Agreement on the Conservation of Albatrosses and Petrels

Ninth Meeting of the Seabird Bycatch Working Group

Florianópolis, Brazil, 6 - 8 May 2019

Assessment of the risk of trawl and longline fisheries to ACAP-listed seabirds in Chile

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SUMMARY

Seabirds are among the most threatened taxa in the world, and their incidental capture in fisheries may play a significant part. Identifying the fisheries where captures occur most often, the species the most impacted, and the demographic impact of these captures is essential to guarantee the viability of these species.

The number of annual potential fatalities and the associated demographic impact on 16 ACAP-listed species in Chilean longline and trawl fisheries were estimated from data on captures recorded by government observers. The analysis focused on fisheries operating below 40°S, where overlap with seabirds may be the highest. Data on fishing effort and observed captures spanned from 2014 to 2017. A Bayesian spatial generalised linear model was used for the estimation, without information of seabird distributions.

Among the 16 species, the total number of annual captures was estimated at 9040 (95% credible interval (c.i.): 8700–9360), but increased to 67,900 (95% c.i.: 47,300–89,700) estimated captures annually when considering cryptic mortality. Over 90% of captures were of black-browed albatross, and 96.8% of all captures were in trawl fisheries using a net-sonde or sonar cable. The capture rate for factory trawl vessels using this cable was 30 times higher than for the one vessel that did not use the cable.

Our results also indicated that the capture rate was 13 times higher for trawl vessels with on-board processing facilities compared with fresher vessels, presumably caused by the larger volume of fish discards during processing.

When considering the demographic impact of incidental captures, black-browed albatross had the highest risk score, with an estimated annual potential fatalities of 55% (95% c.i.: 34%–86%) of the Population Sustainability Threshold. Northern giant petrel and wandering albatross were the second and third most at-risk species, with a risk ratio of 0.14 and 0.10, respectively.

1. INTRODUCTION

Seabirds are among the most threatened taxa in the world, and their incidental capture in fisheries may play a significant part in their threat status. Identifying the fisheries where captures occur most often, the species the most impacted, and the demographic impact of these captures are essential to guarantee the viability of these species.

Chile is one of the 13 parties to the Agreement on the Conservation of Albatrosses and Petrels (ACAP), and is therefore legally required to take measures to reduce the bycatch of the 31 listed species, to protect their breeding colonies, and to control introduced species from breeding sites. Below 40°S, trawl and longline fishing effort overlaps with 16 ACAP-listed species, and government observers have recorded their incidental captures at the species level since 2014. The relevant fishing fleets are relatively small, with seven trawl vessels and 10 longline vessels. Observer coverage has been around 40% for both trawl and longline fisheries between 2014 and 2017.

From the number of observed captures and the amount of observed fishing effort, capture rates may be estimated statistically, based on the total fishing effort, to obtain an estimate of the total number of seabirds captured annually (e.g., Abraham & Richard 2018). The total number of captures may then be compared to an index of population productivity to estimate the demographic impact of these captures to the species viability, therefore quantifying the risk of fisheries to these species (Richard et al. 2017).

In New Zealand, the Spatially-Explicit Fisheries Risk Assessment (SEFRA) framework has been used extensively to assess the risk of fisheries to seabirds (Richard & Abraham 2015, Richard et al. 2017, Sharp 2017). The SEFRA method relies on information of the at-sea distribution of seabirds to extrapolate the capture rate from areas of observed effort to areas without observations. As the distribution of seabird populations breeding or foraging in Chilean waters is poorly known, the SEFRA method was not suitable for the current risk assessment. For this reason, an alternative approach was used that did not depend on seabird at-sea distribution data.

2. METHODS

2.1 Species

Of the 31 species listed under the Agreement on the Conservation of Albatrosses and Petrels (ACAP), we assessed the 16 species that overlap with Chilean fisheries, including 10 albatross, five petrel, and one shearwater species (Table 1).

For the current estimation of the risk of fisheries to Chilean seabirds, these species were split into four species groups, as some species do not have a sufficient number of captures to fit statistical models. At the same time, the grouping recognised that some species interact differently with fisheries. The "*Diomedea*" group included wandering albatrosses and light-mantled sooty albatross, the "*Thalassarche*" group included smaller albatross species (mollymawks), whereas giant petrels formed their own group, and petrels of the *Procellaria* genus were grouped with pink-footed shearwater into "small petrels".

Table 1. List of species included in this study, estimating the risk of fisheries to seabirds in Chilean waters. For the estimation, species were combined into four species groups.

Common name	Scientific name	Species group
Wandering albatross	*Diomedea exulans*	*Diomedea*
Southern royal albatross	*Diomedea epomophora*	*Diomedea*
Northern royal albatross	*Diomedea sanfordi*	*Diomedea*
Light-mantled sooty albatross	*Phoebetria palpebrata*	*Diomedea*
Grey-headed albatross	*Thalassarche chrysostoma*	*Thalassarche*
Black-browed albatross	*Thalassarche melanophris*	*Thalassarche*
Buller's albatross	*Thalassarche bulleri*	*Thalassarche*
Shy albatross	*Thalassarche cauta*	*Thalassarche*
Chatham Island albatross	*Thalassarche eremita*	*Thalassarche*
Salvin's albatross	*Thalassarche salvini*	*Thalassarche*
Southern giant petrel	*Macronectes giganteus*	Giant petrels
Northern giant petrel	*Macronectes halli*	Giant petrels
White-chinned petrel	*Procellaria aequinoctialis*	Small petrels
Westland petrel	*Procellaria westlandica*	Small petrels
Grey petrel	*Procellaria cinerea*	Small petrels
Pink-footed shearwater	*Puffinus creatopus*	Small petrels

2.2 Fishing effort and observed captures

All trawl and longline fisheries operating between 39°S and 57°S that had the highest overlap with ACAP-listed seabird species were included in the analysis. An observer programme was established by the Fisheries Development Institute (Instituto de Fomento Pesquero, IFOP), which led to the monitoring by government observers of approximately 40% of all effort by these fisheries since 2014. The activities of the observers included the recording of all incidental captures of ACAP-listed species by these fisheries at the species level.

A Chilean National Plan of Action to reduce seabird bycatch in longline fisheries was developed in 2005, including mitigation measures and good practices, which led to a reduction in bycatch in longline fisheries (Fondo Investigacion Pesquera & Universidad Austral de Chile 2007). No regulations are yet in place for trawl fisheries.

The trawl fleet considered in this study consisted of seven vessels, targeting a range of fish species. Included in this trawl fleet were four vessels with on-board fish processing facilities, and three fresher vessels (i.e., fish were kept whole without processing)(Table 2). All but two trawl vessels used a net-sonde or sonar cable – hereafter referred simply as net-sonde cable

– to facilitate fishing operations. For modelling and reporting purposes, four trawl fishery groups were distinguished: three groups with on-board processing (surimi factory, non-surimi factory, and factory not using a net-sonde cable), and one group of fresher trawl vessels. The longline fleet was composed of ten vessels, and was split into two groups, the fishery targeting cod and using cachaloteras (net sleeves that cover fishing hooks), and the fishery targeting hake, not using cachaloteras.

