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SEABIRD BYCATCH IN CHILE: A SYNTHESIS OF ITS IMPACTS, AND A REVIEW OF STRATEGIES TO CONTRIBUTE TO THE REDUCTION OF A GLOBAL PHENOMENON

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Abstract

Chile holds globally important colonies of endangered and endemic seabird species, and globally vulnerable nonbreeding species visit its waters. One of the major threats for seabirds in Chilean waters is the impact of fishing activities, both industrial and artisanal, which overlap with seabird breeding and foraging areas. Bycatch in fisheries threatens 27 identified species and two groups of unidentified albatrosses and penguins, with the Black-browed Albatross *Thalassarche melanophrys* as the species most related to bycatch events. Responding to the international call for the voluntary adoption of a plan to reduce the impacts of fisheries on seabirds, Chile generated a National Plan of Action (PAN-AM/Chile) to monitor seabird bycatch, and to mitigate threats to seabirds with emphasis on industrial longline fisheries. Following the successful reduction of seabird bycatch in the demersal longline fishery for Patagonian toothfish *Dissostichus eleginoides*, with zero individuals caught during 2006, Chile is extending the PAN-AM/Chile to include other fisheries that use gear known to cause incidental mortality, such as trawl, purse seine, and gillnets. This initiative is supported by actions associated with the creation of a national scientific committee for biodiversity, and new collaborative research platforms under the auspices of the Chilean Undersecretariat for Fisheries and Aquaculture.

Keywords: Albatross, conservation, fisheries, gillnet, Humboldt Current System, longline, mortality, Oceanic Islands, purse seine, Subantarctic, trawl

Resumen

Chile cuenta con importantes colonias a nivel global de especies de aves marinas endémicas y en peligro, así como especies no reproductivas globalmente vulnerables que visitan sus aguas. Una de las mayores amenazas para las aves marinas en aguas chilenas es el impacto de las actividades pesqueras, tanto industriales y artesanales, las cuales se sobreponen con áreas de reproducción y alimentación de aves marinas. Estas amenazan 27 especies identificadas y dos grupos de albatross y pingüinos no identificados, con el Albatros de ceja negra *Thalassarche melanophrys* como la especie más relacionada a eventos de captura incidental. Respondiendo al llamado internacional para la adopción voluntaria de un plan para reducir los impactos de las pesquerías en aves marinas, Chile generó un Plan de Acción Nacional (PAN-AM/Chile) para monitorear la captura incidental de aves marinas y mitigar amenazas con énfasis en pesquerías industriales de palangre. Seguido a la exitosa reducción de la captura incidental en la pesquería demersal de palangre para Bacalao de profundidad *Dissostichus eleginoides*, con cero individuos capturados durante 2006, Chile está ampliando el PAN-AM/Chile para incluir otras pesquerías que usan artes de pesca con conocida mortalidad incidental, tales como arrastre, cerco y redes agalleras. Esta iniciativa es apoyada por acciones asociadas con la creación de un comité científico de biodiversidad y nuevas plataformas de investigación colaborativa, bajo los auspicios de la Subsecretaría de Pesca y Acuicultura de Chile.

Palabras clave: Albatros, arrastre, cerco, conservación, Islas Oceánicas, mortalidad, palangre, pesquerías, red agallera, Sistema de Corriente de Humboldt, Subantártico

INTRODUCTION

Bycatch is recognized as the major threat to the conservation of seabird species worldwide. The high rate of mortality in these long-lived species is conducive to population declines, and is due to interaction with different fishing gears (Croxall et al. 2012) with its negative effects on demographic status.

The high biological productivity associated with Chile's coast supports major fisheries that operate both in coastal and pelagic waters in these regions, and that deploy a variety of fishing gear, such as demersal and mid-water longline, trawl, gillnet and purse seine. In addition, these activities frequently overlap with breeding and non-breeding seabird species prone to negative interactions with fishing gear such as the hooks of longliners, collisions with cables in trawlers, and entanglement in net gear such gillnet and purse seine.

The important role of Chile for seabird conservation is highlighted especially because the nation's waters include globally important breeding grounds for some albatrosses (e.g. Black-browed *Thalassarche melanophrys*), colonies with endemic species (e.g. Pink-footed Shearwater *Puffinus creatopus*), and non-breeding visiting species such as albatrosses (Diomedidae) from New Zealand (BirdLife International 2004). All these species are overlapping with some of the scattered fishing activities in Chilean waters, whose fishing effort is distributed between industrial and artisanal (i.e. small-scale) fishing. Industrial fishing vessels are >18 m in length. Artisanal activities are related mainly to manual operations in small boats or semi-industrial vessels <18 m; these small-scale activities have a legal exclusive fishing area of 5 miles from the coastline.

The present work includes a review of Chile's actions related to seabird bycatch in different seabird endemism area in Chilean waters. Our paper includes both published information and new data. We also include future steps relating to different stakeholders' collaboration, government actions, and further research to assess Chile's part in the global impact of fisheries on seabird populations.

