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Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2014–15

New Zealand Aquatic Environment and Biodiversity Report 191

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Seabirds are incidentally captured during commercial fishing operations, but assessing the impact of fishing mortalities on seabird populations is hampered by a lack of information. Seabird bycatch is not fully known, and understanding of seabird populations is limited. To manage the effects of fisheries on seabird populations, risk-based approaches are used to assess the population impacts of commercial fisheries on seabirds. In New Zealand, assessments of the risk to seabird populations from fisheries bycatch have been based on a comparison of the ratio between estimates of incidental captures and estimates of seabird population productivity, following the Spatially Explicit Fisheries Risk Assessment framework. This report presents an update of the previous assessment of the risk of commercial fisheries in New Zealand, for 71 seabird taxa that breed in the New Zealand region.

In this risk assessment, estimates of incidental captures were derived from the captures of seabirds recorded by government observers onboard fishing vessels and from data on fishing effort between 2006–07 and 2014–15, and the risk was calculated using annual average fishing effort for the period from 2012–13 to 2014–15. A Population Sustainability Threshold (PST) was used for seabird population productivity, a generalisation of the Potential Biological Removal (PBR) index, based on the total number of breeding pairs, and including the uncertainty in all demographic parameters explicitly.

A total of 16 species were estimated to have a risk that was non-negligible. Black petrel (*Procellaria parkinsoni*) was identified to be the species most at risk from commercial fisheries, and the only species in the "very high risk" category. There were seven species in the next highest estimated risk ranking, "high risk", including (in decreasing order of median risk ratio) Salvin's albatross (*Thalassarche salvini*), flesh-footed shearwater (*Puffinus carneipes*), southern Buller's albatross (*Thalassarche bulleri bulleri*), Westland petrel (*Procellaria westlandica*), Gibson's albatross (*Diomedea antipodensis gibsoni*), New Zealand white-capped albatross (*Thalassarche cauta steadi*), and Chatham Island albatross (*Thalassarche eremita*). A further four taxa had an estimated risk ranking of "medium risk", and four taxa were categorised to be at "low risk". The risk category of the remaining 55 seabird populations was "negligible risk".

The mean number of potential fatalities of the 71 taxa in New Zealand commercial trawl, bottom-longline, surface-longline, and set-net fisheries was estimated at 14 400 (95% c.i.: 11 900–17 500) birds annually. Most fatalities were estimated to occur in trawl fisheries, especially in the inshore fleet (although the estimate is highly uncertain). The estimate of annual potential fatalities includes cryptic mortalities: birds that are killed by the fishing activity but not brought on-board the fishing vessel or not included in captures reported by fisheries observers. The term "potential fatalities" is used to indicate the inherent uncertainty associated with estimating these cryptic fatalities.

Significant changes were made to the methodology to address limitations identified in previous risk assessments. Updates to the methodology included the use of a Population Sustainability Threshold (PST) for seabird population productivity, based on the total number of breeding pairs (rather than the lower quartile used previously in the PBR). This update included changes in the correction factors to meet the long-term goal of populations remaining above half their carrying capacity, in the presence of environmental variability. Other changes from the preceding risk assessment included the use of allometric modelling to reduce variability in the estimates of age at first reproduction and of adult survival. Both parameters were used in calculating the population growth rate under optimal conditions ($r_{\max}$).

Updates from the preceding risk assessment also included the use of an integrated model for estimating fisheries mortalities, to prevent them from exceeding the total annual mortality of the adult population, and to ensure that estimated mortalities, seabird population size, and adult survival were mutually consistent. In addition, the proportion of captures released alive was estimated from the data, and half of

the live releases were assumed to survive on average; the cryptic multiplier, used to estimate the total number of fatalities from the number of observable captures, was disaggregated between fishery groups in trawl fisheries; vulnerability to capture was estimated in a single model across all fishing methods; for selected fisheries, the vulnerability was allowed to vary between the period before and after 2010; the recent split of Stewart Island shag (*Leucocarbo chalconotus*) into two separate species (Otago shag *L. chalconotus* and Foveaux shag *L. stewarti*) was incorporated in the current analysis; furthermore, for black petrel, an updated at-sea distribution was derived.

Applying these changes led to an overall decrease in the estimated risk for all taxa from the previous risk assessment, with most decreases resulting from the removal of the correction factor for the population growth rate r_{max}, and the use of the total population size in the PST calculation.

The current seabird risk assessment supports the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries", which sets out the New Zealand government's framework for reducing the impact of fishing on New Zealand seabird populations.

1. INTRODUCTION

Seabirds are exposed to a number of threats worldwide, including invasive species, climate change, ocean pollution, and habitat degradation (Croxall et al. 2012). Almost half of all seabird species are confirmed or considered to be undergoing population declines, and seabirds have been highlighted as the most threatened bird group on a global scale (International Union for Conservation of Nature 2017). Threats to seabirds also include incidental captures in commercial fisheries, which result from interactions with fishing gear, such as entanglements in nets and captures on hooks. As these interactions frequently result in mortalities, fishing poses a significant threat to seabirds across different regions, including New Zealand.

New Zealand waters support a high number and diversity of seabirds, with around 25% of the world's seabird species breeding in the New Zealand region. On a global scale, New Zealand has been identified as one of few seabird biodiversity hotspots (Karpouzi et al. 2007). The vulnerability of seabirds to commercial fishing activities in New Zealand waters has been recognised in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (NPOA; Ministry for Primary Industries 2013). This key policy for managing the impact of commercial fisheries on seabirds outlines long- and short-term goals, with the latter including a five-year biological risk objective. This objective is aimed at reducing the level of seabird mortality in New Zealand commercial fisheries, and requires that "species currently categorised as at very high or high risk from fishing move to a lower category of risk" (Ministry for Primary Industries 2013).

The current risk assessment is a primary input to the NPOA, as it provides a framework for the five-year biological risk objective, and allows the monitoring of progress towards this goal. Previous studies to assess the risk of commercial fisheries to seabirds that breed in the New Zealand region have focused on the identification of species whose populations may be adversely affected by fishing-related mortalities (Waugh et al. 2009, Rowe 2010, Dillingham & Fletcher 2011, Richard et al. 2011, Sharp et al. 2011, Richard & Abraham 2013c, 2015). The risk assessment presented here addresses limitations in the methodology used for previous assessments (Richard et al. 2011, Richard & Abraham 2013c, 2015), and updates the assessment to use recent fisheries and seabird bycatch data. These recent data include observer records and fishing effort data for the fishing years between 2006–07 and 2014–15, with the risk calculation based on annual average fishing effort for the period from 2012–13 to 2014–15.

The risk assessment is accompanied by supplementary information that provides detailed information on the demographic parameters and at-sea distribution used for the 71 seabird taxa included in the assessment. Due to the size of the supplementary information, it is produced as a separate document (Richard et al. 2017).

Details of the updates and changes in the current risk assessment are outlined in Appendices A to F, summary tables are provided in Appendix G.

2. METHODS

The risk assessment followed the Spatially Explicit Framework for Risk Assessment (SEFRA; Ministry for Primary Industries 2016b, Chapter 3). The risk of fisheries to seabirds is expressed as the ratio of annual potential fatalities (APF) to the Population Sustainability Threshold (PST), an index of population productivity,

$$\mathrm{RR} = \mathrm{APF}/\mathrm{PST}, \tag{1}$$

where RR is referred to as the risk ratio.

The annual potential fatalities are estimated using spatial overlap, and include all fatalities from the fisheries with sufficient observations: trawl, bottom-longline, surface-longline, and set-net fisheries within New Zealand's Exclusive Economic Zone (EEZ). The estimate of annual potential fatalities includes cryptic mortalities, i.e., birds that are killed by the fishing activity but not brought on-board the fishing vessel and not included in captures reported by fisheries observers. The term "potential fatalities" is used to indicate the inherent uncertainty associated with estimating these cryptic fatalities, and the other uncertainties associated with estimating fatalities from observed captures.

The PST is adapted from the Potential Biological Removal index (PBR; Wade 1998), which was developed under the United States Marine Mammal Protection Act to assess the maximum level of human-induced mortality that a population can incur, while being able to stay above half its carrying capacity in the long term (Wade 1998).

In accordance with the NPOA, the risk of fisheries to seabirds was categorised according to the median and the upper limit of the 95% credible interval of the risk ratio:

- Very high risk: median risk ratio above 1 or an upper 95% credible limit above 2,
- High risk: median above 0.3 or an upper 95% credible limit above 1,
- Medium risk: median above 0.1 or an upper 95% credible limit above 0.3,
- Low risk: upper 95% credible limit above 0.1,
- Negligible risk: upper 95% credible limit less than 0.1.

The current risk assessment includes a number of updates to the analysis by Richard and Abraham (2015), resulting from consultation with New Zealand's Ministry for Primary Industries (MPI), the Aquatic Environment Working Group (AEWG), and seabird and fishery experts. These updates include changes to the methodology and to the input data.

The main updates were:

1. Data on fishing effort and observed captures included two more fishing years, and vulnerability to capture was estimated using data for the period between 2006–07 and 2014–15.
2. Annual potential fatalities were estimated based on spatial overlap using data between the 2012–13 and 2014–15 fishing years to reflect the current level and spatial distribution of fishing effort.
3. The total population size rather than the lower quartile was used in calculating the PST.
4. Allometric modelling was used to reduce variability in the estimates of age at first reproduction and of adult survival, which are used in calculating the population growth rate in optimal conditions (r_{max}).
5. No correction was made to the estimate of r_{max}.
6. An overall correction factor of $\phi = 0.5$ for all species was used in the PST formulation, so that seabird populations meet the long-term goal of remaining above half their carrying capacity, in the presence of environmental variability, confirmed by simulations.
7. An integrated model for estimating fisheries mortalities was developed, so that the fishing-related mortality is less than the total annual mortality of the adult population (which was estimated from adult survival). This update ensured that estimated mortalities, population size, and adult survival were mutually consistent.
8. The proportion of captures released alive was estimated from the data, and half of the live releases were assumed to survive on average.
9. Fishery groups were amended and the species demographic parameters updated, following consultation with experts, as directed by MPI.
10. The cryptic multiplier, used to estimate the total number of fatalities from the number of observable captures, was disaggregated between fishery groups in trawl fisheries based on observer data.

11. The total number of fatalities instead of the number of observable captures was assumed to be related to vulnerability.

12. Vulnerability to capture was allowed to vary between the pre- and post-2010 period in fisheries with a sufficient number of observations.

13. Vulnerability was estimated in a single integrated model, instead of modelling each fishing method separately.

14. Stewart Island shag (*Leucocarbo chalconotus*) was split into two separate species, the Otago shag (*L. chalconotus*) and Foveaux shag (*L. stewarti*), following a recent study.

15. An updated, seasonally disaggregated at-sea distribution map for black petrel (*Procellaria parkinsoni*) was used, derived from Global Positioning System (GPS) tracking data.

2.1 New Zealand seabird populations and demographic parameters

The risk assessment included 71 seabird taxa that breed in the New Zealand region (Table 1). Demographic parameters used in the risk assessment included the number of annual breeding pairs, the proportion of adults breeding in any given year, the annual adult survival rate, the age at first reproduction, and the body mass of each species.

Seabird taxonomy followed the recommendations of the Ornithological Society of New Zealand (Ornithological Society of New Zealand checklist committee 2010), with some exceptions. One exception was Stewart Island shag *Leucocarbo chalconotus*, which was split into two separate species, Otago shag (*L. chalconotus*) and Foveaux shag (*L. stewarti*) in 2016, based on a study that showed genetic and morphological differences between the Otago and Foveaux Strait populations (Rawlence et al. 2016).

Another exception was splitting the population of little penguin *Eudyptula minor* into the four forms recognised by Department of Conservation and the New Zealand Threat Classification System (Robertson et al. 2017): northern, southern, Chatham Island, and white-flippered little penguin.

In addition to the 71 taxa, the risk to the “mainland” population of yellow-eyed penguin (South Island and Stewart Island), i.e., excluding the subantarctic population, was assessed independently. The mainland population of yellow-eyed penguin is small (600–800 pairs in 2012; U. Ellenberg, Yellow-Eyed Penguin Trust, pers. comm.), of public interest, and all incidental captures may be of this population. The risk was, therefore, considered for the mainland population separate from the subantarctic population, assuming that all estimated incidental captures in New Zealand were of the mainland population of yellow-eyed penguin.

For each seabird taxon, demographic parameters were obtained from the literature. The main sources of information were in the primary literature, in published books on seabirds, in “grey” literature, and in trusted resources on the internet, such as BirdLife International (http://www.birdlife.org/datazone/species) and the Agreement on the Conservation of Albatrosses and Petrels (ACAP; http://www.acap.aq). Where no demographic information was available, values from proxy species were used instead.

Furthermore, to ensure that the most relevant population information was included in the present study, New Zealand seabird experts were canvassed in September 2016. Experts were sent a document with detailed population information similar to that supplementing the current report, and asked for their feedback and updates. Their responses were compiled by MPI, and the demographic parameters were then updated accordingly (see Appendix G, Tables G-16 to G-18).

To explicitly account for the uncertainty in all parameters, every demographic estimate was assigned a standard deviation (s.d.), or a range when necessary, to match the uncertainties typically reported in the literature (see Appendix A for the process of deriving uncertainties).

Table 1: List of the 71 seabird taxa included in the current risk assessment. Seabird groupings were used for the estimation of vulnerability, of cryptic mortalities in trawl fisheries, and for the correction of total population size.

