10.90 \pm 21.59	18.87 \pm 21.78	36.02 \pm 32.68	76.14 \pm 47.78*	5.90 \pm 12.68	3.05 \pm 6.81
<i>Conger conger</i>	0.58 \pm 0.87	1.16 \pm 1.16**	1.77 \pm 1.92	1.69 \pm 2.23	0.63 \pm 0.98	0
Discards	7.04 \pm 5.84	6.19 \pm 5.42	8.72 \pm 6.26	8.20 \pm 7.11	8.57 \pm 3.80	1.33 \pm 0.85
<i>Fish damaged</i>	4.60 \pm 3.03 (67%)	4.65 \pm 3.11 (79%)	6.12 \pm 4.65 (71%)	6.39 \pm 5.68 (80%)	4.57 \pm 2.89 (53%)	1.14 \pm 1.04 (85%)
<i>Commercial value</i>	0.21 \pm 0.41 (3%)	0.48 \pm 1.23 (8%)	0.09 \pm 0.29 (1%)	0.11 \pm 0.36 (1%)	0.19 \pm 0.43 (3%)	0
<i>Small size</i>	0.37 \pm 0.21 (17%)	0.21 \pm 0.41 (13%)	1.37 \pm 2.39 (17%)	1.71 \pm 3.93 (19%)	1.71 \pm 1.95 (20%)	0
<i>Fish bycatch</i>	0.68 \pm 0.05 (10)**	0.05 \pm 0.22 (1%)	0.97 \pm 1.51 (11)**	0	2.10 \pm 2.06 (24%)	0.19 \pm 0.43 (14%)

Practical applicability

We detected some operational problems during the tori line and weighted line tests. In strong wind and cross wind conditions the tori line was displaced towards the fishing gear, so the captain refused to deploy it under these conditions, alleging that it could lead to potential entanglements with the longline and compromise the fishermen's safety. Moreover, the additional weights increased the likelihood of entanglements between the branchlines and hooks during the setting operations.

Longline sink rate

The sink rate of longlines to 10 m depth varied according to the line configuration considered (Table 4, Mean \pm SD: WFL1 = 0.16 ± 0.02 m/s, WFL2 = 0.14 ± 0.03 , WWL = 0.07 ± 0.01 ; $F_{2,51} = 64.01$, $p < 0.005$). WWL longlines sank at a significantly slower rate than the WFL (post-hoc Tukey's test: $p < 0.005$, WFL2; $p < 0.005$). In addition, the sinking of hooks from the WFL2 was significantly slower than the WFL1 (post-hoc Tukey's test: $p < 0.005$).

The distance astern at which longline hooks were within 10 m of the surface (AW, Table 4) differed between the longline types ($F_{2,48} = 9.25$, $p < 0.005$). WFL2 lines showed the greatest extent of the access window (post-hoc Tukey's test: WFL1; $p < 0.05$, WWL; $p < 0.005$). Conversely, we found that the seabird access to baited hooks was shortest in the WWL configuration. Nevertheless, the shorter distance in WWL was not significant when it was compared to the WFL1.

Hooks showed different sink rates depending on the longline section, and the position with respect to the weights and the floats (Fig 6). Hooks sank faster in the initial section ($BW_{initial-middle}$: $t_{17.728} = 2.998$, $p < 0.05$), and those near to the weight showed greater sink rates than those located near to the float or between the float and the weight ($F_{2,35} = 8.98$, $p < 0.005$; post-hoc Tukey's test: $NB_{initial} - NW_{initial}$, $p < 0.005$; $BW_{initial} - NW_{initial}$, $p < 0.005$). However, the proximity to the float did not reduce the sinking speed ($NB_{initial} - BW_{initial}$, ns; $NB_{middle} - BW_{middle}$, ns). This could be due to the influence of the weight placed close to the float (see Table 1).

The sinking speed of the hooks increased significantly when a lead weight of 10 g or 20 g was added to the branchlines ($F_{2,34} = 15.83$, $p < 0.002$, Fig 7), reaching the same sink rate for the two types of weights (10 g – 20 g = 0.20 m/s). Thus, in both cases, the addition of the weights led to a significant reduction of the seabird access window of at least 30 m ($F_{2,34} = 22.02$, $p < 0.002$; Mean \pm SD; Control = 163.54 ± 7.27 m, 10 g = 131.53 ± 17.96 m, 20 g = 131.50 ± 14.31).

Table 4. Time and sink rate to 10-m depth and 10-m access window by longline configuration. Time needed (seconds) to arrive to 10 m depth and sink rate (meters per second, mean \pm SD) of the hooks for different longline types: “Piedra – bola” system (WFL1 = longline type used by *Cona C.B* and WFL2 = *Mar endins*) and the configuration without floats used by the small-scale vessel *Vigilant* (WWL). Seabird access window (AW) corresponds to the distance astern where the hooks are at 10 m depth. The data used were collected from hooks located at the middle section of the longline and between the float and the weight. The setting speed (mean \pm SD) for each longline type is specified in knots (kts).

Longline	Time (sec.)	Sink rate (m/s)	AW (m)	Setting speed (kts)	N
WFL1	63.38 ± 7.30	0.16 ± 0.02	169.50 ± 23.68	5.26 ± 0.53	33
WFL2	74.57 ± 13.30	0.14 ± 0.03	203.34 ± 45.03	5.28 ± 0.61	13
WWL	144 ± 21.17	0.07 ± 0.01	138.80 ± 42.67	1.85 ± 0.36	8

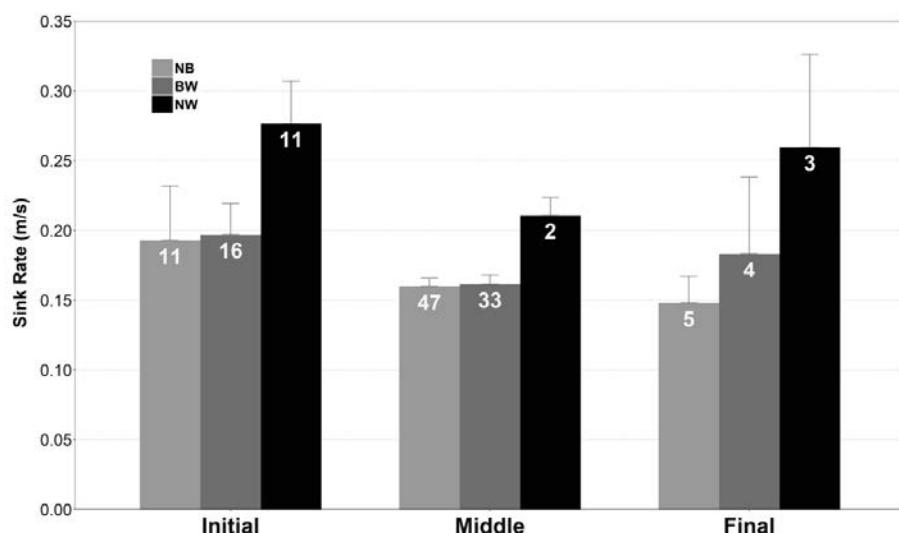


Figure 6. Sink rates of the baited hooks in the first 10 meters depth. The values (mean \pm CI 95%) came from the hooks located at (1) different positions inside of the float-weight sequence (NF = near to the float, BW = between the float and the weight, NW = near to the weight) and (2) longline sections (initial, middle and final). The hook sink rates were collected in the same vessel and from gear with a “Piedra – Bola” configuration (WFL1). Numbers inside bars denote the sample sizes.

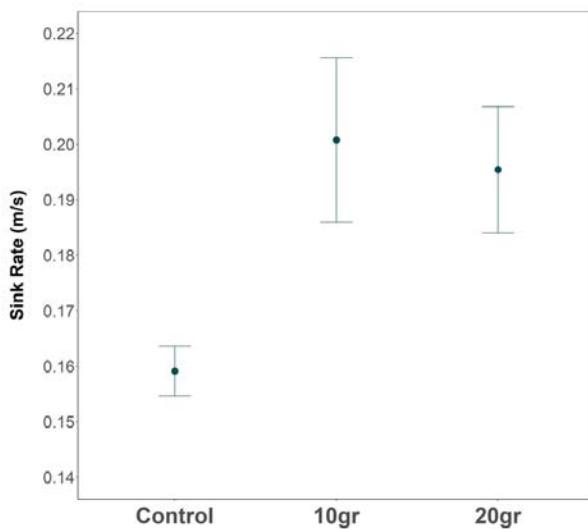


Figure 7. Sink-rate comparison of the longlines set with or without additional weights. The values (mean \pm CI 95%) were registered in the control ($n = 13$) and experimental longlines with an added weight above hooks of 10 g ($n = 14$) and 20 g ($n = 10$). Data were collected from hooks located in the middle section of the longline and near to the floats.

DISCUSSION

We assessed the efficiency and practical applicability of four mitigation measures on artisanal demersal longliners targeting European hake, the most valuable target species of this fleet in the western Mediterranean. Of the mitigation measures tested, night setting appears the most effective measure so far in minimizing seabird bycatch.

Efficacy of mitigation tests on seabird interaction and fish catches

Night setting was the only method tested in the present study that reduced the number of seabirds attending vessels and the frequency of bait attacks with no effect on target catches, and also had positive effect on fish bycatch species. In general, setting at night has proved to be very efficient in demersal longliners, especially in the Southern Ocean (Cherel et al. 1996, Brothers et al. 1999b). Its efficacy is particularly high among seabird species foraging only during daylight hours, but less effective on nocturnal seabirds. Some seabirds do forage at night, particularly during bright moonlight nights, which may compromise the efficacy of night setting (Cherel et al. 1996, Weimerskirch et al. 2000, Sánchez & Belda 2003). In the Mediterranean, although all species are mainly diurnal, there are several species showing some nocturnal activity, such as Scopoli's shearwaters and

Audouin's gulls (Oro 1995, Rubolini et al. 2015). On-board observations conducted on demersal longliners in the same area showed the occurrence of nocturnal bycatch of these species and the Balearic shearwater in different moonlight conditions, but most of them occurred on full moon nights (71%, Cortés et al. 2017). Even so, bird catches at night were far less frequent than catches at dawn or daytime. These findings were also found by Sánchez & Belda (2003), who showed an important reduction of bait losses caused by Scopoli's shearwater in longlines set at night. Consequently, both studies considered night setting as the most promising measure to reduce bycatch in the Mediterranean longliners. In the present study, we did not record any bycatch event during night settings, but we detected a large number of bait attacks by Scopoli's shearwaters in one of the night settings performed during a non-moon day, suggesting this measure may not completely avoid seabird catches and bycatch might not be restricted to moonlight nights. In addition, it should be noted that the frequency of bait attacks recorded could be slightly underestimated due to a reduced visibility at night. Furthermore, setting the longline at night may affect catches of commercial species, leading to economic losses for fishermen (Brothers et al. 1999b). In this regard, this is the first study in the Mediterranean showing night setting having no effects on target catches. However, it increased the probability of catching the European conger, probably due to its nocturnal feeding behaviour (Göthel 1992). Moreover, night setting reduced the catches of fish bycatch species, such as swordfish, ocean sunfish and blue shark. These species perform diel vertical migration so at night these fish stay close to the surface (Carey & Robison 1981, Cartamil & Christopher 2004, Stevens et al. 2010), making an encounter with demersal longline gear less likely. Nevertheless, these findings should be confirmed for longliners targeting fish other than European hake, since the effect of setting time may differ for other fish species with different activity rhythms (Løkkeborg & Pina 1997). Apart from reducing seabird catches, the potential benefits of night setting for fishermen is well illustrated by the fact that some fishermen operating near seabird breeding colonies voluntarily changed to setting their longlines at night to avoid bait losses caused by seabirds, suggesting benefits obtained by reducing bait losses compensate for any decrease in commercial catches or practical problems.

Tori lines have also been demonstrated to be a suitable mitigation method in demersal longliners (Løkkeborg 2011). In this study, the deployment of the tori lines did not influence the overall number of bait attacks. Nonetheless, seabird attacks were displaced further astern, occurring beyond the 45 m covered by the streamers, and they were mainly performed by shearwaters. This can be explained by the greater diving ability of the different shearwater species compared to gull species, as shearwaters can dive several metres and reach baited hooks at a considerable distance astern. Indeed, *Puffinus* shearwaters can dive > 10 m depth (Meier et al. 2015), which means that according to the sinking rates recorded in the present study, shearwaters could still reach baited hooks after the 45 m covered by

the streamers lines (when baited hooks are at 2 m depth) and up to 190 m behind the vessel. Therefore, the use of tori lines would appear to be ineffective in avoiding shearwater bycatch because baited hooks would still be accessible to these species. Previous studies also found that streamers were not able to reduce the catches of diving birds, only those of surface feeding birds (Melvin et al. 2001, Løkkeborg 2003). In addition, the effectiveness of the tori line may be compromised in low wind conditions, when birds attacked baits at shorter distances astern. Indeed, all shearwater catches registered in a tori line settings occurred under calm conditions because of, on windless days, the streamers did not move and did not deter birds away. Similar results were previously found by Ashford et al. (1994), suggesting the efficacy of tori lines is limited to windy days. However, strong crosswinds may also compromise the effectiveness of the tori line by displacing it from the setting area, leading to entanglements with the gear, or by bringing it out of its ideal position to protect the baited hooks (Agnew et al. 2000, Melvin et al. 2001, Løkkeborg 2011). In fact, during these trials fishermen were concerned about the risk of tangles and refused to deploy the streamer line in strong winds. To avoid the adverse influence of calm days and crosswinds, some studies recommended the use of paired scaring lines (Melvin et al. 2001, Dietrich et al. 2008, Løkkeborg 2011). However, the installation of two tori lines on small artisanal demersal longliners would be impractical, compromising the fishing operations and increasing the chance of tangles.

Previous studies illustrated that weighted lines is the most suitable method to reduce catches of diving seabirds in demersal longliners, since it increases longline sink rate and reduces the seabird access window (Moreno et al. 2006, Robertson et al. 2006, Løkkeborg 2011). In addition, the increase in the longline sinking speed could also enhance the fishing efficiency, particularly for those vessels targeting demersal species of very deep waters, since the gear reaches the seafloor earlier, which maximises the bait attractiveness (Robertson et al. 2003). In these experiments, it was not possible to make a direct assessment of the effect of adding weights on seabird attraction and bait attacks due to the low number of birds interacting with the vessel. Alternatively, to evaluate its effect on the bycatch risk we used the hook sink rates and its potential to prevent seabird access to baited hooks. We found that the lines with additional lead weights sank 25% faster than control lines, reducing by 20% (30 m) the seabird access. Even so, the sinking speed obtained (0.20 m/s) was not enough to reduce the catches of the shearwaters as they still had a large access window. Previous studies recommended achieving a longline sink rate of > 0.3 m/s to minimize seabird catches (Robertson 2000), but even though it does not entirely eliminated bycatch risk (Løkkeborg 2011). Consequently, some studies recommended the weighted line in combination with a tori line to achieve an effective reduction in the seabird catches, especially of diving species (Melvin et al. 2001, Dietrich et al. 2008, Løkkeborg 2011). Regarding fish catches, weighted lines probably affected the way the line was settling on the

seabed, since the lead weights could keep the branchlines in a more upright position bringing the baited hooks closer to the seabed, ultimately affecting fish catches. Indeed, weighted lines increased blackmouth catshark catches, possibly because catsharks forages in the near bottom layer and on the seabed (Anastasopoulou et al. 2013). In addition, we found an interesting reduction of non-commercial or protected fish species (common stingray, swordfish and ocean sunfish) in experimental lines, which might also result from the different way the line arrangement on the seabed. Moreover, we found operational problems associated with the addition of lead weights, as these increased the likelihood of tangles during the line settings.

Artificial baits have been proposed as a potential method to reduce seabird bycatch in longline fisheries (Brothers et al. 1999a), however, there is little information about their effectiveness in reducing seabird bycatch and their effect on commercial catches. In this study, similar to the conditions of weighted lines, it was not possible to assess its effect on seabird attraction due to the low number of birds recorded during the control and experimental settings. However, artificial bait setting showed a 77% reduction of the target catches relative to control lines. This result could be explained by differences in the release rate of the chemical feeding stimulants between baits, since this attribute greatly determines catch efficiency (Løkkeborg 1990). Moreover, this method may constitute an extra cost for fishermen to buy the bait, overall rendering it inappropriate for the profitable exploitation of European hake in the study area. Nevertheless, the potential usefulness of other types of artificial bait cannot be completely dismissed

Effects of longline configuration on seabird access area

The seabird access area to baited hooks may vary between vessels according to the longline configuration used, the setting speed and the mainline location of the hooks. Regarding the longline configuration used, the distance between consecutive weights was an important factor in sink rate variation since the increase in distance between weights reduced the sink rate when we compared line configurations with similar weights and set at the same speed. The longline type used in the small-scale vessel (WWL) sank significantly slower than the “Piedra – Bola” system (WFL), mainly due to the combination of lighter weights and the greater distance between them. In this regard, a previous study conducted in the Balearic Sea found that the gears with a greater distance between the weights have a higher seabird bycatch risk (Cortés et al. 2017). Therefore, our study provides evidence that this difference in the bycatch risk with regard to the distribution of the weights could be mainly driven by the variation in the sink rate and its related seabird access window to the baited hooks. Nevertheless, setting speed also influenced sink rates but to a lesser extent (Robertson et al., 2008). The seabird access window in the WWL was significantly shorter than in the WFL2 (139 m vs. 203 m) and similar to WFL1,

probably caused by its lower setting speed, thus indicating that lowering the setting speed of the vessels can decrease bycatch risk by reducing the seabird access window. However, setting speed also determines the final arrangement of the fishing gear on the seabed; faster speeds allow a tension of the mainline which keeps the longline straight and expanded along the sea bottom (Robertson et al. 2008). Vessel speed is sometimes adjusted to obtain an appropriate arrangement of the gear due to the speed and direction of the currents, and so regulating setting speed to manage bycatch risk would thus be impractical. The mainline location of the hooks was also an important factor on bait exposure, since we found differences in sinking rates between different sections of the mainline. The first section of the longline together with the hooks near to the weight sank much faster. As a result, the middle section and the hooks located near to the float and between the float and the weight were more exposed to seabird bait attacks. In the first section, hooks sank faster due to the influence of the anchor, since at the beginning of the setting the anchor has not yet reached the seabed so it pulls the longline towards the bottom at higher speed. In contrast, Seco Pon et al. (2007) showed the opposite results, as they found a higher number of seabird catches in the first part of the longline. However, probably, the differences in the fishing operation characteristics among longline fleets have led to these different results.

CONCLUSIONS

Ideally, to ensure compliance of fishermen with the mitigation measures, the bycatch mitigation strategy must not only minimize seabird catches, but also needs to be cost-effective, practical, safe, accompanied with economic or social incentives, easy to implement, easy to manage and it needs to increase awareness on seabird by-catch and the involvement of fishermen (Gilman et al. 2005, Gilman 2011, Boyd 2014). This study mainly focused on the first three topics, namely efficacy in reducing seabird bycatch, effects on fish catches and practical applicability.

The three endemic species of shearwaters are the most affected seabirds in demersal longliners of the western Mediterranean. These species show negative population trends mainly caused by mortality in commercial fisheries. Therefore, the mitigation strategy in the study area should focus on immediate actions to reduce catches of these species.

Night setting stands out as the most appropriate mitigation measure for demersal longlines in the Mediterranean so far, since it was the most efficient in reducing seabird attraction and bait attacks without compromising target species or having negative effects on fish bycatch species. However, setting the longlines at night does not completely avoid the seabird incidental catches, particularly in those species with some nocturnal activity such us the Scopoli's shearwater, and may increase

the fish commercial catches of nocturnal species, such as the European conger. However, this measure could be implemented at low economic costs and its compliance can be easily monitored and enforced by regulating the fishing schedules of longliners. Tori line also reduced the likelihood of birds being hooked, since it displaced bird attacks further away from the stern, where the baited hooks are at greater depths and thus less accessible to seabirds. However, it was ineffective under calm wind conditions and impractical in strong crosswinds. The use of additional weights and gear configurations with reduced distance between weights (e.g. WFL) showed a higher hook sink rate, leading to a significant reduction of the seabird access window to baited hooks. However, in the present study, this reduction was relatively small and the addition of weights was not enough to reduce seabird catches and resulted in some operational problems. Nevertheless, the significant reduction of the seabird access window are good grounds for believing that introducing other changes in gear structures (e.g. Chilean method) or the addition of weight in some specific longlines may eventually become an effective alternative in reducing seabird bycatch (ACAP 2016b). Nevertheless, gear-specific assessment is required to get optimal and efficient changes in the longline configurations.

ACKNOWLEDGEMENTS

We are grateful to the skippers and crews of longline vessels *Cona C.B.* and *Mar endins* for their recommendations and support during experimental trials. Thanks to Graham Robertson and ATF Argentina (Birdlife) for their advice in the design of the mitigation measures. We also thank Neus Matamala for collecting sink rate data of the small-scale vessel *Vigilant*, and Toni Mulet for the illustrations of the longline configurations and tori line.

DISCUSSIÓ GENERAL



En primer lloc, la present tesis aporta informació essencial sobre les característiques de la flota de palangre demersal que opera a l'oest del Mediterrani, així com la magnitud, l'extensió i els factors que modulen les captures accidentals d'ocells marins. Aquest coneixement ha servit no solament per entendre el fenomen i el seu impacte, sinó també per poder desenvolupar mesures de mitigació adaptades als palangrers demersals de l'àrea d'estudi. En segon lloc, aquesta tesi inclou l'assaig de diversos mètodes per reduir les captures d'ocells. Els assajos efectuats han permès avaluar l'eficàcia i aplicabilitat pràctica de cada mesura per, finalment, definir una proposta d'accions efectives per minimitzar l'impacte de les captures accidentals.