Annual fishing effort was relatively similar in the four trawl fishery groups, with the highest effort by fresher vessels (Table 2). Observer coverage across the trawl groups varied between 33.0 and 58.5%. Longline vessels targeting cod (with cachaloteras) had a higher fishing effort than longliners targeting hake (without cachaloteras), with observer effort of 23.8% and 58.6%, respectively.

There was spatial variation in fishing effort across the six fishery groups, but for each group, observer coverage was representative of the total effort (Figure 1).

Table 2. Summary of the fishing effort by the six fishery groups included in this study between 2014 and 2017 (by quarter). Effort is the number of hook cachaloteras (net sleeves that cover fishing hooks) for longline targeting cod, the number of hooks for longline targeting hake, and number of fishing hours for trawl. Fresher refers to trawl vessels not processing fish, NS to net-sonde cable.

Fishery group	Vessels	Annual effort	% observed	Q1	Q2	Q3	Q4
Trawl with fresher (with NS)	3	2 900	33.0	633	718	800	746
Trawl - factory (with NS)	1	2 790	42.3	475	872	736	705
Trawl - surimi factory (with NS)	1	2 030	52.2	31	658	676	665
Trawl - factory (no NS)	2	1 740	58.5	25	756	650	306
Longline - cod	8	3 750 000	23.8	1 270 000	756 000	617 000	1 100 000
Longline - hake	2	3 010 000	56.6	842 000	956 000	863 000	352 000

There were 8620 total observed captures recorded between 2014 and 2017 (Table 3). Of these total captures, 7920 captures were of black-browed albatross, mostly by trawl factory vessels using a net-sonde cable. Black-browed albatross was the most-captured species in all fisheries except in the longline fishery targeting cod, which had the lowest number of observed captures overall across all fisheries.

There was some variation in fishing effort and also observer effort over time, dependent on the fishery group (Figure 2). In addition, observed seabird captures fluctuated across years, with a decrease in the number of total observed captures in 2017 for all fishery groups, except for longlining targeting cod.

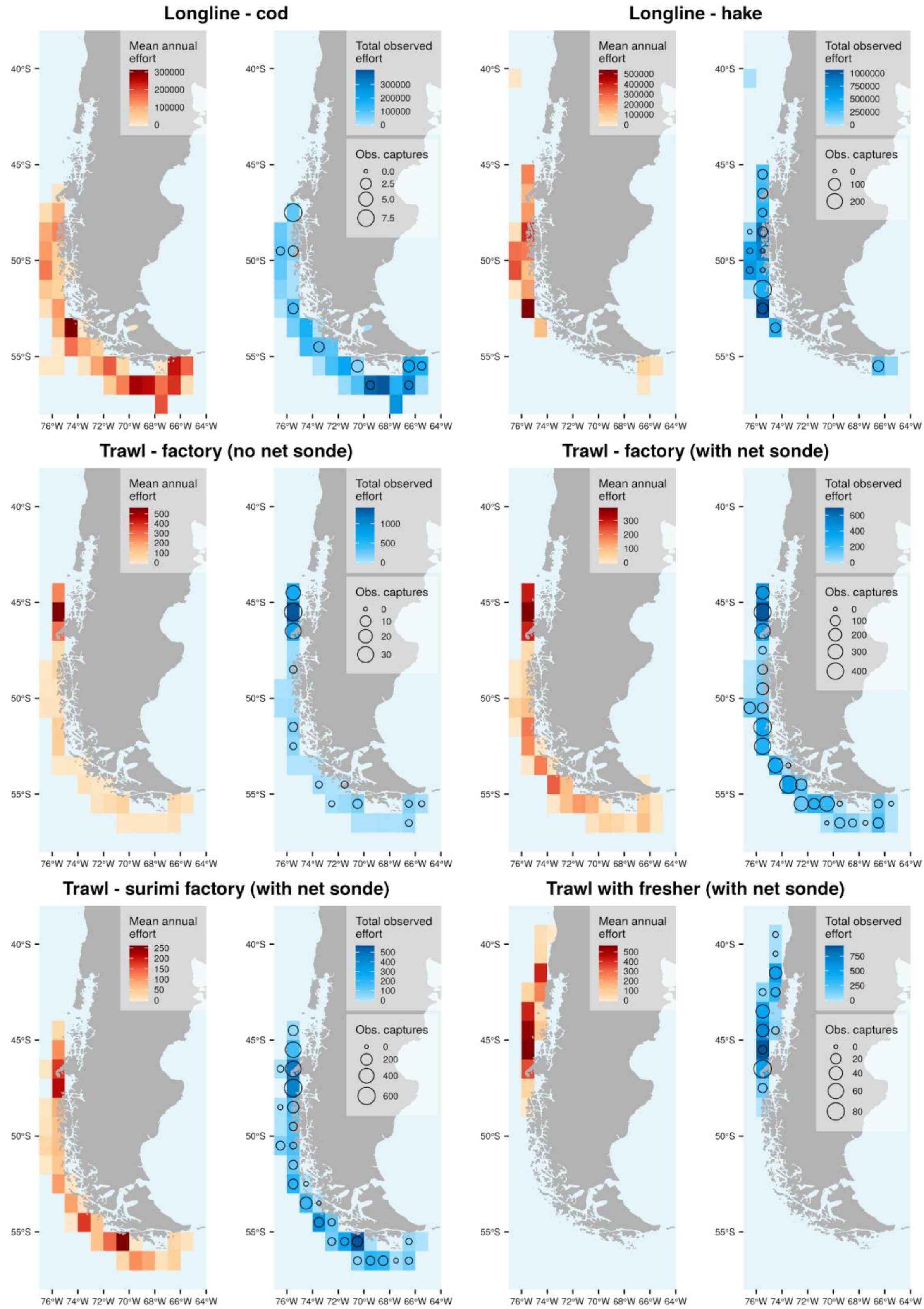

Figure 1. Fishing effort for each of the fisheries considered in this study between 2014 and 2017. The left panel shows the mean annual effort (observed and unobserved). The right panel shows the total observed effort and the number of observed captures of all species. Effort is in number of hook cachaloteras for longline targeting cod, in hooks for longline targeting hake, and number of fishing hours for trawl.

Only 1% of all seabird captures that were observed were released alive (Table 4). This percentage varied across fishery groups and seabird families, and the highest percentage was in the trawl factory fleet not using a net-sonde cable; in this fleet, 28% of all petrels and 18% of all albatross caught were released alive. The lowest percentage was in the trawl factory fleet using a net-sonde cable, with only three birds released alive, out of 4276 captures. Due to the low proportion of captured birds released alive overall and the lack of information on post-release survival rates, all captures were assumed to be fatal in the analysis.

Table 3. Summary of observed captures (2014–2017) of 16 seabird species that are listed by the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and overlap with commercial fisheries in Chilean waters. Number of observed captures by fishing group. Fresher refers to trawl vessels not processing fish, NS refers to net-sonde cable.