Common name	Scientific name	Groups		
		Vulnerability	Cryptic mortality	Population correction
Gibson's albatross	*Diomedea antipodensis gibsoni*	Wandering albatrosses	Large albatrosses	Antipodean albatross
Antipodean albatross	*Diomedea antipodensis antipodensis*	Wandering albatrosses	Large albatrosses	Antipodean albatross
Southern royal albatross	*Diomedea epomophora*	Royal albatrosses	Large albatrosses	Antipodean albatross
Northern royal albatross	*Diomedea sanfordi*	Royal albatrosses	Large albatrosses	Antipodean albatross
Campbell black-browed albatross	*Thalassarche impavida*	Campbell black-browed albatross	Mollymawks & giant petrel	Grey-headed albatross
New Zealand white-capped albatross	*Thalassarche cauta steadi*	White-capped albatross	Mollymawks & giant petrel	Grey-headed albatross
Salvin's albatross	*Thalassarche salvini*	Salvin's albatross	Mollymawks & giant petrel	Grey-headed albatross
Chatham Island albatross	*Thalassarche eremita*	Chatham albatross	Mollymawks & giant petrel	Grey-headed albatross
Grey-headed albatross	*Thalassarche chrysostoma*	Grey-headed albatross	Mollymawks & giant petrel	Grey-headed albatross
Southern Buller's albatross	*Thalassarche bulleri bulleri*	Buller's albatrosses	Mollymawks & giant petrel	Grey-headed albatross
Northern Buller's albatross	*Thalassarche bulleri platei*	Buller's albatrosses	Mollymawks & giant petrel	Grey-headed albatross
Light-mantled sooty albatross	*Phoebetria palpebrata*	Light-mantled sooty albatross	Mollymawks & giant petrel	Antipodean albatross
Northern giant petrel	*Macronectes halli*	Giant petrel	Mollymawks & giant petrel	Giant petrel
Grey petrel	*Procellaria cinerea*	Grey petrel	Medium-sized seabirds	Black petrel
Black petrel	*Procellaria parkinsoni*	Black petrel	Medium-sized seabirds	Black petrel
Westland petrel	*Procellaria westlandica*	Westland petrel	Medium-sized seabirds	Black petrel
White-chinned petrel	*Procellaria aequinoctialis*	White-chinned petrel	Medium-sized seabirds	Black petrel
Flesh-footed shearwater	*Puffinus carneipes*	Flesh-footed shearwater	Medium-sized seabirds	Flesh-footed shearwater
Wedge-tailed shearwater	*Puffinus pacificus*	Shearwaters	Small-sized seabirds	Flesh-footed shearwater
Buller's shearwater	*Puffinus bulleri*	Shearwaters	Small-sized seabirds	Flesh-footed shearwater
Sooty shearwater	*Puffinus griseus*	Sooty shearwater	Medium-sized seabirds	Flesh-footed shearwater
Fluttering shearwater	*Puffinus gavia*	Shearwaters	Small-sized seabirds	Flesh-footed shearwater
Hutton's shearwater	*Puffinus huttoni*	Shearwaters	Small-sized seabirds	Flesh-footed shearwater
Little shearwater	*Puffinus assimilis*	Shearwaters	Small-sized seabirds	Fairy prion
Snares Cape petrel	*Daption capense australe*	Cape petrel	Small-sized seabirds	Fairy prion
Fairy prion	*Pachyptila turtur*	Prions	Small-sized seabirds	Fairy prion
Antarctic prion	*Pachyptila desolata*	Prions	Small-sized seabirds	Fairy prion
Broad-billed prion	*Pachyptila vittata*	Prions	Small-sized seabirds	Fairy prion
Pycroft's petrel	*Pterodroma pycrofti*	Small *Pterodroma* petrels	Small-sized seabirds	Fairy prion
Cook's petrel	*Pterodroma cookii*	Small *Pterodroma* petrels	Small-sized seabirds	Fairy prion
Chatham petrel	*Pterodroma axillaris*	Small *Pterodroma* petrels	Small-sized seabirds	Fairy prion
Mottled petrel	*Pterodroma inexpectata*	Small *Pterodroma* petrels	Small-sized seabirds	Fairy prion
White-naped petrel	*Pterodroma cervicalis*	Large *Pterodroma* petrels	Medium-sized seabirds	Flesh-footed shearwater
Kermadec petrel	*Pterodroma neglecta*	Large *Pterodroma* petrels	Medium-sized seabirds	Flesh-footed shearwater
Grey-faced petrel	*Pterodroma macroptera gouldi*	Large *Pterodroma* petrels	Medium-sized seabirds	Flesh-footed shearwater
Chatham Island taiko	*Pterodroma magentae*	Large *Pterodroma* petrels	Medium-sized seabirds	Flesh-footed shearwater
White-headed petrel	*Pterodroma lessonii*	Large *Pterodroma* petrels	Medium-sized seabirds	Flesh-footed shearwater
Soft-plumaged petrel	*Pterodroma mollis*	Small *Pterodroma* petrels	Small-sized seabirds	Fairy prion
Common diving petrel	*Pelecanoides urinatrix*	Diving petrels	Small-sized seabirds	Common diving-petrel
South Georgian diving petrel	*Pelecanoides georgicus*	Diving petrels	Small-sized seabirds	Common diving-petrel
New Zealand white-faced storm petrel	*Pelagodroma marina maoriana*	Storm petrels	Small-sized seabirds	Storm petrel
White-bellied storm petrel	*Fregetta grallaria grallaria*	Storm petrels	Small-sized seabirds	Storm petrel
Black-bellied storm petrel	*Fregetta tropica*	Storm petrels	Small-sized seabirds	Storm petrel
Kermadec storm petrel	*Pelagodroma albiclunis*	Storm petrels	Small-sized seabirds	Storm petrel
New Zealand storm petrel	*Pealeornis maoriana*	Storm petrels	Small-sized seabirds	Storm petrel
Yellow-eyed penguin	*Megadyptes antipodes*	Yellow-eyed penguin	Diving seabirds	Yellow-eyed penguin
Northern little penguin	*Eudyptula minor f. iredalei*	Little penguins	Diving seabirds	Erect-crested penguin
White-flippered little penguin	*Eudyptula minor f. albosignata*	Little penguins	Diving seabirds	Erect-crested penguin
Southern little penguin	*Eudyptula minor f. minor*	Little penguins	Diving seabirds	Erect-crested penguin
Chatham Island little penguin	*Eudyptula minor f. chathamensis*	Little penguins	Diving seabirds	Erect-crested penguin
Eastern rockhopper penguin	*Eudyptes chrysocome filholi*	Crested penguins	Diving seabirds	Erect-crested penguin
Fiordland crested penguin	*Eudyptes pachyrhynchus*	Crested penguins	Diving seabirds	Erect-crested penguin
Snares crested penguin	*Eudyptes robustus*	Crested penguins	Diving seabirds	Erect-crested penguin
Erect-crested penguin	*Eudyptes sclateri*	Crested penguins	Diving seabirds	Erect-crested penguin
Australasian gannet	*Morus serrator*	Boobies and gannets	Diving seabirds	Shag
Masked booby	*Sula dactylatra*	Boobies and gannets	Diving seabirds	Shag
Pied shag	*Phalacrocorax varius varius*	Solitary shags	Diving seabirds	Shag
Little black shag	*Phalacrocorax sulcirostris*	Solitary shags	Diving seabirds	Shag
New Zealand king shag	*Leucocarbo carunculatus*	Solitary shags	Diving seabirds	Shag
Otago shag	*Leucocarbo chalconotus*	Group foraging shags	Diving seabirds	Shag
Foveaux shag	*Leucocarbo stewarti*	Group foraging shags	Diving seabirds	Shag
Chatham Island shag	*Leucocarbo onslowi*	Group foraging shags	Diving seabirds	Shag
Bounty Island shag	*Leucocarbo ranfurlyi*	Group foraging shags	Diving seabirds	Shag
Auckland Island shag	*Leucocarbo colensoi*	Group foraging shags	Diving seabirds	Shag
Campbell Island shag	*Leucocarbo campbelli*	Group foraging shags	Diving seabirds	Shag
Spotted shag	*Stictocarbo punctatus*	Group foraging shags	Diving seabirds	Shag
Pitt Island shag	*Stictocarbo featherstoni*	Solitary shags	Diving seabirds	Shag
Subantarctic skua	*Catharacta antarctica lonnbergi*	Gulls, terns & skua	Medium-sized seabirds	Shag
Southern black-backed gull	*Larus dominicanus dominicanus*	Gulls, terns & skua	Medium-sized seabirds	Caspian tern
Caspian tern	*Hydroprogne caspia*	Gulls, terns & skua	Medium-sized seabirds	Caspian tern
White tern	*Gygis alba candida*	Gulls, terns & skua	Medium-sized seabirds	Caspian tern

2.2 Population Sustainability Threshold

The PST is an index of the population productivity, adapted from the PBR. 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, and by not including a recovery factor (see details in Appendix D and in the report by Ministry for Primary Industries (2016b, Chapter 3)).

The PST is defined as:

$$\text{PST} = \frac{1}{2}\phi r_{\text{max}} N, \tag{2}$$

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):

$$\lambda_{\text{max}} = \exp\left[\left(A_{\text{opt}} + \frac{S_{\text{opt}}}{\lambda_{\text{max}} - S_{\text{opt}}}\right)^{-1}\right], \tag{3}$$

$$r_{\text{max}} = \lambda_{\text{max}} - 1, \tag{4}$$

where λ_{max} is the maximum annual population growth rate, A_{opt} is the optimal age at first reproduction (i.e., not limited by density dependence, and without human impact), and S_{opt} is the optimal adult annual survival rate.

Values of A_{opt} and S_{opt} were derived from allometric modelling based on the age at first reproduction and adult annual survival of species included in the current risk assessment (see details in Appendix B). The modelling related the two parameters to body mass to then predict the values for each species. This modelling approach was aimed at obtaining more consistent values of r_{max} than were used previously. The correction factor for the estimation of r_{max} used in Richard and Abraham (2015) was no longer required (Appendix D).

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

$$R = \frac{\sum_{i=1}^{\infty} N_i}{\sum_{j=A_{\text{curr}}}^{\infty} N_j}, \tag{5}$$

where N_i is the number of individuals of age i, and A_{curr} is the current age at first reproduction.

By assuming a constant survival rate, taken to be equal to the current adult survival S_{curr} (including human-caused mortality), 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:

$$N_i = N_0 S_0 S_{\text{curr}}^{i-1}, \tag{6}$$

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 5 being a geometric sum, the ratio becomes:

$$R = S_{\text{curr}}^{1-A_{\text{curr}}} \tag{7}$$

Because N_0 and S_0 appear multiplicatively in both the numerator and denominator of the fraction in Equation 5 (from Equation 6), this ratio is independent of clutch size and chick survival. The resulting Gilbert estimate of the population size N^G is:

$$N^G = \frac{2N_{\text{BP}}}{P_B} S_{\text{curr}}^{1-A_{\text{curr}}}, \tag{8}$$

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:

$$N = gN^G, \tag{9}$$

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 Appendix D).

The calculation of the PST used the total population size N instead of a conservative estimate N_{min}, used in the formulation of the PBR. Previously, N_{min} had been calculated from the lower quartile of the distribution of the number of annual breeding pairs (Richard & Abraham 2015). In the current calculation of the PST the full distribution of values for the population size was used.

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 (Appendix D) 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).

2.3 Annual potential fatalities

The mortality of seabirds in fisheries was estimated using data of seabird captures reported by MPI observers. When observers are on-board commercial fishing vessels, they record captures of protected species, including seabirds and marine mammals. The capture events are entered into a database maintained by the National Institute of Water and Atmospheric Research (NIWA) on behalf of MPI. These data are currently housed in the Centralised Observer Database (COD). Preparation of the seabird capture data is described by Thompson and Berkenbusch (2016). Data on fishing effort and observed captures were updated from the previous risk assessment by including the fishing years 2013–14 and 2014–15, extending the assessment period to 2006–07 to 2014–15. Vulnerability was estimated based on data for the same period. Non-fishing related captures, such as birds colliding with the superstructure of the vessels or landing on the deck, were excluded from the dataset.

During the 2013–14 and 2014–15 fishing years, there was a total of 1279 observed seabird captures, including 743 mortalities, and 536 captures of birds released alive. Over the entire study period, there was a total of 4478 observed seabird captures, including 2983 fatal captures, and 1495 captures of birds released alive (Table 2).

To improve the estimation of potential fatalities for taxa with small populations, seabirds were aggregated into species groups (see Table 1). Taxa within the same group are assumed to have a similar vulnerability to capture in fisheries.

In addition to observer data, the estimation of incidental captures required fishing effort data. Records of all fishing events during commercial bottom-longline, surface-longline, trawl, and set-net fishing were obtained, covering the period from 2006–07 to 2014–15. Data were extracted from the *warehou* database (Ministry for Primary Industries 2012), and included target species, vessel characteristics, location, time, and date. Fishing effort was defined as the number of tows for trawl fisheries, the number of lines set for bottom- and surface-longline fisheries, and the net length (in metres) for set-net fisheries.

Fishing effort was assigned to fishery groups (Table 3), as in previous assessments (Waugh et al. 2009, Richard et al. 2011, Richard & Abraham 2013c). Fishery groups were assigned on the basis of the target species of each fishing event, the size of the vessel, and, for trawl fishing targeting middle-depth species, whether the vessel was processing fish on-board or not, as reported by fishers. Fishery groups were used to constrain the estimation of vulnerability. Vessels in the same fishery group are assumed to attract and capture birds in a similar way. In the current study, all trawl, longline, and set-net fisheries were categorised into 19 fishery groups (Table 3).

Table 2: Seabird captures recorded by government observers between the fishing years 2006–07 and 2014–15 in New Zealand commercial trawl, longline, and set-net fisheries. Data include the total number of captures, the number of mortalities, and the number of captures that were released alive.

Species group	Total	Dead	Alive
White-chinned petrel	1 309	810	499
Sooty shearwater	926	614	312
White-capped albatross	732	539	193
Buller's albatrosses	528	348	180
Salvin's albatross	329	232	97
Flesh-footed shearwater	127	87	40
Black petrel	91	46	45
Grey petrel	90	81	9
Wandering albatrosses	67	43	24
Campbell black-browed albatross	40	32	8
Group foraging shags	37	37	0
Westland petrel	34	22	12
Prions	33	5	28
Chatham albatross	24	22	2
Shearwaters	19	12	7
Royal albatrosses	19	12	7
Diving petrels	16	4	12
Large *Pterodroma* petrels	15	11	4
Giant petrel	12	4	8
Yellow-eyed penguin	9	9	0
Gulls, terns & skua	8	5	3
Storm petrels	7	3	4
Cape petrel	3	3	0
Crested penguins	2	1	1
Solitary shags	1	1	0
Total	4 478	2 983	1 495

These fishery groups include changes, such as the merging of the previous fishery groups "large meal trawl" and "large processor trawl" into a single "large processor trawl" group. This change followed the suggestion from the previous seabird risk assessment that the vulnerability of middle-depth trawl fisheries with freezers did not vary depending on the presence or absence of a meal plant (Richard & Abraham 2015).

Additionally, the previous "flatfish trawl" group was merged with the "small inshore trawl" group (vessels of 28 m in length or less), as fishery experts considered the distinction between flatfish and inshore target species unreliable. Nevertheless, this group was split based on vessel length, as small vessels tend to fish in different areas and may operate differently than larger vessels (R. Wells, pers. comm.). The cut-off length was 17 m, splitting the group into vessels at lengths less than 17 m and between 17 and 28 m.

Large bottom-longline (BLL) vessels (length over 34 m) were split into two groups, depending on the use of integrated weight line (IWL).