Característiques de la flota de palangre demersal

Les observacions a bord dels palangrers artesans han permès caracteritzar la flota demersal que opera a l'oest del Mediterrani. La informació recopilada demostra la complexitat de la flota, la qual és diversa en quant a les espècies objectiu, configuracions d'arts emprats i estratègies de pesca. En conseqüència, el risc de captura accidental i el nivell d'impacte sobre els ocells és desigual entre embarcacions. Per aquest motiu, per tal de tractar la problemàtica de les captures accidentals en l'àrea d'estudi, hauria d'aplicar-se un maneig específic per cada grup homogeni de pràctiques pesqueres i tipus d'arts que puguin identificar-se en la flota (Dietrich et al. 2009).

Les embarcacions espanyoles que operen a l'oest del Mediterrani, i que utilitzen el palangre per pescar espècies demersals, es troben inscrites al cens de la flota pesquera operativa en les modalitats de **palangre de fons o arts menors**. Les principals diferències entre ambdues modalitats de pesca resideixen en la freqüència d'ús del palangre, les espècies objectiu, les configuracions dels arts, l'esforç pesquer i la localització dels caladors. No obstant, en els dos casos, existeix una gran variabilitat en quant a les pràctiques pesqueres i les estructures dels arts, el qual està relacionat amb les espècies objectius i els hàbits particulars de cada pescador.

Les embarcacions inscrites en la modalitat de palangre de fons disposen d'una autorització per pescar únicament amb l'art de palangre de fons. En canvi, les embarcacions d'arts menors poden utilitzar diferents tipus d'arts al llarg de l'any, entre ells el palangró (palangre de fons de menor mida). Això fa, doncs, que existeixi una gran variabilitat en la freqüència d'ús del palangró: es poden trobar casos en els que s'utilitza tot l'any, en èpoques determinades o bé molt rarament o mai. A més, aquestes embarcacions no tenen l'obligació d'informar a l'administració del tipus d'art que fan servir en cada jornada de pesca, per tant es desconeix el seu esforç pesquer quan fan servir palangró. A banda d'això, tant les embarcacions censades en la modalitat de palangre de fons com dels arts menors, poden sol·licitar llicències temporals de canvis de modalitat durant un període màxim de 6 mesos,

fet que complica encara més obtindre estimes acurades de l'esforç pesquer per al conjunt de la flota.

Les embarcacions autoritzades per pescar amb palangre de fons de l'àrea d'estudi presenten, generalment, una major eslora respecte als arts menors. A més solen calar un major nombre d'hams en cada jornada de pesca, atès que la normativa els hi permet calar un màxim de 3.000 hams, mentre que els arts menors únicament 2.000 hams. La velocitat de calada també difereix entre modalitats, sent superior en les embarcacions que utilitzen palangre de fons. La localització dels caladors varia en funció de les espècies objectiu encara que solen situar-se mar endins, a prop del talús continental, mentre que els arts menors operen prop de la costa.

Per altra banda, en aquest estudi s'observaren diferències en els elements i l'estructura dels palangres que es fan servir a les dues modalitats de pesca (palangre de fons i el palangró dels arts menors). L'art de palangre de fons es caracteritza per contenir una combinació de flotadors i pesos distribuïts al llarg de la línia, els quals permeten mantindre els hams a diferents altures del fons marí. Aquest tipus d'art es coneix com "Pedra-Bola" i s'utilitza per pescar principalment lluços, besucs de la taca i panegals. Encara que poden diferenciar-se dos tipus d'estructures en funció de la distància entre els flotadors i els pesos ("zigzag" i "piramidal", Figura 2 del Capítol 1). La principal diferència entre ambdues estructures es troba en el rang de fondària on es distribueixen els hams respecte al fons marí, el qual determina les espècies que es poden capturar. En els cas del palangró dels arts menors, generalment no s'afegeixen flotadors a la línia, per tant els hams es situen completament sobre el fons marí. Aquests arts s'utilitzen per pescar orades, pagres, sargs, pagells o altres espècies demersals de fons rocosos. Sovint, els pescadors únicament afegeixen pesos (de menor pes que al "Pedra-Bola") distribuïts de manera regular al llarg de la línia. Encara que també és freqüent que no facin servir cap tipus d'element addicional.

El tipus d'esquer que es fa sevir també varia entre modalitats. En ambdós casos, el més comú és que els hams siguin escats amb peixos, normalment sardina, seitó o verat, però també amb calamars. No obstant, els pescadors de les embarcacions d'arts menors solen utilitzar esquers de menor mida, ja sigui perquè trossegen els peixos o bé perquè utilitzen espècies petites de crustacis o mol·luscs, com ermitans, crancs o espècies de bivalves.

Taxes de captura accidental i mortalitat

Estudis anteriors duts a terme en els palangrers que operen a l'oest del Mediterrani (Belda & Sánchez 2001, García-Barcelona et al. 2010b, Laneri et al. 2010), constataren una elevada mortalitat d'ocells, especialment de baldriga cendrosa i particularment en els palangrers demersals. El present estudi corrobora aquesta

alta incidència en la flota de palangre demersal, amb una estima de 0,58 (0,13 - 1,37) ocells capturats per cada 1.000 hams calats. Aquestes captures afecten especialment a les 3 baldrigues endèmiques del Mediterrani (87% del total d'ocells capturats). No obstant, les taxes de captura accidental varien entre embarcacions i arts de pesca, sent especialment elevades en les embarcacions d'arts menors i en els arts de pesca sense pesos ni flotadors afegits.

La major part dels ocells capturats en aquest estudi foren recuperats morts, no obstant un 19% dels ocells pogueren ser alliberats vius. Encara que l'alliberament d'ocells únicament fou possible en les embarcacions d'arts menors, bé perquè calen a una velocitat baixa, per tant els hi és més fàcil aturar la calada i alliberar l'ocell, o bé perquè els ocells es mantenen vius en la superfície de l'aigua fins la recollida, atès que treballen a menor fondàries i utilitzen braçolades més llargues. Malgrat això, es desconeix la taxa de supervivència dels ocells després del seu alliberament, ja que poden resultar ferits i amb lesions greus, especialment si l'alliberament no s'ha efectuat de manera correcta. Per tant, seria necessari mesurar la mortalitat dels ocells post-alliberament per tal d'inclor-la en l'estima de la taxa de mortalitat anual generada per la flota.

Tenint en compte únicament els registres dels ocells morts, en aquest estudi s'obté una estima de com a mínim 274 ocells, fins a un màxim de 2.198 ocells, que podrien estar morint anualment en els palangrers que operen en el mar catalano-baleà. En particular, s'estima que moren una mitjana de 675 baldrigues cendroses, 123 baldrigues baleàrs i 35 baldrigues mediterrànies per any.

Una de les troballes més rellevants d'aquest estudi és l'elevada mortalitat enregistrada de la Críticament Amenaçada baldriga baleà i de la Vulnerable baldriga mediterrània, ja que estudis anteriors realitzats a l'oest del Mediterrani detectaren una baixa incidència sobre les dues espècies. Aquesta discrepància, en el cas de la flota pelàgica, pot deure's a l'ús d'esquers i hams de major dimensió, la qual cosa disminueix les possibilitats de que les baldrigues petites (*Puffinus*) siguin capturades. Així mateix, l'àrea d'estudi de treballs anteriors no inclogueren algunes de les principals zones d'alimentació d'aquestes espècies, com és la costa catalana (Arcos et al. 2009, Péron et al. 2013, Meier et al. 2015).

En aquesta última regió s'ha documentat captures massives d'ambdues espècies en una sola calada, induïdes pel la seva gran capacitat de busseig i comportament gregari. La primera característica atorga a les baldrigues d'una ampla finestra d'accés als esquers durant la calada, ja que poden arribar a capturar-los inclús quan es troben a diversos metres de profunditat (> 10 m, Meier et al. 2015). A més, quan hi ha un gran nombre d'ocells intentant alimentar-se dels esquers, els individus que s'enganxen als hams augmenten la flotabilitat de la línia, i això fa que els esquers romanguin més temps accessibles per als ocells i, per tant, hi hagi més captures.

Aquests esdeveniments ocorren ocasionalment, no obstant això, pot implicar la mort d'un gran nombre d'individus (desenes o centenars), així com molèsties i pèrdues importants per als pescadors. La baldriga cendrosa també pot ser capturada en esdeveniments massius, encara que solen involucrar un menor nombre d'individus, possiblement per la seva menor capacitat de busseig en comparació a les altres dues baldrigues més petites (< 2 m, Cianchetti-Benedetti et al. 2017).

Convé subratllar que les estimes obtingudes en aquest estudi es troben infravalorades per diverses causes. Entre elles destaca, per una banda, l'absència d'informació sobre l'esforç pesquer als arts menors, atès que es desconeix quines embarcacions i en quina freqüència fan servir palangre, així com la difícil detecció de les captures massives a causa del seu caràcter anecdòtic. De fet, en l'estima de mortalitat anual únicament es consideraren els palangrers de fons de Catalunya que fan servir palangre tot l'any i les embarcacions d'arts menors de Menorca que utilitzen palangró de manera estacional, ja que són les úniques flotes en les que s'ha pogut estimar l'esforç pesquer anual (4.675.851 hams/any). Per altra banda, no tots els ocells capturats són posteriorment recuperats durant la recollida, per tant, part de les captures d'ocells que ocorren no són quantificades (Gales et al. 1998, Brothers et al. 2010).

En general, les captures accidentals d'ocells són esdeveniments que ocorren en baixa freqüència, cosa que dificulta l'obtenció d'estimes robustes de les taxes de captura. De fet, en aquest estudi es detectaren captures d'ocells en tan sols el 12% de les sortides realitzades. És per això que es requereix d'un seguiment rigorós mitjançant observadors, amb suficient cobertura espacial i temporal, per tal de poder avaluar correctament la magnitud d'aquestes captures i identificar les zones d'alt risc (Gilman et al. 2005, Anderson et al. 2011).

Les sortides realitzades en aquest estudi es distribuïren de manera que comprenguessin els principals ports on operen les embarcacions que fan servir palangre. No obstant això, al tractar-se d'una flota majorment artesanal, en algunes embarcacions (particularment als arts menors) no fou possible embarcar un observador al superar-se el nombre màxim de tripulants reglamentari. Per aquest motiu, continuen existint zones que potencialment podrien tenir problemes de captures d'ocells i en les que no s'ha pogut aconseguir informació.

Per tal de resoldre aquest inconvenient, una alternativa efectiva podria ser la implementació en la flota d'un programa de comunicació regular, a través del qual els pescadors reportarien les captures accidentals d'ocells que ocorren en la seva activitat i les tècniques emprades (Gilman et al. 2006, O'Keefe et al. 2014, Tarzia et al. 2017). D'aquesta manera seria possible accedir a un major nombre d'embarcacions i incrementar la cobertura de seguiment. Així mateix, promouria la

col·laboració i implicació directa del sector en solucionar aquest problema. No obstant, per assegurar el seu èxit, aquest programa requereix d'incentius per als pescadors, així com la comprovació regular de la veracitat de les dades recopilades.

Les captures d'ocells, al ser esdeveniments esporàdics i desiguals, són percebudes per alguns pescadors com un assumpte poc rellevant i sense urgència que, en general, no altera de forma significativa el seu treball del dia a dia. Es per això que la major part de pescadors no utilitzen cap tipus de mesura per reduir aquestes captures. No obstant això, tenint en compte el conjunt de la flota, el nivell de mortalitat pot arribar a ser insostenible per a la viabilitat de determinades espècies, especialment si presenten poblacions reduïdes (Moore et al. 2013), com la baldriga balear.

Aquet fet ha sigut constatat en els estudis demogràfics realitzats en les 3 espècies de baldrigues del Mediterrani, els quals demostren un notable declivi de les seves poblacions a causa d'una elevada mortalitat adulta (Oppel et al. 2011, Genovart et al. 2016, 2017b). És per això que la mortalitat que està causant les captures accidentals al palangre és un dels principals responsables de la tendència negativa observada en aquestes espècies. De fet, en el cas de la baldriga balear, s'estima que una mortalitat no natural per sobre dels 100 individus per any seria insostenible per a les poblacions (Genovart et al. 2016). En aquest sentit, el present estudi demostra que la mortalitat per captura accidental als palangrers que operen a l'oest del Mediterrani supera els nivells sostenibles per a l'espècie. A més, cal afegir la mortalitat per captura accidental que ocorre en altres pesqueres, així com en altres regions, durant el període no reproductor (Oliveira et al. 2015), el qual tindria un impacte acumulatiu sobre les seves poblacions.

Per altra banda, l'examen de les baldrigues mortes per captura accidental en el conjunt de la flota palangrera (demersal i pelàgica), revela que aquest impacte es veu agreujat per l'existència d'una mortalitat diferencial entre classes d'edat i sexes, fet que pot empitjorar les implicacions demogràfiques, ja de per si molt severes, sobre les poblacions de baldrigues (Mills & Ryan 2005, Arnold et al. 2006, Genovart et al. 2017b). No obstant, aquesta variació difereix entre espècies, àrees i estacions. En tots els casos, els adults són el grup d'edat més afectat, especialment durant el període pre-posta. Encara que en el cas de la baldriga cendrosa, són també predominants durant la incubació. Per contra, en les baldrigues petites (*Puffinus*), les captures en aquests estadis reproductors soLEN ser escasses. No obstant això, s'observà que la proporció d'adults disminueix al final del període reproductor, mentre que, alhora, es troba un augment de les captures d'immadurs i/o sub-adults. Aquest fet demostra que la mortalitat en els palangrers de l'àrea d'estudi està afectant a totes les classes d'edat. Tot i així, convé subratllat que el nombre d'adults podria estar sent infraestimat atès que al final del període reproductor les gònades

es troben en regressió, cosa que dificulta poder separar entre sub-adults i adults reproductors.

Aquesta major incidència sobre els adults té grans efectes sobre la viabilitat de les poblacions ja que, al ser animals de vida llarga, són altament sensibles a les alteracions de la supervivència adulta (Lebreton & Clobert 1991). Així mateix, com que les baldrigues són animals monògams amb alta cooperació dins de la parella, la pèrdua de la parella té un cost reproductiu associat que pot afectar en última instància la seva eficàcia biològica (Ismar et al. 2010, Sánchez-Macouzet et al. 2014).

A banda d'això, també s'ha trobat que existeix una major mortalitat de mascles en l'època pre-posta en les 3 espècies de baldrigues. En el cas de la baldriga cendrosa, aquest biaix es dona principalment en els caladors pròxims a les colònies de cria (Illes Balears). Encara que aquesta mortalitat diferencial fa que, en conjunt, hi hagi una desviació significativa en la relació entre sexes a favor dels mascles. En canvi, en el cas de les baldrigues petites, s'ha trobat una major proporció de femelles capturades durant l'època d'alimentació dels polls. Com a conseqüència, en el cas dels adults de la baldriga balear, la relació entre sexes es troba desviada significativament cap a les femelles. Aquesta desigual mortalitat entre mascles i femelles podria conduir a un desequilibri en la relació entre sexes de la població, fins al punt de tenir greus efectes sobre la mida efectiva de la població i la fecunditat (Mills & Ryan 2005).

Els diferents biaixos detectats en les captures accidentals resulten, possiblement, per l'existència d'una segregació espacial i temporal de les àrees d'alimentació entre les diferents classes d'edats i sexes (Bugoni et al. 2011, Jiménez et al. 2016a, Gianuca et al. 2017). No obstant, són necessaris més estudis sobre la distribució d'alimentació de les baldrigues i el seu solapament amb les pesqueres per millorar la interpretació de les possibles causes de la desigual mortalitat detectada en aquest estudi.

Per altra banda, a partir de la informació de les anelles recopilades de les baldrigues capturades als palangrers de l'oest del Mediterrani, s'ha pogut determinar que la major part d'exemplars afectats provenen de les colònies de cria localitzades a l'àrea d'estudi, en particular de les illes Balears (Menorca i Mallorca). Encara que també són capturats individus d'altres colònies de l'oest del Mediterrani (França i Itàlia), especialment durant l'època de migració.

Factors que incrementen les captures accidentals i mesures de mitigació

En el present estudi s'ha pogut identificar diversos factors temporals, operacionals espacials i meteorològics que influeixen sobre el risc de captura accidental d'ocells

marins en la flota de palangre demersal del Mediterrani, els quals resulten claus per definir la estratègia de mitigació més efectiva per aquesta flota.

En general, l'època de pesca és el factor més important, seguit pel moment del dia que es realitza la calada. Per tant, existeix un major risc de captura accidental durant l'època de cria dels ocells i quan les calades es realitzen durant la matinada. El tipus i mida de l'esquer, les condicions de vent, la distància entre els pesos col·locats a les línies i el nombre d'hams calats són també factors rellevants, encara que amb menor importància. Com a conseqüència, el risc de captura d'ocells és major quan els pescadors fan servir esquer mixtes (peix i calamars) o bé únicament peix, quan els esquers tenen una mida de més de 10 cm, quan la calada coincideix amb dies de vent moderat - fort, quan fan servir arts que contenen pesos distribuïts a major distància i es calen un major nombre d'hams.

Quan considerem sols la baldriga cendrosa, la distància a la colònia es presenta com un altre factor important (més risc a menor distància de la colònia), mentre que el tipus d'esquer (considerant únicament peixos i calamars) i el nombre d'hams sembla tenir menys importància. Quan tenim en compte el conjunt de la flota palangrera que opera al nord-oest del Mediterrani, tant la pelàgica com la demersal, trobem certes diferències en la importància relativa d'aquests factors sobre el risc de captura de la baldriga cendrosa. En aquest cas, el tipus d'esquer (major risc en esquers mixtes o únicament peix) i l'activitat d'arrossegament (major risc quan existeix un menor nombre d'embarcacions d'arrossegament operant en les proximitats) resulten ser més determinants, mentre que el període (considerant únicament l'estació reproductora) i el vent perdren importància.

Segons les recomanacions de *l'Acord per a la Conservació dels Albatros i Petrells* (ACAP 2016b), les mesures de mitigació més efectives per reduir les captures accidentals d'ocells marins en els palangrers demersals inclou: (1) una restricció temporal i espacial de l'activitat pesquera, (2) la utilització d'un règim apropiat de pes per al palangre per tal de maximitzar la taxa d'enfonsament dels hams escats, (3) la calada nocturna, (4) la utilització de línies espantaocells i (5) un adequat maneig dels descarts per evitar l'atracció d'ocells durant la calada. També es recomana que l'efectivitat de les tècniques de mitigació seleccionades sigui demostrada científicamente, establir estàndards mínims que siguin clars i específics, demostrar que els mètodes de mitigació siguin pràctics, econòmicament viables i àmpliament disponibles, i a més que mantinguin les taxes de captura de les espècies objectiu i que no incrementin les captures accidentals d'altres organismes (ACAP 2016a).

A més, per garantir el compliment de l'aplicació de mesures de mitigació per part dels pescadors, no solament haurien de reduir les captures d'ocells, sinó que també haurien de ser de baix cost, segures, fàcils d'implementar i controlar, així com anar

acompanyades d'incentius. Al mateix temps, l'estratègia de mitigació hauria de definir-se en col·laboració amb els pescadors, per tal de promoure la implicació i conscienciació del sector en resoldre aquesta problemàtica, que no només afecta als ocells sinó també a la seva activitat (Gilman et al. 2005, Gilman 2011, Boyd 2014).

Totes aquestes recomanacions s'han tingut en compte alhora de seleccionar, dissenyar i avaluar la viabilitat de les possibles mesures de mitigació més adients per als palangrers demersals de l'àrea d'estudi.

Estació de l'any

Durant l'època de cria, en particular durant la primavera (Abril – Juny, època pre-posta i incubació de la baldriga cendrosa i de polls en les baldrigues petites), els atacs als esquers es tornen més freqüents i nombrosos en els palangrers de fons. Aquests resultats són coherents amb el patró temporal de les captures accidentals trobat a les observacions a bord dels vaixells i les captures reportades pels pescadors, el qual està relacionat amb la freqüència de les captures massives registrades en aquest estudi.

Encara que els pescadors també reportaren captures eventuals de gran magnitud durant l'hivern (Gener) i la tardor (Octubre). En el primer cas, es tractava d'accidents de baldrigues del gènere *Puffinus* ocorreguts en els palangrers de la costa catalana. Durant l'hivern, que coincideix amb el període de la pre-posta, la baldriga balear i mediterrània augmenten el seu caràcter gregari (Gutiérrez & Figueurola 1995) i intensifiquen l'ús de la plataforma Ibèrica per alimentar-se (Guilford et al. 2012, Péron et al. 2013), fet que afavoreix les captures d'ocells a la costa peninsular. Encara que les captures accidentals també podrien incrementar-se en aquest període pel fet que coincideix amb la veda de la pesca d'encerclament d'algunes regions de Catalunya. Els descarts generats en aquesta pesquera (generalment durant la nit i el crepuscle) són també aprofitats per les baldrigues (Arcos & Oro 2002), per tant, podrien compensar aquesta carència acudint amb més intensitat als palangrers (García-Barcelona et al. 2010a). D'altra banda, les captures reportades durant la tardor corresponien fonamentalment a la baldriga cendrosa. Aquest pic de captures també ha sigut detectat en la flota palangrera pelàgica que opera a l'oest del Mediterrani (Báez et al. 2014), i podria ser causat per un augment d'exemplars en l'àrea, atès que coincideix amb l'època de migració de l'espècie (Péron & Grémillet 2013).