Taxa	All fisheries	Trawl				Longline	
		Fresher with NS	Factory with NS	Surimi factory with NS	Factory no NS	Cod	Hake
All species	8622	243	4276	3259	118	25	701
Black-browed albatross	7920	207	4194	2905	59	6	549
White-chinned petrel	220	6	5	29	42	8	130
Grey-headed albatross	164	9	57	98			
Northern giant petrel	73	6	2	58	3	3	1
Southern giant petrel	50		11	14	4	6	15
Salvin's albatross	45	2		36	1		6
Pink-footed shearwater	36	2		34			
Buller's albatross	32		6	22	4		
Wandering albatross	27	1	1	23		2	
Shy albatross	22	7		15			
Southern royal albatross	14	1		12	1		
Chatham Island albatross	6			6			
Light-mantled sooty albatross	6			6			
Westland petrel	5			1	4		
Grey petrel	1	1					
Northern royal albatross	1	1					

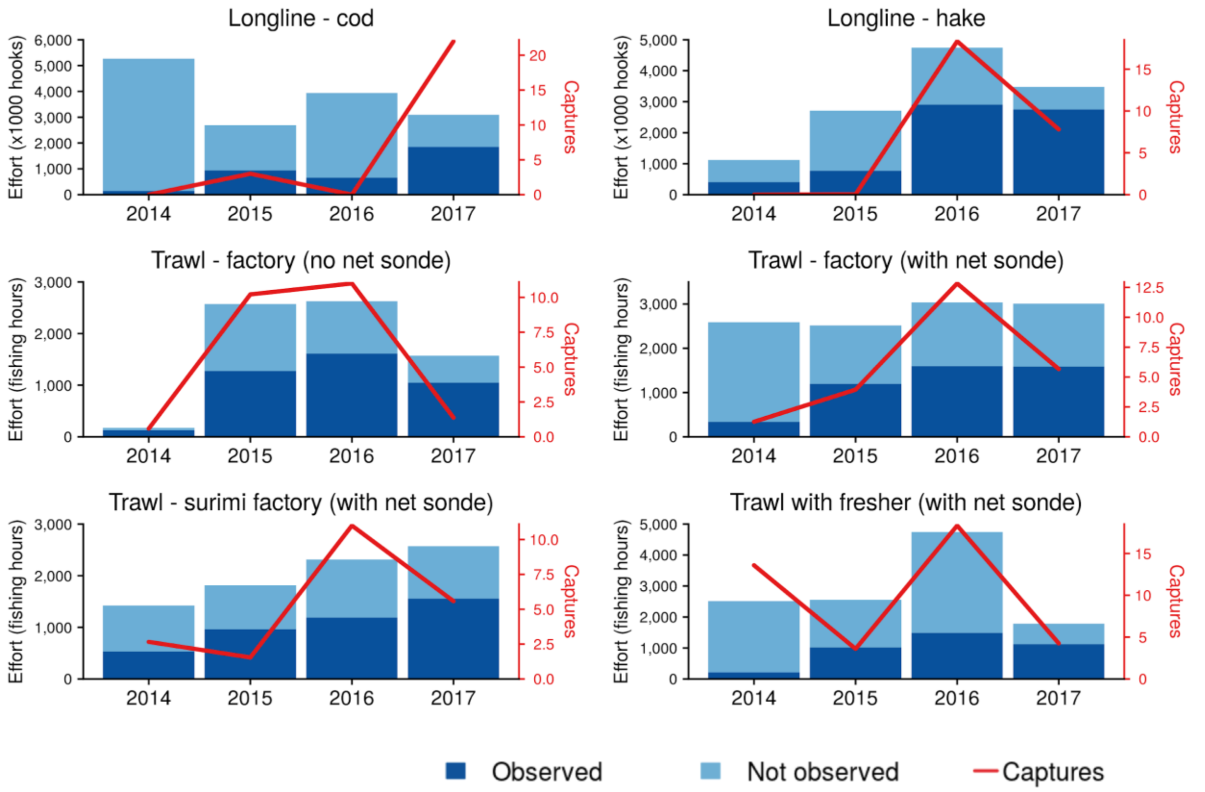

Figure 2. Observed and non-observed fishing effort and observed seabird captures in commercial fisheries in Chilean waters, by year and fishery group (fresher, trawl vessels not processing fish). Number of captures are of 16 seabird species that are listed by the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and overlap with commercial fisheries in Chilean waters.

Table 4. Status of observed seabird captures across all fishery groups, for all albatross and petrel species caught in fisheries in Chilean waters between 2014 and 2017. Fresher refers to trawl vessels not processing fish, NS refers to net-sonde cable.

Fishery group	Albatross			Petrel		
	Captures	**Alive**	**Dead**	**Captures**	**Alive**	**Dead**
Trawl with fresher (with NS)	228	4	224	15	1	14
Trawl - factory (with NS)	4 258	3	4 255	18	0	18
Trawl - surimi factory (with NS)	3 123	27	3 096	136	1	135
Trawl - factory (no NS)	65	12	53	53	15	38
Longline - cod	8	1	7	17	1	16
Longline - hake	555	4	551	146	11	135

2.3 Model

To estimate the number of captures for each species and map grid cell, a spatial Bayesian generalised linear model was fitted to the data on observed captures and fishing effort, for each of the four species groups independently.

For each model, the number of observed captures of species in fishery *f* during quarter *q* and in the map grid cell *i* was assumed to follow a Poisson distribution:

$$C_{sfqi} \sim Poisson(\mu_{sfqi}). \quad (1)$$

The expected number of observed captures was modelled with a fixed species effect v_s, a fixed fishery effect v_f, a random factor varying by species and quarter ϵ_{sq}, a spatial random variable ϕ_i, and scaled by the fishing effort E_f:

$$ln(\mu_{sfqi}) = v_s v_f \epsilon_{sq} \phi_i E_{fi}. \quad (2)$$

The spatial random variable was assigned a conditional autoregressive prior (CAR; Gelfand & Vounatsou 2003) to take into account the spatial autocorrelation between adjacent cells.

The fitted model was then applied to the total fishing effort to estimate the total number of captures that would be observed if all fishing events were observed ("observable captures").

2.4 Annual potential fatalities

Only a proportion of seabird capture interactions are recorded by observers, as not all seabirds that are killed during interactions with fisheries are brought on-board vessels. Examples of this cryptic mortality include birds that drown following collision with trawl warps or get hooked but are not recovered after setting.

Quantifying cryptic mortality is challenging as it is not observable. For longline fisheries, a multi-year study conducted in Australia estimated that half of the birds observed caught during line setting were retrieved during the haul process (Brothers et al. 2010), suggesting that the number of observable captures should be multiplied by two to obtain the total number of fatalities. For New Zealand trawl fisheries, cryptic mortality multipliers were developed based on international literature, on observed warp strike numbers, on the ratio of warp versus net captures, and on some assumptions about mortality rates following warp collisions (see detailed derivation of these cryptic multipliers in Richard et al. 2017). The current study used different cryptic multipliers for the different fishing methods and species combinations (see Table 5), because the multipliers were disaggregated between fishery groups, not applicable to Chile.

Table 5. Cryptic multipliers (mean and 95% credible interval, c.i.) used in this study to calculate the Annual Potential Fatalities from the estimated number of observable captures of seabirds in commercial fisheries in Chilean waters.

		Cryptic multiplier	
Fishing method	**Species group**	**Mean**	**95% c.i.**
Longline	All species	2.08	1.79–2.42
Trawl	Albatross and giant petrels	8.02	4.21–11.80

Other petrels	4.99	2.15–7.85

2.5 Population Sustainability Threshold (PST)

The demographic impact of fishing-related fatalities depends on the population size and the productivity of the species. For example, large seabirds such as great albatrosses breed slowly, produce one egg every two years, and first breed at around 10 years old. Populations of species in this group are not able to sustain as many fatalities as smaller species that breed annually and at an earlier age.