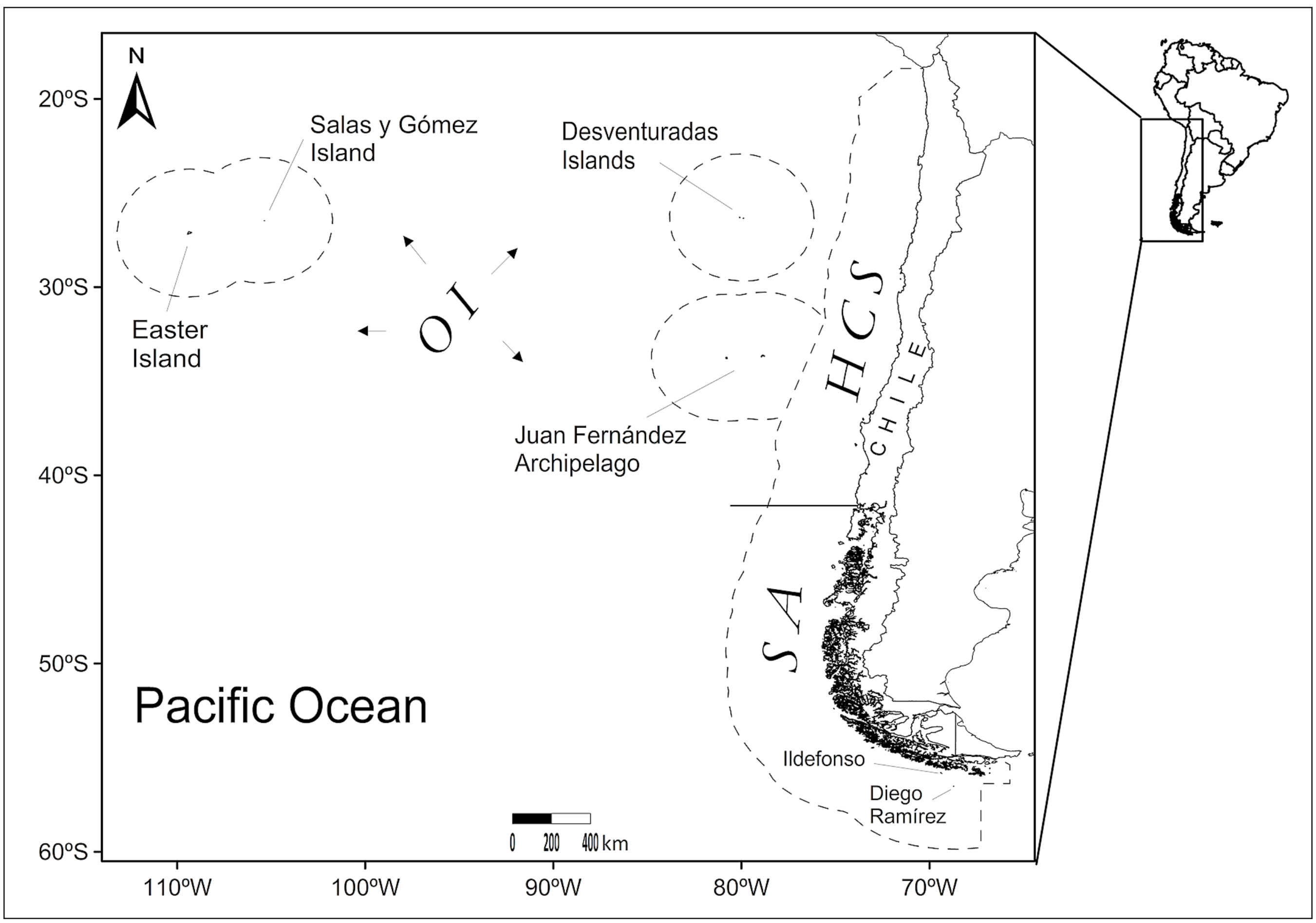

FIGURE 1. Chilean seabird endemism areas: (HCS) Humboldt Current System; (OI) Oceanic Islands, and (SA) Sub-Antarctic islands and fjords (Schlatter and Simeone 1999). Dashed line along the Chilean coast and around the Oceanic Islands represent Chile's Exclusive Economic Zone (EEZ).

Table 1. Fisheries, target resources, and observer coverage during different studies focused on seabird bycatch in Chilean waters. Seabird endemism areas: SA = Subantarctic islands and fjords; HCS = Humboldt Current System; OI = Oceanic Islands (see text for details)

Fishery	General latitude range of fishery[a]	Fishing depth (m)[a]	Seabird endemism area	Observation effort (% of total fishing)	Period covered	Observers on board	Source
Industrial demersal longline for Patagonian toothfish *Dissostichus eleginoides*	South of 47°S	168–2,250	SA	222 sets, 1,310,585 hooks (21%)	2001 (exploratory); 2002–2003 (study)	Trained (seabird identification and mortality assessment)	Moreno et al. (2003)
Industrial demersal longline for austral hake *Merluccius australis* and ling *Genypterus blacodes*	45°–57°S	200–600	SA	96 sets	October-November 2003; March 2004	Trained	Unpubl. data, Moreno et al. (2003), Moreno and Arata (2004); cited by Robertson et al. (2014)
Artisanal demersal longline for austral hake and ling	41°–45°S	100–500	SA	388 sets, 330,632 hooks (78.3%).	1999	Trained	Moreno et al. (2006)
Artisanal demersal longline for Patagonian toothfish	41°–47°S	1,000–2,000	SA, HCS	82 sets, 88,280 hooks (total fishing effort unknown)	2002	Trained	Moreno et al. (2006)
Industrial pelagic longline for swordfish *Xiphias gladius*	29°–32°S	4–10	HCS, OI	Vessels <28m: 1,856 sets, 2,312,258 hooks (62%); Vessels >28m: 864 sets, 1,353,418 hooks (97%)	February 2007–October 2009	Trained (seabird identification and mortality assessment)	Azócar et al. (2010)
Industrial demersal trawl for austral hake, southern blue whiting *Micromesistius australis* and hoki *Macruronus magellanicus*	43°–53°S	200–500	SA	76 trawls (14.3%)	2nd half of 2012	Trained (seabird identification and mortality assessment)	Céspedes et al. (2012)
Industrial demersal trawl for south Pacific hake *Merluccius gayi gayi*	34°–39°S	150–800	HCS	198 trawls (66.7%)	June 2011–August 2012	Trained observer-instructors (instructing scientific fisheries observers on seabird study)	ATF–Chile (2013)