A banda d'això, quan es considera el conjunt de la flota palangrera (demersal i pelàgica), s'observa que la interacció de la baldriga cendrosa pot ser també important durant l'època d'alimentació de polls (Agost – Octubre). En concordança amb aquesta troballa, estudis anteriors també han detectat un major nombre de captures accidentals en aquesta època, i la pre-posta (Març – Maig), en els palangrers demersals d'una altra regió de l'oest del Mediterrani (Illes Columbretes i

Balears; Belda & Sánchez 2001, Laneri et al. 2010). Per tant, s'observa que la temporalitat de les captures varia entre regions i flotes, la qual cosa està relacionada amb la distribució geogràfica de les àrees d'alimentació de les diferents espècies de baldrigues, així com l'abundància local dels ocells i les característiques operacionals dels palangrers (Waugh et al. 2012, Báez et al. 2014). N'és una demostració d'aquest fet l'elevada mortalitat que s'observà en la baldriga cendrosa als palangrers que operaven prop de les seves colònies de cria, possiblement causat per l'elevada abundància local i l'ús d'arts de pesca més perillosos per als ocells, com per exemple el palançó sense pesos.

Al mateix temps, la intensitat d'interacció amb les pesqueres pot estar condicionada per la disponibilitat i distribució de les seves preses naturals (estacionalitat o canvis interanuals de la productivitat marina), així com per variacions en els requeriments energètics i canvis en la dieta al llarg de l'any (Arcos & Oro 2002, Navarro et al. 2009, Louzao, Navarro, et al. 2011, Meier et al. 2015, Gilman et al. 2016). A banda d'això, aquesta interacció i les probabilitats de captura accidental estarien igualment determinades per la pròpia tendència i dinàmica de la flota (canvis en l'esforç pesquer o d'espècies objectiu, localització dels caladors, etc.).

En conseqüència, les taxes de mortalitat i la distribució espacial de les captures podrien estar subjectes a una variació interanual. No obstant això, davant el marcat patró temporal de les captures accidentals, es pot intuir que el maneig de l'activitat palangrera mitjançant una **limitació temporal durant els mesos més conflictius** (p.ex. abril - juny) podria reduir significativament les captures d'ocells.

Per contra, traslladar aquesta limitació a una escala espacial podria resultar inviable, atès que les zones d'alt risc és distribueixen de manera diferent entre espècies i podrien variar entre anys, la qual cosa complicaria la determinació dels límits i extensió de les àrees d'exclusió. A més, la restricció de l'activitat en determinades àrees podria desplaçar l'esforç pesquer cap a altres àrees i, per tant, reubicar el problema, així com tenir importants costos econòmics per als pescadors (O'Keefe et al. 2014, ACAP 2016b).

En el cas de la restricció temporal com a mètode per mitigar les captures d'ocells, la seva delimitació hauria de ser específica per a cada flota (demersal i pelàgica, veure Báez et al. 2013) i àrea de pesca (Catalunya, Balears i País Valencià) per tal d'ajustar-se als períodes crítics de captura accidental. Encara que també cal tenir en compte les pèrdues econòmiques que suposa la parada de l'activitat dels palangrers ja que, per exemple, el pic de captures d'ocells que s'observa durant la primavera coincideix, alhora, amb els mesos de major productivitat de la flota.

Moment del dia

El moment del dia que es realitza la calada també determina el risc de captura d'ocells als palangres. En aquest sentit, existeix un major risc durant la matinada, ja que és el moment en el que els ocells tenen una major activitat (Passos et al. 2010, Dias et al. 2012, Meier et al. 2015, Cianchetti-Benedetti et al. 2017). No obstant això, s'observa que les captures accidentals també poden ser importants durant el dia. En canvi, quan els palangres són calats durant la nit, la interacció amb els ocells i les captures es redueixen significativament.

És per això que la **calada nocturna** es considera com un dels mètodes més eficaços per reduir les captures d'ocells en diferents tipus de pesqueres de palangre (Brothers et al. 1999b, Belda & Sánchez 2001, Løkkeborg 2011). A més, a l'oest del Mediterrani, Sánchez i Belda (2003) trobaren que durant la nit els robatoris dels esquers per part dels ocells es reduïen considerablement, evitant d'aquesta manera pèrdues econòmiques per als pescadors en les èpoques de major interacció.

Malgrat això, la calada nocturna no elimina completament les captures d'ocells, especialment en les nits de major lluminositat (Brothers et al. 1999a, Belda & Sánchez 2001, Delord et al. 2010), ja que poden haver captures d'espècies que s'alimenten durant la nit, com la baldriga cendrosa i la gavina corsa. De fet, en el present estudi s'ha registrat captures d'aquestes dues espècies, així com de la baldriga balear, principalment en nits de lluna plena, encara que representen una baixa proporció de les captures totals (9%). També s'ha observat que la interacció amb els palangres no solament és limita a les nits amb lluminositat, sinó que també pot donar-se en nits sense lluna. Per aquest motiu, es recomana que la il·luminació de la coberta sigui mínima en les calades nocturnes (Barnes et al. 1997), ja que així es pot reduir la visibilitat dels esquers i, per tant, les captures accidentals.

A banda d'això, la calada nocturna pot tenir efectes negatius sobre les captures comercials (Brothers et al. 1999b, Sánchez & Belda 2003), ja que l'horari de pesca està condicionada pels ritmes diaris de les espècies objectiu (Løkkeborg & Pina 1997). En aquest sentit, els assajos realitzats per avaluar la viabilitat de la calada nocturna en els palangrers demersals de l'àrea d'estudi, demostren que per al cas concret del lluç europeu, calar per la nit no té cap efecte sobre les captures objectiu. Encara que es troba que podria incrementar les captures dels congres, atès el seu comportament nocturn (Göthel 1992). A més, la calada nocturna afavoreix que hi hagi menys captures d'espècies no comercials o protegides, com el peix lluna, el peix espasa i la tintorera.

Malgrat d'això, encara que el lluç és una de les espècies més apreciades per als palangrers demersals de l'oest del Mediterrani, existeix una elevada diversitat d'espècies objectius en la flota, les quals varien entre embarcacions i èpoques de

l'any. Per aquest motiu, no es pot descartar que la calada nocturna tingui efectes sobre el rendiment econòmic quan la pesca va dirigida a altres espècies.

Tipus d'esquer

El tipus d'esquer també té una influència important sobre el risc de captura accidental. Generalment, existeix una major probabilitat d'atacs quan els pescadors fan servir esquers mixtes (calamar i peix) o únicament peix (p.ex. sardina o seitó). Mentre que l'abundància d'aquests atacs, i també les taxes de captura, augmenten quan els esquers tenen una mida superior als 10 cm i són mixtes.

Els peixos epipelàgics són les principals preses naturals de les baldrigues, a més dels calamars i altres espècies bentòniques que adquireixen quan es desplacen a la superfície durant la nit o bé mitjançant els descarts pesquers (Granadeiro et al. 1998, Bourgeois et al. 2011, Afán et al. 2014, Meier et al. 2016). Es per això que els pescadors podrien reduir l'atracció dels ocells i, consegüentment, les captures accidentals, si evitessin utilitzar peixos i/o calamars com a esquer. No obstant això, el tipus d'esquer determina la selectivitat de les captures comercials i l'eficiència pesquera (Ingólfsson et al. 2017), per tant, el canvi d'esquer podria ser inviable per algunes espècies objectiu de la flota.

Tot i així, en aquest estudi es comprovà la viabilitat de **l'ús d'esquers artificials**, els quals mostraren resultats positius respecte les captures comercials en altres pesqueries de palangre (<http://www.arombait.com>). Durant els assajos, no es pogué valorar els seus efectes sobre els ocells, no obstant, s'observa que l'ús d'esquers artificials afecta al rendiment econòmic dels pescadors, ja que redueix un 77% les captures de les espècies objectiu (lluç) en comparació amb els esquers convencionals (sardina o seitó). Per tant, es considera inviable l'ús d'aquest tipus d'esquer artificial en la flota de palangre demersal dirigida al lluç. No obstant això, no es descarta la seva utilitat potencial quan la pesca va dirigida a altres espècies, o bé l'ús d'altres esquers artificials.

Una alternativa per reduir les captures d'ocells quan es fan servir esquers atractius per als ocells és la instal·lació d'una **Línia espantaocells (LEP)** en el moment de la calada per tal de limitar l'accés als esquers per part dels ocells (Løkkeborg 2011, ACAP 2016b). El present estudi demostra que la línia espantaocells desplaça els atacs de les baldrigues a més de 45 m de la popa. Dins d'aquesta àrea, els esquers es troben submergits a diversos metres de fondària (al voltant de 2 metres). Per tant, la instal·lació de la LEP redueix el risc de captura accidental.

Malgrat això, a causa de la notable capacitat de busseig de les baldrigues, especialment del gènere *Puffinus*, l'extensió de la LEP assolida no permet protegir la totalitat dels esquers accessibles per aquestes espècies, ja que podrien arribar inclús quan els esquers es troben a 190 m de distància de la popa i enfonsats a 10 m

de fondària. A més, en els dies de vent en calma, l'efectivitat de la LEP es redueix atès que l'absència de moviment en les serpentines afavoreix que les baldrigues ataquin més prop de la popa, quan els esquers es troben pròxims a la superfície. De fet, la major part de les captures de baldrigues registrades quan la LEP es trobava desplegada ocorregueren en aquestes condicions.

Així mateix, durant els dies de vents forts, especialment si són creuats, existeix la possibilitat de que la LEP es desplaci cap al palangre i hi hagi embolicks, o bé que aquesta es situï en una posició que no protegeixi els esquers. Tenint en compte que en aquestes condicions de vent és més probable que hi hagi atacs als esquers, es posa en dubte la idoneïtat de la línia espantaocells com a mètode per mitigar les captures d'ocells en els palangrers demersals de l'àrea d'estudi.

Estudis anteriors han detectat els mateixos problemes i proposen l'ús de dues línies espantaocells per assegurar que els esquers quedin protegits dels ocells (Løkkeborg 2003, Melvin et al. 2004, Dietrich et al. 2008). No obstant això, aquesta recomanació podria ser inviable per als palangrers artesanals ja que, al tractar-se de vaixells de menor mida, es podria incrementar els risc d'embolicks. Alternativament, l'ús de la LEP en combinació amb un increment del pes del palangre, el qual faria acurtar la finestra d'accés als esquers, podria ser també efectiu per reduir les captures d'ocells (Dietrich et al. 2008, Sato et al. 2016).

Configuració del palangre

La configuració del palangre, en relació a la quantitat de pes que s'afegeix a la línia, té una influència important en el risc de captura. En aquest sentit, s'ha trobat que els atacs als esquers són més probables i s'intensifiquen amb l'augment de la distància entre els pesos col·locats a la línia. Així mateix, les taxes de captura accidental són més elevades quan no s'afegeixen pesos als palangres. Això és així perquè el pes i la distància entre els pesos determinen la taxa d'enfonsament dels hams escats (Robertson et al. 2008) i, per tant, la seva exposició i accessibilitat per als ocells.

En aquest estudi, s'ha observat que la extensió de la finestra d'accés dels ocells als hams escats està determinada per la configuració del palangre, la velocitat de calada i la localització dels hams respecte a la línia mare. El palangró (amb pesos afegits) que es fa servir en els arts menors s'enfonsa més lentament que el palangre "Pedra-Bola", a causa d'una major distància entre pesos consecutius i l'ús de pesos més lleugers. Per tant, s'esperaria trobar una major finestra d'accés als esquers en aquest tipus d'estructures. No obstant, la velocitat de la calada també va influir en l'amplitud de la finestra d'accés, de manera que a menor velocitat, més estreta és l'àrea d'accés. És per aquest motiu que en les embarcacions que utilitzen palangró mostren una àrea d'accés menor o semblant als que fan servir palangre "Pedra-Bola". Malgrat això, seria inviable limitar la velocitat de calada per reduir les

captures accidentals, ja que el seu ajust determina l'establiment i estructura final del palangre al fons (Robertson et al. 2008), de manera que podria afectar a les captures comercials. Per altra banda, en el cas del palangre “Pedra-Bola”, es troba que els hams posicionats en la primera secció de la línia i pròxims al pes mostren una major taxa d'enfonsament. Per tant, els hams situats en una secció intermèdia o pròxims al flotador o entre el flotador i el pes es troben més exposats als ocells.

L'addició de pes a la línia, per maximitzar la taxa d'enfonsament dels hams prop de la popa del vaixell, ha demostrat ser un mètode efectiu per reduir les captures d'ocells en els palangrers demersals, especialment de les espècies capbussadores (Robertson et al. 2006, Løkkeborg 2011, ACAP 2016b). Als assajos d'aquest estudi, s'intentà incrementar la taxa d'enfonsament dels esquers afegint ploms sobre els hams. D'aquesta manera, com que la braçolada tenia una longitud de més de 2 metres, s'esperava que els ploms duguessin els hams ràpidament a diversos metres de profunditat, reduint així les possibilitats de que els ocells capturessin els esquers.

Les proves demostraren que els hams s'enfonsaven a una velocitat significativament major quan afegíem els ploms i, per tant, la finestra d'accés es reduïa. Malauradament, la interacció dels ocells amb l'embarcació fou escassa durant aquests assajos i no permeteren valorar si realment tenia un efecte sobre les captures d'ocells. Encara que s'ha pogut confirmar que l'increment de la taxa d'enfonsament que es donava quan s'afegien ploms (25%, 0.2 m/s) no era suficient per reduir les captures d'ocells als nivells desitjables, ja que es recomana una velocitat d'enfonsament de més de 0.3 m/s (Robertson et al. 2008). A banda d'això, s'observa que l'addició de ploms afavoreix les captures de moixina (*Galeus melastomus*), possiblement per un canvi en la posició dels hams respecte al fons marí. Així mateix, existeix una major probabilitat d'embolics durant la calada quan les braçolades contenen ploms.

Davant d'aquests resultats, es recomana buscar mètodes alternatius que permetin assolir una velocitat d'enfonsament dels hams escats adequada per minimitzar les captures d'ocells, ja sigui modificant el pes dels pesos i la distància entre ells (Melvin et al. 2013, Pierre et al. 2013) o bé utilitzant altres tipus de palangre que afavoreixi una menor accessibilitat als esquers per part dels ocells (p.ex. el sistema Xilè, Moreno et al. 2006, Robertson et al. 2014, Tarzia et al. 2017).

No obstant això, pel fet que la flota demersal fa servir una gran diversitat de configuracions de palangre en funció de l'espècie objectiu, es requereix d'unavaluació específica d'aquests canvis per tal de valorar la seva viabilitat i les possibilitats d'implementació en la flota cas per cas.

Nombrer d'hams calats

Un altre factor important, relacionat amb l'art de pesca que es fa servir, és el nombre d'hams calats. S'observa que en les calades amb major nombre d'hams ocorren més atacs als esquers i, per tant, existeix un major risc de captura accidental. Aquest fet podria estar relacionat amb la duració de la calada i la quantitat d'esquer que es llença al mar, el qual influiria sobre l'atracció dels ocells i les oportunitats d'atacar als esquers. Per tant, la realització de **calades curtes** podria afavorir una reducció de les captures d'ocells. Sempre i quan no es realitzin de manera consecutiva dintre d'un període de temps reduït.

Estudis anteriors també han trobat un increment de la mortalitat amb el nombre d'hams (Delord et al. 2010, Winter et al. 2011, Báez et al. 2014), encara que aquesta tendència pot diferir entre espècies (Dietrich et al. 2009). En canvi, hi ha estudis que han considerat el nombre d'hams com a mesura de l'esforç pesquer (Belda & Sánchez 2001, Laneri et al. 2010, Trebilco et al. 2010). No obstant, altres autors suggereixen que l'esforç pesquer no depèn únicament del nombre d'hams i, per tant, s'haurien de considerar altres variables per quantificar-lo, com el nombre de tripulants i l'eslora de l'embarcació (Camiñas et al. 2006, Véran et al. 2007). A banda d'això, estudis anteriors realitzats amb tortugues marines, recomanen utilitzar les operacions de calada com a unitat d'esforç per calcular les taxes de captura, ja que el nombre d'hams és més sensible als canvis en les característiques dels vaixells i els arts de pesca (Camiñas et al. 2006, Báez et al. 2007).

Existeixen altres recomanacions senzilles, però amb grans efectes, per evitar les captures durant la calada i que podrien ser fàcilment integrades en l'activitat diària dels pescadors. Concretament, evitar llençar peix al mar moments abans de la calada, cobrir les caixes d'esquer quan es duen en la coberta i evitar iniciar la calada o interrompre-la quan hi ha un gran nombre d'ocells seguint la embarcació.

Activitat de la pesca d'arrossegament

Per altra banda, igual que altres estudis duts a terme a l'oest del Mediterrani (Laneri et al. 2010, Báez et al. 2014), s'ha trobat una influència de l'activitat d'arrossegament sobre el nivell d'interacció dels ocells i les captures accidentals en les barques de palangre. Aquesta evidència ha estat contrastada mitjançant diverses aproximacions: l'anàlisi de la interacció espacial-temporal entre els ocells marcats amb GPS i els VMS de les pesqueries, els comptatges d'ocells en les observacions a bord de palangrers i els esdeveniments de mortalitat reportats pels pescadors.

En tots els casos, s'observa que el risc de captura accidental en els palangres s'incrementa quan no hi ha activitat d'arrossegament. Això significa que els ocells, en absència d'embarcacions d'arrossegament, acudeixen amb més intensitat als

palangrers per tal de compensar la carència de descarts provinents de la pesca d'arrossegament. Conseqüentment, **restringir l'activitat dels palangrers als dies en que també hi ha pesca d'arrossegament (evitant doncs caps de setmana i vedes)** podria ser una estratègia alternativa per mitigar les captures accidentals als palangres (Laneri et al. 2010, Báez et al. 2014). No obstant això, s'ha observat que, en els palangrers demersals, les captures d'ocells poden ocurrir igualment quan hi ha activitat d'arrossegament. Per tant, la restricció temporal en la pesca de palangre hauria d'anar acompanyada d'altres mesures per evitar les captures d'ocells, ja que la seva aplicació en solitari seria insuficient per evitar aquesta problemàtica.

En relació amb aquest assumpte, convé destacar també la possible influència de la imminent normativa sobre els descarts aprovada per la Unió Europea, la qual pretén eliminar gradualment la producció de descarts mitjançant l'obligació de desembarcar totes les captures a port. D'acord amb els presents resultats, la implementació d'aquesta normativa reduiria la disponibilitat de descarts per als ocells que genera la pesca d'arrossegament i, en conseqüència, podria conduir a un augment substancial de les captures accidentals als palangres. A més, davant aquesta previsible reducció dels descarts, es posa en dubte l'eficàcia de la restricció de l'activitat dels palangrers quan hi ha pesca d'arrossegament com a mètode de mitigació.

CONCLUSIONS FINALS



La flota de palangre demersal que opera a l'oest del Mediterrani és diversa en quant a espècies objectiu, tipus d'arts i mètodes de pesca. Aquesta complexitat dificulta, per una banda, l'obtenció d'estimes acurades de mortalitat, així com la identificació de mètodes de mitigació que siguin aplicables al conjunt de la flota.

El nostre estudi demostra una alta mortalitat d'ocells marins en els palangrers demersals, en particular en les embarcacions d'arts menors i en els arts de pesca amb una taxa d'enfonsament reduïda. Aquesta mortalitat afecta fonamentalment a les tres baldrigues endèmiques del Mediterrani: cendrosa, balear i mediterrània. Per tant, l'estratègia de mitigació hauria d'anar orientada a reduir les captures d'aquestes espècies, en particular de la baldriga balear, ja que els nivells de mortalitat per aquesta espècie resulten especialment insostenibles.

La major susceptibilitat de les baldrigues es deu a la seva gran capacitat de busseig, la qual afavoreix l'accessibilitat als hams escats. Així mateix, el seu comportament gregari induceix a que, en ocasions, es vegin implicades en captures massives de desenes i centenars d'exemplars.

Les estimes de mortalitat obtingudes en aquest estudi probablement es trobin infravalorades, i cal prendre-les com a valors de referència conservadors. Això es deu a la falta d'informació sobre l'esforç pesquer dels arts menors, la difícil detecció de les captures accidentals per la seva relativa baixa freqüència i no tots els ocells capturats accidentalment són recuperats durant la recollida de l'art. A més, continuen havent àrees en les que no s'ha pogut obtindre informació.

La mortalitat per captura accidental als palangrers de l'oest del Mediterrani mostra un biaix cap als adults i un dels dos sexes en les tres espècies de baldrigues. Es confirma, per tant, el sever impacte d'aquestes captures accidentals sobre les poblacions de baldrigues, ja que es tracta d'espècies altament sensibles a la mortalitat adulta. Així mateix, els desequilibris en la relació entre sexes de la mortalitat podria estar agreujant el seu impacte. Per tant, per garantir la viabilitat de les poblacions de baldrigues, es requereix de manera urgent el desenvolupament d'accions efectives per reduir les taxes de captura accidental.

Són necessaris més estudis sobre la distribució d'alimentació de les baldrigues i el seu solapament amb les pesqueries per confirmar les causes de la desigual mortalitat als palangres entre classes d'edat i sexes. Per altra banda, per tal de millorar les prediccions dels ànalsis de viabilitat poblacional, es recomana incorporar la mortalitat diferencial observada en aquest estudi en els models poblacionals de les tres espècies de baldrigues.

Els factors més importants que determinen el risc de captura accidental en els palangres demersals són l'estació de l'any i el moment del dia que es realitza la calada. Altres factors, amb menor importància relativa, són el tipus d'esquer, les

condicions de vent, la distància entre els pesos, la proximitat a la colònia de cria (en el cas de la baldriga cendrosa) i l'activitat de la pesca d'arrossegament.

