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Incidental mortality of seabirds in trawl fisheries: A global review

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ABSTRACT

Seabirds are amongst the most threatened taxa in the world, often due to incidental mortality (bycatch) in fisheries. Hundreds of thousands are thought to be killed worldwide in gillnets and longlines each year, but global mortality in trawl fisheries is unknown. Based on our comprehensive review, bycatch totals from cable strikes and net captures were available for only 25 fisheries. Bycatch rates were highly variable, precluding substitution from monitored to unmonitored fisheries to estimate bycatch totals, and total fishing effort was often unknown, which is also a prerequisite for scaling bycatch rates to estimate total birds killed. Ten, seven and one trawl fishery were known to catch of the order of 100s, 1000s and 10,000s of birds, respectively, and total bycatch from all monitored fisheries sums to ~44,000 birds per year. However, given the scale of cryptic mortality and the many unmonitored or poorly monitored fisheries, the actual global mortality in trawl fisheries will be much higher. The most bycaught species were albatrosses and large petrels (many of which are threatened) in the Southern Hemisphere, and gannets in the Northern Hemisphere. The few long-term studies indicated that mitigation measures (particularly strategic offal management and bird-scaring lines) were effective at reducing bycatch rates. Much improved regulations, and close monitoring of compliance and bycatch rates are essential for ensuring trawl fisheries do not continue to have major impacts on vulnerable seabird populations.

1. Introduction

Fisheries have profound impacts on marine ecosystems, removing a huge biomass of target and non-target species across vast areas of the world's oceans (Halpern et al., 2008; Lewison et al., 2014). Seabirds are amongst the vertebrate groups that are particularly affected by incidental mortality (bycatch), and also face other threats from fisheries including direct competition for the same resources, changes in community structure associated with discard provision, depletion of subsurface predator populations that would otherwise facilitate access to prey, ingestion or entanglement in lost fishing gear, and light-induced vessel strikes (Montevecchi, 2023; Votier et al., 2023). Mortality of seabirds in fisheries has major repercussions for marine ecosystems because of their key roles as predators and scavengers (Einoder, 2009), and their contribution to nutrient cycling both in marine ecosystems and in terrestrial environments where they nest and roost (Otero et al., 2018). Seabirds are declining at a greater rate, and include a higher proportion of threatened species, than terrestrial groups of birds (Croxall et al., 2012; Dias et al., 2019). In the most recent assessment, 31 % of seabird species were listed as globally threatened (Critically Endangered (CE), Endangered (EN) or Vulnerable (VU)), and another 11 % as Near Threatened (NT) on the Red List of the International Union for the Conservation of Nature (IUCN); the three main threats were invasive species at breeding sites, bycatch during fishing operations, and overfishing (Dias et al., 2019).

Seabirds have diverse foraging strategies and distributions, and many are very wide ranging, bringing them into contact with a multitude of fishing fleets and types of gear across national and international waters (Beal et al., 2021; Carneiro et al., 2020; Clay et al., 2019). Fishing intensity has increased in some fisheries within the last decade, as new technologies have been developed, increasing access to new regions and greater depths, and allowing longer storage of the catch without spoiling (Swartz et al., 2010). Seabirds are attracted to fishing vessels to feed on discards and offal, i.e., waste from processing, unwanted catch and used bait (González-Zevallos and Yorio, 2006; Jiménez et al., 2017). As a consequence, birds come into close proximity with fishing gear, putting them at risk of being caught on hooks or entangled in longlines, injured in collision with trawl cables and monitoring wires, or trapped in gillnets (Anderson et al., 2011; Phillips and Wood, 2020; Sullivan et al., 2006; Žydelis et al., 2013). With increasing demands for protein to feed a

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growing human population, it is essential that bycatch is addressed in order to protect seabirds and marine environments, and to move towards effective ecosystem-based management that also ensures sustainability (Halpern et al., 2008; Pauly et al., 2002).

There are published assessments of global bycatch in longline and gillnet fisheries of 160,000 seabirds and 400,000 seabirds, respectively, per year (Anderson et al., 2011; Žydelis et al., 2013). Such reviews greatly increase awareness of bycatch extent, both nationally and internationally, highlight knowledge gaps and provide a standard against which to measure progress in mitigating this major threat. Inaugural legislation in some longline fisheries was developed following the worldwide review of bycatch by Brothers et al. (1999), which pointed out dramatic declines in some seabird populations. This prompted several nations to undertake monitoring and mitigation research, and the Committee of Fisheries (COFI) of the United Nations (UN) Food and Agricultural Organisation (FAO) to develop the first 'International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries' (IPOA-Seabirds); this delegated the responsibility to countries to manage longline fisheries and address bycatch issues in their waters, determine the scale and extent of bycatch, and, if necessary, to develop a National Plan of Action (NPOA) (Good et al., 2020). Initially, management bodies focused on seabird bycatch in high seas driftnet and longline fisheries because the scale of the bycatch problem was much more evident, and it was not until 2009 that the FAO extended the IPOA to trawl fisheries through endorsing a set of 'Best Practice Technical Guidelines' (BPTG). Ecological risk assessments have also been developed for specific fisheries to consider their potential impacts on seabirds (Richard et al., 2017; Small et al., 2013; Tuck et al., 2011; Waugh et al., 2008; Waugh et al., 2012).

International agreements to conserve and protect wildlife that have aided seabird conservation efforts include the Convention on Migratory Species (CMS), and a daughter agreement, the Agreement on the Conservation of Albatrosses and Petrels (ACAP), ratified in 2004 (Phillips et al., 2016). ACAP focuses in particular on research and development of best-practice advice, including for mitigating and monitoring bycatch. The aim is to achieve a favourable conservation status for the listed species, and parties are legally bound to take appropriate conservation actions to attain this objective on a precautionary basis, i.e., if there are threats of 'serious' or 'irreversible' damage, lack of full scientific certainty shall not be used as a reason for postponing measures. Although concerns about seabird bycatch in the late 1990s and early 2000s focused on longlines and gillnets, a growing body of literature indicates bycatch may be of a similar magnitude in some trawl fisheries. Demersal (bottom) trawlers land approximately 19 million tons of fish and invertebrates annually, and the footprint of trawling varies across regions from <10 % to >50 % of the seabed in exclusive economic zones (EEZs) (Amoroso et al., 2018). Despite early estimates indicating that trawling potentially accounts for up to 45 % of all seabird bycatch (Baker et al., 2007), and growing awareness of the potential impacts, there is a paucity of information on seabird interactions in these fisheries at a global scale. Estimation of seabird bycatch in trawl fisheries is particularly challenging because of cryptic mortality. This is mortality that is largely unobservable and can be considered to include all birds killed or seriously injured in interactions with fishing gear that are not landed or counted (Bartle, 1991; Melvin et al., 2011; Richard et al., 2017; Tamini et al., 2015). In addition, trawl fisheries are diverse in terms of types of vessel, fishing gear and other operational practices, which affect seabird bycatch rates. Competition for food off the stern of trawlers attracts seabirds to an area of increased risk, where mortalities and injuries can result from entanglement in the net or collision with trawl cables, paravanes or monitoring wires (also termed third wires or net sonde cables); the latter can lead to birds being dragged under the water due to the force of the moving vessel, or caught in cable splices (Adasme et al., 2019; González-Zevallos et al., 2007; Pierre et al., 2012; Sullivan et al., 2006; Tamini et al., 2023; Tamini et al., 2015; Watkins et al., 2008; Weimerskirch et al., 2000).

There is still no global estimate of seabird bycatch in trawl fisheries, despite its value for highlighting the scale of this threat, identifying the contributing factors and data gaps, and for assessing the effectiveness of changes to regulations or governance. We carried out a comprehensive review of the literature on seabird bycatch rates and totals with the following aims: (i) to estimate a global total, (ii) a gap analysis to identify trawl fisheries for which the total seabird bycatch has not been estimated because monitoring of net captures or cable strikes is inadequate, (iii) to identify the seabird families and species that are most susceptible to bycatch in trawl fisheries in different regions, and (iv) to compare bycatch totals or fishery-wide bycatch rates before and after the introduction of mitigation to illustrate the benefits of effective implementation. The results are discussed in the context of suggesting avenues for further research.

2. Materials and methods

2.1. Literature search and bycatch estimation

We reviewed the peer-reviewed scientific literature, published and unpublished reports, and technical memoranda for studies of seabird bycatch totals in trawl fisheries, from which we extracted the operational area, type of fishery, depth (demersal, pelagic or semi-pelagic), type of vessel, target species, fishing effort, observer coverage, observed mortality, bycatch rate, annual bycatch total and confidence interval, and period. This included searches for "trawl" and "bird or petrel or albatross or fulmar or shearwater or gannet or gull or tern or skua or penguin or cormorant" in Web of Science and using the Advanced search option in Google Scholar. We also contacted 23 regional experts to request further information and any unpublished or updated data on seabird bycatch rates or fishing effort. Studies were included in the primary table in this review if they reported, or provided sufficient information to estimate total seabird mortality in the relevant fishery from both cable strikes and net captures, or if net mortality was very high (>500 birds) even if the warp-strike observation rate was very low or nil. The level of observer coverage was highly variable across fleets, as were the approaches used to record seabird bycatch: depending on the study, this was the total number of birds caught in the net, or the sum of net captures and estimated mortality caused by collisions with cables, the latter including just the birds considered to have been seriously injured or drowned but not the other heavy strikes, all the heavy strikes, or all strikes (heavy and light) assuming a proportion were fatal. Some datasets were generated from voluntary reports or logbooks, which may greatly underestimate bycatch rates compared with dedicated, independent seabird observers (Bugoni et al., 2008). One study included a very high cryptic mortality multiplier (8.02), based on modelled ratios in New Zealand trawl fisheries between total fatalities and total net captures or observed warp strikes (Richard and Adasme, 2019); however, as the resulting estimate of total bycatch was anomalously high (66,447 birds), we have not compared this with bycatch rates in other fisheries or included it in our estimate of global trawl bycatch from monitored fisheries.