Vessels targeting ribaldo were removed from the "other small BLL" group, and merged with the "ling BLL" group, as the two target species live in deep waters, compared with other species targeted by bottom-longline vessels.

The total number of interactions (defined as the number of birds killed or injured by interacting with the fishing gear, including captures and cryptic mortalities, i.e., birds that would not have been recorded by observers and birds that may have survived the interaction) was assumed to be proportional to the overlap (defined as the product of the fishing effort and the density of seabirds at the location of each fishing event). If the seabird density has units of bird km^{-2}, the units of the overlap are bird km^{-2} effort^{-1}. The slope of the relationship between the total number of interactions and the overlap defines the vulnerability to capture. Vulnerability was defined as the product of a species-group vulnerability, a fishery-group vulnerability, and an interaction between the fishery group and species group. Some

Table 3: Fishery groups used in the current risk assessment for the assignment of fishing effort (SBW, southern blue whiting; SQU, squid; SCI, scampi; SNA, snapper; IWL, integrated weight line).

Method	Fishery group	Description
Trawl	Small inshore < 17 m	Targeting inshore species (including flatfish), or targeting middle-depth species (principally hoki, hake, or ling) on vessels less than 17 m length
	Small inshore 17 to 28 m	Targeting inshore species (including flatfish), or targeting middle-depth species (principally hoki, hake, or ling) on vessels more than 17 m length and less than 28 m length
	Southern blue whiting	Targeting southern blue whiting
	Scampi	Targeting scampi
	Mackerel	Targeting mackerel (primarily jack mackerel species)
	Squid	Targeting squid
	Large processor	Targeting middle-depth species, vessel 28 m or longer, processing fish on-board
	Large fresher	Targeting middle-depth species, vessel 28 m or longer, with no processing on-board
	Deepwater	Targeting deepwater species (principally orange roughy or oreos)
Bottom longline (BLL)	Bluenose	Targeting bluenose, and vessel less than 34 m length
	Snapper	Targeting snapper, and vessel less than 34 m length
	Ling and ribaldo	Targeting ling or ribaldo, and vessel less than 34 m length
	Other small BLL vessels	Not targeting snapper, bluenose, ling, or ribaldo, and vessel less than 34 m length
	Large vessels without IWL	BLL vessel 34 m or longer, without integrated weight line
	Large vessels with IWL	BLL vessel 34 m or longer, with integrated weight line
Surface longline (SLL)	Swordfish	Targeting swordfish, and vessel less than 45 m length
	Other small SLL vessels	Not targeting swordfish, and vessel less than 45 m length
	Large vessels	Vessel 45 m or longer
Set net	Set net	All set-net fishing

species have a tendency to be more attracted to fishing vessels than others, or to behave in a way that makes them more likely to be caught when they are around fishing vessels, and some fisheries are more likely than others to catch birds, due to risk factors such as discharge management and the mitigation measures deployed. A model including these two components of vulnerability plus an interaction allowed the estimation of vulnerability in poorly-observed fisheries and for rare species to be informed by the vulnerability of fisheries with higher observer coverage and the vulnerability of common species.

Following the terminology used in the report by Ministry for Primary Industries (2016b, Chapter 3), the total number of interactions of a given species group s in a given fishery group g was assumed to follow a Poisson distribution:

$$I_{sg} \sim \text{Poisson}(\mu_{sg}), \tag{10}$$

$$\mu_{sg} = v_{0_m} v_g v_s \theta_{sg} \epsilon_{sg}, \tag{11}$$

where I_{sg} is the total number of interactions of the species group s in the fishery group g, μ_{sg} is the mean number of interactions of species group s in the fishery group g, v_g is the overall vulnerability of seabirds in the fishery group (reflecting that some fisheries tend to attract more birds than others), and v_s is the vulnerability of the species group (reflecting that some birds have a tendency to be more attracted to fishing vessels than others). The density overlap θ_{sg} between the species group and the fishery group is the product of the fishing effort and the bird density at each fishing event, summed over all fishing events, and ϵ_{sg} is the error associated with the combination of species group and the fishery group. The species-group vulnerability v_s was fixed to 1 for white-chinned petrel, and the fisheries vulnerability v_g was fixed to 1 for deepwater trawl fisheries, large bottom-longline fisheries and large surface-longline fisheries, considered as base cases. Vulnerabilities in other groups (species or fisheries) were expressed relative to these base cases. The vulnerability associated to set-net fisheries was also set to 1, as fisheries for this method formed a single group.

In the previous risk assessment, independent models were fitted to each of the four fishing methods (trawl, bottom longline, surface longline, and set net) to estimate the total number of annual potential fatalities. The intercept v_{0_m} (in Equation 10) varied by fishing method to account for the different scales in vulnerability across methods due to different units of fishing effort.

2.3.1 Species spatial distributions

Calculation of the overlap between seabird distributions and fishing effort required spatial maps of the at-sea distributions of the seabirds included in the assessment. The distribution maps were derived from existing maps published by NABIS and BirdLife International. Three kinds of distribution maps were available:

- NABIS annual distribution maps. These maps contained three layers of seabird density: the Hot Spot layer, the 90% of the population presence layer, and the 100% of population presence. The maps were created from various sources of information (observation at sea, observer data, telemetry, main colony positions). These maps were converted into density maps by assigning a bird density to each layer. Following the choices used previously by Waugh et al. (2009), the hot spot layer was assigned a value of 0.5, the 90% presence layer a value of 0.4, and the 100% presence layer a value of 0.1. The resulting maps were then normalised, so that the density integrated to one across the region of the maps. The NABIS maps are intended to be annual average distributions. They do not provide information on seasonal changes in distribution, such as would occur during annual migrations, or at different stages of the breeding cycle.
- BirdLife International single-layer range maps. These maps represent the range of the species at a global scale. The density of birds is equal to one in the species range and equal to zero outside. Depending on the species, the maps were established from observations at sea, observer data and/or telemetry (GLS, GPS, Argos, and radio tracking). These maps were clipped to the latitude and longitude range used for the distributions, and normalised.
- BirdLife International telemetry global distribution maps. These distribution maps were derived from GPS and Argos satellite tracking data for large Procellariiform species. The maps were composed of remote-tracking data layers, with 50, 75, 90, 95% utility distributions (see BirdLife International (2004) for methods for determining kernel distributions of birds), for non-breeding and breeding range. The maps were clipped to the region of the seabird risk assessment and normalised.

The maps were discretised with a resolution of one thirtieth of degree of latitude and longitude, extending from 57°S to 23°S and from 160°E to 170°W. A single annual-average distribution was derived for species that breed throughout the year (albatrosses of the genus *Diomedea*), for species whose distribution was expected to be similar during the breeding and non-breeding seasons (shags, gulls, terns, and skua), and for species for which available information was insufficient to distinguish the breeding and non-breeding distributions (New Zealand storm petrel, and masked booby). For the remaining taxa, two distribution maps were generated, with one map each for the non-breeding and breeding periods. The only exception was black petrel, for which the breeding season was further disaggregated between the pre-egg laying (October to November), incubation (December to January), and guard and chick rearing (February to May) periods (see Appendix C for a description of the methods used to derive the black petrel distribution).

The distribution of non-breeders was derived from existing maps published by NABIS (National Aquatic Biodiversity Information System) and Birdlife International. Annual distribution maps from NABIS contain three layers of seabird relative density: the hot spot layer, and the 90% and the 100% of the population presence layers. In some cases, other sources of information, including at-sea observations, observer data, telemetry, and main colony positions, were also considered. The maps were intended to indicate annual average distributions, and do not provide information on seasonal changes in distribution, such as would occur during annual migrations, or at different stages of the breeding cycle. These maps were converted into relative density maps by assigning a value to each layer. The hot spot layer was assigned a value of 0.5, the 90% presence layer a value of 0.4, and the 100% presence layer a value of 0.1. The resulting maps were then normalised, so that the distribution integrated to one across the region of the maps.

Maps from BirdLife International were single-layer range maps, representing the range of a species at a global scale. Depending on the taxon, these maps were derived from at-sea observations, observer data and/or telemetry (Light level geolocator, Global Positioning System (GPS), Argos, and radio tracking). In these maps, the relative density of birds is constant within the taxon's range and equal to zero outside it. These maps were clipped to the latitude and longitude range used for the distributions, and normalised.

For the breeding season, two distribution layers were created, one for the non-breeders (as above) and one for the breeders. The relative density of breeders were distributed in discs centred around the colonies, with the discs clipped to avoid land. The radius of these discs (rad_{max}) was found in the literature, but anecdotal sightings were used to provide a minimum radius. We set the maximum radius to 200 km when the radius found in the literature was less than 100 km, and we doubled it otherwise. The relative density of breeders within these discs was assumed to decrease exponentially with the distance to colonies (rad), with a value at the edge of the disc of 1% of the value at the center of the disc:

$$d_B(\text{rad}) = D \begin{cases} e^{\ln(0.01)\frac{\text{rad}}{\text{rad}_{\text{max}}}} & \text{if rad} \leq \text{rad}_{\text{max}} \\ 0 & \text{if rad} > \text{rad}_{\text{max}} \end{cases}, \tag{12}$$

where D is a normalisation constant, such that the integral of d_B over the domain is one.

This exponential decay distribution function was established from 12 trips of breeding Buller's albatross (*Thalassarche bulleri*) tracked by GPS, and 32 trips of breeding northern royal albatross (*Diomedea sanfordi*) tracked by GPS (Filippi & Waugh, unpublished data). This is an approximation that is more realistic than the linear distribution used in other risk assessments (Karpouzi et al. 2007). However, a full study including more tracks and more species would improve the parameterisation of the exponential distributions.

For coastal species breeding around New Zealand (i.e., the eight species of shags, the Caspian tern, and the black-backed gull), both breeder and non-breeder birds were distributed along the coast where they are regularly observed. Equation 12 was also used to calculate the relative density of these birds, but with the radius taken as the closest distance to shore and with a maximum distance of 100 km.

During the breeding season, the number of breeders and non-breeders was a function of the number of annual breeding pairs of the total population size using the following relationships:

$$N_{\text{B}} = 2N_{\text{BP}},$$
$$N_{\text{NB}} = N - 2N_{\text{BP}},$$

where N is the total population size (see Equation 9), N_{BP} the number of annual breeding pairs, N_{B} the number of breeders, and N_{NB} the number of non-breeders.

The distributions of breeders and non-breeders were independently normalised so the relative density of each distribution integrated to unity over the entire region. The normalised distribution of birds during the breeding season was obtained by adding the relative density of breeders and non-breeders, each multiplied by their relative population size (N_{B}/N and N_{NB}/N, respectively). If d_{B} is the normalised distribution of breeders, and d_{NB} is the normalised distribution of non-breeders, then the breeding season d_{BS} distribution is

$$d_{\text{BS}} = \frac{N_{\text{B}}d_{\text{B}} + N_{\text{NB}}d_{\text{NB}}}{N} \tag{13}$$

The normalised distribution of birds during the non-breeding season was the same as the normalised distribution of non-breeders, $d_{\text{NBS}} = d_{\text{NB}}$.

The density distribution of seabirds (∂; with units of bird km^{-2}), is derived from the normalised distribution by multiplying by population size. Some migratory species leave New Zealand's Exclusive

Economic Zone when they are not breeding (either partially or completely). For these species, the total population size was multiplied by a factor p_{NBS} representing the number of birds in New Zealand waters during the non-breeding season relative to the number of birds in New Zealand waters during the breeding season. The values of the factor for each taxon were based on expert knowledge (G. Taylor, pers. comm.) (see information in Richard et al. 2017). The density distribution for a species, s, was therefore:

$$\begin{aligned} \partial_{s\text{BS}} &= d_{s\,\text{BS}}, \\ \partial_{s\text{NBS}} &= p_{\text{NBS}} d_{s\text{NBS}}. \end{aligned}$$

The density distribution of birds in a species group, and season, is obtained by summing the density distributions of all the species in that species group and season.

For Otago and Foveaux shags, the spatial distribution of Stewart Island shag used in the previous seabird risk assessment was split by a north-south line at 169.2° longitude, to reflect the clear separation in the distributions of the two novel species (see Rawlence et al. 2016).

2.3.2 At-sea distribution of black petrel

To derive the at-sea distribution of black petrel, two alternative models were used (see details in Appendix C). The first model was based on the data used in the study of the overlap of black petrel with New Zealand trawl and longline fisheries (Abraham et al. 2015). This model was a simple Bayesian generalised linear model (GLM) that related the counts of black petrel (of birds or GPS positions) to environmental variables. The effect of fishing method was a simple scaler, which was not used when predicting the black petrel distribution, making the prediction fishery-independent. This model was used to predict the at-sea distribution of black petrel during the pre-egg laying and incubation periods.

The second model only used high-resolution GPS tracking data of birds flying in and out of Great Barrier Island (see Appendix C for a full description). A mixture of state-space modelling and step selection functions was used to model the movement process of black petrel when foraging at sea. The behavioural state of birds (leaving or returning to Great Barrier Island, transiting, or resting/feeding), and features determining each movement step were detected as a function of movement metrics and environmental variables. Once fitted, the model was used to make simulations of 5000 tracks, and the tracks were rasterised to derive the density of black petrel across New Zealand waters. This model was used to predict the at-sea distribution of black petrel during the chick-rearing period.

2.3.3 Cryptic mortality

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. The proportion of interactions that would be recorded if there was an observer on-board is given by the probability $p_{\text{observable}}$. The inverse of this probability is the cryptic multiplier, which allows the total number of interactions to be estimated from the observable captures (see details in Appendix E).

The number of observable captures (C'_{sg}) of a given species in a given fisheries group was defined as

$$C'_{sg} \sim \text{Poisson}(p_{\text{observable}} I_{sg}), \tag{14}$$

where I_{sg} is the total number of interactions of species group s in fishery group g (Figure 1). The parameter $p_{\text{observable}}$ is the probability that an incident that occurred while an observer was onboard the vessel would be recorded (see Appendix E for more detail on the estimation of $p_{\text{observable}}$). The probability that a capture is observable is the inverse of the cryptic multiplier (which is the number of fatalities that occurred for each observed capture). Among trawl fisheries, the parameter depended on the fishery group, and also the seabird grouping, as species were categorised according to their size and their diving behaviour (diving seabirds were assumed to not be affected by collisions with warps while at the surface). The species types used to estimate cryptic mortality in trawl fisheries were large albatrosses (*Diomedea* species), mollymawks (*Thalassarche* and *Phoebetria* species) and giant petrel, diving seabirds (penguins, shags, boobies, and gannets), medium-sized seabirds (non-diving seabirds and non-albatross seabirds at least larger than white-naped petrel), and small-sized seabirds (other seabirds like Cape petrel and smaller)(see Table 1).