Els ocells interaccionen amb més intensitat amb els palangrers quan no disposen dels descarts provinents de la pesca d'arrossegament (dies no laborables i vedes). En conseqüència, la nova normativa adoptada per la Unió Europea que pretén prohibir els descarts, podria conduir a un augment de les captures accidentals als palangres. Davant aquest possible escenari, es posa de nou en relleu la necessitat urgent d'implementar mesures de mitigació per minimitzar les captures accidentals d'ocells.

Els assajos duts a terme en aquest estudi per avaluar diversos mètodes de mitigació demostren que la calada nocturna redueix de manera efectiva les captures accidentals d'ocells sense comprometre les captures objectiu o altres espècies no comercials. No obstant això, podrien continuar havent captures d'ocells amb comportament nocturn. També caldria confirmar els seues efectes sobre les captures comercials quan la pesca va dirigida a altres espècies objectiu de la flota que no sigui el lluç europeu.

La instal·lació d'una línia espantaocells (LEP) redueix el risc de captura accidental mitjançant el desplaçament dels atacs als esquers. No obstant això, en determinades condicions de vent pot resultar inefectiva i produir embolics amb el palangre. A més, l'àrea coberta per la LEP és insuficient per protegir la totalitat dels esquers accessibles per a les baldrigues petites (*Puffinus*).

L'addició de ploms per sobre dels hams incrementa la taxa d'enfonsament, conduint a una reducció de la finestra d'accés als esquers. No obstant, és insuficient per reduir les captures de les baldrigues i, a més, pot produir embolics durant la calada. Per tant, es descarta l'ús d'aquesta tècnica per mitigar les captures accidentals en la flota estudiada.

La distància entre els pesos col·locats a les línies influeix sobre el risc de captura accidental, ja que determina la taxa d'enfonsament dels esquers i, per tant, l'exposició als ocells. Per aquest motiu, es recomana incrementar la taxa d'enfonsament dels hams mitjançant l'aplicació d'altres mètodes (p.ex. augmentar el pes i distància entre els pesos, calat automàtic) o bé l'ús d'altres configuracions menys perilloses per als ocells (sistema Xilè).

L'ús dels esquers artificials utilitzats en aquest estudi ha resultat inviable per als palangrers demersals a causa del seu efecte sobre el rendiment econòmic. No obstant això, l'ús d'esquers poc atractius per als ocells durant l'època de major interacció podria reduir les captures d'ocells substancialment. No obstant, aquest mètode pot resultar inviable per determinades espècies objectiu de la flota.

Altres estratègies per reduir les captures d'ocells en la flota demersal estudiada inclouria una restricció de l'activitat pesquera durant els períodes crítics. Encara que per a que resulti efectiu, aquesta limitació hauria de ser específica per cada flota i àrea de pesca, així com anar acompanyada d'altres mètodes de mitigació.

Per últim, davant la complexitat de la flota de palangre demersal que opera en l'àrea d'estudi, l'estrategia per mitigar les captures accidentals d'ocells marins hauria de presentar-se com un joc de possibles mètodes que puguin adaptar-se a les diferents pràctiques pesqueres. Aquest conjunt d'eines inclouria: la calada nocturna, l'ús de mètodes que redueixin l'accés als esquers, evitar l'ús d'esquers atractius per als ocells, així com una limitació temporal de l'activitat en els períodes crítics. Es necessiten, per tant, més estudis per tal d'identificar i avaluar altres tècniques de mitigació que siguin apropiades per als diferents mètodes de pesca i espècies objectiu de la flota.

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APÈNDIXS



APÈNDIX I. GONADAL DEVELOPMENT STAGES OF MALE AND FEMALES IN SHEARWATERS

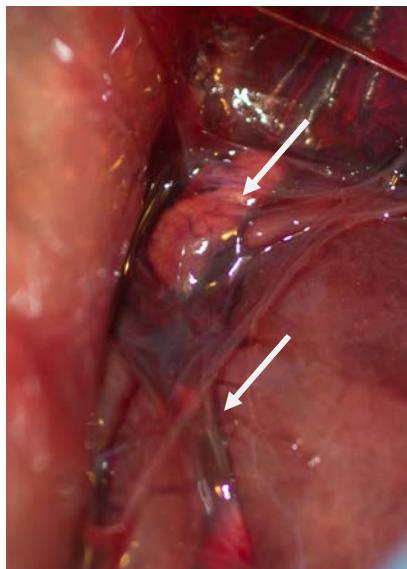


Figure A1. Ovary and oviduct of the juvenile female Mediterranean shearwater

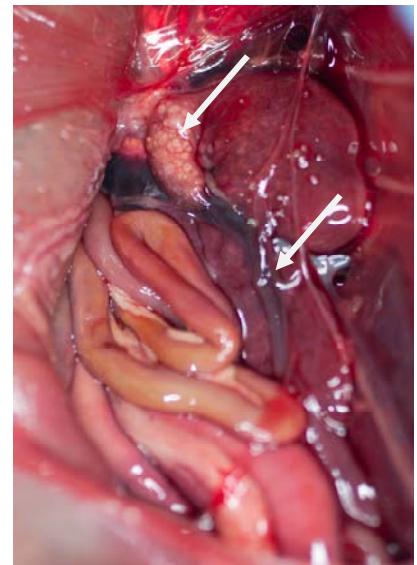


Figure A2. Ovary and oviduct of the immature female Balearic shearwater

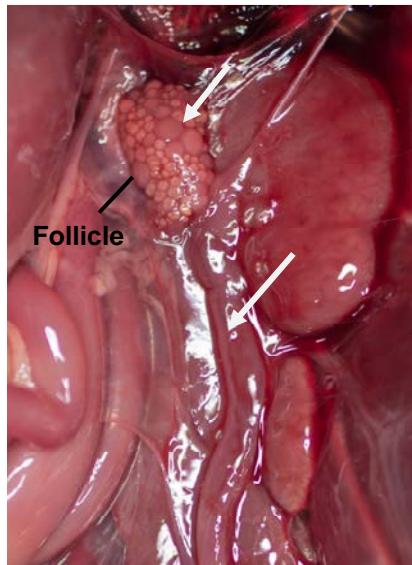


Figure A3. Ovary and oviduct of the subadult female Balearic shearwater

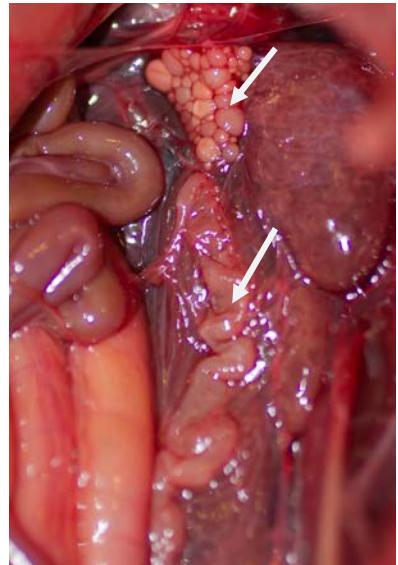


Figure A4. Ovary and oviduct of adult breeding female Balearic shearwater

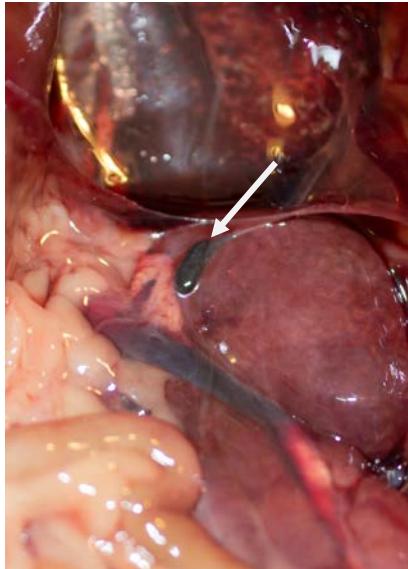


Figure A5. Testicle of the juvenile male Balearic shearwater

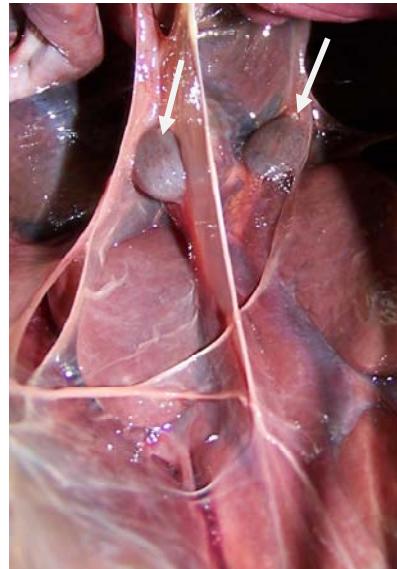


Figure A6. Testes of the immature male Mediterranean shearwater



Figure A7. Testes of the subadult male Scopoli's shearwater

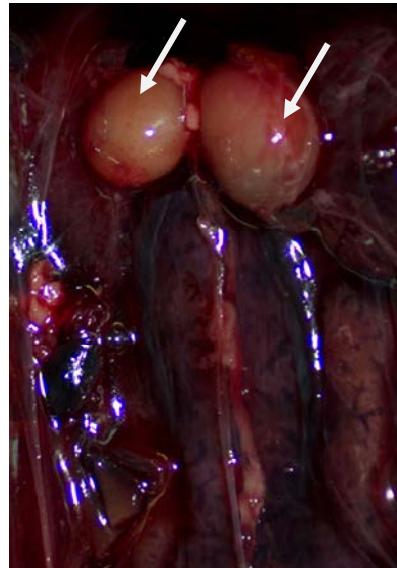


Figure A8. Testes of adult breeding male Scopoli's shearwater

Photographs A1, A2, A3, A4, A5, A7, A8 took by Salvador García-Barcelona and A6 by Teresa Militão.

APÈNDIX II. DESCRIPTION OF THE BANDED SHEARWATERS INCIDENTALLY KILLED BY DEMERSAL (MEDIUM “MD” AND SMALL-SCALE VESSELS “SM”) AND PELAGIC VESSELS (“MS”) OPERATING IN THE NORTH-WESTERN MEDITERRANEAN FROM 2003 TO 2015.

The species considered are Balearic (BS), Mediterranean (MS) and Scopoli's shearwater (SS). Death location refers to the area where the bird was incidentally caught: central-southern Catalonia (C-S CAT), northern Catalonia (N CAT), Balearic Islands (BAL) and Gulf of Lion (GL). The age (years) was determined by the first banding date and the number of years obtained is indicated between brackets. The values with an asterisk denote the minimum age, which corresponds to birds banded when they were more than 1 year old. We considered the first reproduction at age of 6 years old (Oro et al. 2004a, Jenouvrier et al. 2008). Locations in bold correspond to those breeding colonies placed outside of our study area.

Species	Ring	Longline fleet	Death location	Period	Death date	Age	Sex	Colony of origin
BS	5042990	MD	C-S CAT	Chick-rearing	19/05/2003	6	Female	La Trapa, Mallorca, Balearic Is.
BS	5048273	MD	C-S CAT	Chick-rearing	08/05/2007	9	Unknown	Illa Conillera, Mallorca, Balearic Is.
MS	5070034	MD	C-S CAT	Chick-rearing	10/06/2007	6*	Female	La Mola, Menorca, Balearic Is.
MS	FX.17930	SD	N CAT	Chick-rearing	20/05/2014	7*	Unknown	Île de Porquerolles. Îles d'Hyères
SS	6025384	MP	BAL	Migration	01/2001	5*	Unknown	Ses Bledes, Cabrera, Mallorca
SS	EA544094	MP	BAL	Prelaying	04/2003	8	Unknown	Isola di Lavezzi, Corsica
SS	6129323	MP	BAL	Prelaying	04/2003	1*	Unknown	Illa Pantaleu, Mallorca, Balearic Is.
SS	6031148	MP	BAL	Prelaying	04/2003	15*	Unknown	Illa Pantaleu, Mallorca, Balearic Is.
SS	6073239	MP	BAL	Prelaying	04/2003	9	Unknown	Na Plana, Cabrera, Mallorca
SS	6098921	MP	BAL	Prelaying	04/2003	5*	Unknown	Illa Pantaleu, Mallorca, Balearic Is.
SS	6076680	MP	BAL	Prelaying	04/2003	13*	Unknown	Na Plana, Cabrera, Mallorca
SS	6123033	MP	BAL	Prelaying	03/2004	3*	Unknown	Illa Pantaleu, Mallorca, Balearic Is.
SS	6111155	MP	BAL	Migration	01/2004	5*	Unknown	Illa Pantaleu, Mallorca, Balearic Is.
SS	6082394	MP	BAL	Prelaying	16/03/2009	9*	Unknown	Na Pobra, Mallorca, Balearic Is.
SS	6096005	MP	BAL	Prelaying	05/04/2012	16*	Unknown	Na Plana, Cabrera, Mallorca
SS	6025995	MP	BAL	Prelaying	05/04/2012	16	Unknown	Na Pobra, Mallorca, Balearic Is.

APÈNDIX II (*continued*)

Species	Ring	Longline fleet	Death location	Period	Death date	Age	Sex	Colony of origin
SS	6082469	MP	BAL	Prelaying	06/04/2012	13	Unknown	Na Plana, Cabrera, Mallorca
SS	6129380	MP	BAL	Prelaying	05/04/2012	10*	Unknown	Na Plana, Cabrera, Mallorca
SS	6129378	MP	BAL	Prelaying	06/04/2012	11	Unknown	Isle de Xapat, Cabrera, Mallorca
SS	6073967	MP	BAL	Prelaying	02/04/2012	17	Unknown	Ciutadella, Menorca, Balearic Is.
SS	EA544661	MP	BAL	Migration	22/10/2013	12	Unknown	Isola di Lavezzi, Corsica
SS	6131160	MD	C-S CAT	Prelaying	03/05/2007	5	Male	Illa Pantaleu, Mallorca, Balearic Is.
SS	5091321	MD	C-S CAT	Chick-rearing	23/09/2007	<1*	Female	Illa de l'aire, Menorca, Balearic Is.
SS	6026628	MD	C-S CAT	Prelaying	28/05/2008	13	Female	Na Pobra, Mallorca, Balearic Is.
SS	582520	MD	GL	Unknown	Early 2000s	Unknown	Male	Isola di Lavezzi, Corsica
SS	579507	MD	GL	Unknown	Early 2000s	7*	Female	Isola di Lavezzi, Corsica
SS	578513	MD	GL	Unknown	Early 2000s	15*	Unknown	Isola di Lavezzi, Corsica
SS	575273	MD	GL	Unknown	Early 2000s	8*	Unknown	Île Pomègues, Marsella
SS	TA7001	MD	GL	Migration	05/10/2004	6*	Female	Isola di Foradada, Sardinia
SS	TA6945	SD	GL	Incubation	08/06/2006	8*	Male	La Maddalena, Sardinia
SS	6037615	SD	GL	Incubation	06/06/2006	3	Male	Ciutadella, Menorca, Balearic Is.
SS	EA578819	MD	N CAT	Incubation	04/07/2004	Unknown	Unknown	France
SS	TJ9216	MD	N CAT	Migration	09/2014	Unknown	Unknown	Isola Pianosa, Livorno
SS	EA679711	MD	N CAT	Migration	09/2014	Unknown	Unknown	France

APÈNDIX III. EXPLANATORY DESCRIPTION OF THE TRIALS CONDUCTED IN THE ARTISANAL DEMERSAL LONGLINERS: NIGHT SETTING (NS), WEIGHTED LINE (WL), TORI LINE (TL) AND ARTIFICIAL BAITS (AB).

Trial	Period	Area	Methods
NS	May 2013 June 2014	<i>Vilanova i la Geltrú</i>	<p>20 samples. 2 paired longlines of 1050 hooks were set closely, distributed parallel at similar depth. Control line = sunrise or daytime setting Experimental line = night setting (1 hour before the twilight) All moon phases were covered. Depth: 254 – 260 m</p>
WL	July 2013 July 2014	<i>Vilanova i la Geltrú</i>	<p>15 samples. 2 paired longline types were set closely and continuously with a similar depth. Control line = typical gear (2013: 1050 hooks, 2014: 1260 hooks) Experimental line = branchlines with lead weights of 10 g or 20 g 5 cm above the hooks (2013: 1050 hooks, 2014: 840 hooks). Depth: 260 – 463 m</p>
TL	May 2013 May 2014	<i>Vilanova i la Geltrú</i> <i>Llançà</i>	<p>5 samples. 1 single line of 2100 hooks, first half of the line was set without tori line (control) and the other half with tori line (experimental). Longlines were set during sunrise or daytime. Depth: 241 – 260 m</p> <p>7 samples. 2 paired longlines were set closely and continuously during the sunrise, the last one had the tori line installed (experimental). Number of hooks was variable between samples but it ranged between 800 and 1000 hooks set. Depth: 117 – 195 m</p>
AB	June 2013	<i>Vilanova i la Geltrú</i>	<p>5 samples. 2 paired longline were set closely and continuously with a similar depth. One line was baited with conventional bait (control: 1050 hooks) and the other one with artificial baits (experimental: 1050 hooks). Line types were alternated between samples. Depth: 243 – 391 m</p>

APÈNDIX IV NUMBER OF BIRDS FOLLOWING THE VESSEL OF EACH SEABIRD SPECIES IN THE CONTROL AND EXPERIMENTAL SETTINGS OF THE MITIGATION MEASURES TESTED

LARAUD = *Larus audouinii*, HYDPEL = *Hydrobates pelagicus*, CALDIO = *Calonectris diomedea*, PUFMAU = *Puffinus mauretanicus*, STESAN = *Sterna sandvicensis*, LARMIC = *Larus michahellis*, MORBAS = *Morus bassanus*, STEHIR = *Sterna hirundo*, PUFYEL = *Puffinus yelkouan*, STEPOM = *Stercorarius pomarinus*, CATSKU = *Catharacta skua*, LARMEL = *Larus melanocephalus*

Species	Night setting			Tori line			Weighted line			Artificial bait		
	C	E	Total	C	E	Total	C	E	Total	C	E	Total
LARAUD	69	14	83	29	13	42	7	2	9	10	12	22
HYDPEL	41	1	42	14	8	22	8	5	13	3	5	8
CALDIO	37	4	41	28	40	68	4	5	9	6	1	7
PUFMAU	7	0	7	2	6	8	2	5	7	1	0	1
STESAN	4	0	4	0	0	0	0	0	0	0	0	0
LARMIC	3	0	3	26	36	62	0	0	0	1	3	4
MORBAS	3	0	3	2	0	2	0	0	0	0	0	0
STEHIR	2	0	2	0	0	0	0	0	0	0	0	0
PUFYEL	1	0	1	6	8	14	0	0	0	0	0	0
<i>Puffinus</i> spp.	0	0	0	2	1	3	0	0	0	0	0	0
STEPOM	0	0	0	1	0	1	0	0	0	0	0	0
CATSKU	0	0	0	1	0	1	1	0	1	0	0	0
LARMEL	0	0	0	0	1	1	0	0	0	1	0	1
Total	167	19	186	111	113	204	22	17	39	22	21	43
Hooks number	21,000	21,000	42,000	13,585	14,285	27,870	17,850	13,650	31,500	6,300	6,300	12,600

APÈNDIX V. NUMBER OF BAIT ATTACKS OF EACH SEABIRD SPECIES IN THE CONTROL AND EXPERIMENTAL SETTINGS OF THE MITIGATION MEASURES TESTED.

LARAUD = *Larus audouinii*, CALDIO = *Calonectris diomedea*, PUFMAU = *Puffinus mauretanicus*, STESAN = *Sterna sandvicensis*, LARMIC = *Larus michahellis*, PUFYEL = *Puffinus yelkouan*

Species	Night setting			Tori line			Weighted line			Artificial bait		
	C	E	Total	C	E	Total	C	E	Total	C	E	Total
LARAUD	55	0	55	8	0	8	0	1	1	1	0	1
CALDIO	154	33	187	60	151	211	4	0	4	28	3	31
PUFMAU	20	0	20	10	12	22	8	0	8	1	2	3
STESAN	1	0	1	0	0	0	0	0	0	0	0	0
LARMIC	0	0	0	4	8	12	0	0	0	0	0	0
PUFYEL	1	0	1	3	8	11	0	0	0	0	0	0
Total	231	33	264	85	179	264	12	1	13	30	5	35
Hooks number	21,000	21,000	42,000	13,585	14,285	27,870	17,850	13,650	31,500	6,300	6,300	12,600

APÈNDIX VI. NUMBER OF FISH CAUGHT OF EACH SPECIES IN THE CONTROL AND EXPERIMENTAL SETTINGS OF THE NIGHT SETTING, WEIGHTED LINES AND ARTIFICIAL LINE TRIALS.