Where possible, the most recent data on seabird bycatch rates are presented in the results as birds per unit effort (BPUE), which is the number of assumed mortalities per trawling hour. Reported fishing effort was not consistent across fisheries and may have been the number of hauls.yr^{-1}, fishing days.yr^{-1}; or tonnes of fish caught.yr^{-1}. If the details were included in the source study or available elsewhere, we calculated the number of hours trawled.yr^{-1} using information on the season length, number of vessels in a fleet, total trawl duration and number of hauls per day. We report the confidence intervals (95 % CI) if provided (8 studies). The reported coefficient of variation (CV) from one study was also included, but not used to determine the bycatch range. If bycatch data were available from several years, we report the average number of seabirds caught each year. We present the most recent available data in fisheries where there has been a clear change in operational practice to mitigate bycatch.

In two cases, the seabird bycatch totals were not presented in the original study but were estimated from the fishing effort per year and BPUE (Tamini et al., 2021), or information in the paper on the number of vessels in the fishery, mean number of days of operation per year and the number of birds bycaught per day (Favero et al., 2011). As we could not account for potentially major seasonal, spatial and operational variation in seabird bycatch rates in our extrapolations, we have not calculated an associated error and so these two values should be treated with extreme caution. We summed all available estimates of annual mortality for the different fleets to estimate the minimum global seabird mortality for all monitored trawl fisheries included in our review. We have not calculated a confidence interval for this total because the variance depends on the variance associated with the value from each study, which was often missing, and also because this is not a true minimum for global seabird bycatch because of the many unmonitored fisheries (see below).

2.2. Gap analysis

We conducted a gap analysis by searching the literature for trawl fisheries for which the total seabird bycatch could not be estimated because monitoring of net captures or cable strikes was inadequate. This included information in Fishery Improvement Projects (FIP) available for fisheries seeking certification by the Marine Stewardship Council (MSC), and other published and unpublished literature and datasets that provided details on trawl effort or fleet size, and gear type. The review excluded mid-latitude, small scale 'shrimp' fisheries because of the slow speed of trawling, steep angle of trawl cables and lack of published evidence that these represent a mortality risk to seabirds (Barnes et al., 2021).

2.3. Bycatch species composition

In order to identify the seabird families and species that are most susceptible in different regions, we extracted the most recent available data on species composition of seabird bycatch. We only report the proportions of each species for fisheries where the total annual bycatch has been estimated, as otherwise there would be a bias towards species that are more likely to be caught in nets rather than injured in collisions with warp or monitoring cables. This considered the IUCN Red List category and global population size and trend of each seabird species, available from the Birdlife International Data Zone (BirdLife International, 2024).

2.4. Fishery-wide bycatch totals before and after mitigation

Finally, we report changes in annual bycatch totals or fishery-wide bycatch rates before and after the introduction of mitigation in particular fisheries. As there are existing reviews of the effectiveness of different mitigation methods (Agreement on the Conservation of Albatrosses and Petrels, 2023; Bull, 2007, 2009), we did not include comparisons of seabird bycatch rates in mitigation trials, as these may not represent the conditions or operations for the rest of the fleet, or even if they did, the bycatch total could not be calculated because information was missing on total fishing effort.

3. Results

3.1. Bycatch estimates

Bycatch totals from both cable strikes and net captures were available for 25 fisheries, and from very high levels of net captures in a further two fisheries (Table 1; Fig. 1). The way that seabird bycatch was recorded varied extensively amongst fisheries, particularly whether rates were based on observed mortality or serious injury, heavy or light collisions with trawl warp and monitoring cables (see Appendix A for accounts of individual fisheries). The only two fisheries in which the bycatch totals and rates were based on a cryptic mortality multiplier were in the Falklands. Mean or median bycatch rates (BPUE) were highly variable across fleets, with the sum of net captures and warp strikes in Southern Hemisphere fisheries ranging from 0.003 to 0.88 birds per trawl hour, with an overall median of 0.25 birds per trawl hour across all fisheries (Table 1). Estimates of total seabird bycatch were available for 17 fisheries in the Southern Hemisphere and 10 fisheries in the Northern Hemisphere (Fig. 1). Based on these data it appears that >20 times as many birds in total (~42,260 vs. ~1940 birds) are killed in fisheries in the Southern Hemisphere. However, this may largely reflect the much poorer level of monitoring in the Northern Hemisphere, which also precludes a comparison of BPUE.

Based on the data presented here, ten, seven and one trawl fisheries are known or likely to have annual bycatch rates of the order of 100s, 1000s and 10,000s of birds, respectively, summing to a total of ~44,000 birds known to be killed in monitored trawl fisheries.

3.2. Gap analysis

In the gap analysis, we identified 16 fisheries in the Southern or Northern Hemisphere, including several that were very high effort, in which seabird interactions were likely to be an issue but for which there were no publicly available data on bycatch rates, or data were available from net captures and monitoring of warp strikes was limited or non-existent (Table 2). In the Northern Hemisphere, these were in the EEZs of Asia, Europe and adjacent High Seas, and in the Southern Hemisphere included Australia, southern Africa and the High Seas. In many cases, information was not publicly available on fishing effort. If seabird bycatch rates in these unobserved fisheries were similar to those in observed fisheries with limited mitigation, additional mortality could involve tens of thousands of seabirds each year.

3.3. Bycatch susceptibility by species

In most fisheries in the Southern Hemisphere and some in the Northern Hemisphere for which there was an estimate of total annual bycatch, there was information on which species were bycaught, and usually the estimated number of each species killed per year. There were also some fisheries in which the bycaught species but not the relative numbers were known. In total, 21 different species from 7 families were reported as bycatch in Northern Hemisphere fisheries (Tables A1 and A2). These included seven species listed by IUCN as Near-threatened, Leach's Storm Petrel (*Hydrobates leucorhous*) and Pink-footed Shearwater (*Ardenna creatopus*) as Vulnerable, and Balearic Shearwater (*Puffinus mauretanicus*) as Critically Endangered. Quantitative data were only available for fisheries in Scotland (but from 2001), and from the east and west coasts of the US, but on this basis the species captured by far the most frequently (84.1 % of total $n = 1067$) was Northern Gannet (*Morus bassanus*) (Fig. 2).

Bycatch species composition was much better known in the Southern Hemisphere, and included considerably more species (37 in total); these were also from 7 families, including albatrosses (Diomedeidae, 13 species), petrels and shearwaters (Procellariidae, 16 species), and also a penguin (Spheniscidae) and a skua (Stercorariidae) (Tables A1 and A2). Eight species were listed as Near-threatened, eight as Vulnerable (Wandering Albatross *Diomedea exulans*, Southern Royal Albatross *Diomedea epomophora*, Salvin's Albatross *Thalassarche salvini*, Chatham Albatross *Thalassarche eremita*, White-chinned Petrel *Procellaria aequinoctialis*, Pink-footed Shearwater, Flesh-footed Shearwater *Ardenna carneipes* and Black Petrel *Procellaria parkinsoni*) and six as Endangered (Northern Royal Albatross *Diomedea sanfordi*, Grey-headed Albatross *Thalassarche chrysostoma*, Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos*, Indian Yellow-nosed Albatross *Thalassarche carteri*, Westland Petrel *Procellaria westlandica* and Cape Gannet *Morus capensis*). A considerably higher proportion of bycaught species in the Southern

Table 1
Estimated seabird mortality associated with trawl fisheries, worldwide. Annual mortality includes net captures and heavy warp strikes, except for two studies that were of net captures only (indicated by square brackets and a superscript). Shaded cells indicate extrapolations as part of this review (see Methods). BPUE – birds killed per trawling hour. Fishery type - D: Demersal; P: Pelagic. Target Species: An: Argentine Anchovy (*Engraulis anchoita*); At: Atka Mackerel (*Pleurogrammus monopterygius*); Ba: Sea Bass (*Dicentrarchus labrax*); Co: Cod (Gadidae); Cr: Cornalito (*Sorgentinia incisa*); Fl: Arrowtooth Flounder (*Atheresthes Stoma*); Fn: Finfish; Gf: Groundfish; H: Hake (Merlucciidae); Hb: Halibut (*H. stenolepis*); He: Herring (*Clupea harengus*); Ho: Hoki (*Macruronus magellanicus*); *Illex* squid (*Illex argentinus*); Ki: Kingclip (*Genypterus blacodes*); Kr: Antarctic Krill (*Euphausia superba*); Ma: Mackerel (Scombridae); Po: Pollock (*Pollachius*); Ro: Roughy (*Trachichthyide*); Rf: Rockfish (*Sebastes*); Sc: Patagonian Scallop (*Zygochlamys patagonica*); Sh: Shrimp (*Pleoticus muelleri*); So: Sole (Soleidae); Sp: Sprat (*Sprattus*); Sq: Squid (Cephalopoda); To: Patagonian Toothfish (*Dissostichus eleginoides*); Wh: Southern Blue Whiting (*Micromesistius australis*).