The parameter $p_{\text{observable}}$ was constant across fisheries and taxa in longline fisheries. No cryptic mortality was assumed in set-net fisheries.

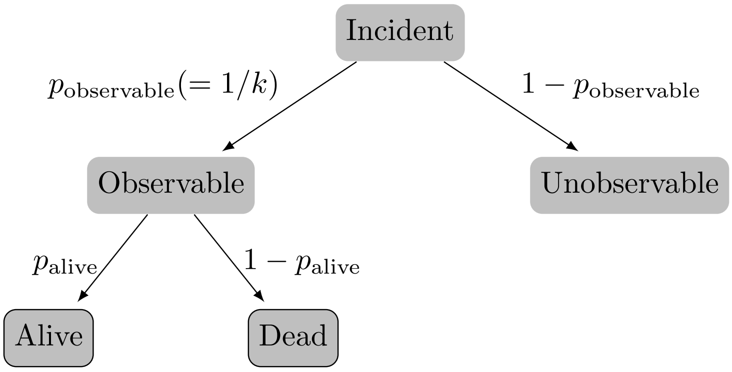

Figure 1: Representation of seabird capture interactions within the model of the estimation of annual potential fatalities. For each incident, there is a probability $p_{\text{observable}}$ that the incident would have been recorded by observers, if they were on-board the vessel. This probability is the inverse of the cryptic multiplier (k). Observable captures are recorded as either released alive (with probability p_{alive}) or as dead. Data of captures released alive and of dead captures (indicated by the boxes with solid borders) were used to estimate the parameters.

2.3.4 Live captures

Observers document whether a captured bird was released alive or whether the capture was fatal. In the previous risk assessments, all seabird captures were considered fatal. Here, the estimation process was amended to allow a proportion of the captured birds released alive to survive (Figure 2).

The probability that a captured bird was released alive, p_{alive}, was introduced in the model, and allowed to vary between species group and fishery group. For the estimation of vulnerability, the observer data consisted of the number of fatal captures, C'_{dead}, and the number of captured birds released alive, C'_{live}, by species and fishery group, instead of the total number of captures. Here, the prime symbol is used to indicate observed quantities (Ministry for Primary Industries 2016b, Chapter 3). In the model, C'_{live} was the product of the number of observable captures and p_{alive}, and C'_{dead} the product of the number of observable captures and $1 - p_{\text{alive}}$.

Because the number of observed captures did not allow an independent estimation of p_{alive} for each species and fishery group, the estimation of this parameter was constrained in a logistic regression, by assuming that the logit of p_{alive} was the sum of a fishery group effect, β_g, and of a species group effect, β_s, i.e., $logit(p_{\text{alive}}) = \beta_g + \beta_s$. An uninformed normally-distributed prior was used for both β_g and β_s, with a mean of 0 and a standard deviation of 10 000.

For the estimation of annual potential fatalities, a proportion p_{survive} of the captured birds released alive was considered to survive the capture after release, and the survival probability varied between species and fishery groups (Figure 2). In the absence of data on this parameter, a uniform beta prior was used for p_{survive}. Using this prior assumes that, on average, half the captured seabirds that were released alive survive the capture after being released (in principle, the posterior distribution could be different from the prior).

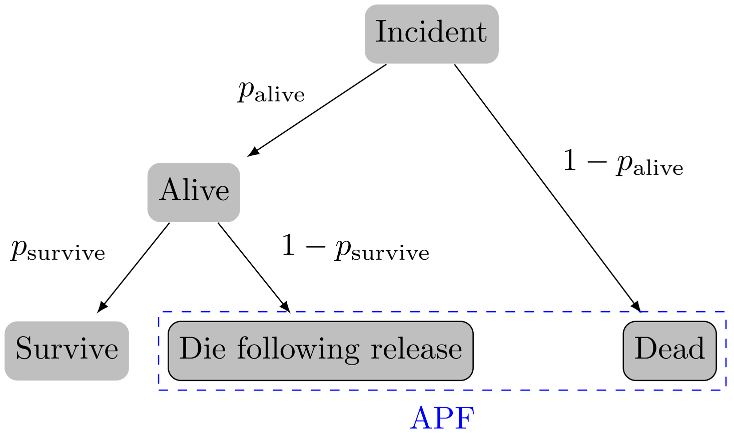

Figure 2: Estimation of annual potential fatalities (APF) of seabirds in commercial fisheries, including direct seabird mortalities and live captures that resulted in mortality following release. Captured seabirds were released alive with a probability p_{alive}, whereas subsequent mortalities following capture occurred with a probability $1 - p_{\text{survive}}$.

2.3.5 Constraining the estimation of fisheries mortality

In the current risk assessment, the estimation of fisheries mortality was constrained so that it did not exceed the total annual mortality of the adult population. Without constraining fisheries mortality, large uncertainties in the annual potential fatalities may lead to mortality rates that are not consistent with the estimates of current adult survival. The constraint used in the current study ensured that the estimated mortalities, population size, and adult survival were mutually consistent.

This constraint assumed that all birds caught in fisheries were adults. This assumption was considered reasonable given that adults represent the majority of captured individuals, as evident from observer data (Table 4). Of the total 1520 captures between 2010–11 and 2014–15 that were identified and aged by experts via necropsy of recovered birds, 1490 captures (98%) were of adults.

The annual adult mortality rate was calculated as one minus the current adult annual survival rate. Annual adult mortality was assumed to follow a beta distribution, with the shape (α) and scale (β) of the distribution being calculated so that the mean (μ) and standard deviation (σ) were the same as the mortality rate (Samaranayaka & Fletcher 2010):

$$\alpha = \mu^2 \left(\frac{1-\mu}{\sigma^2} - \frac{1}{\mu} \right), \tag{15}$$

$$\beta = \alpha \left(\frac{1}{\mu} - 1 \right). \tag{16}$$

The fisheries mortality rate was calculated as the ratio of the annual potential fatalities to the number of adults. The number of adults was assumed to follow a log-normal distribution, with values for the mean and standard deviation of the demographic samples used in the PST calculation. The constraint that the fishing mortality rate is less than the adult mortality rate was modelled using the *dinterval* distribution defined in the software Just Another Gibbs Sampler (JAGS; Plummer 2013), which sets the likelihood to zero for Markov chain Monte Carlo (MCMC) iterations where the fishing mortality exceeds the adult mortality.

2.3.6 Change in fishery vulnerability over time

To allow vulnerability to change over time, the fishery component of vulnerability, v_g, was estimated separately for the period 2006–07 to 2009–10, and for the period 2010–11 to 2014–15. This change in vulnerability was prompted by the increased focus in fisheries management to reduce the incidental

Table 4: Number and proportion of adults among all seabird captures identified and aged by experts based on necropsies. The captures occurred in commercial trawl, bottom-longline, surface-longline, and set-net fisheries between 2010–11 and 2014–15.

Taxon	Total	Adults	Not adults	% of adults
White-chinned petrel	516	515	1	99.8
Sooty shearwater	305	305	0	100.0
New Zealand white-capped albatross	251	238	13	94.8
Southern Buller's albatross	179	179	0	100.0
Salvin's albatross	120	112	8	93.3
Grey petrel	31	30	1	96.8
Flesh-footed shearwater	31	31	0	100.0
Westland petrel	10	10	0	100.0
Campbell black-browed albatross	10	8	2	80.0
Black petrel	9	9	0	100.0
Southern royal albatross	7	7	0	100.0
Cape petrel	7	7	0	100.0
Common diving petrel	5	5	0	100.0
Gibson's albatross	5	5	0	100.0
Fairy prion	4	4	0	100.0
Short-tailed shearwater	4	4	0	100.0
Grey-faced petrel	4	3	1	75.0
Black-browed albatross	3	2	1	66.7
Snares Cape petrel	3	2	1	66.7
Antipodean albatross	3	3	0	100.0
Grey-backed storm petrel	2	2	0	100.0
Chatham Island albatross	2	2	0	100.0
Southern black-backed gull	2	0	2	0.0
New Zealand white-faced storm petrel	1	1	0	100.0
White-headed petrel	1	1	0	100.0
Northern Buller's albatross	1	1	0	100.0
Black-bellied storm petrel	1	1	0	100.0
Double-banded plover	1	1	0	100.0
Cook's petrel	1	1	0	100.0
Antarctic prion	1	1	0	100.0
All	1 520	1 490	30	98.0

capture of seabirds (Ministry for Primary Industries 2016a). For example, for large (28 m length and over) deepwater trawlers, a vessel management plan was developed that provides vessel-specific guidelines for mitigating the incidental capture of seabirds (Deepwater Group Ltd 2009). With an increased effort in reducing the incidental capture of seabirds, it is possible that vulnerability has decreased over time, and this possibility was reflected in the estimation.

In the estimation, the change over time was only allowed for fishery groups with sufficient data (at least 10% of effort observed, and at least 50 observed captures over the whole period). These fishery groups included the large processor trawl fishery group, trawl fisheries targeting southern blue whiting, mackerel, and squid, and surface-longline vessels of 45 m in length and over.

2.3.7 Model fitting

The integrated model (Equation 10) was fitted within a Bayesian statistical framework. This framework allowed the joint estimation of the parameters (e.g., vulnerabilities, proportion of captures released alive) from data on observed fishing effort and seabird captures, and also the prediction of annual potential fatalities on annual total fishing effort.

The vulnerability parameters were estimated from the regression of the number of observed captures on the product of vulnerabilities and the observed overlap of observed fishing effort and seabird densities for each combination of fishery group and species group. The proportion of live captures was fitted from the observed number of captures released alive and the total number of captures.

These estimates were simultaneously used in the model to predict the number of annual potential fatalities from the annual fishing effort (observed and non-observed fishing effort).

The interaction term between the fishery-level vulnerability and species-group-level vulnerability, ϵ_{sg}, was defined as a random effect following a log-normal distribution with mean 1 and a gamma-distributed standard error, with a prior of rate and shape 0.001. The vulnerabilities v_{0_m}, v_g and v_s had a log-normal prior, with a mean 0 and standard deviation of 16. These priors were defined to be uninformed, and re-running the models with different values showed that the impact of these definitions on the posterior distribution of the parameters was minimal. Having estimated the vulnerabilities, the total number of observable captures in each fishery group was then calculated by multiplying the values by the total overlap (including both observed and non-observed fishing effort).

The model was coded in the BUGS language (Spiegelhalter et al. 2003), and fitted using MCMC methods with the software JAGS (Plummer 2013). Two chains were used, with a burn-in period of 10 000 iterations, and the posterior samples taken from 800 000 iterations, thinned by sampling every 400 values.

The model's convergence and mixing was assessed by visually examining the trace of the MCMC chains. The quantities of interest (annual potential fatalities, vulnerabilities) were taken directly from the posterior distributions, represented as samples of 4000 values, of the model output.

Because the adult survival rate, the number of adults, and the cryptic multipliers were random variables in the model, the MCMC-fitting process returns posterior distributions that may be different from the priors. These posterior distributions, in addition to the estimated number of annual potential fatalities, were then used to update the parameters when re-running the seabird risk assessment.

Finally, the risk ratio was calculated as the ratio of the annual potential fatalities to the PST (see schematic of the full calculation in Figure 3).

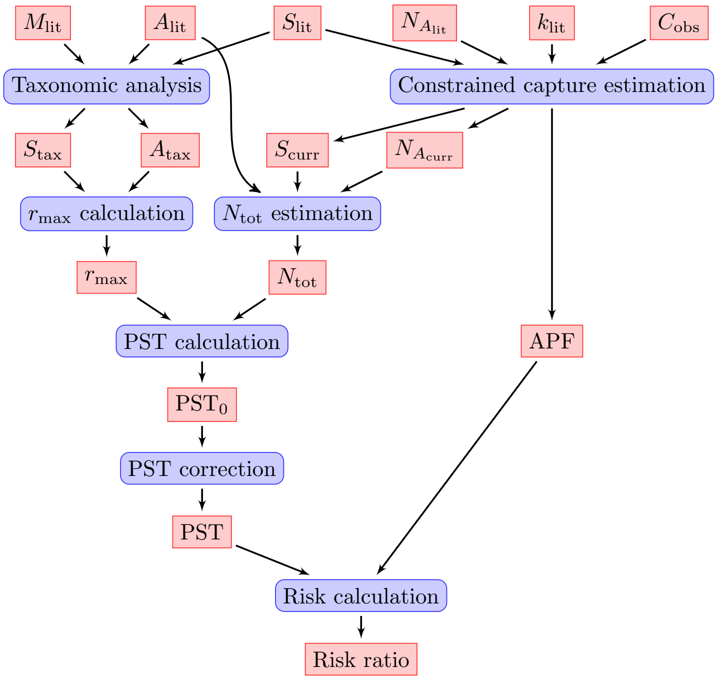

Figure 3: Schematic process of the estimation of risk in the current seabird risk assessment. M: body mass; A: age at first reproduction; S: adult survival rate; N_A: adult population size; k: cryptic mortality multiplier; C: seabird captures; r_{max}: maximum net productivity rate; N_{tot}: total population size; PST: Population Sustainability Threshold; APF: annual potential fatalities. For the indices: lit: from the literature or expert-based; obs: recorded by observers; tax: from the taxonomic analysis; curr: representing current conditions, corrected by the model; tot: total; 0: prior to correction.

2.4 Sensitivities

2.4.1 Sources of risk uncertainty

Because the uncertainty in each parameter is represented as a sample of values, and because the uncertainty is carried through all the estimation process, it is possible to assess which uncertainties have the greatest impact in the final uncertainty in the assessed risk.

From the model and data previously described (hereafter referred to as the base case), the estimation process was repeated, while keeping each time a different parameter to its mean: the number of annual breeding pairs, current and optimal adult annual survival rates, current and optimal age at first reproduction, proportion of adults breeding, annual potential fatalities in each of trawl, bottom-longline, surface-longline, and set-net fisheries. The impact of each uncertainty on the final uncertainty in the risk ratio was measured by calculating the percentage of reduction in the range of the 95% credible interval of the estimated risk ratios when fixing the parameter to its mean.

2.4.2 Sensitivities to the estimation approach

Like any risk assessment, the chosen methodology relied on some subjective decisions to address limitations imposed through the paucity of data on the at-sea distribution of seabirds, their demography and also on fishing and seabird captures. To assess the impact of some of the specific choices in the methods, the current study tested alternative approaches, including different data for the number of breeding pairs of black petrel, and for the size of the mainland population of yellow-eyed penguin. In addition, the updated risk assessment approach presented here was applied to data on fishing effort and captures between 2006–07 and 2010–11, to update the results of Richard and Abraham (2013c), which was used to estimate the risk categories that initially provided the base case for the NPOA (Ministry for Primary

Industries 2013).