The PST is an index of the population productivity, adapted from the Potential Biological Removal (PBR, Wade 1998). It is an estimate of the maximum number of human-caused mortalities that will allow populations to remain above half their carrying capacity after 200 years, with a 95% probability, when the number of annual potential fatalities equals the PST and when considering uncertainty and environmental stochasticity. The PST differs from the PBR by explicitly including the uncertainty in population size, instead of considering a conservative point estimate of population size; it is also different in not including a recovery factor (see details in Richard et al. 2017).

The PST is defined as:

$$\mathrm{PST} = \tfrac{1}{2}\phi\, r_{\max} N, \qquad (3)$$

where $r_{\max}$ is the maximum population growth rate, under optimal conditions, N is the total population size (in individuals), and ϕ is a correction factor that allows for the calibration of the PST to achieve particular management goals.

The maximum population growth rate $r_{\max}$ is estimated by solving the following expressions (Niel & Lebreton 2005):

$$\lambda_{max} = exp\left[\left(A + \frac{S}{\lambda_{max} - S}\right)^{-1}\right], \qquad (4\ \&\ 5)$$
$$r_{max} = \lambda_{max} - 1,$$

where $\lambda_{\max}$ is the maximum annual population growth rate, A is the mean age at first reproduction, and S is the adult annual survival rate.

Following Gilbert (2009), we calculated the ratio of the total number of individuals greater than one year old, to the number of adults using the relationship

$$R = \frac{\sum_{i=1}^{\infty} N_i}{\sum_{j=A}^{\infty} N_j}, \qquad (6)$$

where N_i is the number of individuals of age i.

By assuming a constant survival rate, taken to be equal to the adult survival, for all birds over one year old, and by assuming that the population has an equilibrium age-distribution, the number of individuals of age i is:

$$N_i = N_0\, S_0 S^{i-1}, \qquad (7)$$

where N_0 is the number of individuals of age 0 (chicks), and S_0 is the survival to age 1. Each $\sum_i N_i$ in Equation 6 being a geometric sum, the ratio becomes:

$$R = S^{1-A}. \qquad (8)$$

Because N_0 and S_0 appear multiplicatively in both the numerator and denominator of the fraction in Equation 6 (from Equation 7), this ratio is independent of clutch size and chick survival. The resulting Gilbert estimate of the population size N^G is:

$$N^G = \frac{2N_{BP}}{P_B} S^{1-A}, \quad (9)$$

where N_{BP} is the number of annual breeding pairs, and P_B is the proportion of adults breeding in a year. The population size, *N*, may then be estimated by applying a calibration factor, *g*:

$$N = gN^G, \quad (10)$$

where *g* was estimated for each of 12 test taxa, by comparing the estimates of the population size from the Gilbert (2009) formula with estimates from a demographic model (see Richard et al. 2017a).

The full distribution of values for the population size and the demographic parameters was used to calculate the PST (the summary of these distributions is shown in Table 6).

Table 6. Demographic parameters (mean and 95% credible interval, c.i.) used in the calculation of the Population Sustainability Threshold (PST). AFR, mean age at first reproduction.

Species	AFR		Annual survival		Total population	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Black-browed albatross	9.0	7.1–10.9	0.945	0.930–0.958	3 870 000	2 740 000–5 280 000
Buller's albatross	12.0	9.1–14.9	0.955	0.931–0.979	185 000	92 800–334 000
Chatham Island albatross	12.0	9.2–14.9	0.965	0.942–0.982	29 900	22 400–42 100
Grey petrel	7.0	5.1–8.9	0.935	0.902–0.968	439 000	266 000–706 000
Grey-headed albatross	10.0	7.1–12.8	0.952	0.932–0.967	702 000	481 000–1 010 000
Light-mantled sooty albatross	12.0	9.1–14.9	0.970	0.960–0.979	81 100	51 100–123 000
Northern giant petrel	8.0	6.1–9.9	0.888	0.812–0.962	95 200	44 000–199 000
Northern royal albatross	9.6	8.6–10.5	0.939	0.910–0.967	59 000	40 900–84 000
Pink-footed shearwater	5.5	4.1–6.9	0.932	0.844–0.978	161 000	86 300–264 000
Salvin's albatross	12.0	9.2–14.9	0.965	0.941–0.982	235 000	180 000–335 000
Shy albatross	12.0	9.2–14.8	0.959	0.935–0.975	101 000	75 000–142 000
Southern giant petrel	7.5	7.0–8.0	0.913	0.836–0.961	415 000	256 000–758 000
Southern royal albatross	9.5	8.5–10.5	0.948	0.931–0.963	74 200	57 600–94 800
Wandering albatross	10.0	7.1–12.9	0.953	0.940–0.964	77 600	57 100–104 000

Westland petrel	6.5	4.1–8.9	0.947	0.919–0.974	13 200	7 730–21 100
White-chinned petrel	6.5	4.1–8.9	0.935	0.902–0.968	4 740 000	3 220 000–7 240 000

An overall correction factor ϕ was included in the PST calculation to achieve the long-term management goal of populations remaining above half their carrying capacity, in the presence of environmental variability. Numerical simulations of seabird populations (Richard et al. 2017) showed that this long-term goal was achieved with ϕ=0.5, in the presence of environmental stochasticity (where environmental stochasticity caused variation in the long-term population with a coefficient of variation of 0.2, in the absence of fisheries mortality).

3. RESULTS

3.1 Model diagnostics

The models fitted the observed data reasonably well (Figures 3,4). The highest percentage of observed captures falling outside the predicted 95% credible interval was 6.3% for the model of the *Thalassarche* group. For other models, the percentage was 2.4%, 1.2% and 0.5% for the Giant Petrels, Small Petrels, and *Diomedea* groups, respectively.

Another model diagnostic, the mixing and convergence of the Markov Chain Monte Carlo chains, was also satisfactory for the four models (see trace plots in Figure 3).