Country	Region	Trawl fishery type	Demersal/ Pelagic	Fleets	Target Species	Fishing Effort /year	Obs. effort	Obs. Mort	Mean BPUE	Annual Mortality	95 % CIs / CV	Bycatch data period	Source
Argentina	South-west Atlantic	Argentine Hake Fishery: Side and Stern Haulers	D	Ice-trawl	Ha, Illex Sq, Ki, Ho		0.40 %	10	0.017	1985		2006–2007	(Favero et al., 2011)
Argentina	South-west Atlantic	Industrial Argentine Hake Fleet	D	Freezer	Ha, Ki		2 %	53		2703	CV = 0.8	Dec 2004 – April 2005	(González-Zevallos et al., 2007)
Argentina	South-west Atlantic	Demersal Argentine Hake	D	Stern factory	Ha, Ki	57,188 h	0.4 %	36	0.33	19,090		2008–2010	(Tamini et al., 2015)
Argentina	South-west Atlantic	Argentine Anchovy	P		An	1824 hauls	8.3 %	121	0.55	382-1658[c]		2011–2013	(Paz et al., 2018)
Argentina	South-west Atlantic	Argentine Inshore Red Shrimp Fishery	D	Small inshore	Sh	15,232 hauls	21 %	12	0.003	58		2006–2008	(Marinao and Yorio, 2011)
Argentina	South-west Atlantic	Argentine Hoki fishery	D & P	Stern Factory	Ho, Wh, To	10,210 h	7.3 %	294	0.21	979	322–1806	2012–2019	(Tamini et al., 2023)
Argentina	South-west Atlantic	Industrial Argentine Hake Fleet	D	Side-haul ice-trawler	Ha, Sh, Ki, An	2752 h	5 %	30	0.133	366		2008–2015	(Tamini et al., 2021)
Argentina	South-west Atlantic	Cornalito	P	Inshore	Cr	94.5 hauls		9		99		1998	(Tamini et al., 2002)
Chile	South-east Pacific	Industrial demersal trawl for South Pacific hake	D	Ice-trawl	Ha	296.9 hauls	66.7 %		0.246	890	438–1418	2011–2012	(Suazo et al., 2014); Suazo pers. comm.
Chile	South-east Pacific	Austral Hake, Industrial demersal	D & P	Ice-factory, Surimi & Fresher	Ha, Wh, Ho	9460 h	33–58.5 %	7742	0.06–1.7	8340[d]	8020 – 8650[f]	2013–2016	(Richard and Adasme, 2019)
Falkland Islands		Bentho-pelagic and demersal finfish	D	Factory	Ha, Fin, Sq	23,769 h	2.6 %	5	0.01[a], 0.02[b]	572[e]		July 2021–June 2022	(Falkland Islands Government, 2023, Falkland Islands Government unpublished data)
Falkland Islands		Patagonian Squid	D	Factory	Sq	29,409 h	99 %	101	0.17[f]	303[e]		July 2021–June 2022	(Falkland Islands Government, 2023, Falkland Islands Government unpublished data)
Namibia	South-east Atlantic	Namibia hake	D	Wet fish & freezer	Ha		0.5 %	3		1452	0–3865	2017	(Da Rocha et al., 2021)
New Zealand	South-west Pacific	All	D & P	Factory (>28 m)	Gf	22,641 hauls	48.6 %	338		538	483–600	2020/21	(Ministry for Primary Industries, 2024)
New Zealand	South-west Pacific	All	D & P	Small inshore		41,873 hauls	5.1 %	29		657	533–805	2020/21	(Ministry for Primary Industries, 2024)

(*continued on next page*)

Table 1 (*continued*)

Country	Region	Trawl fishery type	Demersal/ Pelagic	Fleets	Target Species	Fishing Effort /year	Obs. effort	Obs. Mort	Mean BPUE	Annual Mortality	95 % CIs / CV	Bycatch data period	Source
South Africa	South-east Atlantic	Deep-sea	D	Wet fish & freezer	Pa. Ha, Ca. Ha			41	0.56	990	556–1633	2010	(Maree et al., 2014)
Scotland	North Sea, Scotland	Pelagic	P	Wet fish & freezer	Ma, He, Ar				[0.33][c]	[700][c]		2001	(Pierce et al., 2002)
Uruguay	South-west Atlantic	Hake	D	Freezer and fresh	Ha		1.05 %	53	0.49	236/4193[f]	88–284 / 3323-4726[f]	2019	(Jiménez et al., 2022)
USA Alaska	North-east Pacific	Federal Groundfish Fishery	P	Catcher-processer and catcher	Fl. At, Co, Po, So, Rf,	359,550–378,214 h				[827][c]		2011–2021	(Suryan et al., 2007; Tide and Eich, 2022)
USA West Coast	North-east Pacific	Ridgeback Prawn	D & P	Otter	Sh					48		2017–2018	(Jannot et al., 2021)
USA West Coast	North-east Pacific	Hake	P	Catcher processor	Ha		100 %			66		2013–2018	(Jannot et al., 2021)
USA West Coast	North-east Pacific	At-Sea Hake	P	Catcher	Ha		100 %			1		2013–2018	(Jannot et al., 2021)
USA West Coast	North-east Pacific	Limited Entry & Catch Share	D & P		Gf					2		2013–2017	(Jannot et al., 2021)
USA West Coast	North-east Pacific	Open Access (OA) Californian Halibut	D		Hb					21		2013–2018	(Jannot et al., 2021)
USA West Coast	North-east Pacific	OA Pink Shrimp	D		Sh					31		2013–2018	(Jannot et al., 2021)
USA East Coast	Atlantic	All	P	Paired midwater				15		94	75–104	1996–2014	(Hatch, 2018)
USA East Coast	Atlantic	All	D	Otter				10		146	114–181	1996–2014	(Hatch, 2018)

[a] Collisions with warp cables.
[b] Net entanglements.
[c] Net captures only (warp-strike observation rate very low or nil).
[d] Estimate is 66,500 seabirds (credible interval 45,800-88,300) using cryptic mortality multiplier of 8.02, which is much higher than in other studies.
[e] Incorporates cryptic mortality multiplier (assumption that 1 in 3 contacts scored as possible minor injury resulted in mortality).
[f] Modelled scenarios with/without bird scaring lines as there is no estimate of mortality.

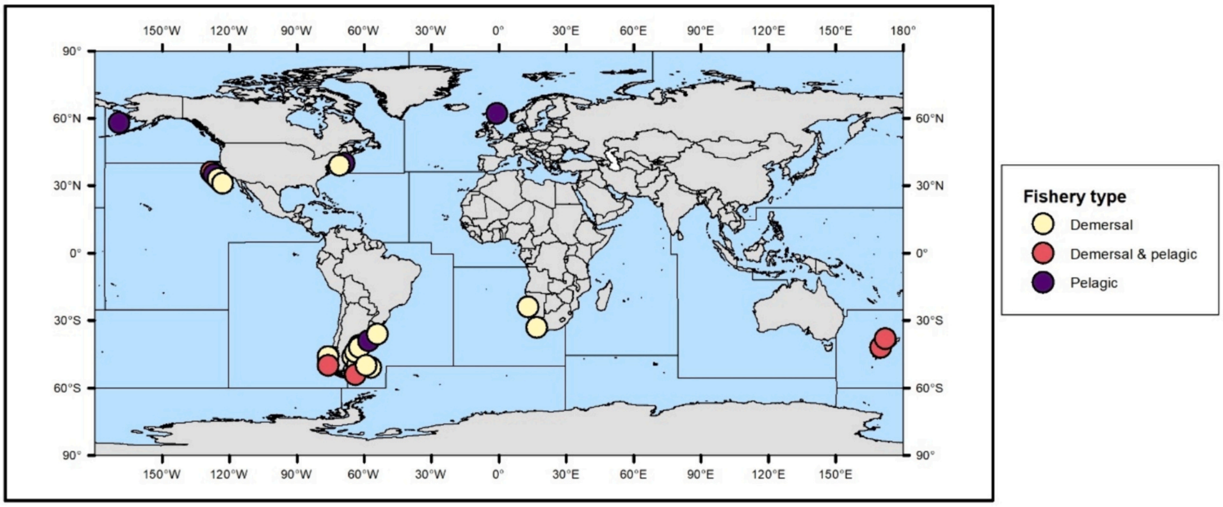

Fig. 1. Availability of data on estimated total seabird bycatch in different trawl fisheries in FAO Major Fishing Areas.

Table 2
Trawl fisheries lacking reliable estimates of total seabird bycatch. NEAFC: North East Atlantic Fisheries Commission. MSC: Marine Stewardship Council. [a]Data available from logbooks on seabird captures in nets, but limited or no monitoring of warp strikes.