Species	Night setting			Weighted lines			Artificial baits		
	C	E	Total	C	E	Total	C	E	Total
<i>Merluccius merluccius</i>	750	713	1463	442	345	787	325	74	399
<i>Galeus melastomus</i>	206	218	424	450	729	1179	31	16	47
<i>Conger conger</i>	11	21	32	24	16	40	4	0	4
<i>Micromesistius poutassou</i>	7	4	11	2	1	3	7	0	7
<i>Scyliorhinus canicula</i>	7	8	15	1	4	5	1	0	1
<i>Brama brama</i>	5	0	5	2	1	3	0	0	0
<i>Dasyatis pastinaca</i>	5	0	5	3	0	3	1	0	1
<i>Mola mola</i>	4	1	5	3	0	3	9	1	10
<i>Polyprion americanus</i>	4	7	11	3	3	6	0	0	0
<i>Ilex coindetii</i>	2	2	4	3	0	3	0	0	0
<i>Phycis blennoides</i>	2	0	2	2	1	3	0	0	0
<i>Pollachius virens</i>	2	0	2	0	0	0	0	0	0
<i>Xiphias gladius</i>	2	0	2	6	0	6	0	0	0
<i>Lepidotus caudatus</i>	1	0	1	0	0	0	0	0	0
<i>Prionace glauca</i>	1	0	1	0	0	0	0	0	0
<i>Thunnus thynnus</i>	1	0	1	0	0	0	0	0	0
<i>Etomopterus spinax</i>	0	1	1	0	0	0	0	0	0
<i>Trachurus trachurus</i>	0	0	0	2	0	2	0	0	0
<i>Helicolenus dactylopterus</i>	0	0	0	1	0	1	1	0	1
<i>Trichiurus lepturus</i>	0	0	0	1	0	1	0	0	0
<i>Scomber japonicus</i>	0	0	0	0	2	2	0	0	0
<i>Galeorhinus galeus</i>	0	0	0	0	0	0	1	0	1
Total	1010	975	1985	945	1102	2048	380	91	472
Hooks number	18,900	18,900	37,800	13,020	9,030	22,050	5,250	5,250	10,500

ARTICLES PUBLICATS



FEATURE ARTICLE



Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates

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ABSTRACT: Bycatch mortality in longline fisheries is considered the main threat at sea for numerous seabird species. These incidental catches occur worldwide, but mortality levels are mainly determined by the specific traits of the fishery operating in each area and the feeding behaviour and local abundance of seabirds. In the Mediterranean, demersal artisanal longliners are known to catch several seabirds, but bycatch rates and the main factors influencing both the probability and the level of seabird bycatch are poorly known. From 2011 to 2015 we conducted 220 trips onboard demersal longline vessels of the Balearic Sea, aiming to study their interaction with seabirds, as well as to understand the detailed procedures of the fishery and the factors that might influence seabird bycatch. Additionally, we recorded bird catches reported by fishermen. We found an average overall bycatch rate of 0.58 birds per 1000 hooks (0.13–1.37, 95 % CI), which would imply a conservative estimate ranging from 274 to 2198 seabirds caught annually on demersal longliners in the study area. The most affected species were the 3 endemic and threatened Scopoli's, Balearic and Mediterranean shearwaters of the Mediterranean (*Calonectris diomedea*, *Puffinus mauretanicus* and *P. yelkouan*, respectively), likely due to their highly aggregative behaviour and diving capabilities. Overall, the main factors influencing bycatch risk were season and time of day. Other influential factors were bait type, wind conditions, gear configuration (specifically, distance between weights), proximity to the breeding colony and the number of hooks. This study shows that mortality caused by demersal longliners is high and may be jeopardizing the viability of the shearwater populations. Therefore, the identification and implementation of mitigation measures is urgently required.



Puffin shearwaters were the seabirds most susceptible to bycatch due to their remarkable diving capabilities.

Photo: Verónica Cortés

KEY WORDS: Artisanal fisheries · On-board observations · Mortality · Mitigation measures · Susceptibility to capture · Shearwaters

INTRODUCTION

Fishing is considered one of the most serious threats to seabirds worldwide, both through bycatch and the over-exploitation of fish prey (Tasker et al. 2000, Croxall et al. 2012). Bycatch in longline fisheries mainly occurs when birds try to steal bait from the hooks while the line is being set. During these attempts, seabirds can become entangled or hooked, and die by drowning when the gear sinks (Brothers

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et al. 1999a). Globally, at least 160 000 seabirds are killed annually in longline fisheries, most of them albatrosses (Diomedeidae), petrels and shearwaters (Procellariidae) (Anderson et al. 2011). Many of these species are threatened, and bycatch has significantly contributed to dramatic declines of their populations (Weimerskirch et al. 1997, Inchausti & Weimerskirch 2001, Lewison & Crowder 2003, Wanless et al. 2009). This is especially so since bycatch influences adult survival, the most sensitive demographic parameter for long-lived organisms with low fecundity and delayed maturity, such as seabirds (Weimerskirch 2002).

Collecting data through on-board observations is the first step to quantifying bycatch and identifying the main drivers affecting bycatch rates. Many factors potentially influence the degree of seabird interactions with longline vessels, such as operational characteristics, type and configuration of the fishing gear, weather conditions at setting and the seabird species present in a given area (Brothers et al. 1999b, Weimerskirch et al. 2000, Gilman 2001, Dietrich et al. 2009). Understanding the relative importance of these factors is crucial to managing and implementing best practices to reduce bycatch for a specific longline fleet and area (Brothers et al. 1999a).

Seabird bycatch is well documented in some regions, such as the Southern Oceans and North Pacific, where industrial longline vessels operate (Brothers 1991, Weimerskirch et al. 2000, Gales et al. 1998). Observer programmes conducted in these regions have allowed the development of mitigation measures adapted to the regional fleets to minimize the incidence of bycatch (Brothers et al. 1999a, Gilman et al. 2003, Løkkeborg 2011). Nonetheless, seabird bycatch rates in many longline fleets are still largely unknown, especially in semi-industrial and artisanal fleets (Anderson et al. 2011). One of the major gaps of knowledge is in the Mediterranean Sea, where longline fishing is arguably the main cause of seabird mortality and possibly the most important factor contributing to the decline of some seabird populations (Cooper et al. 2003, Arcos et al. 2008, Laneri et al. 2010, Genovart et al. 2016). Despite this, fishermen in this area still do not use any mitigation measures to reduce seabird catches. Previous studies in Spain estimated bycatch rates at ca. 0.013–0.049 birds per 1000 hooks in the semi-industrial pelagic longliners (Valeiras & Camiñas 2003, Barcelona et al. 2010). These figures can be considered relatively low, but several characteristics of this fleet make it less problematic compared to artisanal demersal longliners, which use smaller hooks baited with the most common seabird prey in

the area, such as sardine *Sardina pilchardus*. Information from these artisanal fisheries is scarce, but supports the view that they can have a higher impact on seabirds than semi-industrial pelagic longliners. Indeed, a previous study on artisanal demersal longliners operating around the Columbretes Islands showed high mortality rates, reaching up to 0.16–0.69 birds per 1000 hooks (Belda & Sánchez 2001). However, mortality estimates assessed in a small area cannot be extrapolated to other areas because bycatch rates are highly variable locally, due to differences in bird abundances and longline fleet characteristics (Valeiras & Camiñas 2003, Lewison et al. 2014). Therefore, reasonably broad spatial and temporal coverage of on-board observer programmes is required to obtain accurate and reliable bycatch estimates (Gilman et al. 2005, Anderson et al. 2011).

This study provides the first comprehensive data on seabird bycatch by the artisanal demersal longliners operating throughout the entire Balearic Sea (northwestern Mediterranean) based on on-board observations. Our main objectives were to (1) characterize the Spanish Mediterranean demersal longline fishery; (2) determine the degree of interaction with longliners for the different species of seabirds; (3) assess the factors influencing seabird attempts to take bait (taken as a proxy of bycatch risk); and (4) estimate the bycatch mortality of this fleet for the study area.

MATERIALS AND METHODS

Study area

The study was performed in the Balearic Sea (Fig. 1), which includes the Balearic Islands and the northeastern Iberian waters (Catalonia and north of the Valencian region), and marginally extends southwards across the south of the Valencian region. The area holds important seabird breeding colonies, including the entire global population of the Balearic shearwater *Puffinus mauretanicus* and the bulk of that of Audouin's gull *Larus audouinii*, as well as important populations of Scopoli's shearwater *Calonectris diomedea* (Martí & Del Moral 2003). Other breeding species of relevance include the European storm petrel *Hydrobates pelagicus*, the Mediterranean shag *Phalacrocorax aristotelis desmarestii* and the yellow-legged gull *L. michahellis*. All of these species have important foraging grounds in the region, particularly over the Iberian shelf, which also attracts breeding birds from colonies beyond the

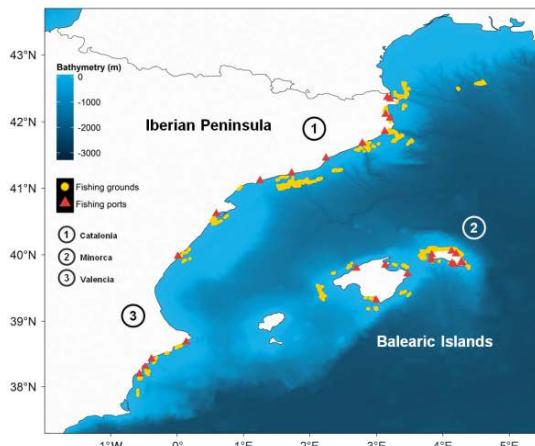


Fig. 1. Fishing grounds in the northwestern Mediterranean in which on-board observations were performed during the study period

study area, particularly Mediterranean and Scopoli's shearwaters (Arcos et al. 2012, Péron & Grémillet 2013, Péron et al. 2013).

The demersal longline fleet in the region consists of artisanal boats ranging from 7 to 15 m in length and 1 to 4 crew members. This artisanal fleet is very heterogeneous and dynamic, with high variability regarding longline configuration and fishing practices, mainly linked to the species targeted and the specific fishing habits of each skipper. Overall, the fleet can be divided into 2 major groups: medium-scale longliners and small-scale vessels. Basic differences between these groups are the distance from the coast where they fish, the type and size of hook and bait, the number of hooks that are set and the longline length. Moreover, small-scale vessels are polyvalent, so they can alternate among different gears throughout the year, such as longline, gillnets, trammel nets or traps. Medium-scale longliners are mainly concentrated on the Catalan coast (11 boats in 2015; Generalitat de Catalunya pers. comm.), with another 6 boats in the Valencian region (in 2015; www.agroambient.gva.es) and only 3 in the Balearic Islands (in 2014; Govern de les Illes Balears pers. comm.). Their activity is reported to the administration, so it was possible to estimate the dimension and fishing effort of the fleet. On the other hand, small-scale vessels are not bound to report on the type of gear used, so their effort is little known. They represent the most important fleet in the Balearic Sea, reaching a few hundreds of boats operating in each sub-region.

Data collection

Observations on board demersal longliners were carried out across the Balearic Sea during 220 fishing days (103 in medium-scale and 117 in small-scale vessels), from January 2011 to January 2015. These comprised 35 artisanal vessels (11 medium-scale and 24 small-scale vessels) from 26 fishing ports. Observation trips were organized attempting to cover the main fishing grounds of the longline vessels in the study area year-round. Detailed descriptions of the fishing gear and practices (e.g. operational characteristics, fishing grounds, target species), were documented for each fishing trip. Specifically for each setting operation, the position, time of day, meteorological data and diverse fishing characteristics were recorded. In addition, observers registered at 10 min intervals all seabirds that followed the vessels during line setting. For each time interval, the number

and distance astern of all attacks on bait performed by each seabird species were also registered and were ranked in 6 intervals: <5, 5–10, 11–20, 21–50, 51–100 and >100 m. In the night settings, counts of birds and attacks were limited by the distance from the stern at which they could be detected, given the illumination provided by the boat. All seabirds bycaught were recorded specifying the species, location and time of catch, when it was possible to recover the bird hooked.

During the 4 yr of study, fishermen also provided information on seabird catches that occurred when no observers were onboard. In some cases, they collected seabird carcasses which allowed us to confirm the species identification. Although these observations were collected irregularly and opportunistically, this information helped us to understand the occurrence, species involved and the main periods of multiple-catch events; an understanding that would have been difficult to obtain solely from the on-board programmes due to the irregularity of the events.

Data analysis

Factors affecting seabird attack rates. During this study, we did not register sufficient bird catches to properly assess what factors have an important influence on bycatch. Instead, we used the number of attacks on baited hooks as a proxy of bycatch risk,

since it reflects the direct interaction with the longline gear. This assumption was supported by the positive and significant correlation between bycatch and attack numbers, both when we considered all settings monitored ($r_s = 0.42$, $p < 0.001$, $N = 309$ settings) and only those in which there were seabird catches ($r_s = 0.71$, $p < 0.001$, $N = 24$).

Generalized linear mixed models (GLMMs) were used to identify the main factors affecting seabird attack rates. Analyses were conducted considering 2 groups: (1) all seabird species together and (2) only Scopoli's shearwaters, one of the species most commonly caught by the demersal longline fleet. In the latter case, we only considered those fishing trips performed during the period in which the species is present in the Mediterranean (March to October).

Count data are characterized by skewed distributions, as a result of a high proportion of zero values and a few events of large counts (flocking behaviour) (Fletcher et al. 2005). Hurdle models are a suitable method for modelling this type of distribution (Welsh et al. 1996, Fletcher et al. 2005, Zuur et al. 2009); these models are characterized by treating the data in 2 parts: (1) presence versus absence (Zero part); and (2) presence observations (Count part).

We analysed the relationship between the occurrence and number of attacks with temporal, spatial, meteorological and operational variables (Table 1). To assess its influence on seabird attraction to longliners, trawling activity was also considered, as previous studies found an important effect on seabird

catches (Laneri et al. 2010, Báez et al. 2014, Soriano-Redondo et al. 2016). Consecutive settings with the same fishing gear characteristics were grouped to avoid pseudoreplication. Vessel identity was included in all models as a random effect to control for the non-independence between sets within the same vessel. The number of birds following the boat was used as an offset in the count data. We only considered the line settings targeting demersal fish. Moreover, settings performed at night and with hooks baited with species of crustaceans and molluscs were not considered in the count data or in either 2 parts of the model due to the low number of events of attacks on bait. Likewise, trawler activity was not considered in the count data due to the low number of observations conducted when trawlers were not operating.

We applied the 'glmmadmb' function from the 'glmmADMB' package (R 3.0.1.). The Zero hurdle part was modelled assuming a binomial (BI) error structure (logit link function = cloglog), while the Count part was analysed considering a truncated version of the Negative Binomial distribution (HNB). We explored the factors selected to check collinearity between them and to remove non-explanatory categories. We then used the variance inflation factor (VIF) to verify the independence of each variable in the estimate of the regression coefficients of the model (Zuur et al. 2010).

Finally, we constructed the following models (see detailed information about the factors considered in Table 1):

Table 1. Explanatory variables used in the analyses of the factors influencing seabird interaction with longliners in the northwestern Mediterranean Sea

Factor	Type	Description
Temporal		
Season (all species)	Categorical	Winter (Dec–Feb), Spring (Mar–May), Summer (Jun–Sep), Autumn (Oct–Nov)
Period (Scopoli's shearwater)	Categorical	Pre-laying (March–1 st week June), incubation (until mid-July), chick-rearing (until mid-October)
Spatial		
Distance to colony	Continuous	Kilometres from the nearest breeding colony (scaled)
Meteorological		
Wind	Categorical	Presence of wind: Beaufort force scale > 1
Operational		
Bait type	Categorical	Fish, cephalopods, mixed (fish + cephalopods)
Bait size	Categorical	Shorter or longer than 10 cm (max. = 20 cm)
Setting time (time)	Categorical	Night, within ±1 h of dawn, daytime
Hooks set (hooks)	Continuous	Number of hooks set (scaled)
Distance between weights	Continuous	Distance between the weights attached to the snoods (scaled)
Trawler activity		
Trawler working days (trawler activity)	Categorical	Overlapping with trawling activity according to their spatial and temporal closures

All species:

Number of attacks (HNB) ~ season + wind + bait type + bait size + time + hooks + distance weights

Occurrence of attacks (BI) ~ season + wind + bait type + bait size + time + hooks + distance weights + trawler activity

Scopoli's shearwater:

Number of attacks (HNB) ~ period + distance to colony + wind + bait size + time + distance weights

Occurrence of attacks (BI) ~ period + distance to colony + wind + bait type + bait size + time + hooks + distance weights + trawler activity

Model selection was made using the model-averaging process. This approach is useful when there is uncertainty about which is the best model (Burnham & Anderson 2002). In this way we obtained model-averaged parameter estimates, taking into account the unconditional variation linked to the uncertainty of the model selection (Burnham & Anderson 2002). We estimated the parameters using the 95 % confidence set of the models where the sum of Akaike weights reached >0.95.

Seabird bycatch and mortality. Bycatch rate was expressed as the number of birds caught per 1000 hooks set. We calculated the average rate for each group of demersal longliners (medium and small-scale vessels), area (Iberia and Balearic Islands) and longline type. Confidence intervals (95 %) were determined using bootstrap re-sampling (10 000 iterations) from observed data.

To estimate the mortality caused by the demersal longliners in the Balearic sea, we only considered the data collected in vessels from Catalonia (Iberia) and Minorca (NE Balearic Islands), as these areas had better spatial and temporal effort coverage allowing reliable estimates. For the medium-scale longliners, we only considered the bycatch rate obtained on the Catalan coast. Fishing effort was estimated using the data of annual fish landings from 2015 provided by the local administration (Generalitat de Catalunya). From this, we estimated the number of vessels operating in the area and the average number of fishing days per year (11 boats: 143 fishing days for each vessel and 3 141 281 hooks set by the entire fleet). For the small-scale vessels, we were only able to estimate mortality for Minorca. There we could collect data on the boats with sufficient detail to estimate fishing effort through surveys of fishermen (18 boats: 78 fishing days and 1 534 572 hooks). In the Iberian area, we did not have enough information to estimate the effort of these vessels; therefore it was not possible to

evaluate the mortality caused by this fishery. In all cases, mortality estimates were only based on dead birds and did not include birds released alive.

To evaluate differences in bycatch susceptibility among species and longline type, we used the chi squared (χ^2) test to compare the proportion of birds caught during the observations onboard with the expected proportion of birds that could potentially be caught (Y), as indicated by (1) the number of birds observed following vessels and (2) the observed number of attacks on baited hooks. The proportions were calculated as:

$$Y_{ij} = \frac{n_{ij}}{N_j} \quad (1)$$

where n_{ij} is the individual number of i species for each j source of data considered (attendance, attacks), and N is the total number of all species vulnerable to bycatch.

RESULTS

Characteristics of the demersal longline fishery

The fishing grounds of the medium-scale demersal vessels stretched from 1.5 to 36 nautical miles (n miles) offshore (mean \pm SD = 8.7 \pm 3.4), at depths between 22 and 549 m (mean \pm SD = 271.7 \pm 112.9). They manually set from 338 to 4800 hooks (1888 \pm 731) per fishing day at 1.2 to 10.5 knots (5.04 \pm 1.58). The size of the hooks was 3.57 \pm 0.30 and 1.64 \pm 0.26 cm of total length and of gape, respectively. In the case of the small-scale vessels, several boats used demersal longlines seasonally, mainly in accordance with the temporal pattern of fish abundance, market conditions and time closures of specific target species. However, a few vessels used longlines year round. Their fishing grounds were usually close to the coast, ranging from 0.3 to 19 n miles (2.3 \pm 1.7, at depths between 7 and 609 m (mean \pm SD = 81.8 \pm 71.7). They set from 147 to 2610 hooks (957 \pm 538) each fishing day at 0.9 to 7 knots (2.93 \pm 0.95). Hook sizes were 2.97 \pm 0.48 cm for overall length and 1.42 \pm 0.41 cm for the gape.

For both vessel types, hooks were commonly baited with fish, usually sardine, European anchovy *Engraulis encrasicolus* and round sardinella *Sardinella aurita*, but sometimes with cephalopod species. Fishermen from the small-scale vessels frequently used smaller-sized bait, either because they cut fish into small pieces or baited with other small species of crustaceans and molluscs. Longlines were mainly set

during daylight (84 % of the settings observed; N = 316), either at dawn (48%) or during daytime (36%), while setting at night was less frequent (16%). The soak time (the time lapse between the setting and the hauling) of the longlines varied among vessels and target species. Most often longlines were hauled 1 to 2 h after setting, although some fishermen left longlines in the water for ca. 15 h.

Irrespective of the type of vessel, longline configurations can be classified into 2 types according to the distribution of the hooks relative to the seabed: (1) the Piedra-Bola (PB) system (Fig. 2a,b), which is characterized by using a combination of weights and floats, so that hooks are kept at different depths, and (2) the bottom longline (Fig. 2c) which keeps the hooks level over the seafloor by only attaching weights to the snoods at regular intervals. The PB system may also be divided in 2 different sub-groups: the zigzag (Fig. 2a) and the pyramidal structure (Fig. 2b). The main differences between these structures are the distance between weights and the distance from the float to the nearest weight (Table 2), these being shorter in the zigzag structure. The zigzag structure was most commonly used by the medium-scale vessels (78 % of the fishing trips conducted), mainly employed for fishing European hake *Merluccius merluccius* and blackbelly rosefish *Heliocolenus dactylopterus*. Pyramidal structures were less frequent (8 %) and were used to target blackspot seabream *Pagellus bogaraveo*. In addition, some fishermen occasionally used this structure for fishing pelagic species (7 %), such as Ray's bream *Brama brama*. In this case, they used larger floats and more weights attached to the branch lines (5.4 ± 2.4 kg) placed at greater distances (556.0 ± 72.7 m). Bottom longlines (Fig. 2c) were typically used in small-scale vessels (86 %) for fishing a wide diversity of demersal fish, such as common pandora *Pagellus erythrinus*, toothed bream *Dentex dentex* and gilt-head seabream *Sparus aurata*. In this type of fishing gear, we could distinguish 2 different longline configurations based on whether fishermen did or did not use weights attached along the mainline (Table 2; 50%, bottom-weights; 36%, bottom-no weights).