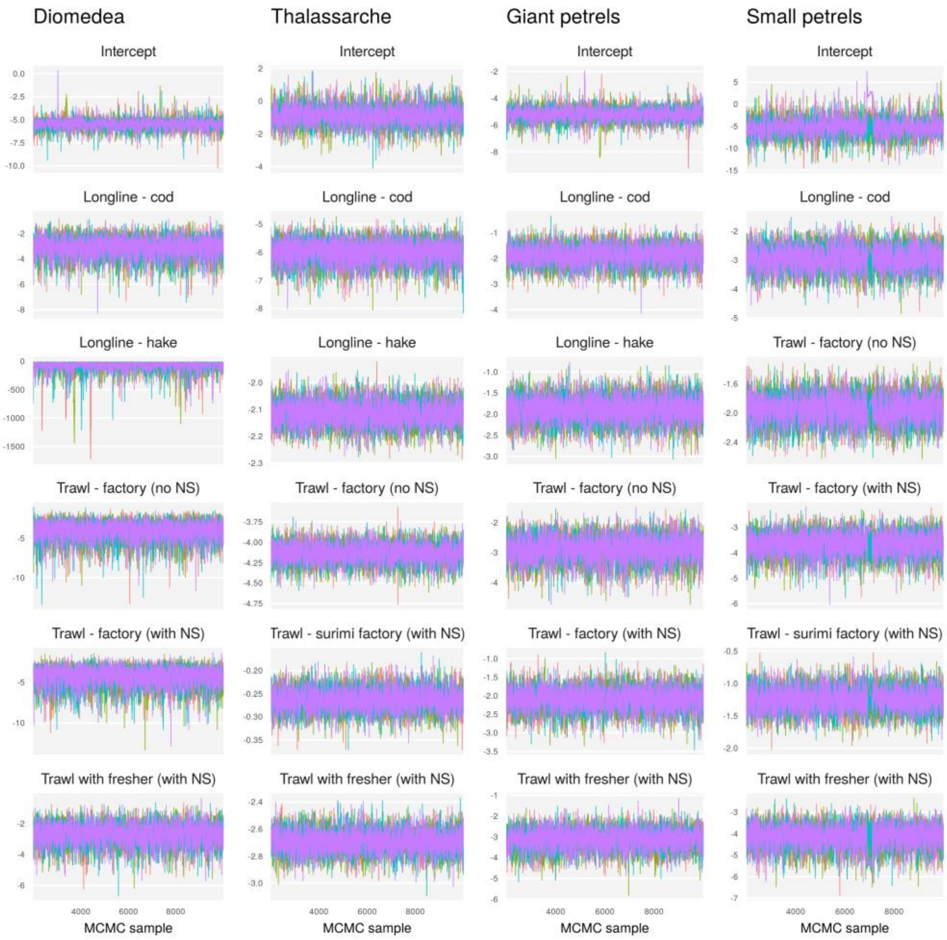

Figure 3. Trace plots of the main parameters of the capture estimation models. One model was fitted to each species group separately, and four Markov Chain Monte Carlo chains were run.

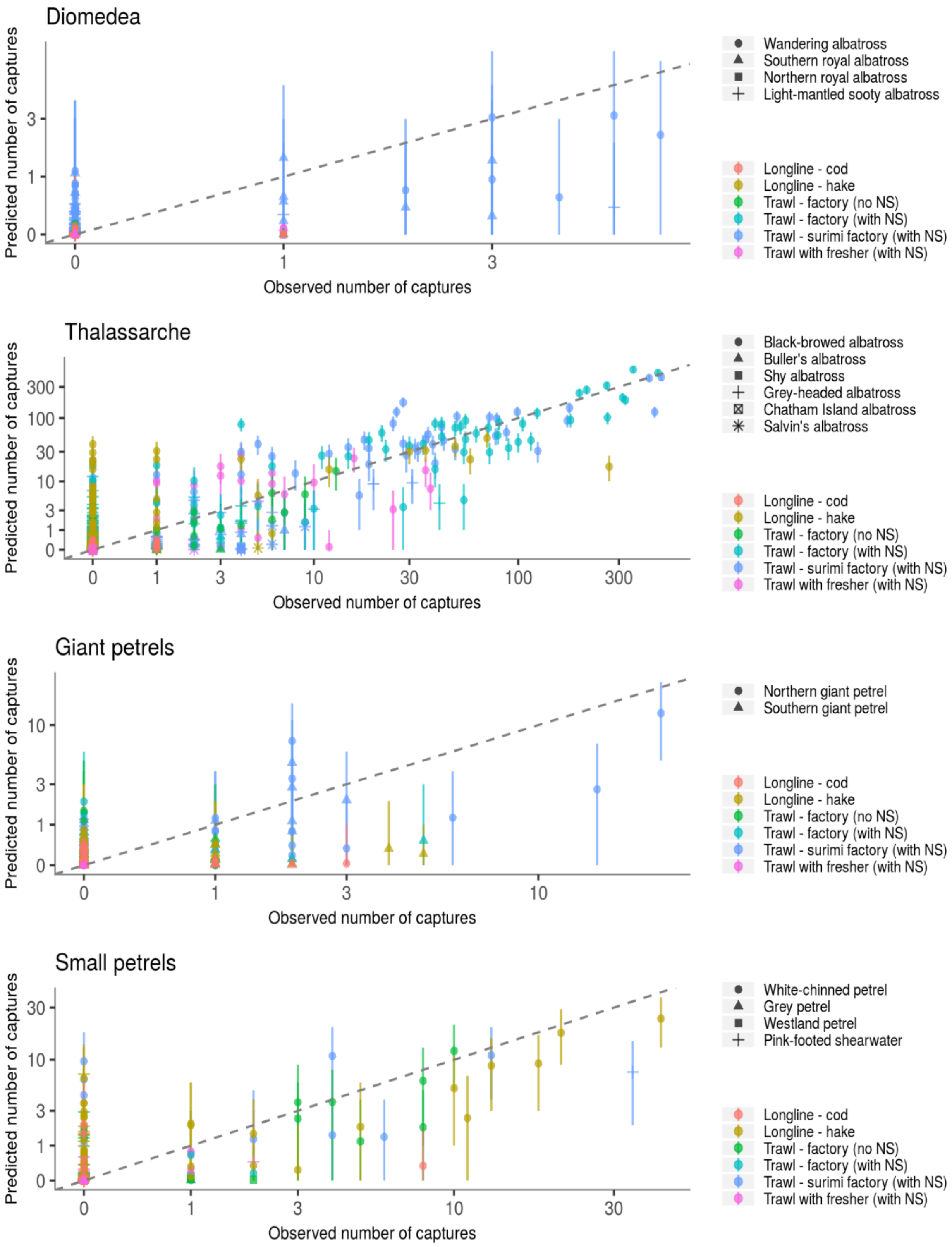

Figure 4. Comparison of the estimated and observed numbers of seabird captures for each model, species, fishery group, and map grid cell for seabirds in Chilean waters. Fishery group included trawl vessels not processing fish (fresher) and fishing with and without net-sonde cable (NS).

3.2 Estimated captures

Across all six fisheries included in the analysis, the annual number of observable captures was estimated at 9 040 (95% credible interval (c.i.): 8700–9360), including 8340 (95% c.i.: 8020–8650) in trawl and 700 (95% c.i.: 600–786) in longline fisheries.

When considering cryptic mortality, the total annual potential fatalities was 67,900 (95% c.i.: 47,300–89,700), including 66,500 (95% c.i.: 45,800–88,300) in trawl and 1460 (95% c.i.: 1230–1660) in longline fisheries.

Over half of the APF were in the trawl fleet with on-board factory and using the net-sonde cable (Table 7), followed by the trawl fleet manufacturing surimi, and the trawl fleet with on-board freshers, both also using the net-sonde cable. These three fishery groups were responsible for 97% of all APF, whereas the longline fisheries targeting hake and cod and the trawl fleet not using a net-sonde cable were together responsible for 3% of all APF.

Over 90% of all APF were of black-browed albatross (Table 8), with an estimated 8290 (95% c.i.: 7 980–8 590) annual observable captures, and 63,500 (95% c.i.: 43,600–84,700) annual potential fatalities. The second highest APF estimate was of grey-headed albatross at 1300 (95% c.i.: 807–1910), and the third highest APF was of white-chinned petrel at 776 (95% c.i.: 557–991).

Table 7. Observable captures and annual potential fatalities (APF) of all 16 seabird species listed by the Agreement on the Conservation of Albatrosses and Petrels (ACAP), for each Chilean fishery included in the study. Shown are the mean and 95% credible interval (c.i.) and the percentage of APF.