Fishery	Region	Demersal/ Pelagic	Fleet; Target Species	Fishing Effort (year)	Sources
Australia	EEZ	D & P	Southern and Eastern Scalefish and Shark Fishery (SESSF)[a]	17,199 t	(Butler et al., 2023)
Canada	Newfoundland and Labrador; Maritime and Gulf of St Lawrence	D & P	Bottom and mid-water[a]		(Ellis et al., 2013; Hedd et al., 2016)
CCAMLR	Southern Ocean	P	Antarctic Krill[a]	415,508 t (2022)	(CCAMLR Secretariat, 2023b)
CCAMLR	Southern Ocean		Heard Island and McDonald Island (HIMI), Mackerel Icefish	1024 (2022)	(CCAMLR Secretariat, 2023a)
NEAFC	Celtic Sea	P & D		1574	(ICES, 2021)
NEAFC	North Sea	P & D		3152 days	(ICES, 2021)
NEAFC	North Sea	D		1832 days	(ICES, 2021)
South Africa	South-east Atlantic	P	Inshore shallow- water; Cape Hake, Agulhas Sole	18,556 hauls	(Attwood et al., 2011)
Namibia	South-east Atlantic	P	Midwater	22 vessels, 387 trips	Da Rocha pers. comm.
Namibia	South-east Atlantic	D	Monkfish, Sole	19 vessels, 214 trips	Da Rocha pers. comm
Russia	Sea of Okhotsk	P	Mid-Water; Walleye Pollock	144,132 t	(Marine Stewardship Council, 2021)
Russia	North-east Atlantic	D	Otter; Cod, Haddock, Saithe	40,903 t	(Marine Stewardship Council, 2019)
Korea	Yellow Sea	D	Large offshore (pair trawl); Largehead Hairtail, Flounders, Croakers		(Park et al., 2016)
Korea	East, Yellow and South Sea	D	Offshore Medium; Flounders, Blackmouth Goosefish, Croakers, Shrimps, Cuttlefish		(Park et al., 2016)
Korea	South Sea				(Park et al., 2016)
UK	EEZ	P	Bass and mid-water[a]		(Northridge et al., 2020)

Hemisphere than in the Northern Hemisphere (38 % vs. 14 %) were listed as Vulnerable or a higher threat category. Across the Southern Ocean, species estimated to be caught in their thousands were, in order and as a percentage of the total, Black-browed Albatross *Thalassarche melanophris* (23,176 birds, 68 %), Southern Giant Petrel *Macronectes giganteus* (2812 birds, 8 %), Northern Giant Petrel *Macronectes halli* (1941 birds, 5 %), Magellanic Penguin *Spheniscus magellanicus* (1427 birds, 4 %) and Cape Petrel *Daption capense* (1305 birds, 4 %), and in their hundreds were five albatross and three petrel or shearwater species, Kelp gull *Larus dominicanus* and Imperial Shag *Leucocarbo atriceps* (Table A2, Fig. 2).

3.4. Bycatch estimates in fisheries before and after mitigation

Annual bycatch totals reported for several fisheries were substantially lower following the introduction of effective mitigation. These reductions were: from 9300 to 990 birds in the South African wet fish and freezer fleets, associated with use of bird-scaring lines and halving of fishing effort (Maree et al., 2014); from 7030 birds in 2009 to 1452 birds in 2017 in the Namibian demersal trawl for hake, associated with a requirement to use bird-scaring lines, and practical bycatch-mitigation training (Da Rocha et al., 2021); from ~2900 birds in 2002/03 to ~1500 birds in 2019/20 by trawlers in the New Zealand EEZ, including a reduction in the warp strike rate from 2.9 birds per 100 tows in 2003–2006, to 0.7 birds per 100 tows after 2007 in the New Zealand squid trawl fishery, which resulted from a range of technical, operational and legislative changes including offal management and use of bird-scaring lines, and a reduction in fishing effort (Ministry for Primary Industries, 2024; Reid et al., 2023), and; from 1529 birds in 2002/03 to 572 birds (including cryptic mortality) in 2021/22 in the finfish

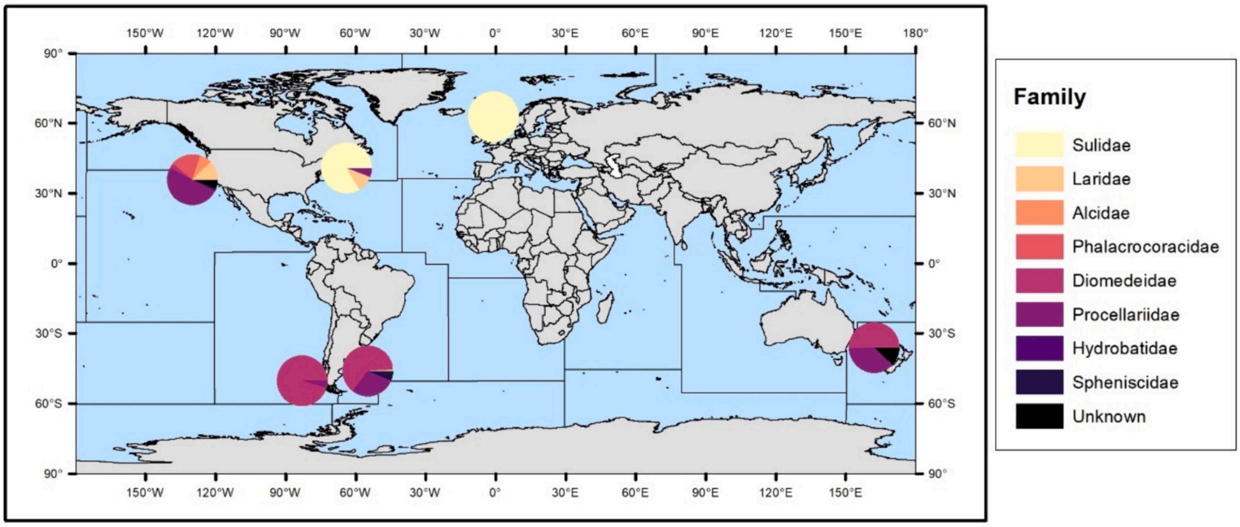

Fig. 2. Seabird bycatch composition by family in monitored trawl fisheries in FAO Major Fishing Areas.

fishery around the Falklands, associated with use of bird-scaring lines, improved discard management and net binding (Falkland Islands Government, 2023; Sullivan et al., 2006).

4. Discussion

4.1. Bycatch estimates and species composition

Our review highlighted the substantial variation in bycatch rates amongst fisheries (Table 1). In many fisheries there are major seasonal changes in seabird bycatch rates, related to the number of birds in attendance behind vessels and species composition (Adasme et al., 2019; Favero et al., 2011; Hatch, 2018). Most seabirds are wide ranging and carry out long migrations, so these changes result from the varying degree of central-place constraint - which limits foraging distances - across breeding stages, and from the breeding to nonbreeding seasons (Carneiro et al., 2020; Clay et al., 2019). In some fisheries, bycatch rates may also increase seasonally in association with influxes of large numbers of juvenile seabirds after fledging (Frankish et al., 2021; Frankish et al., 2020). Only two of the bycatch totals in monitored fisheries accounted for cryptic mortality, even though the vast majority of birds killed or injured in collisions with cables are not recovered (Watkins et al., 2008). Recent studies have tried to assess the scale of cryptic seabird mortality associated with particular processes in fisheries, including warp and third-wire strikes, loss of carcasses from longline hooks, and birds caught and released alive that later die from their injuries (Phillips and Wood, 2020; Richard et al., 2017; Zhou et al., 2020). Ideally, fisheries-specific and, better still, species-specific scalars would be used that account for unobserved events to generate more realistic bycatch totals for trawl fisheries, but this is likely to remain a challenging and contentious area.

The monitoring protocol and format of the reported bycatch data were very variable. Depending on the study, there was information on numbers of birds killed or injured by different gear components (net entanglements, collisions with the net monitoring or warp cables), the location (on the water or in flight), timing of the interaction (during setting, towing and haul back), severity of the cable strike (heavy or light), and season. In the review, we followed the conclusions of the authors of each study in terms of whether a collision was considered to be sufficient to cause serious injury or mortality and therefore be counted as bycatch. Given the high variability in bycatch rates related to operational practices, scavenging-species composition, season, use of mitigation etc., and the advice of experts that were contacted as part of this review, we deemed it inappropriate to make data substitutions for unmonitored fisheries. Regardless, based on the most recent data available, at least ~44,000 birds are killed per year by monitored fleets (Table 1). However, this is inevitably a major underestimate of the real global total for two reasons. Firstly, only two of the fisheries-specific values in Table 1 took account of cryptic (unobserved) mortality. Secondly, it was not possible to estimate seabird bycatch by unmonitored fleets, which together sum to much higher fishing effort than those for which bycatch totals are available. Amoroso et al. (2018) estimated the bottom trawl footprint on the world's continental shelves was 3848 × 10^3 t y^{-1}, of which 939 × 10^3 t y^{-1} (i.e., ~24 %) was taken in five regions (North Benguela Current, South Benguela Current, East Agulhas Current, Argentina and South Chile) for which the minimum annual seabird bycatch is ~37,000 birds in the demersal, or demersal/pelagic fisheries in Table 1. There is no comparable regional study of pelagic trawling, but, globally the landings total ~ 40–50 % of those from demersal trawling since 2000 (Cashion et al., 2018; Watson and Tidd, 2018). The extensive variability in bycatch rates preclude substitution from monitored to unmonitored fisheries and therefore development of a mathematical model to scale observed seabird bycatch to a global total from these landings ratios would be extremely challenging, particularly as a major portion of global trawl effort is in mid-latitude inshore fisheries where few birds are killed (Barnes et al., 2021). Nevertheless, given the scale of both cryptic mortality and unobserved fishing effort at higher latitudes, the actual global mortality in trawl fisheries will be much higher than the total of ~44,000 birds in monitored fisheries. This compares with global estimates for longline and gillnet fisheries of 160,000 and 400,000 birds, respectively (Anderson et al., 2011; Žydelis et al., 2013).