For black petrel, the initial estimation used the same population size estimate as was used in the previous risk assessment, i.e., a mean of 4630 (95% c.i.: 1970–9780) annual breeding pairs (Richard & Abraham 2015). The estimate was derived from the recovery of banded birds caught in fisheries, constrained at the lower end by the estimate from a survey of a 350 000 square metre area on Great Barrier Island in the 2013–14 breeding season (Bell et al. 2013b). At the upper end, the estimate was constrained by the count of black petrel during the non-breeding season off the coast of South America, from 15 cruises between 1980 and 1995 (Spear et al. 2005). Data from the Great Barrier Island survey do not include the total population, and are, therefore, likely to represent an underestimate of the total population size of black petrel. At the same time, the estimate from the surveys in South American waters is likely to be an overestimate due to potential misidentifications during the counts, and the extrapolation of black petrel density outside the surveyed area. For this reason, the risk analysis of fisheries to black petrel was repeated based on recent survey data from Great Barrier and Little Barrier islands (Bell et al. 2016b, 2016a).

The most recent survey of Great Barrier Island led to an estimated 880 breeding pairs (1760 ± 125 breeding adults) within the survey area (Bell et al. 2016b). On Little Barrier Island, the black petrel population survey conducted in the 2015–16 breeding season led to an estimated 620 pairs (Bell et al. 2016a). Based on these data, the risk analysis was repeated, using a range between 1400 and 1600 annual breeding pairs for the black petrel population size.

In the current and previous seabird risk assessments, the risk of fisheries to yellow-eyed penguin was estimated for both the New Zealand population and for the mainland population only (South and Stewart islands, excluding the subantarctic population), assuming that all incidental captures in the New Zealand region were of the mainland population. The estimate used for the mainland population size of yellow-eyed penguin was 600–800 breeding pairs. Nevertheless, recent, preliminary data of nest counts in South and Stewart islands during the 2016–17 breeding season suggest that the mainland population of yellow-eyed penguin consists of 273–374 breeding pairs only (Yellow-Eyed Penguin Trust, unpublished data). To investigate the potential consequences of this population decline on the estimated risk of fisheries to yellow-eyed penguin, the risk calculations were repeated with this preliminary estimate.

3. RESULTS

3.1 Model fit

There was a close relationship between estimated and observed data, indicating a close model fit (Figure 4). Of the 4380 strata of fishing group, species group, capture status (live or dead), and time period (before or after 2010–11) in the estimation, only 2% of the observed number of captures were outside the 95% credible interval of the estimated number of captures.

There were 11 strata with over 40 captures for which the observed number of captures was outside the predicted 95% credible interval. All of the 11 strata were in trawl fisheries, including nine strata in the squid target fishery (Table 5). The remaining strata were trawl fisheries targeting scampi and large-vessel trawl fisheries with processor plants. Of the 11 strata, the observed captures were lower than predicted in three of the strata, and higher in the remaining eight strata.

3.2 Vulnerabilities

The vulnerability of seabirds to capture was estimated as the product of an intercept, v_{0_m}, for each fishing method, multiplied by a species-group vulnerability, v_s, and a fishery-group vulnerability, v_g (Tables 6, 7, 8). The fishery-group vulnerability was estimated for two separate time periods, an early period from 2006–07 to 2009–10, and a late period from 2010–11 to 2014–15. There was also a species-group fishery random effect, the combined vulnerability for each species group and fishery (see Appendix G.4).

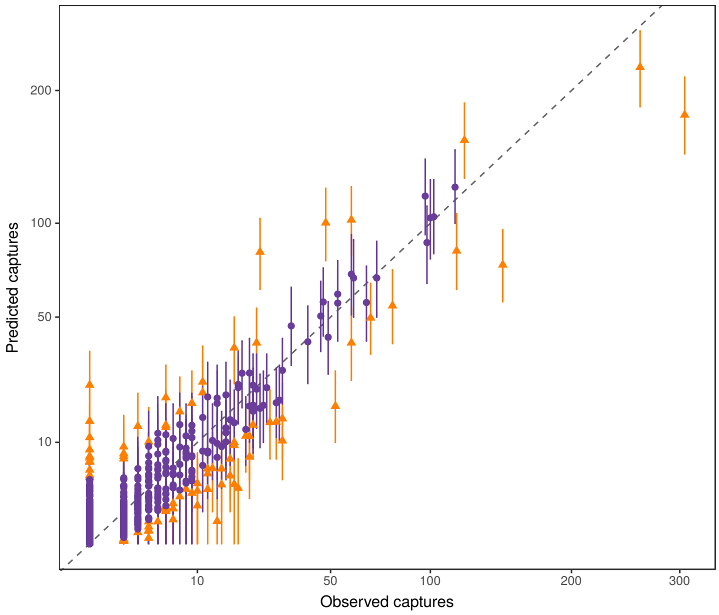

Figure 4: Comparison of the number of seabird captures recorded by government observers and predicted by the model used to estimate the number of annual potential fatalities. Each point represents a stratum of species group, fishery group, capture status (live or dead), and time period (before or after 2010–11). Strata for which the number of observed captures was within the 95% credible interval of the predicted number are shown in purple, other strata are shown in orange.

Table 5: Strata of fishery group, species group, time period (before or after 2010–11), and capture status (live or dead), with over 40 observed seabird captures for which the number of observed captures was outside the estimated 95% credible interval (c.i.). Shown are the number of observed captures, and the mean and 95% c.i. of the estimated number of captures. Strata are listed in decreasing order of the number of observed captures.

Fishery group	Species group	Period	Live/dead	Observed captures	Predicted captures	
					Mean	95% c.i.
Trawl - squid	White-chinned petrel	Late	Live	305	179	148–212
Trawl - squid	White-chinned petrel	Late	Dead	261	221	186–256
Trawl - squid	Sooty shearwater	Early	Dead	147	76	57–96
Trawl - squid	Sooty shearwater	Late	Dead	121	159	130–189
Trawl - squid	White-capped albatross	Early	Dead	116	84	63–106
Trawl - squid	White-capped albatross	Late	Live	79	55	39–73
Trawl - squid	Sooty shearwater	Early	Live	68	50	35–66
Trawl - large processor	Sooty shearwater	Late	Live	59	39	26–54
Trawl - squid	White-chinned petrel	Late	Dead	59	102	81–124
Trawl - scampi	White-chinned petrel	Late	Dead	52	18	10–29
Trawl - squid	White-chinned petrel	Early	Live	48	100	78–123

Black petrel had the highest mean species-group vulnerability (Table 6), with a vulnerability that was 24.92 (95% c.i.: 5.04–73.95) times higher than the vulnerability of white-chinned petrel. Both these species are in the *Procellaria* genus, and may be expected to have similar vulnerability to capture. The vulnerability reflects propensity to capture, for a given seabird overlap. Estimates of the vulnerability are sensitive to errors in the population size and the distribution, which both affect density. Many of the seabird distributions are poorly determined, and any errors will be compensated for by a corresponding change in the vulnerability (and to a lesser extent in the population size). Other species with high vulnerabilities were Salvin's albatross, Buller's albatross, Chatham Island albatross, Campbell black-browed albatross, New Zealand white-capped albatross, and flesh-footed shearwater. These species all had a species vulnerability with a 95% c.i. that was higher than the value for white-chinned petrel. In contrast, gulls, terns, skua, and small *Pterodroma* petrels had the lowest values for species-group vulnerability.

Comparisons of the fishery-group vulnerability (Table 8) are restricted to the same fishing method, owing to the different units of fishing effort for each fishing method (i.e., tows for trawling, sets for longlining, and net length for set netting). The intercept varied by fishing method to scale vulnerability between the fishing methods (Table 7). Within trawl fisheries, there were few fisheries whose vulnerability was significantly different from the reference group. In trawl fisheries, early-period mackerel trawl, early-period squid trawl and large fresher trawl had 95% credible intervals that were less than one (Table 8). No fishery groups in the other methods had credible intervals that did not include one. In bottom-longline fisheries, the vulnerability associated with large vessels not using integrated weight line was higher than the vulnerability of vessels using integrated weight line. This difference highlights the efficiency of this mitigation measure to reduce the incidental capture of seabirds.

For fishery groups with sufficient data, vulnerabilities were estimated separately for the periods 2006–07 to 2009–10 and 2010–11 to 2014–15 to assess potential changes in vulnerability over time. These fisheries included the large processor trawl fishery group, trawl fisheries targeting southern blue whiting, mackerel, or squid, and surface-longline vessels over 45 m length (Figure 5). For the trawl fisheries, the estimated mean vulnerability increased between the two time periods, with a mean increase of between 30% and 90%, depending on the fishery group. This increase in vulnerability suggests an overall increase in estimated seabird capture rate in these fisheries, for fishing at the same location and at the same time of year. For the large surface-longline fishery group, the estimation showed a decrease in mean vulnerability over time.

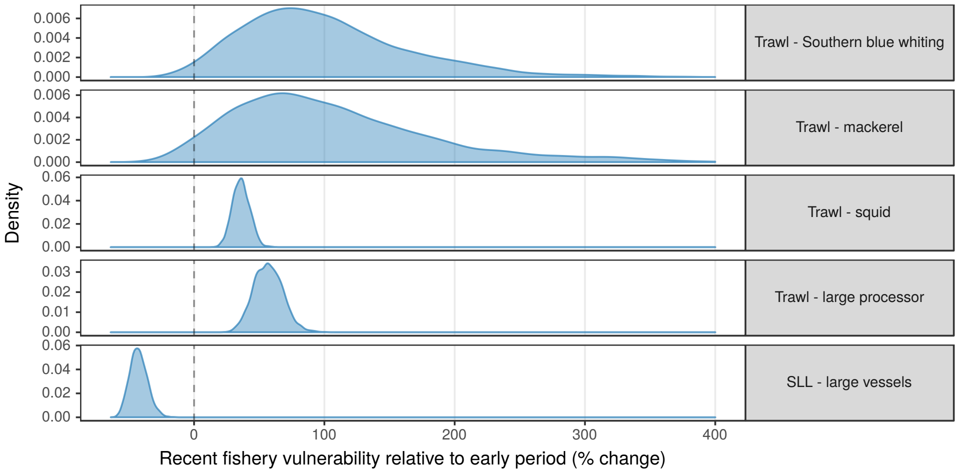

Figure 5: Change in fishery-group vulnerability, between the periods 2006–07 to 2009–10 and 2010–11 to 2014–15, as estimated in the model. Change is expressed in percentage of change from the earlier period for each fishery group, with a positive change representing an increase in vulnerability over time (SLL, surface longlining).

3.3 Risk to seabirds

Annual potential fatalities were derived by applying the vulnerabilities to the total annual overlap (including unobserved fishing) between 2012–13 and 2014–15, and the risk ratio was derived as the ratio of annual potential fatalities to the PST. The highest risk ratio was for black petrel (Table 9 and Figure 6). The PST for this species was an estimated mean of 437 (95% c.i.: 220–834) individuals, while the mean number of annual potential fatalities was estimated to be 468 (95% c.i.: 316–666). These estimates resulted in a median risk ratio of 1.15 (95% c.i.: 0.51–2.03), with the estimated number of annual potential fatalities typically higher than the PST – the probability that the number of annual potential fatalities

Table 6: Vulnerability (mean and 95% credible interval, c.i.; v_g) of seabirds to capture in trawl, longline, and set-net fisheries used in the estimation of observable captures, for each species group. Note that this is only the species-specific component of the vulnerability, there is also a fishery-related vulnerability, a method-specific intercept, and a species-fishery interaction.

Species group	Vulnerability	
	Mean	95% c.i.
Black petrel	24.92	5.04–73.95
Salvin's albatross	19.94	5.11–53.83
Buller's albatrosses	10.75	2.77–29.96
Chatham albatross	7.07	1.13–22.88
Campbell black-browed albatross	6.8	1.59–19.75
White-capped albatross	6.13	1.66–15.99
Flesh-footed shearwater	5.06	1.14–14.59
Westland petrel	4.34	0.86–13.03
Giant petrel	4.05	0.65–12.68
Grey petrel	3.77	0.90–10.74
Wandering albatrosses	2.92	0.55–9.14
Royal albatrosses	1.19	0.24–3.63
White-chinned petrel	1	1.00–1.00
Yellow-eyed penguin	0.65	0.05–2.65
Cape petrel	0.38	0.03–1.59
Grey-headed albatross	0.19	0.01–0.99
Group foraging shags	0.16	0.02–0.62
Light-mantled sooty albatross	0.14	0.00–0.72
Solitary shags	0.09	0.01–0.37
Sooty shearwater	0.08	0.02–0.23
Storm petrels	0.07	0.01–0.22
Diving petrels	0.05	0.01–0.16
Large *Pterodroma* petrels	0.03	0.01–0.10
Crested penguins	0.03	0.00–0.11
Shearwaters	0.02	0.00–0.07
Little penguins	0.01	0.00–0.07
Boobies and gannets	0.01	0.00–0.06
Prions	0.01	0.00–0.04
Small *Pterodroma* petrels	0	0.00–0.02
Gulls, terns & skua	0	0.00–0.01

Table 7: Vulnerability (mean and 95% credible interval, c.i.; v_{0m}) of seabirds to capture in trawl, longline, and set-net fisheries used in the estimation of observable captures, for each fishing method.

Method	Vulnerability	
	Mean	95% c.i.
Trawl	0.015	0.005–0.037
Surface longline	0.081	0.022–0.214
Bottom longline	0.009	0.002–0.022
Set net	0.002	0.000–0.005

exceeded the PST was 63%. Although the estimated number of annual potential fatalities was high, observed captures of black petrel have typically been low, reflecting low observer coverage in the fisheries where they are caught. Between the fishing years 2006–07 and 2014–15, there were 8 observed captures of this species in trawl fisheries, 62 observed captures in bottom-longline fisheries, and 21 observed captures in surface-longline fisheries.

Among the 71 seabird taxa included in this risk assessment, only black petrel was in the "very high risk" category (Table 9, Figure 6). There were seven species in the "high risk" category: Salvin's albatross, flesh-footed shearwater, Westland petrel, southern Buller's albatross, Chatham Island albatross, New Zealand white-capped albatross, and Gibson's albatross. There were five populations in the "medium risk" category: northern Buller's albatross, Antipodean albatross, yellow-eyed penguin (when only considering the mainland population and assigning all potential fatalities to this population), Otago shag, and northern giant petrel. The risk of four populations was categorised as "low risk", including spotted shag, yellow-eyed penguin (whole New Zealand population), Campbell black-browed albatross, and northern royal albatross. The risk of the remaining 55 taxa was categorised as "negligible risk".