Seabird species and abundance

Seabirds were present in 67 % of 316 settings monitored, totalling 1969 individuals from 16 species (Table 3). The most frequent species behind the vessels were Scopoli's shearwater (37 % of the sets), yellow-legged gull (27 %), Audouin's gull (11 %),

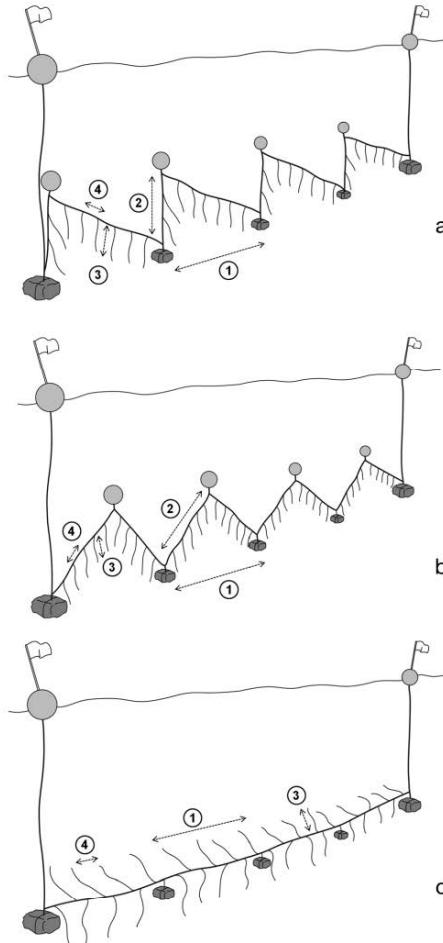


Fig. 2. Longline configurations used by the demersal fleet: (a,b) the Piedra-Bola system (a = PB-zigzag, b = PB-pyramidal) and (c) the bottom longlines (bottom-weights). 1 = distance between weights; 2 = minimum distance between the weight and the float; 3 = length of branch lines; 4 = distance between hooks. Drawing by Toni Mulet

Balearic shearwater (7 %) and Mediterranean gull *Larus melanocephalus* (6 %).

Attempts to take baits occurred in 38 % of the settings monitored, totalling 2180 events (Table 3). The main species involved in these attacks were Scopoli's shearwater (58 %), Balearic shearwater (17 %), yellow-legged gull (10 %) and Audouin's gull

Table 2. Fishing gear characteristics of the most commonly used longline types by demersal longliners of the Balearic Sea. PB: Piedra-Bola configuration. Distance values and lengths are expressed in metres. Values correspond to mean \pm SD. Value in brackets refers to the number of fishing trips in which the fishing gear was used. Medium: medium-scale vessels (N = 103 fishing trips), Small: small-scale vessels (N = 116 fishing trips)

Type of vessel:	Gear:		PB-zigzag		PB-pyramidal		Bottom-weights		Bottom-no weights	
	Medium	Small	Medium	Small	Medium	Small	Medium	Small	Medium	Small
% usage and (n)	78 (80)	10 (11)	8 (8)	4 (5)	14 (15)	50 (58)	36 (42)			
Weight (kg)	2.1 \pm 0.4	1.2 \pm 1	3.61 \pm 1.1	0.5 \pm 0.1	1.10 \pm 0.47	0.8 \pm 0.8				
Distance between weights	97.3 \pm 28.4	113.6 \pm 32.0	120.8 \pm 27.7	201.4 \pm 242.8	887.1 \pm 539.7	411.3 \pm 364.0				
Min. distance of weight to float	17.9 \pm 9.6	30.6 \pm 12.2	96.7 \pm 87.4	101.4 \pm 122.8						
Length of branch lines	1.92 \pm 0.1	2.1 \pm 0.2	2.0 \pm 0.0	2.0 \pm 0.0	1.3 \pm 0.7	2.4 \pm 0.6	2.2 \pm 0.29			
Distance between hooks	3.9 \pm 0.9	5.0 \pm 1.1	3.5 \pm 0.6	5.6 \pm 0.7	6.0 \pm 1	6.8 \pm 1.9	6.2 \pm 0.44			

(8%) (Table 3). Considering only the settings performed during daytime (N = 265), we found that most attacks occurred within 5 to 20 m behind the stern of the boat (89%). For small-scale vessels, attacks mainly occurred at 5 to 10 m from the stern (53%), while for medium-scale boats, the attacks were most frequent from 10 to 20 m (74%). Regarding the gear configuration used (Fig. 3), for PB-zigzag, most attacks occurred from 10 to 20 m astern (85%), while for bottom-weights attacks occurred more often at 5 to 10 m (61%). For the bottom-no weights, attacks also occurred in the first 10 m (40%), but were more frequent from 10 to 20 m (52%).

Factors influencing seabird attacks

All species. Season and the bait used were the most important factors influencing the number of attacks (Table 4). The number of attacks was greater in spring and when fishermen used bait larger than 10 cm, but it decreased when only fish bait was used. Moreover, the number of attacks was higher on windy days and with an increased number of hooks set. The occurrence probability of attacks was mainly influenced by the setting time, the season, and the bait type used; it increased in settings at dawn, during spring and when fishermen used fish bait. In addition, occurrence

Table 3. Number of birds (mean \pm SD, total birds within brackets, N = 316 settings) of each species observed following vessels (attendance), species occurrence (%), total occurrence days within brackets), number of bait attacks (mean \pm SD; total attacks within parentheses, N = 298) and occurrence of attack events (%; in parentheses number of days on which attacks observed) from the sets observed onboard demersal longliners

Common name	Taxon	No. attending	% bird occurrence	No. of attacks	% attack occurrence
Scopoli's shearwater	<i>Calonectris diomedea</i>	8.3 \pm 13.5 (730)	27.8 (88)	22.1 \pm 57.1 (1280)	19.13 (57)
Balearic shearwater	<i>Puffinus mauretanicus</i>	5.7 \pm 16.0 (142)	7.9 (25)	19.2 \pm 56.6 (365)	6.4 (19)
Yellow-legged gull	<i>Larus michahellis</i>	4.7 \pm 6.5 (536)	35.8 (113)	6.2 \pm 9.9 (212)	11.4 (34)
Audouin's gull	<i>Larus audouinii</i>	3.2 \pm 3.5 (232)	22.8 (72)	5.7 \pm 6.7 (183)	10.7 (32)
Mediterranean shearwater	<i>Puffinus yelkouan</i>	3.5 \pm 2.7 (35)	3.2 (10)	7.5 \pm 8.3 (30)	1.3 (4)
Mediterranean gull	<i>Larus melanocephalus</i>	3.1 \pm 3.1 (107)	11.1 (35)	1.6 \pm 1.4 (13)	2.7 (8)
Small shearwaters	<i>Puffinus</i> spp.	2.7 \pm 2.6 (30)	3.5 (11)	6.8 \pm 6.7 (27)	1.3 (4)
Black-legged kittiwake	<i>Rissa tridactyla</i>	2.7 \pm 2.4 (38)	4.4 (14)	4.9 \pm 5.2 (44)	3.0 (8)
Sandwich tern	<i>Sterna sandvicensis</i>	2.6 \pm 2.01 (13)	1.6 (5)	4.7 \pm 2.2 (14)	1.0 (3)
European storm-petrel	<i>Hydrobates pelagicus</i>	2.3 \pm 1.4 (75)	10.1 (32)	0	0
Black-headed gull	<i>Chroicocephalus ridibundus</i>	1.5 \pm 1.0 (6)	1.3 (4)	9 \pm 0.00 (9)	0.3 (1)
Common tern	<i>Sterna hirundo</i>	2 (4)	0.6 (2)	0	0
Northern gannet	<i>Morus bassanus</i>	1.2 \pm 0.5 (6)	1.6 (5)	1.3 \pm 0.6 (4)	1.0 (3)
Great skua	<i>Catharacta skua</i>	1 (1)	0.3 (1)	0	0
Lesser black-backed gull	<i>Larus fuscus</i>	1 (3)	1.0 (2)	0	0
Pomarine skua	<i>Stercorarius pomarinus</i>	1 (1)	0.3 (1)	0	0
Great cormorant	<i>Phalacrocorax carbo</i>	5 (5)	0.3 (1)	0	0

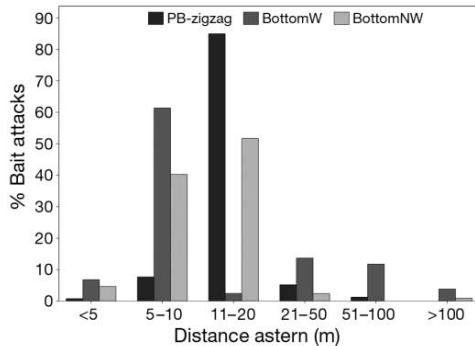


Fig. 3. Proportion of bait attacks (%) performed by seabirds at different distance-intervals from the vessel stern considering separately the gear configurations most commonly used by demersal longliners of the study area. PB-zigzag = Piedra-Bola (zigzag configuration). BottomW = longline with only weights attached along the mainline (bottom-weights). BottomNW = longline without either weights or floats (bottom-no weights). Piedra-Bola and bottom longline configurations correspond to gear of the medium and small-scale vessels, respectively. The PB-pyramidal configuration was not considered here due to low sample size

probability was greater on windy days and at larger weight to weight distances.

Scopoli's shearwater. The number of attacks was greater in the pre-laying and incubation periods than during chick-rearing (Table 4), and also when larger

bait was used. In addition, the number of attacks increased on windy days and with the distance between weights. The occurrence probability of attacks was mainly influenced by the setting time and the season; it increased during dawn settings and during the incubation period. Moreover, the occurrence probability was higher on windy days, but decreased with the increased distance to breeding colonies.

Seabird bycatch and mortality

Bycatch occurred in 9% of the settings monitored (12% of the fishing days), totalling 109 birds of 7 species out of 342 022 hooks observed (Table 5). In addition, 1 bird was caught during the hauling operations. Most birds were caught by the small-scale vessels (81%) when comparing type of vessels, and in the bottom-weight configuration (55%) when considering the gear type. However, most of these catches occurred in a single setting that caught 48 *Puffinus* spp. The remaining catches occurred in the bottom longlines without weights (25%), PB-zigzag configuration (17%) and in the PB-pyramidal configuration targeting pelagic fish (2%). Overall average bycatch rate obtained in the study area was 0.58 birds per 1000 hooks (0.13–1.37, 95% CI; N = 211 fishing trips). The highest bycatch rate was found in the small-scale vessels (Fig. 4), especially those from peninsular ports: 1.56 birds per 1000 hooks (0–4.67;

Table 4. Parameters estimated in the model averaging selection (coefficient values and unconditional standard errors) for each variable included in the 2 hurdle processes: Count (number of attacks) and Occurrence (presence probability of attacks), considering all seabird species and only Scopoli's shearwater *Calonectris diomedea*. RI: relative variable importance (sum of the Akaike weights from all models in the set where the factor occurs). Coefficient values denote the direction and the effect size. Parameters of the categorical factors (*in italics*) were calculated relative to the reference categories (coefficient takes the value 0): autumn (Season); prelaying (Period); calm (Wind); cephalopods (Bait type); bait size <10 cm (Bait size); dawn/night (Time); weekend or trawling moratorium (Trawler activity).

Number of attacks in night settings was not considered in the analysis. The most important factors are indicated in **bold**

Fixed factors	Categories	All species				Scopoli's shearwater			
		Count	RI	Occurrence	RI	Count	RI	Occurrence	RI
(Intercept)		-1.00 ± 0.48		-2.86 ± 0.69		-0.03 ± 0.63		-3.24 ± 0.78	
Season/Period	<i>Spring/Incubation</i>	1.43 ± 0.36	1	0.93 ± 0.35	1	-0.09 ± 0.49	1	1.03 ± 0.48	0.89
	<i>Summer/Chick-rearing</i>	0.44 ± 0.35		0.18 ± 0.38		-2.52 ± 0.81		0.04 ± 0.61	
	<i>Winter</i>	0.16 ± 0.46		-0.01 ± 0.41		—		—	
Distance to colony	Number	—	—	—	—	-0.43 ± 0.31	0.41	-0.71 ± 0.35	0.82
Wind	<i>Occurrence</i>	0.27 ± 0.12	0.62	0.60 ± 0.20	0.99	0.53 ± 0.20	0.79	0.83 ± 0.34	0.91
Bait type	<i>Fish</i>	-0.75 ± 0.30	0.97	0.96 ± 0.32	0.96	—	—	0.66 ± 0.52	0.25
	<i>Mixed</i>	0.21 ± 0.26		0.77 ± 0.35		—		0.51 ± 0.46	
Bait size	<i>> 10 cm</i>	0.85 ± 0.25	1	0.15 ± 0.30	0.28	1.59 ± 0.48	1	0.44 ± 0.42	0.37
Time	<i>Dawn</i>	—	0.51	1.38 ± 0.46	1	—	0.25	1.50 ± 0.69	1
	<i>Day</i>	-0.35 ± 0.22		0.75 ± 0.49		0.27 ± 0.24		-0.24 ± 0.79	
Hooks	Number	0.27 ± 0.12	0.79	0.17 ± 0.12	0.51	—	—	-0.13 ± 0.23	0.29
Distance weights	Number	0.22 ± 0.16	0.44	0.44 ± 0.13	1	0.39 ± 0.22	0.59	0.19 ± 0.17	0.38
Trawler activity	<i>Occurrence</i>	—	—	-0.44 ± 0.30	0.52	—	—	-0.17 ± 0.51	0.25

Table 5. Number of seabirds caught during the on-board observations (2011–2015), by species, area and vessel type. Number of individuals recovered alive is indicated in brackets. No birds were caught in medium-scale vessels from the Balearic Islands (10 350 hooks). Bycatch rate = number of birds per 1000 hooks (mean + CI 95%). Mortality = number of birds killed annually as estimated from the bycatch rate obtained. Species binomials are given in Table 3

Species	Peninsula		Balearic Islands Small-scale (68 410 hooks)	Total (342 022 hooks)
	Medium-scale (218 453 hooks)	Small-scale (44 809 hooks)		
Balearic shearwater	5	—	8 (8)	13
Mediterranean shearwater	2	1 ^a (1)	—	3
Scopoli's shearwater	5	—	27 (5)	32
Unidentified shearwater:				
<i>Puffinus</i> spp.	1	45 ^b (3)	2 (2)	48
Audouin's gull	2	—	2 (1)	4
Yellow-legged gull	3	—	4 (1)	7
Black-legged kittiwake	2	—	—	2
Northern gannet	1	—	—	1
Total	21	46	43	110
Bycatch rate	0.12 (0.05–0.21)	1.56 (0–4.67)	0.59 (0.18–1.15)	0.58 (0.13–1.37)
Mortality	357 (126–642)	—	675 (148–1556)	1,032 (274–2198)

^aBycaught during hauling; ^bbycatch occurred in only 1 setting, and most were *Puffinus yelkouan*; however, it was not possible to check the ratio between both *Puffinus* species

$N = 48$). However, this rate was obtained from only 1 mass catch event (Table 5). Small-scale vessels from the Balearic Islands also showed a high bycatch rate: 0.59 birds per 1000 hooks (0.18–1.15; $N = 65$), with Scopoli's shearwater being the main species affected (Table 5). Concerning the longline configuration used, we found the highest bycatch rates in both types of bottom gear, especially in the longlines without weights (Fig. 4).

Most birds caught were recovered dead (81%). Only in the small-scale vessels, due to their lower setting speed, was it possible for fishermen to stop and release hooked birds alive. On the other hand, these longliners normally set in shallower waters and their branch lines are long enough for birds to reach the surface and survive until hauling.

Fishermen reported 739 birds caught when we were not onboard, during the 4 yr study period (Table 6). Most of these birds were shearwaters (95%), which were frequently captured in multi-catch events (up to 200 birds in a single event).

According to onboard observations, bycatch primarily occurred from March to July (Fig. 5a), being especially high in May. This seasonal pattern was roughly consistent with the fishermen's reports, which also showed low levels of bycatch in summer and early autumn, and a small peak in winter (Fig. 5b).

Seabird bycatch was greater in the daytime ($N = 53$ birds, Fig. 6), mainly influenced by a massive catch registered at midday (45 *Puffinus* spp. in 1 setting).

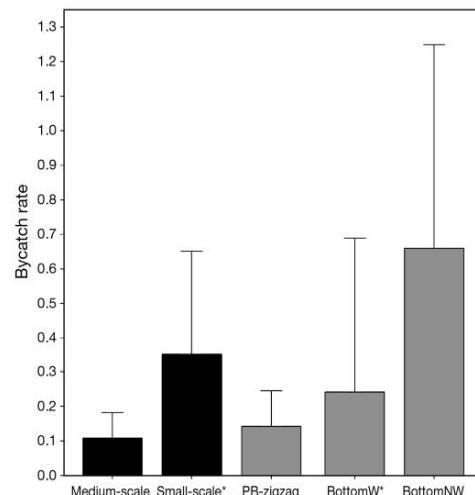


Fig. 4. Bycatch rate (birds caught per 1000 hooks, mean \pm 95% CI) according to both the vessel type (left) and the most common gear configurations (right) in the study area. Vessel type includes medium-scale ($N = 103$ fishing trips) and small-scale vessels ($N = 117$) of the study area. Gear configuration includes PB-zigzag (Piedra-Bola in zigzag, $N = 73$), BottomW (bottom-weight, longline with only weights attached along the mainline, $N = 56$), and BottomNW (bottom-no weights, longline without either weights or floats, $N = 42$). The PB-pyramidal configuration was not considered here due to low sample size. *The massive catch of small shear-waters is not included in the data

Settings during the night resulted in fewer catches ($N = 7$) that mainly occurred during full moon (71%). In this case, the species most affected were nocturnal feeders, such as Scopoli's shearwaters ($N = 2$) and Audouin's gulls ($N = 2$). However, Balearic shearwaters were also caught at night ($N = 3$). Additionally, a higher bycatch rate of shearwaters and gulls was found when a mix of cephalopods and fish were used as bait (Fig. 7).

The annual mortality estimated for the medium-scale vessels from Catalonia was 357 (126–642) birds, while for Minorca's small-scale vessels it was 675 (148–1556) birds. Therefore, considering both areas together, we obtained a minimum annual mortality for the Balearic Sea of 1032 (274–2198) birds in the setting operations, including 683 (46–1818) Scopoli's shearwaters, 123 (0–278) Balearic shearwaters and 35 (0–85) Mediterranean shearwaters.

Susceptibility to bycatch

The proportions of species of birds observed following the vessels differed from the proportion of birds caught (Table 7, $\chi^2 = 53.47$, df = 7, p < 0.001). That is, shearwater species (Scopoli's shearwater: $\chi^2 = 4.62$, df = 1, p < 0.05; and *Puffinus* spp.: $\chi^2 = 29.48$, df = 1, p < 0.001) and gannets *Morus bassanus* ($\chi^2 = 4.72$, df = 1, p < 0.05) were substantially more frequently caught than expected. In contrast, yellow-

legged gulls were less often caught than expected from their attendance ($\chi^2 = 14.53$, df = 1, p < 0.001). Likewise, the proportion of attacks on baited hooks obtained for each species also differed from the proportion of birds caught ($\chi^2 = 18.12$, df = 7, p < 0.05). Catches of *Puffinus* spp. ($\chi^2 = 4.61$, df = 1, p < 0.05) and gannets ($\chi^2 = 10.07$, df = 1, p < 0.01) occurred more often than expected from their proportion of attacks. However, the proportion of catches of Scopoli's shearwater was lower compared to the relative frequency of their attacks ($\chi^2 = 4.21$, df = 1, p < 0.05).

On the other hand, there was no difference in the proportion of birds caught in each longline type from their attendance ($\chi^2 = 0.06$, df = 3, p = 0.99) and the attacks observed ($\chi^2 = 0.01$, df = 3, p = 0.99).

DISCUSSION

Our study confirms that artisanal demersal longliners in the Balearic Sea cause high seabird mortality. This is particularly so for Scopoli's shearwaters around the Balearic Islands and, most importantly, for small (*Puffinus*) shearwaters off the Iberian Peninsula, often involving multi-catch events. We also provide detailed information on the fishery, which is diverse in specific gear configurations and fishing strategies, and assess which are the main factors influencing seabird bycatch. This is a first step towards understanding seabird bycatch and develop-

Table 6. Number of birds reported by fishermen (maximum birds registered per event is indicated in brackets) in each year of the study period ($N = 739$ birds, 15 boats). Total events = number of fishing days in which bird catches were reported. Total bycatch = number of birds bycaught including those events registered in the on-board observations. Some species could not be identified to species level, so these are grouped by genus or in a general group. (*) indicates small-scale vessels. 2015 is comprised of January only. Species binomials are given in Table 3

Species	2011	2012	2013	2014	2015	Total events	Total bycatch
Balearic shearwater	–	3	5	11 (3)	–	19	97
Mediterranean shearwater	–	–	–	14 (4)	–	6	49
Scopoli's shearwater	1	30 (12)	1 + 30* (30)	49 (20) + 12* (9)	–	20	166
Unidentified shearwaters:							
<i>Puffinus</i> spp.	–	18 (8)	20 (10)	130* (130) + 33 (30)	20 (20)	12	269
<i>Puffinus</i> and <i>Calonectris</i>	200 ^a (200)	38 (38)	–	8 (4) + 80* (80)	–	3	215
<i>Puffinus</i> or <i>Calonectris</i>	–	–	–	8 (4)	–	4	8
Northern gannet	1	3	5 (2)	–	–	8	10
Audouin's gull	1	3 (2)	10 (4)	–	–	8	18
Mediterranean gull	–	–	4 (4)	1	–	2	5
Sandwich tern	–	–	–	1	–	1	1
Unidentified gulls	–	–	2	–	–	1	2
Yellow-legged gull	–	–	–	–	–	–	7
Black-legged kittiwake	–	–	–	–	–	–	2
						Total	849

^aWe were able to check 109 individuals provided by the fisherman. The birds identified were: 65 Balearic shearwaters, 32 Mediterranean shearwaters and 12 Scopoli's shearwaters

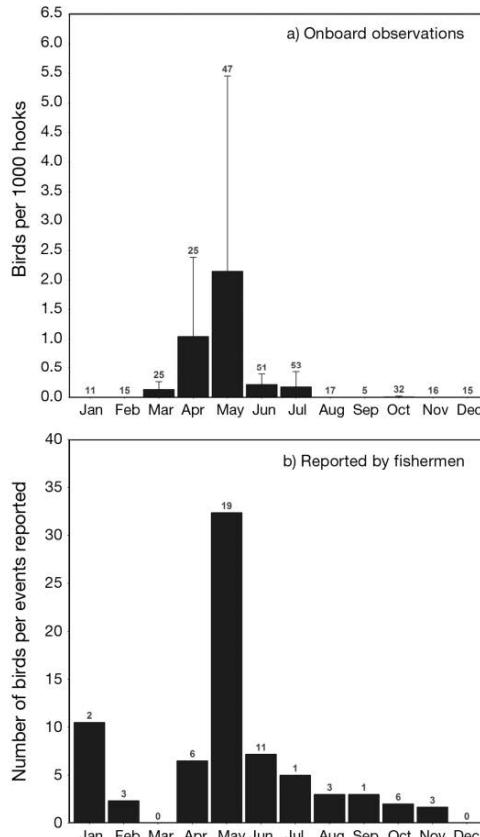


Fig. 5. Monthly occurrence of bycatch according to (a) onboard observations data (mean bycatch rate + 95 % CI) and (b) birds reported by fishermen (raw numbers). Numbers above bars specify (a) the number of settings observed and (b) the number of events reported

ing appropriate mitigation measures. However, the high diversity of configurations and strategies makes it difficult to accurately estimate bycatch or to identify easy mitigation solutions applicable to the whole fleet.