Total bycatch of seabirds in trawl fisheries appears to be considerably lower in the Northern Hemisphere, as the main trawl fisheries where seabird bycatch is known or likely to be high are over the continental shelves around Australia, New Zealand, South America and southern Africa, where the species most susceptible to injury in trawl fisheries – albatrosses and large petrels – are highly abundant (Carneiro et al., 2020; Clay et al., 2019). Bycatch rates in some of these fisheries have reduced substantially since the early 2000s because of improved regulation (Da Rocha et al., 2021; Maree et al., 2014; Ministry for Primary Industries, 2024). However, population sizes of albatrosses and petrels in the Southern Hemisphere continue to decline because they are bycaught by other trawl fleets and in other types of fisheries (Phillips et al., 2016). Over 50 species were recorded as bycatch, but by far the highest rates were for the larger bodied species (albatrosses, giant, Cape and *Procellaria* petrels, and shearwaters; Tables A1 and A2). Factors that increase the mortality risk for these species are their long foraging ranges during breeding, and even wider distributions during the nonbreeding period, so many populations overlap with multiple fisheries and jurisdictions (Beal et al., 2021; Carneiro et al., 2020; Clay et al., 2019). The albatrosses forage at the sea surface with outstretched wings, a behaviour which exacerbates interactions with trawl cables, and have a competitive advantage in accessing discards related to a dominance hierarchy over smaller species such as gulls and skuas, for which bycatch rates were much lower (Tables A1 and A2). Bycatch rates of *Procellaria* petrels are high because they are active not only in daylight but also at night, particularly if there is moonlight (Mackley et al., 2011). As such, they feed in large numbers behind fishing vessels if there is moonlight or deck lighting at night (Jiménez et al., 2020; Petersen et al., 2009).

Estimated seabird bycatch in South American fisheries formed a high proportion of the global total for monitored fisheries. However, this partly reflects wider monitoring, greater transparency, and acknowledgement of the need to better understand and address the problem of seabird bycatch. There are large seabird breeding populations in the region, and the waters attract numerous migrant seabirds from elsewhere (Beal et al., 2021). The predominant species reported as bycatch in South American waters was the Black-browed Albatross (Adasme et al., 2019; Marinao and Yorio, 2011; Paz et al., 2018; Tamini et al., 2015). This is listed globally as Least Concern, although the population at South Georgia is in steep decline (Poncet et al., 2017). Several species listed as Vulnerable or Endangered are also killed in trawl fisheries in this region (Adasme et al., 2019; Paz et al., 2018; Richard and Adasme, 2019; Tamini et al., 2021), some of which are mainly or entirely from breeding populations at South Georgia, all of which are decreasing (Berrow et al., 2000; Poncet et al., 2017).

There is compelling evidence that use of mitigation can greatly reduce fleet-wide bycatch rates of seabirds (Section 3.4). However, it is worth noting that a substantial reduction in fishing effort was also a contributing factor in some cases (Maree et al., 2014). Although use of streamer lines and practical training reduced seabird mortality in trawl fisheries off Namibia, a proportionally greater percentage reduction for the longline fleet in the same area (Da Rocha et al., 2021) emphasises the greater operational and enforcement challenges in trawl fisheries. Indeed, progress in reducing bycatch by the trawl fisheries around the Falklands and New Zealand was achieved by closer monitoring and tighter legislation, as well as the technical and operational changes (Falkland Islands Government, 2023; Ministry for Primary Industries, 2024; Reid et al., 2023).

By comparison, there were relatively few studies of bycatch in trawl fisheries in the Northern Hemisphere, and clear knowledge gaps exist for fisheries in European and Asian waters (Table 2). Albatrosses are greatly outnumbered in continental waters of the northeast Pacific, and the abundant, smaller taxa have much greater opportunities to dive for discards and offal, and subsequently are at greater risk of collision with cables or entanglement in trawl nets. The northern gannet was the most common species caught in trawl fisheries in the North Atlantic (Ellis et al., 2013; Hatch, 2018; Jannot et al., 2021). Although categorised as Least Concern, this species has a wide distribution, and the total bycatch is therefore likely to be much higher in fisheries where observer coverage was low or nil. As well as injuries sustained in collisions with trawl cables, gannets can also be caught in substantial numbers in nets, e.g., 20 in just two hauls reported by Pierce et al. (2002). A preliminary study in the Mediterranean reported bycatch of Balearic Shearwater, which is abundant around vessels during operations in shallow waters (Abelló and Esteban, 2012). This species is Critically Endangered, underlining the necessity for further data from this region. Other threatened species recorded in trawl bycatch in the Northern Hemisphere include Pink-footed Shearwater, which is listed as Vulnerable. Although recorded in low numbers, observer coverage is limited and the scale of cryptic mortality is largely unknown, which underlines the need for much improved monitoring and regulation.

4.2. *Gap analysis*

The latest report of the International Council for the Exploration of the Sea (ICES) Working Group on Bycatch of Protected Species (WGBYC) documents the difficulties in acquiring fisheries data in order to complete seabird assessments, as reports from member and non-member states included inconsistencies or were incomplete (ICES, 2021). This is a common issue, and efforts to standardise data reporting would improve accuracy and confidence in future bycatch estimates. Seabird bycatch cannot be estimated in numerous fisheries because data on bycatch rates are unavailable, sparse, or only include net captures, and in many cases there is no available estimate of total fishing effort. As such, even rough extrapolations are impossible. This applies in particular to Russian and Asian waters. In the US, the National Oceanic and Atmospheric Administration (NOAA) monitor federal fisheries (3–200 nautical miles offshore in the EEZ), but not those closer to the coast. Off South Africa, the midwater Cape Horse Mackerel (*Trachurus capensis*), multi-target inshore and crustacean trawl fisheries are not assessed. Although seabird bycatch is not considered to be a major issue (Angel, pers. comm.), this would be useful to confirm, particularly given the presence of Cape Gannets, and because comparable, small inshore trawl fisheries off New Zealand do record bycatch. In Namibia, although there are fisheries observers on midwater trawl vessels targeting monkfish *Lophius* spp. and Sole (*Austroglossus microlepis*), seabird interactions are not assessed. Although there are some data on seabirds killed in nets and in collisions with cables in the CCAMLR region and off southern Australia (Butler et al., 2023, CCAMLR Secretariat, 2023a), these are inadequate for estimating total seabird bycatch in the fisheries. Similarly, although there are some data on seabird bycatch in European trawl fisheries, the level of monitoring remains low and the scale of bycatch remains largely unknown (ICES, 2021).

4.3. *Bycatch reporting*

There was considerable uncertainty around the levels of seabird bycatch reported in most published studies because observer coverage rarely exceeded 10 % of fishing effort by the relevant fleet (Table 1). Recording of seabird bycatch by on-board observers remains challenging in practical terms because most mortality is cryptic, and decisions on whether collisions with cables are sufficient to cause major injury are to some extent subjective (Bartle, 1991; Melvin et al., 2011; Tamini et al., 2015). In addition, mortality is often clustered temporally, so high numbers of cable collisions that occur over a short period may be missed entirely. There can also be extensive variation in bycatch rates associated with specific vessels, and observers may have been deployed on those that operate to a higher standard than others, particularly in terms of adherence to mitigation requirements, or standards improve once observers are on board. Illegal, Unreported and Unregulated (IUU) fishing also occurs in some areas (Park et al., 2020; Welch et al., 2022), and those vessels likely will not use seabird-bycatch mitigation nor, by definition, report fishing effort. Although there are ongoing efforts to improve the coverage and quality of monitoring of seabird bycatch, under-reporting continues to be a major problem.

4.4. *Progress in bycatch mitigation, and monitoring of compliance*

Across the globe, a range of organisations and structures provide the impetus for reducing seabird bycatch in trawl fisheries. Under umbrella UN legislation, the FAO Code of Conduct for Responsible Fisheries, nations are obliged to consider non-target and other environmental and biodiversity-related impacts. However, NPOAs are voluntary, and few effectively link seabird bycatch risk to specific objectives and management actions (Good et al., 2020). In contrast, by ratifying ACAP, the 13 signatories are obliged to achieve and maintain a favourable conservation status for albatross and petrels (Phillips et al., 2016). This requires national fisheries regulators to develop appropriate rules and implement seabird-bycatch mitigation and monitoring. Most countries and relevant Regional Fisheries Management Organisations (RFMOs) have made some form of mitigation mandatory, including prohibiting the use of third (monitoring) wires, discard management or use of BSLs, but very few require best practice according to ACAP (Baker et al., 2024).