[a] Robertson et al. (2014)

FIGURE 2. Training workshop on seabird identification and bycatch monitoring. ATF-Chile instructors are training IFOP's scientific observers. Photo by L.A. Cabezas.

METHODS

Endemism areas of seabirds in Chilean waters

Chile's linear coastline extends approximately 4000 km, from Latitude 18°21' south to 60° south (Figure 1). Chilean seas can be subdivided into three main seabird endemism areas (Schlatter and Simeone 1999). These are (i) the Subantarctic islands and fjords (SA), from Chiloé to south of the Diego Ramírez archipelago (41˚47' south to 60° south); (ii) the Humboldt Current System (HCS), from the northern limit (18°21' south) to Chiloé Island (41˚47' south); and (iii) the Oceanic Islands (OI), comprising Easter Island, Salas y Gómez Island, Desventuradas Islands, and the Juan Fernández Archipelago.

Seabird bycatch in Chilean waters

We review the history and state of knowledge of seabird bycatch in Chilean waters, and also current information and actions on these topics. The main sources of new information are key contributions from unpublished field records and local literature searches. From this, we present a summary of fisheries covered by scientific observers (Table 1). Table 1 is presented in relationship to three main sources of seabird bycatch information for Chilean waters: (i) the National Plan of Action for Reducing Bycatch of Seabirds in Longline Fisheries (PAN-AM/Chile); (ii) Instituto de Fomento Pesquero (Institute for the Promotion of Fisheries [IFOP]); and (iii) the Albatross Task Force–Chile (ATF-Chile).

IFOP and ATF-Chile cooperate in providing bycatch observers. IFOP provides scientific observers; they are trained in seabird identification and bycatch monitoring during workshops by ATF-Chile instructors (Figure 2). The observers are later assigned by local authorities during government fisheries programs, or are authorized to deploy as independent monitors on focal fisheries.

In addition, local researchers are taking the first steps in the field to identify and quantify seasonal interactions between seabirds and unassessed fisheries, including the industrial and artisanal purse seine fisheries, and the artisanal gillnet fishery at various latitudes along the Chilean coast. Information from different initiatives is currently available in the form of unpublished results, which are especially associated with small-scale (artisanal) fisheries.

RESULTS AND DISCUSSION

Biological diversity: Seabirds in Chilean waters

Several breeding colonies of seabirds are found in this mosaic of different endemism areas, including petrels and shearwaters (Procellariidae), gulls (Laridae), pelicans (Pelecanidae), penguins (Sphenisciformes), and albatrosses (Diomedidae). These areas are also frequented by a range of non-breeding species, including those coming from southern and tropical regions. They include albatrosses such as the Salvin's *Thalassarche salvini*, Chatham *T. eremita*, Royal *Diomedea epomophora* and *D. sanfordi,* Wandering *D. exulans,* Antipodean *D. antipodensis,* and Waved *Phoebastria irrorata*, all of which are considered globally threatened species (IUCN 2013).

As examples, the HCS in particular is considered one of the most productive marine systems in the world (Belkin 2009) and holds a large number and abundance of seabird species (Spear and Ainley 2008). On the other hand, the SA region is a complex geographic area with thousands of islands, fjords and channels. In this part of Chile there are important breeding sites for albatrosses, shearwaters and penguins. For albatrosses the two most important islands are Diego Ramírez and Ildefonso in the southern section of this region (between 55°48' and 56°31' south; Figure 1), which together hold over 20% of the global populations of Black-browed and Gray-headed *Thalassarche chrysostoma* Albatrosses (Robertson et al. 2007; Moreno and Robertson 2008).

In a global assessment of seabird conservation status, threats and priority actions, Chile was listed in the top three most important countries in terms of the number of breeding seabird species and the total number of visitor species recorded within waters of national Exclusive Economic Zones (EEZ) (Croxall et al. 2012). These authors attribute commercial fisheries as one of the principal threats to seabirds.