The overall average bycatch rate obtained in this study for the demersal longline fishery was 0.58 (0.13–1.37) birds per 1000 hooks. This rate is within the range of previous studies on demersal longliners from the Columbretes Islands (0.16–0.69 birds per 1000 hooks, Belda & Sánchez 2001), and higher than that found in previous studies in the pelagic longlin-

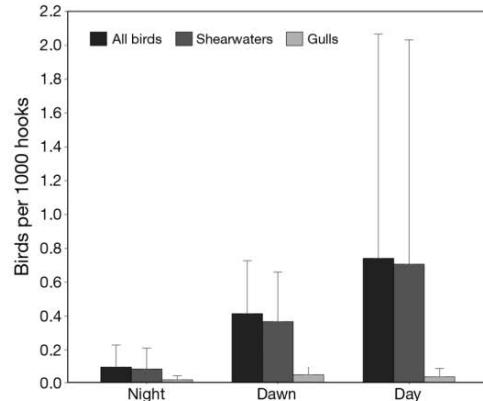


Fig. 6. Bycatch rates (+ 95 % CI) in demersal longliners in relation to the 3 different setting time intervals considered: night ($N = 51$ settings); dawn ($N = 150$, ± 1 h from sunrise); and daytime ($N = 115$). Data are grouped by all bird species, shearwaters only (*Calonectris diomedea* + *Puffinus* spp.) and gulls only (*Larus michahellis*, *L. audouinii*, *Rissa tridactyla*)

ers from the western Mediterranean (0.01–0.05 birds per 1000 hooks, Barcelona et al. 2010, Valeiras & Camiñas 2003; 0.25 birds per 1000 hooks, Belda & Sánchez 2001). In previous studies, the most caught species were Scopoli's shearwater and yellow-legged gull, while catches of small shearwaters (*Puffinus* spp.) were comparatively low (Belda & Sánchez 2001, Valeiras & Camiñas 2003, Barcelona et al. 2010, Laneri et al. 2010). In contrast, our study reports for the first time high bycatch rates in demersal longlines of 2 globally threatened seabirds, namely the Critically Endangered Balearic shearwater and the Vulnerable Mediterranean shearwater (BirdLife International 2017), confirming previous suspicions (Arcos et al. 2008, ICES 2013). Along with Scopoli's shearwater, these small shearwaters were the most commonly caught by demersal longliners in the Balearic Sea, particularly on the Catalan continental shelf, where important foraging grounds are located (Arcos et al. 2012, Péron et al. 2013, Meier et al. 2015). This high incidence of capture is subject to irregular catches, often involving dozens to even hundreds of individuals, thus complicating the detection and quantification of the problem. Demographic studies carried out on these 2 *Puffinus* species, Balearic and Mediterranean shearwaters, showed a severe decline in their populations related to high mortality at sea (Oppel et al. 2011, Genovart et al. 2016), altogether indicating that incidental catches likely represent the most relevant cause of their decline.

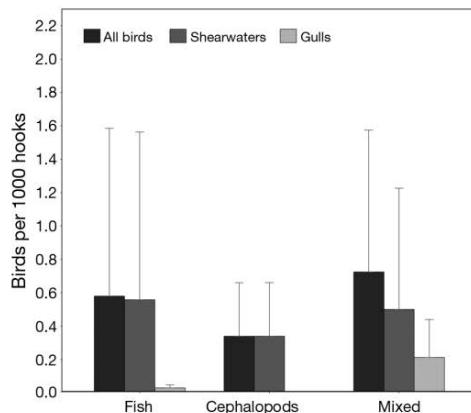


Fig. 7. Mean numbers of birds bycaught (+ 95 % CI) in demersal longliners in relation to bait category: fish ($N = 150$ settings), cephalopods ($N = 106$) and mixed ($N = 39$, fish + cephalopods). Data are grouped by all bird species, shearwaters only (*Calonectris diomedea* + *Puffinus* spp.) and gulls only (*Larus michahellis*, *L. audouinii*, *Rissa tridactyla*)

We estimated that at least 274 to 2198 birds are killed annually by the demersal longliners in the Balearic Sea. However, this number should be considered a gross underestimation because (1) not all birds caught during settings are retrieved during gear hauling due to carcasses falling off the hooks,

Table 7. Bycatch susceptibility of the different seabird species (expressed as the % of birds potentially bycaught) and in different longline configurations by considering the proportion of birds caught ($N = 64$ birds) in relation to the birds attending vessels and to the birds attacking bait. Proportions are based on numbers registered during on-board observations. The massive catch event of small shearwaters (Table 5) and the data from the Piedra-Bola (PB)-pyramidal gear to target pelagic fish are not included in the analysis. * $p < 0.05$, ** $p < 0.01$. Species binomials are given in Table 3

Species/gear	% of birds potentially bycaught		% of birds caught
	By attendance	By attacks	
Scopoli's shearwater	39.50*	60.05*	50.00
<i>Puffinus</i> spp.	11.21**	19.83*	28.19
Yellow-legged gull	28.06**	8.46	10.94
Audouin's gull	12.57	8.13	6.25
Black-legged kittiwake	2.06	2.07	3.13
Northern gannet	0.33*	0.19**	1.56
Mediterranean gull	5.58	0.61	0
Sandwich tern	0.70	0.66	0
PB-zigzag	0.35	0.31	0.30
PB-pyramidal	0.02	0.00	0
Bottom-weights	0.18	0.27	0.26
Bottom-no weights	0.44	0.40	0.42

becoming untangled from the line or being removed by scavenging marine species, which may result in an underestimation by more than half (Gales et al. 1998, Gilman et al. 2003, Brothers et al. 2010); (2) it is difficult to detect mass catch events of birds through on-board observer programmes with low coverage, due to their stochastic nature; and (3) the estimate is solely based on catches occurring on small-scale vessels from the Minorca coast and medium-scale longliners from the Catalan coast, as these were the only areas where it was possible to obtain reliable fishing effort data. Especially, there is a lack of information about the fishing effort of the small-scale vessels operating in the area, which hampers obtaining an accurate estimate of the mortality caused by this fishery.

We found that susceptibility to bycatch as indicated by the proportion of birds attending vessels and those attacking the bait, greatly differed among species; in particular, it was greater in the shearwater species and gannets, and lower in the more common yellow-legged gull. This taxon-specific risk varies with the feeding ecology and behaviour of each species (Weimerskirch et al. 2000). Indeed, the lower number of bait attacks by gull species, despite being the most common birds attending longline vessels, is likely due to their lower diving capabilities, which limits their access to the baited hooks once these sink into the water. In contrast, shearwaters are strong divers that can reach the baited hooks even when these are several metres underwater, reaching depths down to 28 m (Meier et al. 2015), thus increasing their bycatch risk. Likewise, in the case of the northern gannet, the species also showed a high susceptibility to being caught in longlines due to its high deep-diving ability (Ropert-Coudert et al. 2009), although relatively few catches were recorded due to its relatively low occurrence behind vessels.

Season was the most important factor influencing seabird attacks on baited hooks. In addition, the setting time also had a large effect on attack occurrence probability. Other factors such as type and size of the bait, wind conditions, distance between weights and number of hooks set also had a significant, albeit lower, influence on the seabird interaction with longline vessels. When considering only Scopoli's shearwater, distance to the colony became an additional factor of relevance, whereas bait type and the number of hooks had no significant effects.

Previous studies in the area reported higher seabird bycatch during the breeding period (Belda & Sánchez 2001, García-Barcelona et al. 2010, Laneri et al. 2010). We found that the number of attacks on bait was greatest in spring (April to June), when most Mediterranean seabirds are breeding. The spring

also had the highest level of seabird bycatch registered from onboard observations as well as from fishermen's reports. In the case of the *Puffinus* species, this season coincides with their chick-rearing period. In Scopoli's shearwater, it includes both the pre-laying and incubation periods. These results coincide with those by Laneri et al. (2010), but differ from other studies carried out in the western Mediterranean, which found greater catches of Scopoli's shearwaters during the chick-rearing and fledging periods (October; Belda & Sánchez 2001, García-Barcelona et al. 2010, Báez et al. 2014). These differences might be related to small to medium-scale geographical differences between these groups of studies, matching different spatiotemporal distribution patterns of the shearwaters, and highlight the relevance of applying a local approach to management. We can infer from this that an appropriate seasonal regulation of the fishing effort might significantly reduce seabird bycatch in the study area, although it could also entail significant economic losses for the artisanal fishermen since this period coincides with the most productive months of the fishery.

Settings during daylight hours increased the attack occurrence probability, and it was further increased when longlines were set at dawn, agreeing with previous studies (e.g. Belda & Sánchez 2001, Laneri et al. 2010). This is because seabird species in the Mediterranean are mainly diurnal and are particularly active at dawn and dusk (Passos et al. 2010, Dias et al. 2012, Meier et al. 2015). Concordantly, incidental catches were most frequent at dawn, although catches can also be high during daytime. Several studies recommend night setting as the most suitable method for reducing seabird bycatch in multiple types of longline fisheries (Brothers et al. 1999b, Belda & Sánchez 2001, Løkkeborg 2011). However, its effectiveness may vary depending on the seabird community occurring in a particular area. Some seabirds are active feeders at night and could also be caught during this period, especially on nights with bright moonlight or a full moon (Brothers et al. 1999b, Belda & Sánchez 2001, Delord et al. 2010). In this study, we found that seabird interactions were significantly reduced at night, with only 9% of all catches reported during this time period. This result is particularly relevant for the Critically Endangered Balearic shearwater, as this species is mostly active in daylight, specifically during the crepuscular hours (Meier et al. 2015), so that catches at night are less likely. Indeed, only 3 of 64 *Puffinus* shearwaters caught during the onboard observations were Balearic shearwaters captured at night, all of them on the same boat in 2 consecutive

days, coinciding with a full moon. Thus, night setting appears to be a promising mitigation measure in the Mediterranean. Moreover, it could be relatively easy to enforce effectively compared to other potential mitigation measures, although it might reduce catches of target species and lead to economic losses for fishermen (Brothers et al. 1999a, Sánchez & Belda 2003). Careful experimental approaches should assess the practical applicability of night setting and quantify its effects on target species as well as on other non-target species of fish potentially sensitive to longlining bycatch (e.g. elasmobranchs), and confirm the efficacy of this mitigation method in different moonlight conditions.

Another important factor influencing attacks was the type of bait used. The number of attacks was greater when fishermen used mixed bait and cephalopods than when they used fish bait. Mixed bait also increased the bycatch rate, possibly because different species tend to select different bait types (Trebilco et al. 2010). However, this effect was largely due to a higher capture of gulls. On the other hand, the attack occurrence probability was greater for hooks baited only with fish than those using other types of bait. When considering only Scopoli's shearwater, however, we did not find a significant effect of the type of bait used. The number of attacks also increased when fishermen used bait larger than 10 cm, which agrees with the prey size selected by shearwaters (Arcos 2001) and Audouin's and yellow-legged gulls when feeding on trawler discards in the western Mediterranean (Arcos et al. 2001).

Wind conditions at setting also had an important influence on the attacks. In general, the abundance and the occurrence of attacks increased on windy days. Some fishermen also reported that seabird catches increased on very windy fishing days (pers. comm.). Previous studies evaluating effects of weather conditions on seabird bycatch showed contrasting results. Some also detected an increase in seabird interactions under bad weather conditions (Brothers et al. 1999b, Weimerskirch et al. 2000, Delord et al. 2010), since water turbulence may keep baited hooks near the surface and therefore available to seabirds for a longer time, thus increasing bycatch risk. Alternatively, increased interactions could also be due to a greater difficulty for birds to find and capture their natural prey under these conditions, leading to an increased interaction with fishing vessels. In contrast, other studies did not detect any effect of wind speed on seabird bycatch (Klaer & Polacheck 1998) or found that its influence varied from species to species (Dietrich et al. 2009).

Specific gear configuration, namely the distance between weights, also had an important influence on seabird bycatch; increased distances led to a greater likelihood of bait attacks and, in the case of Scopoli's shearwater, it increased the number of attacks. This makes sense, as greater distances and lighter weights slow the longline sink rate (Robertson et al. 2007) and therefore increase seabird access to the baited hooks. We found these characteristics in the bottom longliners used by small-scale vessels in the study area. Despite this, we did not find significant differences in bycatch susceptibility among longline types. However, bycatch rates were higher in the bottom longlines, especially those that did not have weights attached. This may be explained by the greater exposure of the bait to seabirds, which could increase the attacks and in turn the risk of being caught. Nevertheless, to properly evaluate the accessibility of the baited hooks to seabirds it would be necessary to measure the sink rate of the different longline types used.

Setting the longlines near breeding colonies increased the probability of Scopoli's shearwaters attacking baits, an effect previously reported in several other studies (Weimerskirch et al. 2000, Dietrich et al. 2009, Trebilco et al. 2010). However, the number of shearwater attacks did not change significantly with distance. In fact, 17% of the catches recorded for this species occurred at more than 70 km from the nearest breeding colony. This result shows that the risk of mortality in this species can also be high in fishing grounds far from their breeding colonies.

The number of hooks set increased the attacks if we considered all seabird species. In general, previous studies found an increase in the incidental mortality with the number of hooks deployed per set (Delord et al. 2010, Báez et al. 2014), but its influence may differ among species (Dietrich et al. 2009). Nonetheless, other studies did not assess its effect, as they considered the number of hooks set as a simple measure of the fishing effort (Belda & Sánchez 2001, Trebilco et al. 2010).

Overall, we found that the likelihood of attacks at line setting was greater on days when trawlers were not operating, although the importance of this factor was relatively low compared to the other factors. Nevertheless, this result agrees with previous studies carried out in the western Mediterranean, which found an increase in the probability of birds attending longliners and/or greater incidental catches during non-working days of the trawlers (García-Barcelona et al. 2010, Laneri et al. 2010, Báez et al. 2014, Soriano-Redondo et al. 2016). Trawler discards

have a great influence on foraging behaviour of scavenging species (Bartumeus et al. 2010, Cama et al. 2013, Bécares et al. 2015), so the absence of trawler activity can induce birds to search for alternative food resources, such as bait used by longline vessels.

CONCLUSIONS

Our results show that demersal longline fisheries catch high numbers of the 3 endemic species of shearwater in the Mediterranean, all of them of conservation concern, calling for urgent and effective action to reduce their bycatch rates. The present study provides insight on the factors influencing bycatch in the Balearic Sea, which should be taken into account when designing the most appropriate mitigation measures for the region. It also shows that setting at night and implementing temporal closure of the fishery during the most conflictive months are the most promising strategies to reduce seabird bycatch. Nevertheless, further studies directed toward the effectiveness of these strategies to reduce seabird bycatch and their potential effects on fishing activity are desirable. Streamer lines and the increase of bait sink rate by adding weight to the line, or a combination of different mitigation measures, have also been proven to be very effective in some demersal fisheries from other regions (Brothers et al. 1999b, Dietrich et al. 2008, Løkkeborg 2011, Melvin et al. 2013), but should be carefully evaluated in the Mediterranean, since the diving capability of the 3 shearwater species may render these mitigation methods less effective.

Acknowledgements. We are grateful to the skippers and crews of fishing vessels that voluntarily collaborated in this project. We thank Cristina Aranguren, Éric Dominguez, Lluïsa Ferrer, Manel Mamano, Pau Marquès, Neus Matamalas, Toni Mulet, Blanca Sarzo, Adriana Rodríguez, Oriol Torres and David Torrens for making observations on the fishing vessels, and Rosario Allué (Generalitat de Catalunya) and Francesc Roselló (Govern de les Illes Balears) for providing fishing effort data. We also thank Oliver Yates from RSPB and 2 anonymous referees for their helpful comments and recommendations, and to Andy Smith and Bob Bonn for providing language help. This study was funded by the Fundación Biodiversidad (18PCA4328, 2012-13; 2013-14; 2014-15) and the Spanish government (CGL2009-11278/BOS, CGL2013-42585-P), and also received financial support from the EC LIFE+ Project INDEMARES. V.C. was supported by a PhD grant from the Generalitat de Catalunya (FI/DGR/2011), and J.M.A. was partially supported by the Segré Fondation through the BirdLife Seabird Task Force.

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Editorial responsibility: Rory Wilson,
Swansea, UK

*Submitted: July 27, 2016; Accepted: December 18, 2016
Proofs received from author(s): February 2, 2017*

SCIENTIFIC REPORTS



OPEN

Relative abundance and distribution of fisheries influence risk of seabird bycatch

Received: 06 June 2016

Accepted: 28 October 2016

Published: 23 November 2016

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Fisheries provide an abundant and predictable food source for many pelagic seabirds through discards, but also pose a major threat to them through bycatch, threatening their populations worldwide. The reform of the European Common Fisheries Policy (CFP), which intends to ban discards through the landing obligation of all catches, may force seabirds to seek alternative food sources, such as baited hooks from longlines, increasing bycatch rates. To test this hypothesis we performed a combined analysis of seabird-fishery interactions using as a model Scopoli's shearwaters *Calonectris diomedea* in the Mediterranean. Tracking data showed that the probability of shearwaters attending longliners increased exponentially with a decreasing density of trawlers. On-board observations and mortality events corroborated this result: the probability of birds attending longliners increased 4% per each trawler leaving the longliner proximity and bird mortality increased tenfold when trawlers were not operating. Therefore, the implementation of the landing obligation in EU waters will likely cause a substantial increase in bycatch rates in longliners, at least in the short term, due to birds switching from trawlers to longliners. Thus the implementation of the landing obligation must be carefully monitored and counterbalanced with an urgent implementation of bycatch mitigation measures in the longline fleet.

Effects of fishing on marine megafauna are widespread and diverse, mainly due to overfishing, production of discards and bycatch^{1–3}. Bycatch, the incidental capture of non-target species, is of particular concern for long-lived species with low reproductive rates and delayed sexual maturity, such as seabirds¹. Baited hooks offer the opportunity for an easy meal, yet these entail a very high risk of birds being hooked and subsequently drowned. A recent global review estimated seabird bycatch by longlines in 160,000–320,000 birds per year⁴. In fact, for some species, the current rates of bycatch are unsustainable for their long-term viability^{5,6}.

On the other hand, fishery discards may also have profound impacts on the breeding biology, distribution and population dynamics of seabirds, by making available demersal and benthonic species otherwise naturally inaccessible^{9–11}. Worldwide discards are estimated to be 8% of the total catch (i.e. around 7,000,000 tonnes discarded annually²). Ultimately, discards seem to be responsible for the increases in population sizes of several scavenging species over the last decades, such as large gulls^{9,12}.

Seabird-fishery interactions are of particular concern in the Mediterranean¹³; an enclosed and low-productive sea with a high degree of endemism¹⁴. Four seabird species are endemic to the basin and commonly caught by fishing gear, particularly in longlines: the Audouin's gull *Larus audouinii*, and the Scopoli's shearwater *Calonectris diomedea*, Yelkouan *Puffinus yelkouan* and Balearic shearwaters *Puffinus mauretanicus*^{15,16}. Among these, the Yelkouan and Balearic shearwaters are globally threatened (Vulnerable and Critically Endangered, respectively¹⁷). According to conservative estimates, at least 5,000 birds could be killed annually in the region¹⁸. In particular, the bycatch of Scopoli's shearwaters represents over 50% of all birds caught in longlines in some areas of the Western Mediterranean, which would imply that 4–6% of the local population breeding in the Balearic Islands is killed every year^{4,19,20}. For these species, bycatch by other gears appears to be far less relevant in the region^{15,16}.

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In the Mediterranean Sea, discards are estimated to be 18% of the catch (i.e. around 230,000 tonnes discarded annually), with trawlers being responsible for 15 to 65% of the discards¹⁸. Discard availability modifies the diet, foraging strategies and distribution of seabirds^{21–24}, with some species obtaining up to 75% of their energy needs from this resource^{25,13}.