Many seabirds feed on discards, which are abundant and relatively predictable. Discards are dumped off the side of the trawler or through factory scuppers, attracting birds to feed on the surface. As the vessel advances, the warps and monitoring wires enter the water in the area of highest risk to birds, directly astern of the vessel. The cables may also strike birds in the air. Active discarding during trawling therefore leads to substantial increases in collisions and bird mortalities (Favero et al., 2011; González-Zevallos and Yorio, 2006; Sullivan et al., 2006; Watkins et al., 2008). The predominant mechanism by which seabird bycatch can be prevented is through discard management, which greatly reduces the number of seabirds attracted to trawlers and number of collisions with cables (Kuepfer et al., 2022; Pierre et al., 2012). If discards cannot be retained on board until the vessel returns to port, then batch discarding or mincing can also be effective in reducing bycatch rates or abundance of some species (Kuepfer et al., 2022; Pierre et al., 2012).

Cable strikes are reduced effectively by use of Bird Scaring Lines (BSLs or tori lines), which are deployed from the stern to create a physical barrier that discourages birds from entering the area directly around the trawl warps (Agreement on the Conservation of Albatrosses and Petrels, 2023; Jiménez et al., 2022; Koopman et al., 2018; Melvin et al., 2011; Reid and Edwards, 2005). However, despite their efficiency at reducing rates of seabird interactions, there are operational challenges associated with use of BSLs on different vessel types and in certain weather conditions (e.g. high winds). In some regions, BSLs are not used during the shooting of the net in order to avoid entanglements in trawl gear (Da Rocha et al., 2021). Safety issues, particularly in rough weather, can also affect compliance. In an attempt to resolve these operational difficulties, an offsetting device termed the 'Tamini Tabla' was developed in Argentina, which adds weight to the BSLs and employs angled fins to keep the streamers away from the trawl cables in strong crosswinds (Agreement on the Conservation of Albatrosses and Petrels, 2023). Welding extension arms to the handrails at the stern of the vessel to create an improved attachment point for the BSLs can also reduce entanglements with cables. In the Chilean industrial Austral Hake and Argentinian Hoki fisheries, most of the seabird bycatch is on vessels using a third (monitoring) wire (Adasme et al., 2019; Tamini et al., 2023). Third wires are banned in some other fisheries (Jiménez et al., 2022), and in CCAMLR waters unless an exception is requested for legitimate reasons, whereas in US fisheries a snatch-block device pulls the third wire close to the stern and reduces mortalities (Melvin et al., 2011). A similar method is under developmental testing in Chile (C.G. Suazo pers. comm.). Capture rates in the net are higher in side-haul trawlers than in other trawl fisheries on the Patagonian Shelf; however, as many of the birds are alive, training in safe handling and release of seabirds would help to reduce the impact (Tamini et al., 2021). Other seabird-bycatch mitigation measures trialled in trawl fisheries include bird bafflers and water sprayers; however, they may be difficult to implement on smaller vessels in particular (Agreement on the Conservation of Albatrosses and Petrels, 2023; Koopman et al., 2018).

Effective seabird-bycatch mitigation requires regulations on the use of BSLs or other technical solutions, and operational practices such as controls on discarding; effective monitoring of compliance and seabird bycatch rates; and enforcement. This requires increased resources in most fisheries to improve observer coverage and hence representativeness. Electronic Monitoring (EM) is particularly useful for monitoring compliance, but despite the advantages in terms of cost - although review of footage can be time-consuming - its uptake has been slow due to operational difficulties and perceived invasion of privacy (Gilman et al., 2019; van Helmond et al., 2020). Improved education and engagement is required as part of any changes to fishing practices and should emphasise the benefits of EM. Implementation of EM in tandem with observer programmes and evolving mitigation measures is essential for understanding and addressing seabird-bycatch in trawl fisheries.

4.5. Conclusions

Although seabird bycatch in trawl and longline fisheries has been reduced considerably in some national and high-seas fisheries in the last 1–2 decades, it remains amongst the highest threats to seabirds globally in terms of the scope (proportion of population affected) and severity (role in causing population decline) (Dias et al., 2019). Our review highlighted the lack of data on seabird bycatch rates and totals in many trawl fisheries. As such, the real global total will greatly exceed the ~44,000 birds per year in monitored fisheries. The impacts of this mortality on particular species or populations depend on abundance, life-history strategy (clutch size, breeding frequency and success, age at recruitment, longevity) and other sources of mortality, including bycatch in other types of fishery (Good et al., 2023; Richard et al., 2017; Small et al., 2013). Standardised data-collection protocols need to be established, and extrapolation frameworks developed that allows meaningful comparison of bycatch rates and totals across fleets and countries. Fishing effort needs to be better quantified. Observer coverage (human or electronic) of seabird bycatch in many trawl fleets is inadequate and needs to increase greatly, focusing on regions where there is an obvious risk of negative interactions given the densities of susceptible species. Monitoring should distinguish injury or mortality associated with collisions with warp cables, monitoring cables and paravanes, and net captures during shooting, towing and hauling. Research is required on how best to account for cryptic mortality to improve estimates of fleet-specific and global trawl mortality. Finally, management bodies should prioritise effective offal management as the principal means of mitigating seabird bycatch in trawl fisheries. The seabird species that are affected by bycatch in trawl fisheries are amongst the most wide ranging of any animals, but their distributions are sufficiently well-known from tracking studies that the political responsibilities for their conservation can be assigned readily (Beal et al., 2021). Understanding and mitigating bycatch of seabirds is a global responsibility that benefits greatly from international cooperation and improved knowledge-exchange.

CRediT authorship contribution statement

Richard A. Phillips: Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Emma Fox:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Rory Crawford:** Writing – review & editing, Supervision. **Stephanie Prince:** Writing – review & editing, Supervision. **Oliver Yates:** Writing – review & editing, Supervision.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