Fisheries interactions: Background on seabird bycatch in Chilean waters

The attraction of seabirds to fishing vessels is due to the presence of discards and/or offal at the sea surface. This is particularly true for trawl vessels with onboard processing facilities (ATF-Chile 2013). In longline fisheries an additional attraction is the use of fish and/or squid as bait (Moreno et al. 2007). In purse seine fisheries seabirds often forage on the same species targeted by the fishery (Schlatter et al. 2009). Negative interactions between seabirds and fisheries occur when seabirds: (i) collide with cables that support trawl nets (trawl warp cable) or are used to communicate with net sensors (third wire); (ii) become entangled in nets or lines; or (iii) are hooked. While all these interactions can cause injury through trauma, the main cause of mortality is drowning. At least 27 identified seabird species and unidentified penguins and albatrosses (Table 2) were identified among the seabird bycatch for Chilean waters.

Table 2. Seabird species for which mortality records in Chilean fisheries exist (years 1999-2014). *Gear:* G = Gillnet, PS = Purse seine, T = trawl, DL = Demersal longline, PL = Pelagic longline; *Size category of fishery:* (A) = Artisanal, (I) = Industrial. *Endemism area*: SA = Subantarctic islands and fjords, HCS = Humboldt Current system, OI = Oceanic islands. *IUCN status:* LC = Least concern, NT = Near threatened, VU = Vulnerable, EN = Endangered (IUCN 2013). See text for details.

Species	Fishery	Endemism area	IUCN status (population trend)	Source
Wandering Albatross *Diomedea exulans*	PL(I)	OI	VU (decreasing)	ATF (2007), González et al. (2012)
Southern Royal Albatross *D. epomophora*	PL(I)	OI	VU (stable)	González et al. (2012)
Black-browed Albatross *Thalassarche melanoprys*	DL(I), DL(A), T(I), PL(I)	SA, HCS, OI	NT (decreasing)	Moreno et al. (2003), ATF (2007), Céspedes et al. (2012), ATF–Chile (2013), Suazo et al. (2013)
Gray-headed Albatross *T. chrysostoma*	DL(I), PL(I)	SA, OI	EN (decreasing)	Moreno et al. (2003), González et al. (2012)
Salvin's Albatross *T. salvini*	T(I), L(I)	HCS, OI	VU (unknown)	ATF (2007), ATF-Chile (2013)
Buller's Albatross *T. bulleri*	PL(I)	OI	NT (stable)	ATF (2007), González et al. (2012)
Shy Albatross *T. cauta*	PL(I)	OI	NT (unknown)	Moreno et al. (2007)
Albatross (unidentified) Diomededae	PL(I)	OI	—	ATF (2007)
Southern Giant Petrel *Macronectes giganteus*	T(I), PL(I)	SA, OI	LC (increasing)	ATF (2007), Céspedes et al. (2012)
Northern Giant Petrel *M. halli*	PL(I)	OI	LC (increasing)	González et al. (2012)
Southern Fulmar *Fulmarus glacialoides*	DL(I), PL(I), T(I)	SA, HCS	LC (stable)	Moreno et al. (2003), González et al. (2012), IFOP (unpubl. data)
Cape Petrel *Daption capense*	DL(I), T(I), PL(I)	SA, HCS, OI	LC (stable)	Moreno et al. (2003, Céspedes et al. (2012), González et al. (2012), ATF-Chile (2013)
White-chinned Petrel *Procellaria aequinoctialis*	DL(I,A), T(I), PL(I)	SA, HCS, OI	VU (decreasing)	Moreno et al. (2003, 2006), ATF (2007), Céspedes et al. (2012), ATF-Chile (2013)
Westland Petrel *Procellaria westlandica*	DL(I)	SA	VU (stable)	Cabezas (unpubl. data)
Gray Petrel *Procellaria cinerea*	PL(I)	OI	NT (decreasing)	Moreno et al. (2007)
Common Diving Petrel *Pelecanoides urinatrix*	DL(I)	SA	LC (decreasing)	Moreno et al. (2003)
Pink-footed Shearwater *Puffinus creatopus*	PS(I,A), T(I)	HCS	VU (unknown)	Cabezas and Suazo (2011), ATF–Chile (2013), Suazo (unpubl. data)
Sooty Shearwater *P. griseus*	DL(I), PS(A,I)	SA, HCS	NT (decreasing)	Brito (2002), Moreno et al. (2003), Suazo and Steffen (unpubl. data)
Peruvian Pelican *Pelecanus thagus*	PS(I,A), T(I)	HCS	VU (stable)	Brito (2002, ATF-Chile 2013), ATF-Chile (unpubl. data)

Table 2, continued

Species	Fishery	Endemism area	IUCN status (population trend)	Source
Peruvian Booby *Sula variegata*	PS(A)	HCS	LC (stable)	ATF-Chile (unpubl. data)
Guanay Cormorant *Phalacrocorax bougainvillii*	G(A), PS(I,A)	HCS	NT (decreasing)	Simeone et al. (1999), Brito (2002)
Red legged Cormorant *P. gaimadi*	G(A)	HCS	NT (decreasing)	Simeone et al. (1999), Suazo and Steffen (unpubl. data)
Neotropical Cormorant *P. brasilianus*	PS(A)	HCS	LC (increasing)	IFOP (unpubl. data)
White-tailed Tropicbird *Phaethon lepturus*	PL(I)	OI	LC (decreasing)	González et al. (2012)
Kelp Gull *Larus dominicanus*	DL(A), T(I)	SA, HCS	LC (increasing)	Moreno et al. (2006), ATF–Chile (2013)
Gray Gull *Larus modestus*	PS(A)	HCS	LC (decreasing)	ATF–Chile (unpubl. data)
Humboldt Penguin *Spheniscus humboldti*	G(A), PS(I,A)	HCS	VU (decreasing)	Simeone et al. (1999), Brito (2002)
Magellanic Penguin *S. magellanicus*	DL(A), G(A), PS(A)	SA, HCS	NT (decreasing)	Simeone et al. (1999), Ojeda et al. (2011), Pütz et al. (2011), Suazo et al. (2013), Suazo and Steffen (unpubl. data)
Penguin (unidentified) *Spheniscus* sp.	DL(A), G(A)	SA, HCS	—	Simeone et al. (1999), Moreno et al. (2006)