Large seabirds were found to be the most at risk, due to a combination of their low productivity (with a late age at first breeding, and a single egg produced every one or two years), and a propensity to interact with commercial fisheries. Of the eight species in the "very high risk" or "high risk" categories, five were albatrosses, and the remaining species were *Procellaria* petrels or large shearwaters.

Following black petrel, the species second-most at risk was Salvin's albatross, which was in the "high risk" category with a median risk ratio of 0.78 (95% c.i.: 0.51–1.09). The mean PST was 3598 (95% c.i.:

Table 8: Vulnerability (mean and 95% credible interval, c.i.; v_g) of seabirds to capture in trawl and longline fisheries used in the estimation of observable captures, for each fishery group. Small vessel size classes for trawling were $<$17 m and 17 to 28 m length, for bottom longlining (BLL) $<$34 m length, and for surface longlining (SLL) $<$45 m length. Early and late time periods were 2006–07 to 2009–10 and 2010–11 to 2014–15, respectively (IWL, integrated weight line; SN, set net).

Method	Fishing group	Period	Vulnerability	
			Mean	95% c.i.
Trawl	Small inshore < 17m		0.47	0.09–1.40
	Small inshore < 28m		1.34	0.29–3.79
	Southern blue whiting	Early	0.85	0.14–2.92
		Late	1.59	0.28–5.23
	Scampi		1.1	0.24–3.10
	Mackerel	Early	0.19	0.04–0.60
		Late	0.36	0.08–1.03
	Squid	Early	0.74	0.67–0.81
		Late	1	1.00–1.00
	Large processor	Early	1.02	0.28–2.66
		Late	1.59	0.44–4.18
	Large fresher		0.24	0.02–0.91
	Deepwater		1.01	0.19–3.06
BLL	Bluenose		1.51	0.22–5.16
	Snapper		1	1.00–1.00
	Ling and ribaldo		4.36	0.87–13.45
	Other small BLL vessels		4.07	0.85–11.98
	Large vessels without IWL		3.16	0.43–10.97
	Large vessels with IWL		0.86	0.14–2.91
SLL	Swordfish		3.12	0.57–9.96
	Other small SLL vessels		2.25	0.47–6.66
	Large vessels	Early	1.77	1.39–2.22
		Late	1	1.00–1.00
SN	Set net		1	1.00–1.00

Figure 6: Risk ratio for different seabird taxa, based on data between 2006–07 and 2014–15. The risk ratio is displayed on a logarithmic scale, with the threshold of the number of potential bird fatalities equalling the Population Sustainability Threshold (PST) represented by the black vertical line, and the distribution of the risk ratios within their 95% credible interval indicated by the coloured shapes, including the median risk ratio (vertical line). Seabird taxa are listed in decreasing order of the median risk ratio. Taxa with a risk ratio of almost zero were not included (95% upper limit less than 0.05). The risk ratio of yellow-eyed penguin refers to the mainland population only, based on the assumption that all estimated fatalities were of the mainland population, and the number of annual breeding pairs was between 600 and 800.

2709–4941) individuals, and the mean number of annual potential fatalities was 2778 (95% c.i.: 2028–3764). Between the fishing years 2006–07 and 2014–15, there were 290 observed captures of Salvin's albatross in trawl fisheries, 31 observed captures in bottom-longline fisheries, and 7 observed captures in surface-longline fisheries.

The third highest risk ranking was for flesh-footed shearwater, with a median risk ratio of 0.67 (95% c.i.: 0.39–1.15). The mean PST of this species was 1451 (95% c.i.: 1033–1998) individuals, and the mean number of annual potential fatalities was 987 (95% c.i.: 623–1561). Between the fishing years 2006–07 and 2014–15, there were 49 observed captures of flesh-footed shearwater in trawl fisheries, 68 observed captures in bottom-longline fisheries, and 7 observed captures in surface-longline fisheries.

The other five species in the "high risk" category had a median risk ratio of less than 0.5: Westland petrel, southern Buller's albatross, Chatham Island albatross, New Zealand white-capped albatross, and Gibson's albatross. For birds in the "high risk" category, the probability that the annual potential fatalities were higher than the PST was less than 10%.

These risk categories were based on the median and upper 95% credible limit of the risk ratio. From the samples of the risk ratio, the probability that the risk is larger than 1 was calculated, indicating species for which the number of annual potential fatalities exceeded the PST (Table 9). For black petrel, the only species in the "very high risk" category, the probability that the risk ratio was larger than 1 was 63%. For birds in the "high risk" category, the probability that the risk ratio is larger than 1 was less than 10%.

Table 9: Population Sustainability Threshold (PST), total annual potential fatalities (APF) in trawl, longline, and set-net fisheries, risk ratio with $f = 1$ ($\text{RR} = \text{APF}/\text{PST}$), and the probability that $\text{APF} > \text{PST}$ for seabird taxa in the current risk assessment. Taxa are ordered in decreasing order of the median risk ratio. The risk to yellow-eyed penguin was assessed for the entire New Zealand population, but also for the mainland population only, based on the assumption that all estimated fatalities were of the mainland population, and the number of annual breeding pairs was between 600 and 800. Taxa names are coloured according to their risk category. Red: risk ratio with a median over 1 or upper 95% credible limit (u.c.l.) over 2; dark orange: median over 0.3 or u.c.l. over 1; light orange: median over 0.1 or u.c.l. over 0.3; yellow: u.c.l. over 0.1. PST and APF values were rounded to three significant digits.

	PST		APF		Risk ratio		P(APF > PST)
	Mean	95% c.i.	Mean	95% c.i.	Median	95% c.i.	
Black petrel	437	220–834	468	316–666	1.15	0.51–2.03	0.63
Salvin's albatross	3 600	2 710–4 940	2 780	2 030–3 760	0.78	0.51–1.09	0.08
Flesh-footed shearwater	1 450	1 030–2 000	987	623–1 560	0.67	0.39–1.15	0.08
Westland petrel	350	234–520	180	67–407	0.48	0.18–1.19	0.06
Southern Buller's albatross	1 370	901–2 160	528	371–745	0.39	0.22–0.66	0.00
Chatham Island albatross	425	296–623	155	89–246	0.36	0.18–0.66	0.00
NZ white-capped albatross	10 900	7 630–15 800	3 830	2 690–5 380	0.35	0.21–0.58	0.00
Gibson's albatross	496	331–736	166	106–242	0.34	0.19–0.59	0.00
Northern Buller's albatross	1 630	1 050–2 570	397	294–523	0.25	0.14–0.41	0.00
Antipodean albatross	364	251–513	74	45–115	0.20	0.11–0.36	0.00
Yellow-eyed penguin (mainland)	121	80–179	23	8–47	0.18	0.07–0.45	0.00
Otago shag	285	182–425	41	22–64	0.14	0.07–0.28	0.00
Northern giant petrel	336	159–805	47	14–112	0.14	0.03–0.47	0.00
Spotted shag	3 710	1 780–6 900	335	215–484	0.09	0.04–0.20	0.00
Yellow-eyed penguin	287	191–425	23	8–47	0.08	0.03–0.19	0.00
Campbell black-browed albatross	1 980	1 010–3 590	153	88–264	0.08	0.04–0.18	0.00
White-chinned petrel	25 600	16 300–41 100	1 360	1 080–1 720	0.05	0.03–0.09	0.00
Northern royal albatross	716	342–1 360	34	10–92	0.04	0.01–0.16	0.00
Foveaux shag	207	130–316	8	2–15	0.04	0.01–0.08	0.00
Grey petrel	5 530	3 220–9 140	203	123–340	0.04	0.02–0.08	0.00
Southern royal albatross	848	596–1 170	19	6–41	0.02	0.01–0.05	0.00
Snares Cape petrel	1 600	602–4 030	19	2–74	0.01	0.00–0.06	0.00
Little black shag	338	153–655	3	0–11	0.01	0.00–0.04	0.00
Pied shag	1 120	702–1 680	9	0–29	0.01	0.00–0.03	0.00
Grey-faced petrel	29 900	19 200–49 500	146	57–321	0.00	0.00–0.01	0.00
Fluttering shearwater	36 100	15 100–72 700	140	68–272	0.00	0.00–0.01	0.00
Fiordland crested penguin	636	295–1 230	4	0–23	0.00	0.00–0.04	0.00
Sooty shearwater	617 000	291 000–1 240 000	1 470	790–2 810	0.00	0.00–0.01	0.00
Grey-headed albatross	695	349–1 250	3	0–15	0.00	0.00–0.03	0.00
Common diving petrel	135 000	47 800–309 000	317	46–1 250	0.00	0.00–0.01	0.00
Light-mantled sooty albatross	869	666–1 120	3	0–15	0.00	0.00–0.02	0.00
Hutton's shearwater	15 000	9 300–23 400	22	4–80	0.00	0.00–0.01	0.00
Northern little penguin	1 510	934–2 330	2	0–8	0.00	0.00–0.01	0.00
White-headed petrel	34 300	16 600–66 100	19	6–40	0.00	0.00–0.00	0.00
Southern little penguin	1 520	918–2 380	1	0–7	0.00	0.00–0.00	0.00
NZ white-faced storm petrel	332 000	137 000–669 000	131	28–376	0.00	0.00–0.00	0.00
Australasian gannet	9 440	4 240–19 300	5	0–20	0.00	0.00–0.00	0.00
Buller's shearwater	56 000	34 500–103 000	18	6–47	0.00	0.00–0.00	0.00
Southern black-backed gull	334 000	137 000–703 000	87	29–200	0.00	0.00–0.00	0.00
Fairy prion	329 000	214 000–506 000	127	15–566	0.00	0.00–0.00	0.00
Little shearwater	21 800	14 100–33 100	5	1–12	0.00	0.00–0.00	0.00
Black-bellied storm petrel	15 600	8 850–25 700	4	0–15	0.00	0.00–0.00	0.00
Cook's petrel	49 400	27 400–89 300	14	0–76	0.00	0.00–0.00	0.00
Broad-billed prion	69 100	45 700–105 000	11	1–35	0.00	0.00–0.00	0.00
Antarctic prion	154 000	77 200–289 000	22	4–60	0.00	0.00–0.00	0.00
Snares crested penguin	6 840	4 770–9 620	1	0–4	0.00	0.00–0.00	0.00
Mottled petrel	47 700	30 400–77 600	7	0–41	0.00	0.00–0.00	0.00
Auckland Island shag	473	198–952	0	0–1	0.00	0.00–0.00	0.00
Bounty Island shag	26	14–44	0	0–0	0.00	0.00–0.00	0.00
Subantarctic skua	67	44–100	0	0–0	0.00	0.00–0.00	0.00
Caspian tern	170	96–282	0	0–1	0.00	0.00–0.01	0.00
Chatham Island shag	76	46–116	0	0–3	0.00	0.00–0.04	0.00
Campbell Island shag	492	230–944	0	0–0	0.00	0.00–0.00	0.00
Chatham Island little penguin	1 510	935–2 390	1	0–5	0.00	0.00–0.00	0.00
White-flippered little penguin	466	275–737	0	0–3	0.00	0.00–0.01	0.00
Eastern rockhopper penguin	11 100	6 800–17 500	1	0–3	0.00	0.00–0.00	0.00
Erect-crested penguin	17 800	12 600–24 600	1	0–3	0.00	0.00–0.00	0.00
White-bellied storm petrel	232	105–458	0	0–0	0.00	0.00–0.00	0.00
White tern	26	15–43	0	0–0	0.00	0.00–0.00	0.00
South Georgian diving petrel	10	5–18	0	0–1	0.00	0.00–0.07	0.00
NZ king shag	39	24–61	0	0–3	0.00	0.00–0.07	0.00
Kerm. storm petrel	11	4–25	0	0–0	0.00	0.00–0.00	0.00
Masked booby	52	28–89	0	0–0	0.00	0.00–0.00	0.00
NZ storm petrel	51	6–192	0	0–1	0.00	0.00–0.04	0.00
Pitt Island shag	104	61–161	0	0–2	0.00	0.00–0.03	0.00
Chatham petrel	42	23–76	0	0–0	0.00	0.00–0.00	0.00
Chatham Island taiko	2	1–4	0	0–0	0.00	0.00–0.00	0.00
Pycroft's petrel	412	246–723	0	0–1	0.00	0.00–0.00	0.00
Soft-plumaged petrel	499	137–1 280	0	0–0	0.00	0.00–0.00	0.00
Wedge-tailed shearwater	5 930	3 120–10 500	0	0–0	0.00	0.00–0.00	0.00
Kerm. petrel	781	511–1 320	0	0–1	0.00	0.00–0.00	0.00
White-naped petrel	7 010	3 320–13 800	0	0–0	0.00	0.00–0.00	0.00

3.4 Annual potential fatalities by fishery

The risk assessment estimates the annual potential fatalities by fishery, allowing the contribution to the risk from each fishery to be assessed. Across the four fishing methods included in the assessment, the mean number of annual potential fatalities of the 71 seabird taxa was estimated at 14 400 (95% c.i.: 11 900–17 500) birds for the fishing years between 2012–13 and 2014–15 (Table 10). Trawl fisheries were associated with the highest number of annual potential fatalities, with a mean of 10 800 (95% c.i.: 8390–13 800) seabirds per year. The mean number of annual potential fatalities in bottom-longline fisheries was estimated at 2420 (95% c.i.: 1930–2950), followed by a estimated mean 1090 (95% c.i.: 868–1340) annual potential fatalities in surface-longline fisheries. The lowest estimated number of annual potential fatalities was in set-net fisheries, with 98 (95% c.i.: 55–166) birds per year.

Table 10: Total annual potential fatalities of seabirds in trawl, bottom-longline (BLL), surface-longline (SLL), and set-net (SN) fisheries by target fishery, between 2012–13 and 2014–15. The mean and 95% c.i. are shown, and sorted in descending order within each fishing method.