Fishery group	**Observable captures**		**APF**		**Perc.**
	Mean	**95% c.i.**	**Mean**	**95% c.i.**	
Trawl - factory (with NS)	4 730	4 490–4 970	37 900	25 700–50 700	55.8
Trawl - surimi factory (with NS)	3 150	2 960–3 330	25 000	17 400–33 100	36.8
Trawl with fresher (with NS)	364	296–438	2 880	1 900–4 030	4.2
Trawl - factory (no NS)	96.9	66–132	667	414–980	1.0
Longline - hake	633	550–718	1 320	1 120–1 520	1.9
Longline - cod	66.7	30–94	139	60.5–197	0.2

The estimated capture rate, i.e., the number of ACAP-listed seabirds incidentally captured per unit of effort, was highest for the trawl fishery with a factory on board and not manufacturing surimi, at 1.70 (95% c.i.: 1.61–1.78) observable captures per hour of fishing, and 13.60 (95% c.i.: 9.22–18.19) potential fatalities when including cryptic mortality (Table 9). The capture rate in the trawl factory fleet manufacturing surimi was similar, although lower. These capture rates were around 30 times higher than in the trawl factory fleet not using the net sonde cable, which capture rate was 0.06 (95% c.i.: 0.04–0.08) observable captures and 0.38 (95% c.i.: 0.24–0.56) potential fatalities per hour of fishing.

Table 8. Observable captures and Annual Potential Fatalities (APF) by seabird species, in Chilean fisheries included in this study. Shown are the mean and 95% credible interval (c.i.), ordered by decreasing mean APF.

Species	**Observable captures**		**APF**	
	Mean	**95% c.i.**	**Mean**	**95% c.i.**
Black-browed albatross	8 290	7 980–8 590	63 500	43 600–84 700
Grey-headed albatross	171	128–220	1 300	807–1 910
White-chinned petrel	234	176–286	776	557–991
Northern giant petrel	79	50–112	524	311–773
Salvin's albatross	49	28–76	373	183–628
Southern giant petrel	55	32–84	351	186–553
Buller's albatross	35	16–58	268	114–478
Wandering albatross	29	12–50	214	83–378
Shy albatross	24	10–42	182	63–355
Pink-footed shearwater	42	18–60	145	54–227
Southern royal albatross	15	4–30	111	27–232
Chatham Island albatross	6	0–16	50	0–138
Light-mantled sooty albatross	7	0–16	49	0–131
Westland petrel	5	0–14	17	0–52
Northern royal albatross	1	0–6	8	0–50
Grey petrel	1	0–6	4	0–23

The capture rate in the trawl fresher fleet, using a net sonde cable, was over twice the rate of the factory trawl fleet not using a net sonde cable, with a mean 0.13 (95% c.i.: 0.10–0.15) observable captures, and 0.99 (95% c.i.: 0.66–1.39) potential fatalities per hour of fishing.

The estimated capture rate in the longline fishery targeting hake was 0.21 (95% c.i.: 0.18–0.24) observable captures, and 0.44 (95% c.i.: 0.37–0.50) potential fatalities per 1000 hooks. It was 0.02 (95% c.i.: 0.01–0.03) observable captures and 0.04 (95% c.i.: 0.02–0.05) potential fatalities per 1000 cachaloteras in the longline fishery targeting cod.

The spatial distribution of estimated captures varied between species (Figure 5). However, the APF were most concentrated off the coast by 46°S, where the ocean is high in productivity and represents the spawning ground of a number of fish species.

Table 9. Annual Potential Fatalities of seabirds by species and Chilean fishery group (fresher, trawl vessels not processing fish; NS, net-sonde cable). Shown are the mean and 95% credible interval.

Species				Trawl		Longline
	Surimi factory	Factory (with NS)	Factory (no NS)	Fresher	Hake	Cod
Black-browed albatross	11 500 (7 860–15 500)	18 200 (12 300–24 400)	208 (104–344)	1 300 (831–1 860)	488 (406–579)	11.7 (1.8–28.4)
Buller's albatross	41.4 (7.4–90)	82.7 (28.1–158)	1 (0–10.7)	6.1 (0–24)	2.7 (0–8.6)	0.1 (0–1.9)
Chatham Island albatross	8.3 (0–31.8)	15.1 (0–47.2)	0.1 (0–0)	1.1 (0–10.8)	0.3 (0–2.3)	0 (0–0)
Grey petrel	0.6 (0–7.2)	0.1 (0–0)	0.3 (0–5)	0.2 (0–4.5)	0.6 (0–4.2)	0.2 (0–2.1)
Grey-headed albatross	233 (126–366)	374 (219–567)	5.3 (0–22.4)	26.7 (0–63.2)	12.2 (3.8–23.6)	0.2 (0–2.2)
Light-mantled sooty albatross	20.5 (0–57.3)	0.6 (0–9.5)	0.4 (0–7.9)	2.4 (0–16.8)	0 (0–0)	0.6 (0–4.2)
Northern giant petrel	173 (88.5–280)	33.9 (0–79.8)	14.4 (0–45)	21 (0–59.9)	8.9 (1.8–20)	10.4 (1.8–24.3)
Northern royal albatross	3.4 (0–21.6)	0.1 (0–0)	0.1 (0–0)	0.4 (0–8)	0 (0–0)	0.1 (0–2.1)
Pink-footed shearwater	24.1 (3.6–58.6)	7.5 (0–8)	10 (0–29.9)	7.7 (0–25.4)	15.3 (4.2–29.2)	7.9 (0–13.7)
Salvin's albatross	60 (17.6–118)	113 (46.2–204)	1.3 (0–11.1)	8.2 (0–29.4)	3.4 (0–9.4)	0.1 (0–2)
Shy albatross	30.1 (0–73.5)	54.8 (12.4–118)	0.5 (0–8.6)	4.1 (0–20.5)	1.5 (0–6.2)	0 (0–0)
Southern giant petrel	110 (46.2–192)	25.4 (0–64.6)	9 (0–32.6)	15.3 (0–46.6)	6.9 (0–16.6)	9 (0–21.5)
Southern royal albatross	46.5 (8.7–102)	1.3 (0–11.6)	1 (0–10.9)	5.1 (0–25.3)	0 (0–0)	1.2 (0–6.3)
Wandering albatross	88.5 (30.5–163)	2.8 (0–18.9)	2 (0–16.2)	10.9 (0–40.6)	0 (0–0)	2.7 (0–10.7)
Westland petrel	2.5 (0–13.1)	0.3 (0–5.9)	1.9 (0–11.6)	0.7 (0–7)	2.4 (0–8.5)	0.8 (0–4.1)
White-chinned petrel	124 (64.2–201)	19.2 (0–41.5)	78.2 (34–137)	26.4 (2.6–61)	116 (80.4–155)	24.4 (4–41.9)

Table 10. Estimated capture rates of seabirds in the six Chilean fishery groups included in this study (fresher, trawl vessels not processing fish; NS, net-sonde cable). Rates (mean and 95% credible interval, c.i.) are shown for observable captures and for Annual Potential Fatalities (i.e., including cryptic mortality). The rates represent the number of seabirds caught per hour of fishing for trawl, per 1000 cachaloteras for the cod longline fishery, and per 1000 hooks for the hake longline fishery. Fisheries are sorted by method and by decreasing mean capture rate.