Interactions in the Subantarctic (SA)—The SA region is a complex geographic area and an important fishing ground for demersal species such as the austral hake *Merluccius australis,* ling *Genypterus blacodes*, and Patagonian toothfish *Dissostichus eleginoides*, which are targeted by trawlers and by both artisanal and industrial longliners. Observation of industrial demersal longline fishing operations in the Patagonian toothfish fishery indicated that 1588 seabirds were killed during 2002 (Moreno and Arata 2006; Moreno et al. 2008). The Black-browed Albatross was the most-affected species, with 97.9% of the overall mortality. Observation of artisanal demersal longline operations in the fjords and channels of Patagonia recorded minimal numbers of seabird bycatch (Moreno et al. 2006, Suazo et al. 2013). This was mainly attributed to the faster sink rates of demersal fishing lines, due to a weight (0.3–1 kg) attached near the end of each secondary line with a series of hooks, which reduces the access of seabirds to baited hooks (for details see Moreno et al. 2006).

Four species were recorded in bycatch events for the industrial demersal trawl in the SA area during spring–summer (Céspedes et al. 2012). The estimated mortality rate was 1.77 birds/trawl (Table 3), with the Black-browed Albatross as the main bycatch (92.5%), along with three petrel species. In contrast, studies in other regions showed lower mortality rates, with a mean 0.26 birds/trawl for the squid fishery around the Snares and Auckland Islands, New Zealand (Bartle 1991), and maximum rate of 0.11 birds/trawl during demersal fish catches around the Kerguelen Islands, Indian Ocean (Weimerskirch et al. 2000), both during the austral summer.

Interactions in the Humboldt Current System (HCS)—Seabird bycatch evidence in the HCS indicates that pursuit-diving seabirds such as penguins and shearwaters are killed incidentally during their winter migration towards lower latitudes. Magellanic *Spheniscus magellanicus* and Humboldt *S. humboldti* Penguins are vulnerable to drowning in industrial and artisanal purse seines and gillnets (Simeone et al. 1999; Schlatter et al. 2009, Pütz et al. 2011, ATF-Chile unpubl. data); 1380 individuals were recorded in a single mass-mortality event in purse seine gear (Schlatter et al. 2009). These fisheries target small pelagic species, principally the anchovy *Engraulis ringens* and common sardine *Strangomera bentincki*. Pelicans, boobies (Sulidae), shearwaters, and cormorants (Phalacrocoracidae) are also killed or injured in these types of fisheries (see Table 2). Gillnets are deployed in artisanal fisheries along the Chilean coast (mainly between 18˚ and 42° south) for pelagic species such as the palm ruff *Seriorella violacea* and corvina drum *Cilus gilberti*. While no official seabird mortality estimates exist for these fisheries (Žydelis et al. 2013), unpublished data suggest that artisanal gillnets may kill >5000 birds per year in southern Chile alone (Luna-Jorquera unpubl. results).

Another fishery that impacts seabirds in the HCS is the industrial trawl fishery for south Pacific hake *Merluccius gayi gayi*. Seven species among albatrosses, pelicans, petrels, shearwaters and gulls are affected (Table 2). A monitoring effort of 198 trawls over 15 months during 2011 and 2012 indicated a higher the estimated mortality during summer than winter, reaching 890 seabirds (0.098 birds/trawl) through collisions with cables (ATF-Chile 2013; Table 3). The near-threatened Black-browed Albatross was the most-affected species, representing 35% of the total mortality.

During this same study on trawl in the HCS, hourly mortality rates for summer (0.031 birds/hour for spring–summer) were lower than estimations for the Falklands trawl fishery during the austral spring (0.082 birds/hour; Sullivan et al. 2006) and around important breeding grounds for Black-browed Albatrosses. However, during winter the trawl mortality rates for the HCS reached 0.152 birds/hour. The latter figure includes non-breeding subantarctic breeders such as Black-browed Albatrosses, in addition to endemic species from the SA such a Peruvian Pelican *Pelecanus thagus*. Thus, this review shows the importance of assessing bycatch as a function of contrasting seasonal blocks, an approach that is adjusted to seasonal abundance and distribution patterns of seabirds.

Our observations in this trawl fishery have detected seabird mortality due to net entanglements that occur while the gear is floating at the sea surface, when birds forage on fish remains or whole fish

Table 3. Seabird bycatch rates in longline and trawl fisheries for different seabird endemism areas in Chilean waters. Seabird endemism areas: SA = Subantarctic islands and fjords, HCS = Humboldt Current system, OI = Oceanic islands (see text for details). All bird species are combined for each fishery and study.