Method	Fishery	Annual potential fatalities	
		Mean	95% c.i.
Trawl	Inshore	4 800	3 140–7 080
	Hoki	1 540	1 140–2 050
	Flatfish	1 210	804–1 820
	Middle depth	1 060	777–1 410
	Scampi	777	489–1 150
	Squid	775	561–1 020
	Deepwater	237	120–433
	Ling	174	121–252
	Hake	91	62–124
	Southern blue whiting	80	41–140
	Jack mackerel	38	19–65
BLL	Small vessel, ling	1 090	809–1 410
	Snapper	523	385–681
	Minor targets	254	170–364
	Hapuka	238	140–398
	Large vessel, ling	192	130–268
	Bluenose	125	49–223
SLL	Bigeye	422	318–548
	Small vessel, southern bluefin	359	277–450
	Swordfish	262	170–372
	Large vessel, southern bluefin	33	19–49
	Minor targets	9	4–16
	Albacore	2	0–5
SN	Shark	42	24–65
	Flatfish	31	13–62
	Minor targets	21	9–39
	Grey mullet	4	0–11
Total	Total	14 400	11 900–17 500

The number of annual potential fatalities in trawl fisheries was sufficiently high to result in the “high risk” category for New Zealand white-capped albatross, Salvin’s albatross, southern Buller’s albatross, Westland petrel, and flesh-footed shearwater (Appendix G.5, Table G-31). Among trawl fisheries, annual potential fatalities were highest in inshore trawl fisheries (Appendix G.5, Table G-27), with a mean of 4800 (95% c.i.: 3140–7080) seabirds per year, predominantly New Zealand white-capped albatross and Salvin’s albatross. The number of annual potential fatalities of these two species in inshore trawl fisheries were sufficiently high to result in their ranking in the “high risk” category. Other trawl fisheries with a mean number above 1000 annual potential fatalities included fisheries targeting hoki, flatfish, and middle-depth species. Annual potential fatalities in these fisheries were mostly of New Zealand white-capped albatross and Salvin’s albatross.

Among all bottom-longline fisheries, the small-vessel (less than 34 m in length) fishery targeting ling had the highest estimated annual potential fatalities (Appendix G.5, Table G-28), with a mean of 1090 (95% c.i.: 809–1410) birds annually. The species predominantly involved in these fishing mortalities were white-chinned petrel, Salvin's albatross, and Chatham Island albatross. Annual potential fatalities of Chatham Island albatross in this fishery were sufficiently high to result in the "medium risk" ranking of this species. The number of annual potential fatalities in the small-vessel fisheries targeting snapper were the second-highest estimates among the bottom-longline fisheries, with a mean of 523 (95% c.i.: 385–681) seabirds per year, predominantly of flesh-footed shearwater and black petrel. For these two species, the annual potential fatalities in snapper target fisheries were sufficiently high to result in the "medium risk" ranking. For black petrel, annual potential fatalities in bottom-longline fisheries targeting bluenose were also sufficiently high to rank this species in the "medium risk" category. Across all bottom-longline fisheries, annual potential fatalities of black petrel and flesh-footed shearwater were sufficiently high to rank them in the "high risk" category, while annual potential fatalities of flesh-footed shearwater and Chatham Island albatross in these fisheries resulted in the "medium risk" ranking for these two species.

Surface-longline fisheries with the highest number of annual potential fatalities were fisheries targeting bigeye tuna, and the small-vessel fleet targeting southern bluefin tuna (vessels less than 45 m long). For these two fisheries, the estimated mean number of annual potential fatalities was 422 (95% c.i.: 318–548) and 359 (95% c.i.: 277–450) seabirds, respectively (Appendix G.5, Table G-29). Most annual potential fatalities in the fishery targeting bigeye tuna involved black petrel and northern Buller's albatross. For black petrel, annual potential fatalities in this fishery were sufficiently high to result in a risk category of "medium risk". In comparison, in the small-vessel southern-bluefin tuna fishery, annual potential fatalities were mostly of New Zealand white-capped albatross. For Gibson's albatross, the number of annual potential fatalities in the swordfish target fishery resulted in the "medium risk" for this species.

Set-net fisheries had relatively low numbers of annual potential fatalities, with the total mean of 98 (95% c.i.: 55–166) seabirds per year. Among set-net fisheries, fisheries targeting shark species had the highest estimated annual potential fatalities, with a mean of 42 (95% c.i.: 24–65) birds per year, mostly of yellow-eyed penguin.

The estimation of annual potential fatalities included estimation of the probability that a capture incident was observable. For consistency with previous rassessment (e.g., Richard & Abraham 2015) this probability is presented as the cryptic multiplier (the inverse of $p_{\text{observable}}$). The cryptic multiplier was lowest in mackerel trawl fisheries (Table 11), varying from 1.8 (95% c.i.: 1.2–2.8) for medium-sized seabirds, to 5.3 (95% c.i.: 1.3–15.0) for small-sized seabirds. In contrast, the cryptic multipliers were higher but also had a higher uncertainty in small inshore, large fresher, and deepwater trawl fisheries. The highest estimated cryptic multiplier was for small-sized seabirds in the inshore fleet of vessels between 17 and 28 m length, with a mean of 104.0 (95% c.i.: 26.9–272.7).

Table 11: Cryptic multiplier (mean and credible interval, c.i.) by species group and modelled trawl fishery group, summarised from the posterior distributions after model fitting. The "mollymawks" species group included giant petrel.

Trawl fishery	Large albatrosses		Mollymawks		Medium-sized seabirds		Small-sized seabirds		Diving seabirds	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Small inshore < 17 m	13.9	5.2–26.6	18.7	11.6–28.2	14.6	3.3–40.9	104.0	26.9–272.7	1.3	1.0–1.6
Small inshore 17 to 28 m	15.8	7.5–27.2	18.2	11.9–26.7	15.0	5.3–32.9	106.5	33.3–260.5	1.3	1.1–1.7
Southern blue whiting	7.9	2.4–18.2	13.6	8.1–21.3	5.2	1.8–11.6	55.6	13.4–146.6	1.3	1.1–1.6
Scampi	4.8	1.6–10.8	7.3	4.2–11.6	2.4	1.3–4.0	27.2	6.9–72.5	1.3	1.1–1.6
Mackerel	2.8	1.2–5.7	4.5	2.0–8.7	1.8	1.2–2.8	5.3	1.3–15.0	1.3	1.1–1.6
Squid	3.0	1.3–6.1	5.4	3.7–7.5	1.9	1.3–2.6	7.1	2.1–17.7	1.3	1.1–1.6
Large processor	4.4	1.7–9.8	7.0	4.7–9.9	2.4	1.4–3.8	13.4	3.7–34.4	1.3	1.1–1.7
Large fresher	12.0	3.4–26.4	16.6	8.7–27.9	32.4	3.4–130.3	90.9	18.0–271.2	1.3	1.1–1.6
Deepwater	13.9	6.3–25.1	19.4	12.4–28.8	32.9	7.6–90.5	91.5	28.5–224.2	1.3	1.1–1.6

Estimation of the annual potential fatalities also included the probability that a captured bird was released alive. This probability varied among species and fishery groups (see Appendix F, Figure F-13). The probability of a live release was high for prions, giant petrels, diving petrels, gulls, shearwaters and black petrel. In contrast, it was close to zero for Cape petrel, shag species, and yellow-eyed penguin across the different fishery groups.

Among fishery groups, the probability of birds being released alive was highest in set-net fisheries and in bottom-longline fisheries targeting bluenose. The probability was lowest for small bottom-longline vessels (less than 34 m long) targeting species other than bluenose, trawl fisheries targeting southern blue whiting, scampi, and deepwater trawl fisheries.

For black petrel in the bottom-longline fishery targeting bluenose, the estimate of the probability that a captured bird was released alive was relatively high. This estimate was influenced by an observed capture event of 27 black petrel individuals during a single bluenose bottom-longline fishing trip of this fishery, of which 25 individuals were released alive. These captures represented almost a third of all recorded captures of this species, and almost half of all captures recorded in this fishery.

3.5 Sources of risk uncertainty

The source of uncertainty in the risk ratio was disaggregated by fixing each of the demographic parameters and the annual potential fatalities to its mean, independently of each other. This sensitivity analysis highlighted the influence of some of the input parameters on the risk ratio, evident in the decrease in the 95% credible interval of the risk ratio (Figure 7, and see details in Table G-36). The uncertainty in annual potential fatalities was not further disaggregated between the vulnerability or cryptic mortality.

For the 60 taxa for which the sensitivity to uncertainties could be calculated (i.e., with a risk ratio different to zero and some uncertainties above zero), the highest sensitivity to the uncertainty in the annual potential fatalities was in trawl fisheries; this parameter was the most influential parameter for 30 taxa. The second most important parameter was the uncertainty in annual potential fatalities in bottom-longline fisheries, which was the most influential parameter for 15 species. The uncertainty in the number of annual breeding pairs had the third highest influence on the resulting uncertainty in the risk ratio, and was the most important parameter for 8 taxa.

In contrast, the uncertainty in the risk ratio was not sensitive to the uncertainties in the age at first reproduction (both from the literature and from the taxonomic analysis) or the uncertainty in the adult annual survival rate from the taxonomic analysis.

Among the 16 seabird taxa most-at-risk, there were clear differences in the influence of the uncertainty in the input parameters on the uncertainty in the risk ratio (Figure 7). For black petrel, the uncertainty in the risk ratio was almost exclusively determined by the uncertainty in the number of annual breeding pairs. For Salvin's albatross, which had the second highest risk ranking, uncertainties in several of the parameters influenced the uncertainty in the risk ratio. These parameters included annual potential fatalities in trawl fisheries, followed by the adult annual survival rate and the age at first reproduction, which had both been obtained from the literature.

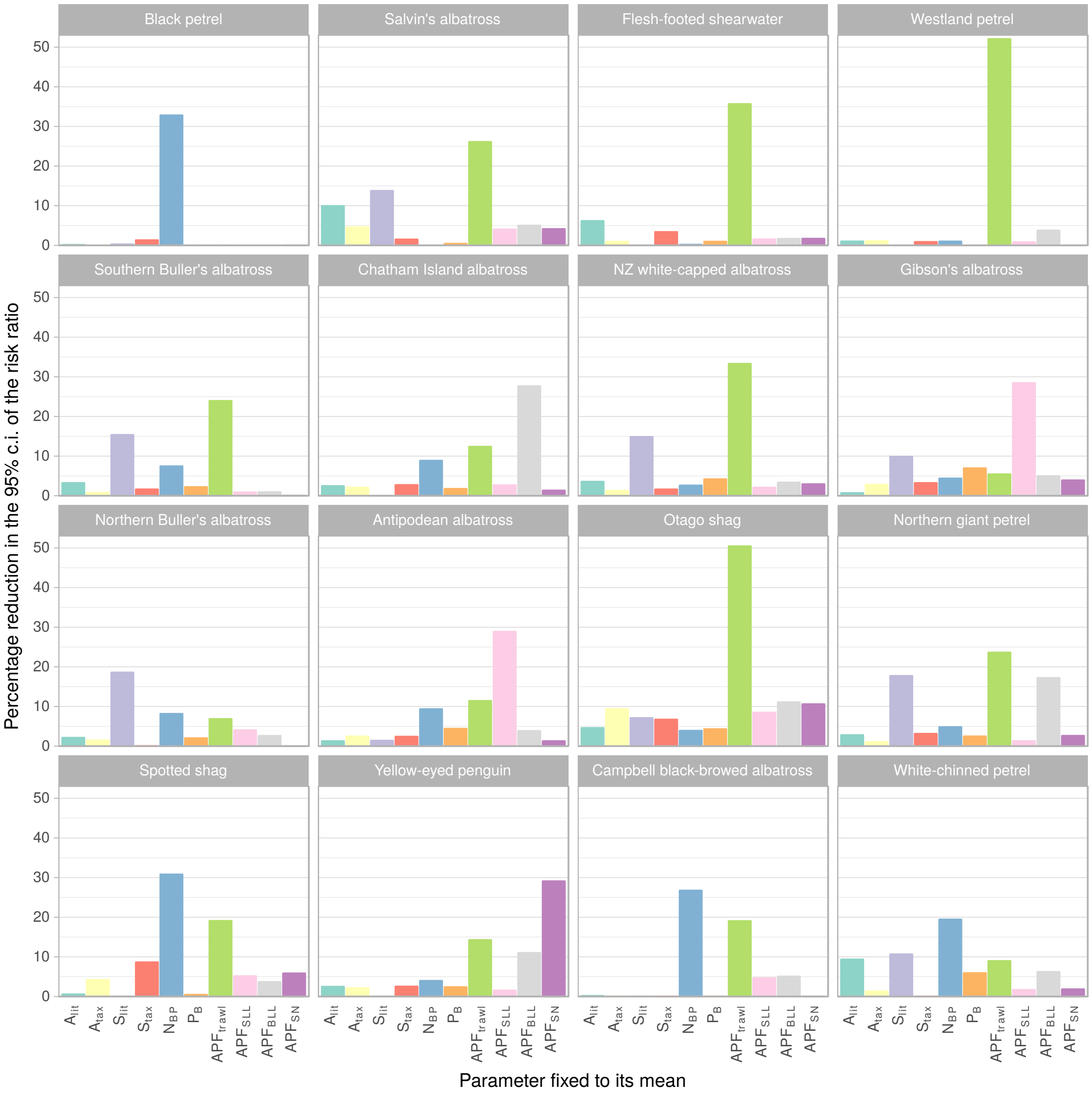

Figure 7: Sources of the uncertainty in the risk ratio for the 16 most-at-risk seabird taxa. Values are percentage decrease in the 95% credible interval of the risk ratio for each parameter, when fixed to the mean independently of each other. Parameters include age at first reproduction A and adult survival rate S (from the literature or from taxonomic analysis), the number of annual breeding pairs N_{BP}, the proportion of adults breeding in a year, P_{B}, and annual potential fatalities (APF) in trawl, surface-longline (SLL), bottom-longline (BLL), and set-net (SN) fisheries.

3.6 Sensitivities to changes in methodology and data

Several sensitivities were carried out, repeating the risk analysis with different assumptions. For black petrel and yellow-eyed penguin, the estimation process was repeated, updating the population size with recent surveys. These sensitivities are only indicative, as data on captures may have been recorded when the population size was different from these recent surveys. For black petrel, the population estimate was based on the 2015–16 surveys of Great Barrier and Little Barrier islands (Bell et al. 2016b, 2016a), without considering earlier data from South America by Spear et al. (2005). Using this lower population estimate in the estimation process led to an increase in risk ratio for this species from a median of 1.15 (95% c.i.: 0.51–2.03) to 2.11 (95% c.i.: 1.63–2.58) (Table G-38). At the same time, the uncertainty decreased owing to a more precise population estimate. Furthermore, the probability of annual potential fatalities exceeding the PST increased from 63% to 100% for black petrel.

Similarly, when data from the most recent survey of yellow-eyed penguin on South and Stewart islands were used, assuming that all annual potential fatalities were from this population, the risk ratio for the mainland population doubled (Table G-38). The risk ratio for mainland yellow-eyed penguin increased from a median 0.18 (95% c.i.: 0.07–0.45) to 0.36 (95% c.i.: 0.12–0.90), and as a consequence, the risk category increased from “medium risk” to “high risk”. Furthermore, the probability of annual potential fatalities exceeding the PST increased from 0.025% to 1.45% for this population.