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References

Abelló, P., Esteban, A., 2012. Trawling bycatch does affect Balearic shearwaters *Puffinus mauretanicus*. Revista Catalana d'Ornitologia 28, 34–39.
Adasme, L.M., Canales, C.M., Adasme, N.A., 2019. Incidental seabird mortality and discarded catches from trawling off far southern Chile (39–57° S). ICES J. Mar. Sci. 76, 848–858.
Agreement on the Conservation of Albatrosses and Petrels, 2023. ACAP Review of Mitigation Measures and Best Practice Advice for Reducing the Impact of Pelagic and Demersal Trawl Fisheries on Seabirds. Agreement on the Conservation of Albatrosses and Petrels, Hobart, Australia. https://www.acap.aq/resources/bycatch-mitigation/mitigation-advice/3949-acap-2021-trawl-mitigation-review-and-bpa/file.
Amoroso, R.O., Pitcher, C.R., Rijnsdorp, A.D., McConnaughey, R.A., Parma, A.M., Suuronen, P., Eigaard, O.R., Bastardie, F., Hintzen, N.T., Althaus, F., 2018. Bottom trawl fishing footprints on the world's continental shelves. Proc. Natl. Acad. Sci. USA 115, E10275–E10282.
Anderson, O.R., Small, C.J., Croxall, J.P., Dunn, E.K., Sullivan, B.J., Yates, O., Black, A. D., 2011. Global seabird bycatch in longline fisheries. Endanger. Species Res. 14, 91–106.
Attwood, C.G., Petersen, S.L., Kerwath, S.E., 2011. Bycatch in South Africa's inshore trawl fishery as determined from observer records. ICES J. Mar. Sci. 68, 2163–2174.
Baker, G.B., Double, M.C., Gales, R., Tuck, G.N., Abbott, C.L., Ryan, P.G., Petersen, S.L., Robertson, C.J.R., Alderman, R., 2007. A global assessment of the impact of fisheries-related mortality on shy and white-capped albatrosses: conservation implications. Biol. Conserv. 137, 319–333.
Baker, G.B., Komyakova, V., Wellbelove, A., Beynon, N., Haward, M., 2024. The implementation of ACAP best practice advice to mitigate seabird bycatch in fisheries: issues and options. Mar. Policy 160, 105879.
Barnes, T.C., Candy, S.G., Johnson, D.D., 2021. Characterising seabird vessel interactions associated with demersal ocean trawling: vessel attendance by birds depends on intrinsic and extrinsic predictors. Endanger. Species Res. 44, 327–338.
Bartle, J.A., 1991. Incidental capture of seabirds in the New Zealand subantarctic squid trawl fishery, 1990. Bird Cons. Int. 1, 351–359.
Beal, M., Dias, M.P., Phillips, R.A., Oppel, S., Hazin, C., Pearmain, E.J., Adams, J., Anderson, D.J., Antolos, M., Arata, J.A., 2021. Global political responsibility for the conservation of albatrosses and large petrels. Sci. Adv. 7, eabd7225.
Berrow, S.D., Croxall, J.P., Grant, S.D., 2000. Status of white-chinned petrels *Procellaria aequinoctialis* Linnaeus 1758, at Bird Island, South Georgia. Antarct. Sci. 12, 399–405.
BirdLife International, 2024. Data Zone. http://datazone.birdlife.org/species/search.
Brothers, N.P., Cooper, J., Løkkeberg, S., 1999. The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. In: FAO Fisheries Circular No. 937. Food and Agriculture Organisation of the United Nations, Rome.
Bugoni, L., Mancini, P.L., Monteiro, D.S., Nascimento, L., Neves, T.S., 2008. Seabird bycatch in the Brazilian pelagic longline fishery and a review of capture rates in the southwestern Atlantic Ocean. Endanger. Species Res. 5, 137–147.
Bull, L.S., 2007. Reducing seabird bycatch in longline, trawl and gillnet fisheries. Fish Fish. 8, 31–56.
Bull, L.S., 2009. New mitigation measures reducing seabird by-catch in trawl fisheries. Fish Fish. 10, 408–427.
Butler, I., Patterson, H., Bromhead, D., Galeano, D., Timmiss, T., Woodhams, J., Curtotti, R., 2023. Fishery Status Reports 2023. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra. https://doi.org/10.25814/vgp4-xr81.
Carneiro, A.P., Pearmain, E.J., Oppel, S., Clay, T.A., Phillips, R.A., Bonnet-Lebrun, A.S., Wanless, R.M., Abraham, E., Richard, Y., Rice, J., 2020. A framework for mapping the distribution of seabirds by integrating tracking, demography and phenology. J. Appl. Ecol. 57, 514–525.
Cashion, T., Al-Abdulrazzak, D., Belhabib, D., Derrick, B., Divovich, E., Moutopoulos, D. K., Noël, S.-L., Palomares, M.L.D., Teh, L.C., Zeller, D., 2018. Reconstructing global marine fishing gear use: catches and landed values by gear type and sector. Fish. Res. 206, 57–64.
CCAMLR Secretariat, 2023a. Fishery Report 2022: *Champsocephalus gunnari* at Heard Island (Division 58.5.2). Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia. https://fishdocs.ccamlr.org/FishRep_HIMI_ANI_2022.pdf.
CCAMLR Secretariat, 2023b. Fishery Report 2022: *Euphausia superba* in Area 48. Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia. https://fishdocs.ccamlr.org/FishRep_48_KRI_2022.pdf.
Clay, T.A., Small, C., Tuck, G.N., Pardo, D., Carneiro, A.P.B., Wood, A.G., Croxall, J.P., Crossin, G.T., Phillips, R.A., 2019. A comprehensive large-scale assessment of fisheries bycatch risk to threatened seabird populations. J. Appl. Ecol. 56, 1882–1893.
Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Cons. Int. 22, 1–34.
Da Rocha, N., Oppel, S., Prince, S., Matjila, S., Shaanika, T.M., Naomab, C., Yates, O., Paterson, J.R., Shimooshili, K., Frans, E., 2021. Reduction in seabird mortality in Namibian fisheries following the introduction of bycatch regulation. Biol. Conserv. 253, 108915.
Dias, M.P., Martin, R., Pearmain, E.J., Burfield, I.J., Small, C., Phillips, R.A., Yates, O., Lascelles, B., Borboroglu, P.G., Croxall, J., 2019. Threats to seabirds: a global assessment. Biol. Conserv. 237, 525–537.
Einoder, L.D., 2009. A review of the use of seabirds as indicators in fisheries and ecosystem management. Fish. Res. 95, 6–13.
Ellis, J., Wilhelm, S., Hedd, A., Fraser, G., Robertson, G., Rail, J.-F., Fowler, M., Morgan, K., 2013. Mortality of migratory birds from marine commercial fisheries and offshore oil and gas production in Canada. Avian Conserv. Ecol. 8, 4.
Falkland Islands Government, 2023. Fisheries Department Fisheries Statistics, Volume 27, 2022, 94. F.F. Department Stanley. https://www.falklands.gov.fk/fisheries/publications/fishery-statistics?task=download.send&id=293:fisheries-statistics-27-2022&catid=7.
Favero, M., Blanco, G., García, G., Copello, S., Seco Pon, J., Frere, E., Quintana, F., Yorio, P., Rabuffetti, F., Cañete, G., Gandini, P., 2011. Seabird mortality associated with ice trawlers in the Patagonian shelf: effect of discards on the occurrence of interactions with fishing gear. Anim. Conserv. 14, 131–139.
Frankish, C.K., Phillips, R.A., Clay, T.A., Somveille, M., Manica, A., 2020. Environmental drivers of movement in a threatened seabird: insights from a mechanistic model and implications for conservation. Divers. Distrib. 26, 1315–1329.
Frankish, C.K., Cunningham, C., Manica, A., Clay, T.A., Prince, S., Phillips, R.A., 2021. Tracking juveniles confirms fisheries-bycatch hotspot for an endangered albatross. Biol. Conserv. 261, 109288.
Gilman, E., Legorburu, G., Fedoruk, A., Heberer, C., Zimring, M., Barkai, A., 2019. Increasing the functionalities and accuracy of fisheries electronic monitoring systems. Aquatic Conserv.: mar. Freshw. Ecosyst. 29, 901–926.
González-Zevallos, D., Yorio, P., 2006. Seabird use of discards and incidental captures at the argentine hake trawl fishery in the Golfo San Jorge. Argentina. Mar. Ecol. Prog. Ser. 316, 175–183.
González-Zevallos, D., Yorio, P., Caille, G., 2007. Seabird mortality at trawler warp cables and a proposed mitigation measure: a case of study in Golfo San Jorge, Patagonia. Argentina. Biol. Conserv. 136, 108–116.
Good, S., Baker, G., Gummery, M., Votier, S., Phillips, R., 2020. National Plans of action (NPOAs) for reducing seabird bycatch: developing best practice for assessing and managing fisheries impacts. Biol. Conserv. 247, 108592.
Good, S., Gummery, M., McLennan, S., Dewar, K., Votier, S., Phillips, R., 2023. Evaluating the appropriateness of risk-based approaches to assess the sustainability of fishery impacts on seabirds. Endanger. Species Res. 51, 161–172.
Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952.
Hatch, J.M., 2018. Comprehensive estimates of seabird-fishery interactions for the US northeast and mid-Atlantic. Aquatic Conserv.: Mar. Freshw. Ecosyst. 28, 182–193.
Hedd, A., Regular, P.M., Wilhelm, S.I., Rail, J.F., Drolet, B., Fowler, M., Pekarik, C., Robertson, G.J., 2016. Characterization of seabird bycatch in eastern Canadian waters, 1998–2011, assessed from onboard fisheries observer data. Aquatic Conserv.: Mar. Freshw. Ecosyst. 26, 530–548.
ICES, 2021. In: Working Group on Bycatch of Protected Species (WGBYC) (Ed.), I.S. Reports. https://doi.org/10.17895/ices.pub.9256.
Jannot, J.E., Wuest, A., Good, T.P., Somers, K.A., Tuttle, V.J., Richerson, K.E., Shama, R. S., McVeigh, J.T., 2021. Seabird bycatch in U.S. west coast fisheries, 2002-18.
Jiménez, S., Xavier, J.C., Domingo, A., Brazeiro, A., Defeo, O., Viera, M., Lorenzo, M.I., Phillips, R.A., 2017. Inter-specific niche partitioning and overlap in albatrosses and petrels: dietary divergence and the role of fishing discards. Mar. Biol. 164, 174.
Jiménez, S., Domingo, A., Winker, H., Parker, D., Gianuca, D., Neves, T., Coelho, R., Kerwath, S., 2020. Towards mitigation of seabird bycatch: large-scale effectiveness of night setting and Tori lines across multiple pelagic longline fleets. Biol. Conserv. 247, 108642.
Jiménez, S., Páez, E., Forselledo, R., Loureiro, A., Troncoso, P., Domingo, A., 2022. Predicting the relative effectiveness of different management scenarios at reducing seabird interactions in a demersal trawl fishery. Biol. Conserv. 267, 109487.
Koopman, M., Boag, S., Tuck, G.N., Hudson, R., Knuckey, I., Alderman, R., 2018. Industry-based development of effective new seabird mitigation devices in the southern Australian trawl fisheries. Endanger. Species Res. 36, 197–211.
Kuepfer, A., Sherley, R.B., Brickle, P., Arkhipkin, A., Votier, S.C., 2022. Strategic discarding reduces seabird numbers and contact rates with trawl fishery gears in the Southwest Atlantic. Biol. Conserv. 266, 109462.
Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydelis, R., McDonald, S., DiMatteo, A., Dunn, D.C., Kot, C.Y., 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc. Natl. Acad. Sci. USA 111, 5271–5276.
Mackley, E.K., Phillips, R.A., Silk, J.R.D., Wakefield, E.D., Afanasyev, V., Furness, R.W., 2011. At-sea activity patterns of breeding and nonbreeding white-chinned petrels *Procellaria aequinoctialis* from South Georgia. Mar. Biol. 158, 429–438.