Fishery group	Observable captures		APF	
	Mean	95% c.i.	Mean	95% c.i.
Trawl - factory (with NS)	1.7	1.61–1.78	13.6	9.22–18.20
Trawl - surimi factory (with NS)	1.55	1.46–1.64	12.3	8.57–16.30
Trawl with fresher (with NS)	0.13	0.10–0.15	0.99	0.66–1.39
Trawl - factory (no NS)	0.06	0.04–0.08	0.38	0.24–0.56
Longline - hake	0.21	0.18–0.24	0.44	0.37–0.50
Longline - cod	0.02	0.01–0.03	0.04	0.02–0.05

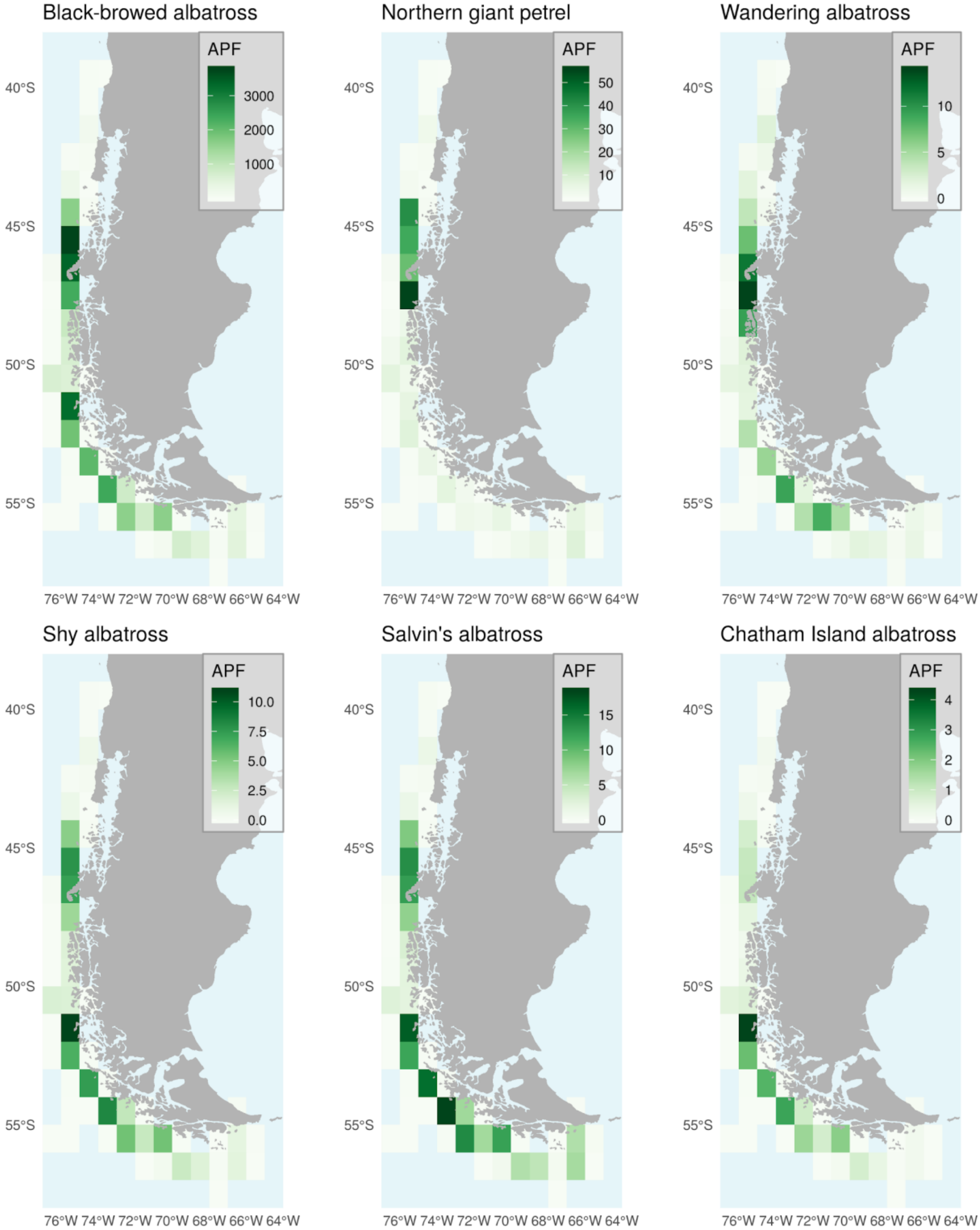

Figure 5. Annual Potential Fatalities (APF) of the six seabird species with the highest estimated risk from Chilean fisheries.

3.3 Risk estimation

When considering the demographic impact of annual potential fatalities, black-browed albatross was distinctly the species most at risk from Chilean fisheries; the estimated number of APF in Chilean waters represented 55% (95% c.i.: 34–86%) of the PST, estimated at 57,600 (95% c.i.: 41,300–79,100) individuals per year (Figure 6; Table 11).

Northern giant petrel was the second species most at risk, with the APF representing 14% (95% c.i.: 6–35%) of the PST of 1920 (95% c.i.: 810–3810) individuals per year. The third most-at-risk species was wandering albatross with the estimated APF at 10% (95% c.i.: 4–20%) of the PST. All other species had an estimated mean APF below 10% of their PST (Table 11).

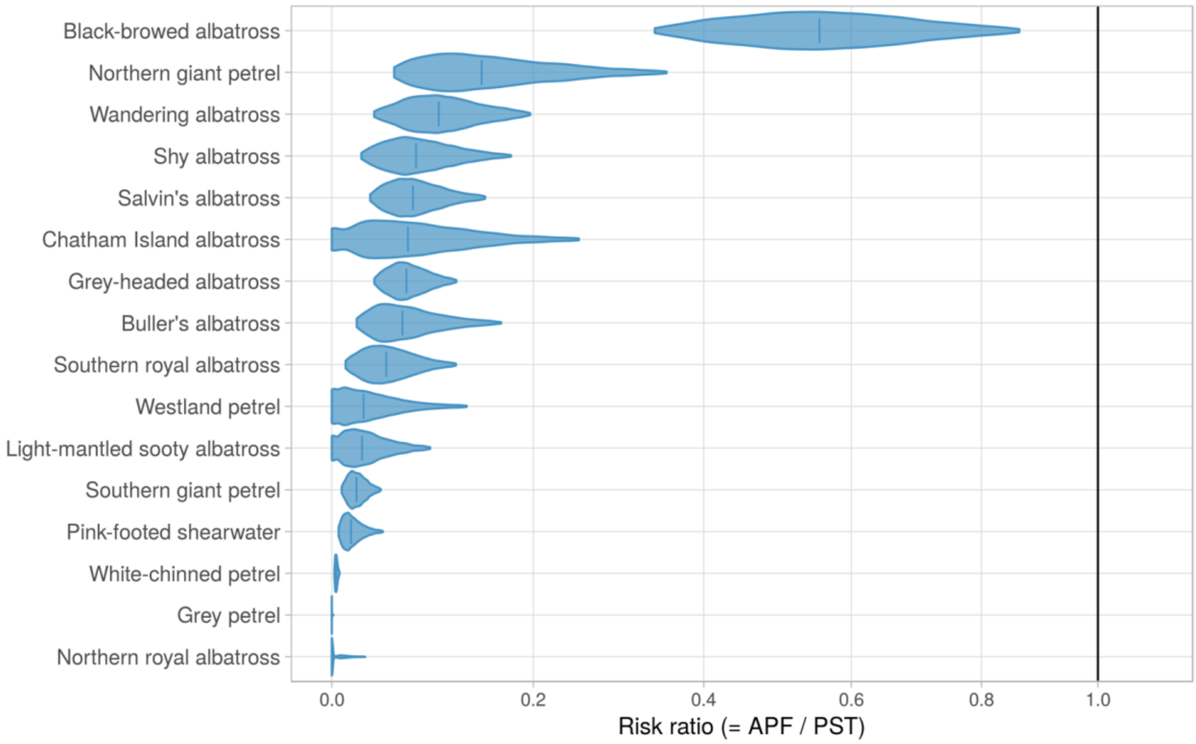

Figure 6. Risk ratios for the ACAP-listed taxa considered in this study. A risk ratio over 1, shown by the vertical line, indicates that annual potential mortalities exceeded the Population Sustainability Threshold.