Fishery	Seabird endemism area	Bycatch rate	Source
Industrial demersal longline for Patagonian toothfish *Dissostichus eleginoides*	SA	1.285 birds/1000 hooks	Moreno et al. (2003)
Industrial demersal longline for austral hake *Merluccius australis* and ling *Genypterus blacodes*	SA	0.018 birds/1000 hooks for Black-browed Albatross	Unpubl. data, Moreno et al. (2003), Moreno and Arata (2004); cited by Robertson et al. (2014)
Artisanal demersal longline for austral hake and ling *Genypterus blacodes*	SA	0.030 birds/1000 hooks	Moreno et al. (2006)
Artisanal demersal longline for Patagonian toothfish	SA, HCS	0.047 birds/1000 hooks	Moreno et al. (2006)
Industrial pelagic longline for swordfish *Xiphias gladius*	OI	0.032-0.104 birds/1,000 hook	Azócar et al. (2010)
Industrial demersal trawl for austral hake, southern blue whiting *Micromesistius australis*, and hoki *Macruronus magellanicus*	SA	1.776 birds/trawl	Céspedes et al. (2012)
Industrial demersal trawl for south Pacific hake *Merluccius gayi gayi*	HCS	0.393 birds/trawl (winter), 0.098 birds/trawl (summer); 0.152 birds/trawling hour (winter), 0.031 birds/ trawling hour (summer)	ATF - Chile (2013)

that are stuck in the folds and mesh of the trawl. Although no counter-measures were trialled in our study period, the use of net binding has prevented similar net entanglements in other fisheries (Roe 2005). Before each setting, the net is bound at intervals with breakable strings, which prevents the mesh from opening on the surface and improves its rate of sinking. However, a simpler method to prevent this source of seabird interaction is the habitual cleaning of nets before the next trawl is deployed. This involves shaking fish remains out the mesh while preparing the gear on deck.

Entanglement of scavenging birds should not be underestimated for Chile, where mortalities associated with net entanglement at the surface reached up 37% of all dead birds (ATF–Chile 2013). Thus, overall estimations of bycatch for trawl fisheries should be considered as conservative, since cryptic sources of mortality may exist. These can include net entanglements on the surface and strikes with trawl gear cables, even when no seabird bycatch has been recorded in the gear when it is retrieved on board.

Interactions in the Oceanic Islands (OI)—The waters around the OI support a pelagic longline fishery for swordfish *Xiphias gladius,* sharks, and tunas (e.g. blue shark *Prionace glauca* and bigeye tuna *Thunnus obesus*). A total of 12 species of seabird have been reported taken incidentally in this fishery (González et al. 2012). The main species killed are Black-browed Albatrosses, Wandering Albatrosses, and White-chinned Petrels *Procellaria aequinoctialis* (Table 2), with a higher occurrence of these events during winter (Azócar et al. 2010, Barría et al. 2012, González et al. 2012). The greatest bycatch record for this fishery was in 2007, with 128 individuals (73.9% of all mortality) from 11 species, among them albatrosses, petrels, and shearwaters (Azócar et al. 2010; Table 3). Subsequently, when larger vessels (>28 m) left the fishery after 2007, seabird mortality dropped to a level of around 20 individuals per year during the next two monitored periods (Azócar et al. 2010). This pelagic longline fishery potentially impacts other migratory species from New Zealand, Australia and the Chilean oceanic islands. These include the Black petrel *Procellaria parkinsoni* (Cabezas et al. 2012), and the Juan Fernández *Pterodroma externa* and Masatierra *P. defilippiana* Petrels (Cabezas unpubl. data).

Seabird bycatch mitigation in Chile

A national commitment: Government initiatives and researchers' participation—Since the earliest records of Procellariiform mortality in fisheries (Brothers 1991), longline fishing has increasingly been recognized as one of the main threats to albatross and petrel populations globally (Anderson et al. 2011). The United Nations Food and Agriculture Organization's International Plan of Action (FAO 1999) called for member states to respond to this issue by developing a national plan of action to reduce the bycatch of seabirds in their EEZs. In 2001, Chile started a process of expert consultation through the Fisheries Research Fund (Fondo de Investigación Pesquera [FIP]; www.fip.cl), which generated participation in the diagnosis of seabird mortality levels and the development of PAN-AM/Chile.

The strategy to reach the objectives of this plan involved the following steps: (i) estimate the magnitude of the problem in the Chilean EEZ; (ii) develop an action plan, if needed; (iii) implement mitigation measures in fisheries where negative interactions occur with seabirds; (iv) research, and (v) training of fishermen on the issue of bycatch and mitigation measures (Moreno and Arata 2005). This process was focused on the Chilean longline fleet, and particularly the fisheries for Patagonian toothfish and swordfish.

PAN-AM/Chile was established through Supreme Decree No. 136 of 2007, issued by Chilean fisheries authorities and supported with the signature of Chile's president. The plan specified mandatory measures for three longline fisheries. In the Patagonian toothfish longline fishery, these measures included the use of bird-scaring streamer lines during all sets and the use of 8.5-kg weights placed every 40 meters on the main line (Moreno and Arata 2005). These two measures deter seabirds from attacking baited hooks and reduce the amount of time baited hooks are available at the sea surface, respectively. In the austral hake and ling longline fishery, night setting was recommended as the main mitigation measure, complemented with the use of streamer lines during all sets and the use of 8-kg weights (no distance specified) on the main line. For the swordfish pelagic longline fishery, prescribed mitigation measures included night setting, the use of streamer lines, and the addition of 60- to 75-g lead weights to branch lines to increase the sink rate (Moreno and Arata 2005). The weights are on lead swivels that are attached to the monofilament line with crimps, and placed ca. 3.5 m from the hook.