Maree, B.A., Wanless, R.M., Fairweather, T.P., Sullivan, B.J., Yates, O., 2014. Significant reductions in mortality of threatened seabirds in a south African trawl fishery. Anim. Conserv. 17, 520–529.
Marinao, C.J., Yorio, P., 2011. Fishery discards and incidental mortality of seabirds attending coastal shrimp trawlers at Isla Escondida, Patagonia, Argentina. Wilson J. Ornithol. 123, 709–719.
Marine Stewardship Council, 2019. Russian Federation Barents Sea Cod, Haddock and Saithe. https://fisheries.msc.org/en/fisheries/russian-federation-barents-sea-cod-haddock-and-saithe/@@view.
Marine Stewardship Council, 2021. Norebo Sea of Okhotsk Mid-Water Trawl Pollock Fishery. https://fisheries.msc.org/en/fisheries/norebo-sea-of-okhotsk-mid-water-trawl-pollock-fishery/.
Melvin, E.F., Dietrich, K.S., Fitzgerald, S., Cardoso, T., 2011. Reducing seabird strikes with trawl cables in the Pollock catcher-processor fleet in the eastern Bering Sea. Polar Biol. 34, 215–226.
Ministry for Primary Industries, 2024. Protected species bycatch in New Zealand fisheries. https://protectedspeciescaptures.nz/PSCv7/.
Montevecchi, W.A., 2023. Interactions between fisheries and seabirds: Prey modification, discards, and bycatch. In: Young, L.C., VanderWerf, E.A. (Eds.), Conservation of Marine Birds. Elsevier, pp. 57–95.
Northridge, S., Kingston, A., Coram, A., 2020. Preliminary Estimates of Seabird Bycatch by UK Vessels in UK and Adjacent Waters. JNCC, Peterborough. https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=20461.
Otero, X.L., La Peña-Lastra, D., Pérez-Alberti, A., Ferreira, T.O., Huerta-Diaz, M.A., 2018. Seabird colonies as important global drivers in the nitrogen and phosphorus cycles. Nat. Commun. 9, 1–8.
Park, J., Lee, J., Seto, K., Hochberg, T., Wong, B.A., Miller, N.A., Takasaki, K., Kubota, H., Oozeki, Y., Doshi, S., 2020. Illuminating dark fishing fleets in North Korea. Sci. Adv. 6, eabb1197.
Park, Y., Seo, Y.I., Oh, T.Y., Lee, K., Zhang, H., Kang, M., 2016. Anchovy distributional properties by time and location: using acoustic data from a primary trawl survey in the South Sea of South Korea. J. Mar. Sci. Technol. 24, 20.
Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries. Nature 418, 689–695.
Paz, J.A., Pon, J.P.S., Favero, M., Blanco, G., Copello, S., 2018. Seabird interactions and by-catch in the anchovy pelagic trawl fishery operating in northern Argentina. Aquatic Conserv.: Mar. Freshw. Ecosyst. 28, 850–860.
Petersen, S., Honig, M., Ryan, P., Underhill, L., Goren, M., 2009. Seabird bycatch in the demersal longline fishery off southern Africa. Afr. J. Mar. Sci. 31, 205–214.
Phillips, R.A., Wood, A., 2020. Variation in live-capture rates of albatrosses and petrels in fisheries, post-release survival and implications for management. Biol. Conserv. 247, 108641.
Phillips, R.A., Gales, R., Baker, G., Double, M., Favero, M., Quintana, F., Tasker, M.L., Weimerskirch, H., Uhart, M., Wolfaardt, A., 2016. The conservation status and priorities for albatrosses and large petrels. Biol. Conserv. 201, 169–183.
Pierce, G.J., Dyson, J., Kelly, E., Eggleton, J.D., Whomersley, P., Young, I.A., Santos, M. B., Wang, J., Spencer, N.J., 2002. Results of a Short Study on By-catches and Discards in Pelagic Fisheries in Scotland (UK), 15. Aquat. Living Resources, pp. 327–334.
Pierre, J.P., Abraham, E.R., Richard, Y., Cleal, J., Middleton, D.A.J., 2012. Controlling trawler waste discharge to reduce seabird mortality. Fish. Res. 131, 30–38.
Poncet, S., Wolfaardt, A.C., Black, A., Browning, S., Lawton, K., Lee, J., Passfield, K., Strange, G., Phillips, R.A., 2017. Recent trends in numbers of wandering (*Diomedea exulans*), black-browed (*Thalassarche melanophris*) and grey-headed (*T. chrysostoma*) albatrosses breeding at South Georgia. Polar Biol. 40, 1347–1358.
Reid, K., Baker, G.B., Wells, R., 2023. Mitigation of seabird bycatch in New Zealand squid trawl fisheries provides hope for ongoing solutions. Emu-Austral Ornithol. 123, 195–205.
Reid, T., Edwards, M., 2005. Consequences of the Introduction of Tori Lines in Relation to Seabird Mortality in the Falkland Islands Trawl Fishery, 2004/2005. Falklands Conservation, Stanley, Falkland Islands.
Richard, Y., Adasme, L., 2019. Assessment of the risk of trawl and longline fisheries to ACAP-listed seabirds in Chile. In: Ninth Meeting of the Seabird Bycatch Working Group, Agreement on the Conservation of Albatrosses and Petrels. SBWG9 Doc 08, Florianópolis, Brazil.
Richard, Y., Abraham, E., Berkenbusch, K., 2017. Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15. In: New Zealand Aquatic Environment and Biodiversity Report. 191, Wellington, New Zealand. https://files.dragonfly.co.nz/publications/pdf/Richardetal_2017_AEBR191.pdf.
Small, C., Waugh, S.M., Phillips, R.A., 2013. The justification, design and implementation of ecological risk assessments of the effects of fishing on seabirds. Mar. Policy 37, 192–199.
Suazo, C.G., Cabezas, L.A., Moreno, C.A., Arata, J.A., Luna Jorquera, G., Simeone, A., Adasme, L., Azócar, J., García, M., Yates, O., 2014. Seabird bycatch in Chile: a synthesis of its impacts, and a review of strategies to contribute to the reduction of a global phenomen. Pacific Seabirds 41, 1–12.
Sullivan, B.J., Reid, T.A., Bugoni, L., 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. Biol. Conserv. 131, 495–504.
Suryan, R.M., Dietrich, K.S., Melvin, E.F., Balogh, G.R., Sato, F., Ozaki, K., 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific rim countries and spatial overlap with commercial fisheries in Alaska. Biol. Conserv. 137, 450–460.
Swartz, W., Sala, E., Tracey, S., Watson, R., Pauly, D., 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). PLoS One 5, e15143.
Tamini, L., Chavez, L., Dellacasa, R., Crawford, R., Frere, E., 2021. Incidental capture of seabirds in Argentinean side-haul trawlers. Bird Cons. Int. 31, 591–604.
Tamini, L., Dellacasa, R., Chavez, L., Marinao, C., Góngora, M., Crawford, R., Frere, E., 2023. Bird scaring lines reduce seabird mortality in mid-water and bottom trawlers in Argentina. ICES J. Mar. Sci. 80, 2393–2404.
Tamini, L.L., Perez, J.E., Chiaramonte, G.E., Cappozzo, H.L., 2002. Magellanic penguin *Spheniscus magellanicus* and fish as bycatch in the cornalito *Sorgentinia incisa* fishery at Puerto Quequén, Argentina. Atlantic Seabirds 4, 109–114.
Tamini, L.L., Chavez, L.N., Góngora, M.E., Yates, O., Rabuffetti, F.L., Sullivan, B., 2015. Estimating mortality of black-browed albatross (*Thalassarche melanophris*, Temminck, 1828) and other seabirds in the Argentinean factory trawl fleet and the use of bird-scaring lines as a mitigation measure. Polar Biol. 38, 1867–1879.
Tide, C., Eich, A.M., 2022. Seabird bycatch estimates for Alaskan groundfish fisheries: 2021. In: U.S. Department of Commerce, NOAA Technical Memorandum, pp. 1–46. https://doi.org/10.25923/01e2-3s52.
Tuck, G.N., Phillips, R.A., Small, C., Thompson, R.B., Klaer, N.L., Taylor, F., Wanless, R. M., Arrizabalaga, H., 2011. An assessment of seabird-fishery interactions in the Atlantic Ocean. ICES J. Mar. Sci. 68, 1628–1637.
van Helmond, A.T., Mortensen, L.O., Plet-Hansen, K.S., Ulrich, C., Needle, C.L., Oesterwind, D., Kindt-Larsen, L., Catchpole, T., Mangi, S., Zimmermann, C., 2020. Electronic monitoring in fisheries: lessons from global experiences and future opportunities. Fish Fish. 21, 162–189.
Votier, S.C., Sherley, R., Scales, K., Camphuysen, K., Phillips, R., 2023. An overview of the impacts of fishing on seabirds, including identifying future research directions. ICES J. Mar. Sci. 80, 2380–2392.
Watkins, B.P., Petersen, S.L., Ryan, P.G., 2008. Interactions between seabirds and deep-water hake trawl gear: an assessment of impacts in south African waters. Anim. Conserv. 11, 247–254.
Watson, R.A., Tidd, A., 2018. Mapping nearly a century and a half of global marine fishing: 1869–2015. Mar. Policy 93, 171–177.
Waugh, S.M., Baker, G.B., Gales, R., Croxall, J.P., 2008. CCAMLR process of risk assessment to minimise the effects of longline fishing mortality on seabirds. Mar. Policy 32, 442–454.
Waugh, S.M., Filippi, D.P., Kirby, D.S., Abraham, E., Walker, N., 2012. Ecological risk assessment for seabird interactions in Western and Central Pacific longline fisheries. Mar. Policy 36, 933–946.
Weimerskirch, H., Capdeville, D., Duhamel, G., 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. Polar Biol. 23, 236–249.
Welch, H., Clavelle, T., White, T.D., Cimino, M.A., Van Osdel, J., Hochberg, T., Kroodsma, D., Hazen, E.L., 2022. Hot spots of unseen fishing vessels. Sci. Adv. 8, eabq2109.
Zhou, C., Brothers, N., Browder, J., Jiao, Y., 2020. Seabird bycatch loss rate variability in pelagic longline fisheries. Biol. Conserv. 247, 108590.
Žydelis, R., Small, C., French, G., 2013. The incidental catch of seabirds in gillnet fisheries: a global review. Biol. Conserv. 162, 76–88.