To further complicate matters, interactions among different fisheries may lead to unexpected indirect effects on seabirds. Some recent studies in the Mediterranean provided evidence that the attendance of Scopoli's shearwaters to trawlers and longliners may depend on the relative activity schedules of these fleets^{26–28}. When trawlers do not operate, shearwaters may seek alternatives to discards, such as baits used by longline fisheries, with a consequent increase in the risk of being hooked^{27,28}. This possibility needs to be fully explored, since changes in fishery schedules or discard availability can occur at any time, and a proper management may minimize their negative impacts on seabird mortality. Indeed, the reform of the Common Fisheries Policy (CFP, <http://ec.europa.eu/fisheries/cfp/>) by the European Union (EU), among other measures, is implementing the elimination of discards through the so called *landing obligation*, with the aim of reducing the impact of fisheries on marine ecosystems. Therefore, there will be a gradual reduction in discards, from now to 2019, that could severely affect the Mediterranean seabird community, including the threatened shearwater species¹³. Thus, there is an urgent need to improve our understanding about the undesirable interactions among different fishery activities on seabird mortality.

To cast light on this problem, we studied the interaction between Scopoli's shearwater and fishing boats, and how different fishery schedules and vessel distribution patterns affect bycatch on the western Mediterranean Sea. Specifically, we used three different approaches: (1) individual GPS trajectories of Scopoli's shearwaters and Vessel Monitoring System (VMS) trajectories of fishing boats to study spatiotemporal dynamics, and establish whether vessel densities determine shearwaters choice between longliners and trawlers; (2) seabird counts on-board longliners to determine the main drivers influencing seabird attendance during longline settings, focusing particularly on the potential influence of trawler activity in the surrounding area; and (3) 13 complete years of bycatch data from one longline vessel to understand whether the rate of bycatch increases on days when trawlers do not operate.

Results

Spatiotemporal interactions. Overall, we tracked 65 shearwaters in two different years, 2010 and 2012, with 4 birds being tracked both years. We obtained trajectories from 90 GPS deployments, 30 trajectories corresponding to 38 foraging trips in 2010 and 60 trajectories corresponding to 145 foraging trips in 2012 (Fig. 1). Birds mainly foraged in the Catalan shelf and the Menorca channel, areas used by both trawlers and longliners (Fig. 1). We obtained 267 interaction events, where a bird followed a vessel, 246 interactions occurred with trawlers and 21 with pelagic longliners. From those, only 86 events corresponded to events in which at least one longliner and one trawler were fishing simultaneously in the same area (Fig. 1). From those interactions, 72 were with trawlers and 14 with longliners. Interactions with longliners mainly happened in the Menorca channel, close to the breeding areas, while interactions with trawlers happened both in the Catalan shelf and in the Menorca channel. We found no direct effect of the number of longliners in the area on the probability of interaction with either a trawler or a longliner. However, the probability of interacting with a longliner increased as the number of trawlers decreased ($P = 0.029$), from nearly 0% when 20 or more trawlers were in the area, to 40% probability of interaction when only 1 trawler was present (Fig. 2).

On-board censuses. We found that the number of attacks to the bait and the number of birds following a vessel was correlated ($r_s = 0.38$, $P = 0.004$). Since sample size for seabird attendance was greater than for bait attacks, we used seabird attendance as a proxy for bycatch risk on subsequent analyses, allowing us to study the ultimate factors that influence it. Analysis of relative importance showed that setting time was the main variable to account for shearwater presence and abundance behind longliners: shearwaters were more likely to occur in greater numbers at twilight (Tables 1 and 2). Bait type and longline type also had an important effect on bird attendance, birds being more likely to interact with longliners when they used mixed baits (fish and cephalopods, instead of only one of both) and when they targeted pelagic species (instead of demersal species) (Tables 1 and 2). The distance to the nearest breeding colony had a relatively high influence on shearwater abundance; the further away from colony areas the less likely it was to detect birds attending longliners (Tables 1 and 2). The number of hooks in each setting had a very low effect on the presence and abundance of birds attending longliners (Tables 1 and 2). The breeding stage of the birds (pre-laying, incubation or chick-rearing) and the meteorological conditions did not affect bird attendance to longliners (Tables 1 and 2). The probability of birds attending longliners increased 4% per each trawler leaving the longliner surroundings, but bird abundance was not affected by the number of trawlers (Tables 1 and 2).

Bycatch data. From 2003 to 2015, we collected all birds hooked in a longline boat from Vilanova i la Geltrú after arrival to the port. During this period, 67 Scopoli's shearwaters became entangled in the fishing gear and died. We found that the number of birds caught differed significantly among the days of the week; it was higher on Sundays and Mondays than on the remaining days ($\chi^2 = 17.63$, $p < 0.001$). In fact, 51% (34 individuals) of the birds were hooked on Sundays, when trawlers do not operate, and 28% (19 individuals) on Mondays, when longline vessels start operating before trawlers after the weekend rest. From Tuesday to Friday, only 14 birds were hooked across the 13 years covered. In addition, we found that the probability of a bycatch event (when one or several birds were hooked) followed the same pattern: events were more likely to occur on Sundays and on Mondays than on the rest of the week days (12 bycatch events occurred on a Sunday, 5 on a Monday and 6 from Tuesday to Friday; $\chi^2 = 4.9$, $p = 0.03$).

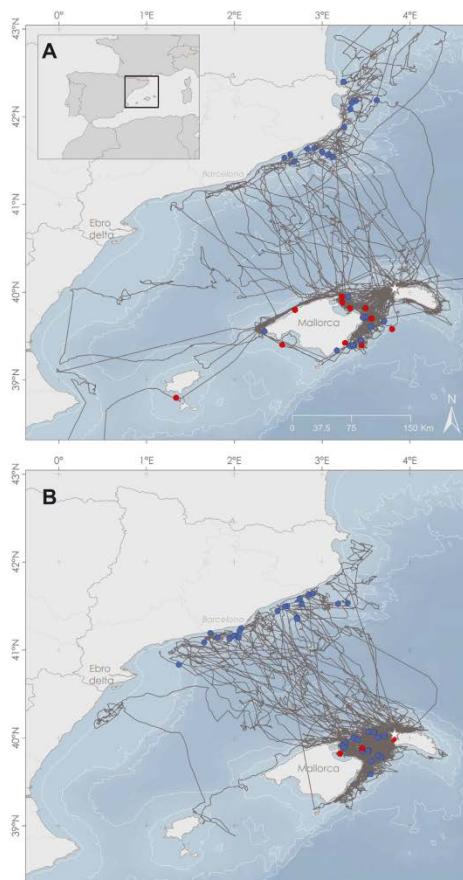


Figure 1. Shearwater GPS tracks (in grey) and concurrent interactions between shearwaters and fishing vessels (dots) inferred from the Vessel Monitoring System (VMS) in 2010 (A) and 2012 (B). Red dots correspond to interaction with longliners and blue dots to interactions with trawlers. Maps were generated with ArcGis version 10.3 (URL: <https://www.arcgis.com>).

Discussion

The concurrent analysis of GPS data from seabirds and vessels showed the importance of the spatiotemporal distribution of operating trawlers in determining the probability of seabirds interacting with longliners: the higher the density of trawlers, the less likely birds interacted with a longliner. On-board censuses of seabird attendance to longliners corroborated this result, showing that attendance, which can be taken as a proxy of bycatch risk, increased when trawlers were not operating in the longliner proximity. Finally, dead birds collected by fishermen showed that seabird catches were significantly and substantially greater on days when trawlers did not operate. Hence, results from these three different approaches point towards the same direction: seabird bycatch in longliners significantly increases when trawlers operate in low densities or do not operate.

In this regard, the reform of the CFP, which intends to substantially reduce or even eliminate fishery discards, might dramatically increase seabird bycatch risk, at least in the short term, by forcing seabirds to intensify their foraging efforts, including the search of an “easy meal”, i.e. switching from trawler discards to longline baits. Our results show that, at present, trawlers are acting as a buffer of the seabird interactions with longliners, such that the probability of shearwaters interacting with a longliner decreases from 40% when only one trawler is present in the area to almost 0% when >20 trawlers are present (Fig. 2). The same pattern applies to the on-board

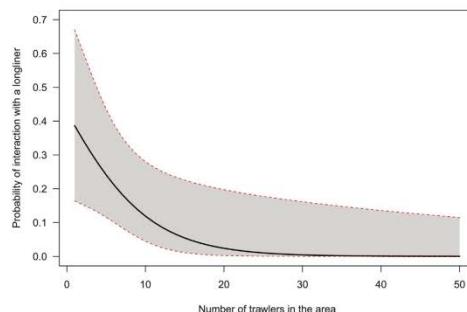


Figure 2. Probability of interaction between shearwaters and longliners as a function of the number of trawlers in the area. Black line represents the predicted values from the model and the grey area represents the 95% confidence intervals.

Variable	Value	Std. Error	RI
Presence - Zero part (Intercept)	-0.84	1.01	
Bait: Fish	1.75	1.11	0.93
Bait: Mixed	2.73	1.38	
LT: Pelagic	1.96	1.31	0.59
Time: Daytime	-1.39	0.79	0.90
Trawlers	-0.18	0.24	0.53
SDC	-0.27	0.45	0.42
Period: Incubation	0.11	0.47	0.35
Period: Prelaying	-0.41	0.74	
Wind: Windy	-0.07	0.34	0.24
SHS	0.02	0.16	0.24
<i>Abundance – Count part (Intercept)</i>			
LT: Pelagic	0.15	0.40	0.31
Time: Daytime	-0.53	0.46	0.76
Trawlers	-0.01	0.09	0.22
SDC	-0.15	0.19	0.55
Period: Incubation	0.01	0.07	0.05
Period: Prelaying	0.01	0.11	
Wind: Windy	-0.03	0.16	0.20
SHS	-0.08	0.14	0.39

Table 1. Coefficient, standard errors and relative importance (RI) of each variable for shearwaters attendance to longliners. See Table 2 for detailed explanation of the variables.

observations and bycatch rates. For each trawler leaving the surroundings of a longliner, the probability of seabirds following the longliner increases by 4%; and the rate of bycatch experiences a tenfold increase when trawlers do not operate. The reduction of discards is therefore likely to result in a substantial increase in bycatch rates of Scopoli's shearwaters, to a level that could be completely unsustainable for some western Mediterranean populations²⁹. Moreover, our results can reasonably be extrapolated to other seabird species targeting trawler discards in the Mediterranean which are also known to be caught in longlines, such as the Audouin's gull and the Yelkouan and Balearic shearwaters²³. The latter is of particular concern given its sensitive conservation status, since bycatch appears to account for almost half the adult mortality estimated for the species⁸.

Given the concern of bycatch for many Mediterranean seabirds, including the four endemic species, it is urgent to take into account this multi-fisheries interaction when designing fishing regulations, in order to minimise its potentially detrimental effect. As a first approach, our results suggest that precluding longline vessels (both demersal and pelagic) to set their lines when trawlers are not operating might substantially contribute to this aim. However, given that (trawling) discards will anyway be reduced in the short run, our results also call for an immediate enforcement of effective mitigation measures in longliners to reduce seabird bycatch. Since our results also point out that the strongest influence on seabird attendance to longliners was the time of setting, operational measures regulating the setting timing should contribute to minimise the problems. Indeed, seabirds were more prone to interact with longliners during sunset and sunrise. These results have also been observed in

Variable	Abbreviation	Type	Description
Breeding period	Period	Categorical	Pre-laying (March – 1st week June), incubation (until mid-July) or chick-rearing (until October)
Distance to colony	SDC	Continuous	Distance from the nearest colony (scaled km)
Wind	Wind	Categorical	Windy or still
Bait composition	Bait	Categorical	Fish, cephalopods or mixed (fish + cephalopods)
Setting time	Time	Categorical	1h ± of the twilight or rest of the daytime
Longline type	LT	Categorical	Demersal or pelagic
Hooks setting	SHS	Continuous	Number of hooks setting (scaled)
Number of trawlers	Trawlers	Continuous	Number of trawler within 6 km from the longliner
Longliner ID		Random	Boat identifier

Table 2. Explanatory variables used in the analyses of Scopoli's shearwaters interaction with longliners.

other studies which showed that many diurnal seabirds have activity peaks at dawn and dusk^{19,27,30}. Since most seabirds affected by longliners in the Mediterranean are basically diurnal, a promising mitigation measure to be applied in this region would be night setting, as previously suggested in other studies^{19,30–34}. This measure could be easily implemented at low economic costs, and compliance could be monitored and enforced to some extent through the control of fishing schedules of longliners by harbour authorities, as it is currently done for other types of fisheries. However, fishermen could be reluctant because it would require a rearrangement of their schedules and it could also limit the number of setting operations, particularly during the relatively short summer nights. Therefore, further work is needed to assess the efficacy and viability of this measure as well as of other mitigation measures that have proven successful in other regions. Among them, the use of tori-lines, the increase of sinking rates of the line through configuration changes, or a combination of the above, might also contribute to minimise seabird bycatch in Mediterranean longliners^{31,34–37}.

In conclusion, our study highlights the importance of combining various sources of information to achieve robust and complementary results on the complex effects of fishing activities on seabird bycatch. In particular, three different approaches indicated that the risk of a seabird to be captured in longlines increases dramatically when trawlers are not present in the area where longliners operate. That is, when trawlers stop providing discards seabirds may switch from trawlers to longliners, and therefore the landing obligation being implemented by the CFP must be carefully monitored and counterbalanced with the urgent implementation of mitigation measures. In a more general sense, our results point out that to determine the best management practices of the different fishing fleets, we need to study unexpected impacts rising from the interactions among different types of fisheries. Therefore, impacts of changes on the discard availability must be carefully evaluated and monitored across the different fleets to avoid catastrophic effects on seabird populations as well as on other components of the marine ecosystem.

Methods

Spatiotemporal interactions. To establish the spatiotemporal interaction between tracked birds and fisheries, we obtained data from two main sources: GPS devices for tracking shearwaters and the VMS for tracking vessels. GPS-tracking of Scopoli's shearwaters was conducted in Cala Morell (Menorca, Balearic Islands, Spain; 40°3'N, 3°52'E), in two different years. In 2010, birds were tracked during the incubation period, from the 18th June to the 8th July; and in 2012 during the chick rearing period, from the 25th July to the 20th September. This area holds the largest Scopoli's shearwater colony of the Balearic Islands, tentatively estimated in 1,000–6,000 pairs^{38,39}. Scopoli's shearwaters were captured at night by hand or using looped poles on the nest, when they flew back to the colony to feed their offspring or for incubation shifts. We used GPS loggers (Perthold Engineering LLC, weighing 20 g⁴⁰) sealed to be waterproof and programmed to record bird position each 2.5 or 5 minutes. Loggers were attached to the back of the birds using Tesa® tape⁴¹. At deployment, birds were ringed, sexed (through biometric measures) and weighed. In an attempt to minimise adverse effects on the birds, total mass of the device did not exceed 3% of the birds body mass⁴². At recovery, GPS devices were detached and birds were weighed. On average, we found a 25 g decrease on bird weight after tag retrieval (Paired t-test, $t = 4.4138$, $df = 83$, $p < 0.001$), that we do not expect to have relevant effects on the foraging behaviour of the birds⁴³. In 2010, we deployed 30 GPS tags in 25 individuals, whereas in 2012, 79 GPS loggers were deployed on 56 individuals. In order to minimise the possible impact of tagging birds on their breeding success, only one adult bird per nest was tagged. Birds carried loggers from 3 to 17 days before retrieval, recording from 1 to 9 foraging trips. These protocols were approved by *Servei de Protecció d'Espècies*, from the Balearic Islands Government. The methods were carried out in accordance with the relevant guidelines and bird handling and tagging protocols.

The Vessel Monitoring System (VMS) is a satellite-based monitoring system, implemented by the European Union, that provides data on the location, course and speed of fishing vessels over 12 m long⁴⁴. In the Spanish Mediterranean, 90% of trawlers and 60% of pelagic longliners use this localization system, although only a few demersal longliners and artisanal (polyvalent) vessels use it⁴⁵. The default frequency of VMS locations is one fix every two hours. Consequently, the spatiotemporal combination of VMS and GPS data was obscured by the uncertainty about the position of each vessel in the two hour gap between two consecutive locations. Taking into account this limitation, to cover the potential interactions between birds and vessels throughout the entire vessel trip, we identified all bird locations within a ± 1 h interval and within a 5 km buffer from a vessel location (as maximum speeds of vessels are around 5 km/h). Next, we applied a second filter selecting bird trajectories where

the bird bearing diverged in less than $\pm 30^\circ$ from the vessel bearing (estimated from consecutive locations). This bird bearing was considered the mean bearing for all locations inside each buffer of spatiotemporal coincidence. We chose $\pm 30^\circ$ because after some trials this angle emerged as the most biologically meaningful figure. For each bird–vessel interaction location, we assessed the number of vessels within a ± 1 h interval and a 30 km radius. We chose 30 km as it has been shown that some procellariforms can detect food resources up to 30 km away^{46,47}. We focused our research in two types of fisheries, trawling and pelagic longlining, since shearwaters tend to associate with them in search of food. Demersal longliners, including artisanal (polyvalent) vessels were excluded from this analysis, despite also attracting (and catching) seabirds, since most of them are too small to carry the VMS system (see above). Moreover, we only selected the interaction events where at least one trawler and one longliner were present in the area to control for the fisheries different regime and ensure that when birds interacted with a trawler they had also the option to interact with a longliner and vice versa.

We used a generalized linear mixed model that included year as a random effect, number of trawlers and number of longliners as fixed effects and a binomial response, either the bird interacted with a longliner or it interacted with a trawler. We calculated the AIC values of all candidate models and selected the model with the lowest AIC value as the best model for explaining bird interaction with fisheries.

On-board censuses. At-sea surveys were carried out during 3 consecutive years (2011–2013) covering the main fishing grounds of longline fisheries in the Catalan shelf and Balearic Islands, during the period where the species was present in the Mediterranean (March–October). The counts were conducted during 102 longline settings from 20 small-scale vessels operating in the NW Mediterranean (16 demersal and 4 pelagic longliners). Here we only considered the maximum number of Scopoli's shearwaters following the vessels at the end of each 10-min counts in each setting operation, as well as the number of attacks to the bait and the number of birds incidentally captured. The number of birds hooked (26 birds in nine events) was too low to perform reliable statistical analyses. Fishing habits, detailed description of fishing gear used and meteorological data were noted in each fishing trip (Table 2). The number of trawlers in a 6 km radius around the longliner was also recorded in each 10-min survey.

Bycatch events are relatively rare and patchy, thus being difficult to monitor through low-effort observer programmes. We evaluated seabird attendance to longliners as a proxy of seabird attacks, which are more closely related to seabird bycatch and therefore mortality. Generalized linear mixed models (GLMMs) were used to identify the main factors influencing Scopoli's shearwater interaction with longliners. Abundance data is characterized by having a high proportion of zero values and a skewed distribution of non-zero positive values caused by large counts of individuals (flocking behaviour)⁴⁸. Hurdle models are a suitable method for modelling this type of distributions, which is characterized by treating the data in two parts: (1) presence/absence of the species (Zero part) and (2) the abundance when the species is present (Count part)^{48–51}. We analysed the relationship between the number and presence of Scopoli's shearwaters and temporal, spatial and operational variables (Table 2). Trawler presence in the surrounding area was also considered to assess their influence on seabird attraction to longliners. Longliner identity was used as a random effect. We used "glimmADMB" function from the "glimmADMB" R package (R version 3.1.2). Zero hurdle part was modelled with the assumption of a binomial error structure (logit link function), while in the Count part a truncated version of the Negative Binomial distribution was considered (log link function). We checked collinearity between predictors and removed redundant ones. Then, we used the variance inflation factor (VIF) to verify the independence of each variable on the estimate of the regression coefficients of the model⁵².

Relative importance analysis was carried out with the model-averaging approach. This approach is useful when there is a large uncertainty about a set of models⁵³. In this way, we obtained model-averaged parameter estimates that were directly comparable to each other⁵³. We estimated the parameters from the set of all models for which the sum of Akaike weights reached >0.95 .

Bycatch records. From 2003 to 2015 fishermen from a single demersal longline vessel fishing off the Catalan coast recorded and handed over Scopoli's shearwater carcasses accidentally caught in their longline. To establish temporal bycatch patterns, we analysed whether the number of birds hooked and the number of capture events differed among the days of the week by using a Pearson's Chi-squared Test for Count Data with Bonferroni correction.

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Acknowledgements

We thank the *Conselleria d'Agricultura, Medi Ambient i Territori* of the *Govern de les Illes Balears* for permission and support in conducting fieldwork. We acknowledge the Fundacion Biodiversidad (18PCA4328; 20121964, FEP-FB), *Ministerio de Economía y Competitividad* and *Fondos FEDER* (CGL2009-11278/BOS, CGL2013-42585-P) for funding. SEO/BirdLife was supported by EC LIFE+ Project INDEMARES. We thank Eric Domínguez, Joan Ferrer, Lluïsa Ferrer, Pau Marqués, Blanca Pérez, Oriol Torres and David Torrens for carrying out on-board censuses and Robert Manzano, Helena Navalpotro, Marcel Gil and Santi Bateman for fieldwork assistance, and Rafael Triay for local assessment in Menorca. We also thank the *Fundación Biodiversidad* and the Secretaría General de Pesca (MAGRAMA) for providing VMS data and crews of fishing vessels that voluntarily collaborated in this project, especially La Cona C.B. crew for the bycatch data. We are grateful to Santi Álvarez-Fernández for technical support; to Jorge S. Gutiérrez and Stephen C. Votier for helpful suggestions on the drafts of the manuscript.

Author Contributions

A.S.R. collected and analysed the data and wrote the paper; V.C. collected and analysed data and made comments in the manuscript; J.M.R.G. and S.G. provided advice in analytic and ecological issues and logistic support throughout all the stages of the study and discussed drafts of the manuscript; J.B., B.R. and J.M.A. collected the data and made comments on the manuscript and J.G.S. conceived the study and wrote the paper.

Additional Information

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Soriano-Redondo, A. *et al.* Relative abundance and distribution of fisheries influence risk of seabird bycatch. *Sci. Rep.* **6**, 37373; doi: 10.1038/srep37373 (2016).

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