Following the development of the PAN-AM/Chile, the next stage was to monitor implementation and effectiveness. A more comprehensive monitoring program onboard the pelagic longline fleet revealed a higher mortality than previously identified (Moreno et al. 2007), including a greater number of visitor species in Chilean waters (Table 2). During this second stage of the PAN-AM/Chile for the swordfish fishery (supported by FIP), observations revealed low compliance in the use of streamer lines during day and night settings (Moreno et al. 2007), although the use of 60- to 75-g line weights was adopted throughout the fishery.

In the longline fishery for Patagonian toothfish, compliance with recommendations in the PAN-AM/Chile led to zero seabird mortality in 2006 (Moreno et al. 2007). This great achievement was attributed to a change in fishing technology, from the Spanish longline system to a "Chilean" longline or trotline system. As described in Robertson et al. (2008, 2014), the Spanish system uses two lines set in parallel—a hauling line (*retenida*), and a hook line (*linea madre*) with numerous secondary lines or branch lines (*barandillos*) that connect the two main lines. In contrast, the Chilean longline system uses a single main line, equivalent to the Spanish *retenida*. Hooks are now attached to short snoods in clusters near the ends of each branch line, where a weight is also attached.

This fishing gear adaptation represented a technology transfer from the artisanal longline fishery for toothfish (boats <18 m long). Industrial fishermen configured the gear to include a 10-m secondary line placed every 20 m along the main line. Each secondary line carries 6 to 10 hooks, with a weight 4-8 kg at its terminal end; this makes the secondary line sink fast and prevents seabird bycatch (Moreno et al. 2008). A further improvement of the method made by fishermen included a "net sleeve" that covers the catch and prevents damage by sperm *Physeter macrocephalus* and killer whales *Orcinus orca* during hauling.

Adoption of the Chilean system was also supported by full compliance with measures proposed in the PAN-AM/Chile for the Patagonian toothfish longline fishery: (i) the disposal of processing discards on the opposite side of the vessel from the hauling bay, which avoids incidental capture of scavenging seabirds during hauling of the gear; (ii) setting lines with minimal deck lights; and (iii) the use of bird-scaring lines (Moreno et al. 2007). The transition from Spanish to Chilean gear configuration started during 2006-2007 and was completed in 2008. The measures are recognized among the most innovative initiatives in Chilean fisheries (Castilla et al. 2013). The changes are associated with an increase of 23% in breeding pairs of Black-browed Albatrosses from 2002 through 2012 at their two main colonies in SA Chile (Robertson et al. 2014). In this way, low-cost modifications to fishing gear can improve catches of target species and save seabirds from bycatch. These changes can easily be transferred and adopted by longline fleets around subantarctic waters.

On the other hand, a direct assessment of seabird bycatch and compliance with the mitigation measures proposed in the PAN-AM/Chile are still pending for the industrial longline fishery for austral hake in SA waters, as well as for other Chilean fisheries farther north.

In 2008 an expert consultation was held on technical guidelines for the application of best practices in the International Plan of Action/National Plan of Action for Seabirds (IPOA/NPOA–Seabirds; FAO 2008). This publication recommended the inclusion of trawl and gillnet fisheries in all National Plans for Action–Seabirds. Recognising this, the Albatross Task Force in central-southern Chile (latitude 33 to 42° south) assessed seabird interactions in the trawl fishery for south Pacific hake between June 2011 and August 2012. Of the 34 seabird species observed in this fishery, seven species were found to be vulnerable to mortality through collisions with trawl warp cables and the third wire (netsonde), plus entanglements in the net while foraging for offal and discards (Table 2). During this study, the experimental deployment of bird-scaring lines on 54.5% of the 198 monitored trawls resulted in zero bird mortalities through cable strikes, especially during the winter period when mortality events are almost six times higher than during summer (ATF-Chile 2013). This review, in addition with the current work carried out by scientific observers from IFOP in industrial trawl for austral hake in Subantarctic waters, has reinforced the sense of urgency to upgrade the implementation of the PAN-AM/Chile to include other fisheries.

New government initiatives for science-based seabird conservation—In 2011 the Chilean Undersecretariat for Fisheries and Aquaculture (Subsecretaría de Pesca y Acuicultura) created a National Scientific Committee for Biodiversity–Seabirds (Comité Científico Nacional de Biodiversidad–Aves Marinas; CCNB-AM) to support current and future conservation actions.

The CCNB-AM is a working group of scientists and conservation professionals with the objective to formulate scientifically supported recommendations on the population status, conservation, and fisheries interactions of seabirds. The goal is to apply practical knowledge to the conservation of seabirds in Chilean waters.