Table 11. Population Sustainability Threshold (PST), Annual Potential Fatalities (APF) and risk ratio (APF/PST) for the 16 seabird species listed by the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and that overlap with Chilean fisheries. Shown are the mean and 95% credible interval (c.i.).

Species	**PST**		**APF**		**Risk ratio**	
	Mean	**95% c.i.**	**Mean**	**95% c.i.**	**Median**	**95% c.i.**
Black-browed albatross	57 600	41 300–79 100	31 800	21 800–42 300	0.55	0.34–0.86
Northern giant petrel	1 920	810–3 810	262	156–386	0.14	0.06–0.35
Wandering albatross	1 030	769–1 370	107	41–189	0.10	0.04–0.20
Shy albatross	1 100	798–1 560	91	31–177	0.08	0.03–0.18
Salvin’s albatross	2 400	1 650–3 490	186	92–314	0.08	0.04–0.15
Chatham Island albatross	306	211–446	25	0–69	0.07	0.00–0.25
Grey-headed albatross	9 300	6 450–13 200	651	403–954	0.07	0.04–0.12
Buller’s albatross	2 060	1 010–3 730	134	57–239	0.07	0.02–0.17
Southern royal albatross	1 040	783–1 360	55	13–116	0.05	0.01–0.12
Westland petrel	246	130–409	9	0–26	0.03	0.00–0.13
Light-mantled sooty albatross	796	486–1 220	25	0–66	0.03	0.00–0.09
Southern giant petrel	8 110	4 620–15 000	175	93–276	0.02	0.01–0.05
Pink-footed shearwater	3 650	1 680–6 770	73	27–114	0.02	0.01–0.05
White-chinned petrel	94 600	58 900–141 000	388	278–495	0.00	0.00–0.01
Northern royal albatross	864	559–1 270	4	0–25	0.00	0.00–0.03
Grey petrel	8 300	4 640–13 400	2	0–12	0.00	0.00–0.00

4. DISCUSSION

This report is a preliminary assessment of the risk of fisheries in Chilean waters to ACAP species. The method used did not rely on the at-sea distribution of species, unlike the SEFRA framework.

Our estimate of 8340 (95% c.i.: 8020–8650) annual observable captures in Chilean trawl fisheries is lower than the estimate provided by Adasme et al. (2019). Their estimate of 9900 captures was obtained by multiplying the observed capture rate by the total annual fishing effort. When considering cryptic mortality, the estimate of the number of black-browed albatross killed by Chilean fisheries may be around 70,000, potentially representing 55% of the PST. The PST includes the productivity of the entire world population of black-browed albatross, and the APF in Chilean waters may therefore exceed the productivity of the local population, which represents 20% of the world population (ACAP 2010).

Our estimates of Annual Potential Fatalities relied on cryptic mortality multipliers that were developed in New Zealand, and that included some strong assumptions about how seabirds interact with fishing gear and their associated mortality. Including cryptic mortality led to a scaling of the number of observable captures by a factor of 8 and 2 in trawl and longline fisheries, respectively. Cryptic mortality is poorly known, however, and more studies are necessary to improve our estimates of the total number of seabird fatalities resulting from fisheries interactions.

The trawl fleet with on-board fish processing tends to discharge a large quantity of fish waste at sea and to attract higher number of birds than trawlers with a fresher (Pierre et al. 2010). This notion was supported by our results when comparing the estimated capture rate between the trawl factory fleet and the fresher fleet, with the former having a capture rate that was around 15 times higher than the latter fleet. However, the use of the net-sonde cable appeared to have a larger effect than discard management, since trawl factory vessels using a net-sonde cable had an estimated capture rate that was 30 times higher than the factory fleet not using one. The capture rate in the factory fleet not using a cable was less than half that of the trawl fresher fleet, despite the discarding of fish waste. In addition, the proportion of captured birds released alive was the lowest in the trawl factory fleet using a net-sonde cable, whereas it was the highest when the net sonde cable was not used. Because all captures were assumed to be fatal in the analysis, the estimated risk of the trawl factory fleet without a net-sonde cable is likely to be overestimated.

Despite the strong differences in capture rates, the role of the net-sonde cable is only tentative, due to the different spatial distributions of the fishing effort and the small number of vessels in each fleet (there were only two vessels for the trawl factory fleet not using a net-sonde cable). Other confounding effects are, therefore, possible. Should these effects be supported with more data, mitigating the use of net-sonde cables and discard management may represent a promising way to reduce incidental mortalities in Chilean trawl fisheries.

The method used in this study assumed that the identification of captured species by the observers was accurate. This assumption is strong given the difficulty for observers to closely examine captured birds. In Chile, identifications are not subsequently validated by experts either from photographs or necropsy (as, for example, in New Zealand), so the mis-identification rate is unknown. Further validation of identifications would be beneficial and improve the quality of the analysis.

Internationally, longline fisheries have been considered the primary driver of seabird bycatch globally, with some estimates suggesting that at least 160 000 seabirds are killed annually in longline fisheries (Anderson et al. 2011). The management of fishing practices and of mitigation techniques has, therefore, been focused on these fisheries around the world, and successfully led to a reduction of bycatch in Chile and New Zealand (Suazo et al. 2014, Robertson et al. 2017, Abraham & Richard 2018). For instance, cachaloteras were introduced in Chile to the longline fleet targeting cod in 2006 to prevent the incidental capture of orca (*Orcinus orca*) and sperm whale (*Physeter macrocephalus*); their introduction also reduced the bycatch of seabirds to none thanks to a faster sinking rate (Moreno et al. 2008).

Our analysis suggests that in Chilean waters, as in New Zealand waters (Richard et al. 2017), seabirds now face a larger threat from trawl fisheries than from longline fisheries. Mitigating bycatch in trawl fisheries would be beneficial to the impacted species.

5. ACKNOWLEDGMENTS

The visit of Luis Adasme to New Zealand was funded by ACAP through the grant “Evaluacion de riesgo de captura incidental de aves marinas en pesqueries del Pacifico Sur”. Yvan Richard was funded through Fisheries New Zealand project SEA2018-28. We are grateful to these agencies for facilitating this collaboration. We also thank Igor Debski (New Zealand Department of Conservation) and Nathan Walker (Fisheries New Zealand) for their guidance and discussions about this work.

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