This includes a proposal for improvements to the existing PAN-AM/Chile, and

FIGURE 3. New efforts to understand seabird bycatch are concentrating on artisanal gill net and purse seine fisheries distributed in Chilean waters. *Top*: Gillnets in south-central Chile overlap with seasonal migration and juvenile dispersal of penguins, such as this juvenile Magellanic Penguin. *Bottom*: Purse seines operate in breeding and feeding areas of endemic species such as Pink-footed Shearwater. Photos by C.G. Suazo.

research to mitigate seabird mortality in all domestic fisheries through the adoption of best practices. A recent update of the General Law on Fisheries and Aquaculture (Law No. 20,657 of February 6, 2013) established mandatory technical support for decision-making (recommendations from experts). In order to implement this change, the Undersecretariat for Fisheries and Aquaculture has established eight new Technical Scientific Committees, including one dedicated to biodiversity and environmental issues. This development means that the former CCNB-AM has now been expanded to include the conservation of highly migratory species and sharks (Chondrichthyes) within a wider context for conservation of biodiversity.

Notwithstanding this change in committee structure, it is expected that the CCNB-AM will continue to improve PAN-AM/Chile, contribute new assessments and proposals for mitigation measures, and identify best fishing practices.

Finally, estimation of bycatch levels in any fishery is made more difficult by activities that are illegal, unregulated, and unreported. These are still a widespread issue among countries (Trouwborst 2008). In some cases, these activities are supported by organized groups (Österblom et al. 2011) with an international working structure to avoid regulatory actions by countries. On the Chilean scene, there are intrusions by artisanal vessels into other artisanal or industrial administrative fishing areas (Oyarzún et al. 2003). Industrial operations also overlap onto artisanal fishing grounds.

Under a wider view that includes international waters, the Chilean government is currently focused on acquiring international commitments to improve regulatory systems, through actions by its Ministry of Foreign Affairs (e.g. Our Ocean Conference). In addition, local actions through the fisheries authorities are on the current agenda, in order to address the problem of intrusions with measures such as remote tracking of vessels and monitoring of onboard practices.

New efforts: other fisheries— Currently, local researchers are taking the first steps in the field to identify and quantify seasonal interactions between seabirds and unassessed fisheries. They are focusing on the industrial and artisanal purse seine fisheries and the artisanal gillnet fishery at various latitudes along the Chilean coast, which strongly affect diving species such as shearwaters, cormorants, and penguins through entanglement in fishing gear (ATF-Chile unpubl. data; Suazo and Steffen unpubl. data; Figure 3). One example comes from artisanal purse seine fishery in south-central Chile (approximately 39°S). Here, preliminary data suggest mortality of pursuit-diving species such as the Pink-footed and Sooty *Puffinus griseus* Shearwaters, among 13 other species associated with this fishery. In this study, 55.6% of 9 exploratory sets during the austral spring resulted in a mean combined bycatch of 11.4 individuals per set. This was comprised of 81% Pink-footed and 19% Sooty Shearwaters (ATF-Chile unpubl. results). Of course, these first results from ATF-Chile's study must not be considered a final, absolute estimate, since the studies are part of ongoing systematic monitoring. Our monitoring will work towards future bycatch mitigation in the purse seine fishery. We plan to expand our work to additional latitudes along the HCS, add the winter period, and include other species with feeding methods such as plunge diving (e.g. Peruvian booby *Sula variegata*; Table 2).

However, there is a long way to go before we understand the level of negative interactions with seabirds and other taxa in unstudied fisheries. These include trawling for crustaceans in coastal waters and the drift net fishery for swordfish in pelagic waters. For the latter fishery there are past records of marine turtle bycatch since the second part of the 1980s (Frazier and Brito 1990), but there was also unreported mortality of fish, birds, dolphins and whales (Brito in litt.) This fishery operated strongly in central Chile until the end of the 1990s.

New efforts: collective involvement in land-based conservation— Other ongoing efforts include the promotion of citizen engagement to systematically monitor events of beached seabirds along the Chilean coast. The standardized collection of this information will contribute towards the generation of Internet open-access databases, a good example of which is the seabird strandings network (*Red de Varamientos de Aves Marinas*; REVAM). This initiative, born during 2013 in northern Chile, currently has simultaneous monitoring covering the coast between north-central (29°S) and south-central Chile (39°S), with voluntary support of regional representatives (Miranda-Urbina in litt.). Thus, this network compiles information from throughout Chile pertinent to seabird mortality events, likely related to fisheries but also to other causes such as contamination and disease.

Some of these early instances are already materializing as joint projects on topics of seabirds and their interactions with fisheries. These initiatives are of current interest to the national fisheries authority, and also where the collaboration of citizen action along coasts and islands of Chile is expected. Citizens, in turn, are already demonstrating a growing commitment to working with administrators of public protected areas, and they are focused on long-term efforts, such as protection of breeding colonies of the endemic Pink-footed Shearwater.

CONCLUDING REMARKS

Today, the commitment from Chile is progressing towards a better understanding of the level of seabird bycatch, and the generation of strategies to implement effective protection of threatened seabirds. Thus, Chilean participation is active in different international forums, such as the Agreement on the Conservation of Albatrosses and Petrels (ACAP), with the promotion of new species for listing, such as the Pink-footed Shearwater; the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR); and the South Pacific Regional Fisheries Management Organisation (SPRFMO). These organizations facilitate actions by Chile towards the assessment and mitigation of the negative effects of bycatch. And, in turn, our local initiatives can also be externalized to different contexts in international collaboration.

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