When the period was changed from data to 2010–11 to data to 2014–15, the risk category changed for seven species (Table G-38): from “medium” to “high” for Westland petrel and Gibson’s albatross, and from “negligible” to “low” for northern royal albatross. In particular, the risk ratio of Westland petrel doubled from a median of 0.24 (95% c.i.: 0.08–0.72) to 0.46 (95% c.i.: 0.18–1.19), and that of northern royal albatross approximately tripled, from a median of 0.013 (95% c.i.: 0.002–0.053) to 0.043 (95% c.i.: 0.012–0.163). In contrast, the risk category decreased from “medium” to “low” for spotted shag and yellow-eyed penguin, and from “low” to “negligible” for Foveaux and New Zealand king shags.

3.7 Changes from the preceding risk assessment

Changes in the methodology and updates to the data resulted in a marked decrease in the risk ratio for most taxa, when compared with the previous seabird risk assessment (Richard & Abraham 2015, see Appendix G, Table G-34). The risk category decreased for 22 taxa. Species with a previous risk category of “very high risk” decreasing to the risk category “high risk” included southern Buller’s albatross, Salvin’s albatross, Gibson’s albatross, flesh-footed shearwater, and New Zealand white-capped albatross, while it decreased to the “medium risk” category for northern Buller’s albatross. Among the species that were previously in the “high risk” category, the risk category decreased to “medium risk” for Antipodean albatross and to “low risk” for Campbell black-browed albatross. The risk categories also decreased for seven species that were previously in the “medium risk” category, and for 10 species that were previously in the “low risk” category.

The impact of the changes was explored by re-running the risk assessment, with each change in methodology, or update to the data, reverted to how it was previously. When reverting each change, there were a number of species with increases and decreases in the risk categories (Figure 8; and see Table G-37 for the corresponding risk ratios and risk categories for all taxa).

The change in the calibration of the PST had the largest impact on the risk categories (Figure 8). The use of the total population size in the PST calculation, instead of the total population size derived from the lower quartile of the number of breeding pairs, also led to a reduction in risk ratios, although to a lesser extent. The difference was more pronounced for taxa with a higher uncertainty in the estimate of the population size. When re-running the updated base case with N_{min} instead of N_{tot}, the PST decreased by an average of 20%. The highest reduction in the PST was for New Zealand storm petrel, with a decrease from a mean of 51 (95% c.i.: 6–192) to 11 (95% c.i.: 5–21) due to high uncertainty in the population size (this species was rediscovered in 2003 and there are few data available). The risk category increased for four species when re-running the base case with N_{min} for the PST calculation (Table G-37).

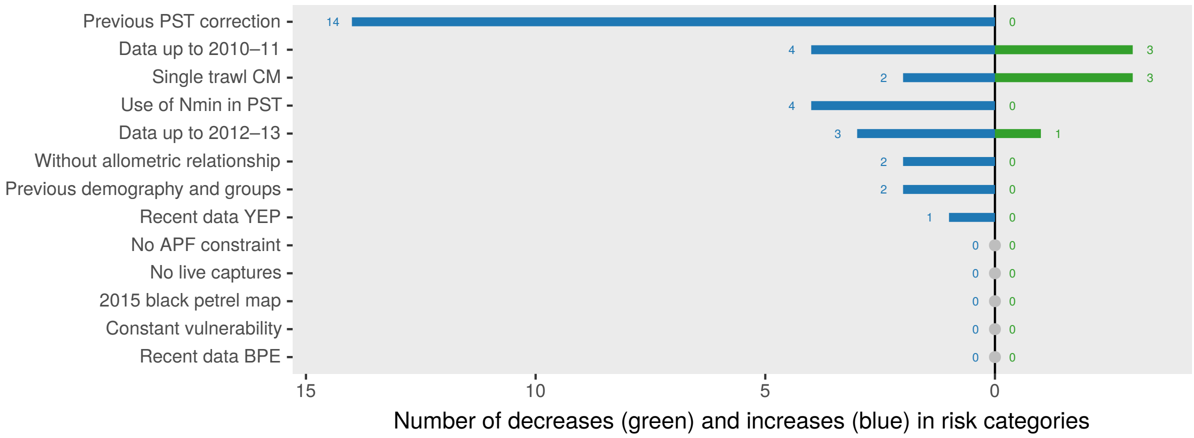

Figure 8: Number of species with decreases (in green) and increases (in blue) in risk categories for a range of model variations used in the current seabird risk assessment, in comparison with the base model. Model versions are sorted in decreasing order of the total number of changes in risk rankings. PST, Population Sustainability Threshold; CM, cryptic mortality; Nmin, estimate of the number of annual breeding pairs; YEP: yellow-eyed penguin; APF, annual potential fatalities; BPE, black petrel.

Another reason for the decrease in risk ratios compared with the preceding risk assessment by Richard and Abraham (2015) was the use of allometric modelling to estimate adult survival and age at first reproduction used in the calculation of r_{max}. This modelling reduces the variation in individual estimates of these parameters, so that very low or high survival estimates for a particular taxon do not strongly affect the risk ratio. Using literature estimates of adult annual survival and age at first reproduction directly, without using allometric models, led to an increase in the risk category of two species (Table G-37).

Updates of the demographic parameters and of the fishery groups only led to small changes in risk ratios (Table G-37). Compared with the results from the re-run of the updated base model with the same demographic parameters and fishery groups as used by Richard and Abraham (2015), the risk category changed for only two species: it decreased from "low' risk" to "negligible risk" for white-chinned petrel and New Zealand king shag. Without changing the risk categories, the median risk ratios increased for Westland petrel and the mainland population of yellow-eyed penguin, but decreased for black petrel, Salvin's albatross, flesh-footed shearwater, and New Zealand white-capped albatross.

Using data on captures and fishing up to 2012–13, as in the previous risk assessment, led to an increase in risk category for three species, and a decrease in one species (Table G-37). Otherwise, the updated data did not influence the risk category.

When the risk assessment was re-run without constraining the annual potential fatalities by the estimated natural mortality, the risk category remained the same for all taxa (Table G-37). Nonetheless, the risk slightly increased for all taxa at "high risk" and "very high risk", except for Gibson's albatross. The highest increase in risk ratio was for Salvin's albatross, with the median risk ratio increasing from 0.78 (95% c.i.: 0.51–1.09) to 0.90 (95% c.i.: 0.55–1.41), and for black petrel, from 1.15 (95% c.i.: 0.51–2.03) to 1.31 (95% c.i.: 0.55–3.20). This increase was due to an increase in annual potential fatalities (for all at-risk species apart from Gibson's albatross), and a decrease in PST through a decrease in the population size (for black petrel and Salvin's albatross).

Allowing some birds to survive after capture only led to a small decrease in risk ratios (Table G-37). When the risk assessment was re-run, but with the assumption that all captures were fatal, none of the risk categories changed. There were small decreases in risk for the species at risk with the largest proportion of observed captures released alive. For black petrel, the mean risk ratio decreased from a median of 1.40 (95% c.i.: 0.69–2.16) to 1.15 (95% c.i.: 0.51–2.03). For flesh-footed shearwater the median risk decreased from 0.82 (95% c.i.: 0.49–1.31) to 0.67 (95% c.i.: 0.39–1.15).

The disaggregation of cryptic mortality multipliers in trawl fisheries was the only update that led to an overall increase in risk ratio (Table G-37). Re-running the base case with a single cryptic mortality multiplier led to the risk category of black petrel to decrease from "very high risk" to "high risk", and the risk category of Westland petrel and New Zealand white-capped albatross to decrease from "high risk" to "medium risk".

The remaining changes did not change the risk categories of the associated taxa (Table G-37). These changes included the use of a new at-sea distribution map for black petrel, and a change over time in vulnerability for fisheries with sufficient data. These changes, however, contributed to a decrease in risk ratios.

4. DISCUSSION

4.1 Monitoring progress within the NPOA framework

We provided an assessment of the risk of commercial fisheries to seabirds in New Zealand waters, including data to the 2014–15 fishing year. The risk assessment process estimated the risk from commercial longline and trawl fishing for 71 seabird taxa that breed in the New Zealand region. In the context of the National Plan of Action (NPOA, Ministry for Primary Industries 2013), the risk assessment allows seabird populations to be assigned risk categories, enabling the monitoring of fisheries impacts on seabirds against clearly defined management goals. In this assessment, only black petrel was found to be in the "very high risk" NPOA category. There were seven species in the "high risk" category, including Salvin's albatross, flesh-footed shearwater, Westland petrel, southern Buller's albatross, Chatham Island albatross, New Zealand white-capped albatross, and Gibson's albatross.

Management objectives of the NPOA (to be achieved by June 2018) include the goal that "species currently categorised as at very high or high risk from fishing move to a lower category of risk" (Ministry for Primary Industries 2013). To achieve the monitoring of fisheries impacts on seabirds towards this goal, the risk assessment process was updated to include the most recent fisheries and observer data. At the same time, improvements were made to the risk assessment process, and other data informing the risk assessment were updated. The need for these updates and changes to the risk assessment is balanced with the need for comparability of the outcomes over time.

An earlier risk assessment provided the initial risk categories for seabird populations breeding in the New Zealand region, based on data between the 2006–07 and 2010–11 fishing years (Richard & Abraham 2013c). This earlier risk assessment also provided a framework for identifying limitations and improvements for future risk assessments, such as the species and fisheries groups used in the estimation (Walker et al. 2015). A subsequent risk assessment implemented these improvements, and also addressed earlier errors in the methodology, while including fisheries and observer data up to the 2012–13 fishing year (Richard & Abraham 2015). The findings from this subsequent risk assessment allowed comparisons with the earlier analysis, revealing only small changes in the risk rankings when the updates were limited to fishing and observer data.

The current study provides a further update by including data to the 2014–15 fishing year, and by implementing additional changes and improvements to input data and the methodology. These updates resulted in marked changes in some of the risk rankings, in particular decreases in the risk categories for some of the seabird taxa that were previously identified to be at "very high risk", such as Salvin's albatross, flesh-footed shearwater, southern Buller's albatross, and New Zealand white-capped albatross (see Richard & Abraham 2013c). To provide a direct comparison between the preceding and the current risk assessments, it is necessary to use consistent methods for both time periods. For this reason, the current, updated methodology was applied to data for the period from 2006–07 to 2010–11, the same period used by Richard and Abraham (2013c).

For six of the eight species that were ranked at "very high risk" and "high risk" using data from the earlier time period, there were no differences in the risk category between the earlier and current time periods, while there were increases in the risk category for two species. The six species for which the risk ranking remained the same were black petrel in the "very high risk" category, and Salvin's albatross, flesh-footed shearwater, Chatham Island's albatross, southern Buller's albatross, and New Zealand white-capped albatross in the "high risk" category. For another two species, Gibson's albatross and Westland petrel, the risk ranking increased from "medium risk" to "high risk" when including the recent data.

For some of the taxa in the lower risk categories, the current risk assessment resulted in a decrease in the risk ranking. For spotted shag and Campbell black-browed albatross, the risk category decreased from "medium risk" to "low risk", and for New Zealand king shag, it decreased from "low risk" to "negligible risk" (although the change in risk ratios was relatively small).

4.1.1 Comparison with other studies

There were a number of changes to the methodology in the current risk assessment. These changes and updates to the data have caused a marked reduction in the risk ratio for some high-risk species. For example, in the preceding assessment (Richard & Abraham 2015), the risk ratio for black petrel was estimated as 11.3 (95% c.i.: 6.8–19.8). In the current assessment, the risk ratio for black petrel was reduced to 1.15 (95% c.i.: 0.51–2.03) (see Appendix G, Table G-34, for a comparison between risk ratios estimated by Richard and Abraham (2015) and by the current study, for all species). The decrease in the estimated risk was associated both with a four-fold increase in the productivity index (from a mean PST of 100 to a mean of 437; Appendix G, Table G-32, following improvements in the PST calculation), and a halving of the estimated fatalities (from a mean APF of 1130 to a mean of 468; Appendix G, Table G-33).

One change was the revised calibration of the PST, which is proportional to the product of the optimal growth rate (r_{max}), and the population size (N). The study by Dillingham and Fletcher (2011) provides an independent estimation of r_{max} for New Zealand seabird species. Their estimates of r_{max} were also based on the method by Niel and Lebreton (2005), and they provide point estimates of λ_{max} (with $r_{\text{max}} = \lambda_{\text{max}} - 1$) for 21 of the taxa included in the current assessment. For 16 of these taxa, the values were within the 95% credible interval of the r_{max} values estimated here (Figure 9).

For five species, the current estimates of r_{max} were higher than values estimated by Dillingham and Fletcher (2011), including estimates for black petrel (a mean of 0.091 cf. 0.070), light-mantled sooty albatross (a mean of 0.061 cf. 0.050), Hutton's shearwater (a mean of 0.110 cf. 0.089), grey petrel (a mean of 0.080 cf. 0.070), and Buller's shearwater (a mean of 0.111 cf. 0.090). Across all taxa, the mean ratio of the mean r_{max} from this study to the r_{max} estimated by Dillingham and Fletcher (2011) is 1.04, suggesting that the values of r_{max} estimated by both studies are close.

Overall, the optimal growth rate parameters in this study are broadly consistent with the values used by Dillingham and Fletcher (2011). Differences for *Procellaria* petrels reflect the different approaches taken by the two studies. The current risk assessment distinguished r_{max} values for *Procellaria* species based on differences in weight, as allometry predicts a higher r_{max} for smaller species of the same family. Black petrel is significantly smaller than the other *Procellaria* species, with a weight of 700 g, compared with grey petrel (1130 g), Westland petrel (1200 g), and white-chinned petrel (1320 g). In comparison, the study by Dillingham and Fletcher (2011) assigned an r_{max} value of 0.07 for all *Procellaria* petrels.

For northern royal albatross, the r_{max} value from the current risk assessment is close to results from the analysis of long-term population data. The population of northern royal albatross at Taiaroa Head increased from a mean estimate of 123 to a mean estimate of 207, over the fourteen-year period between 1996–97 and 2010–11 (Richard et al. 2015). This population increase implies an annual growth rate of 0.038 over this period. This annual growth rate is close to the range of r_{max} of 0.047 (95% c.i.: 0.039–0.055), estimated for northern royal albatross in the current risk assessment. Although the population at Taiaroa Head has been managed (primarily increasing chick survival), and there has been some documented immigration, fledged juveniles and adults are subject to fisheries mortality, allowing comparison of the estimated r_{max} value with the estimate in the current study.

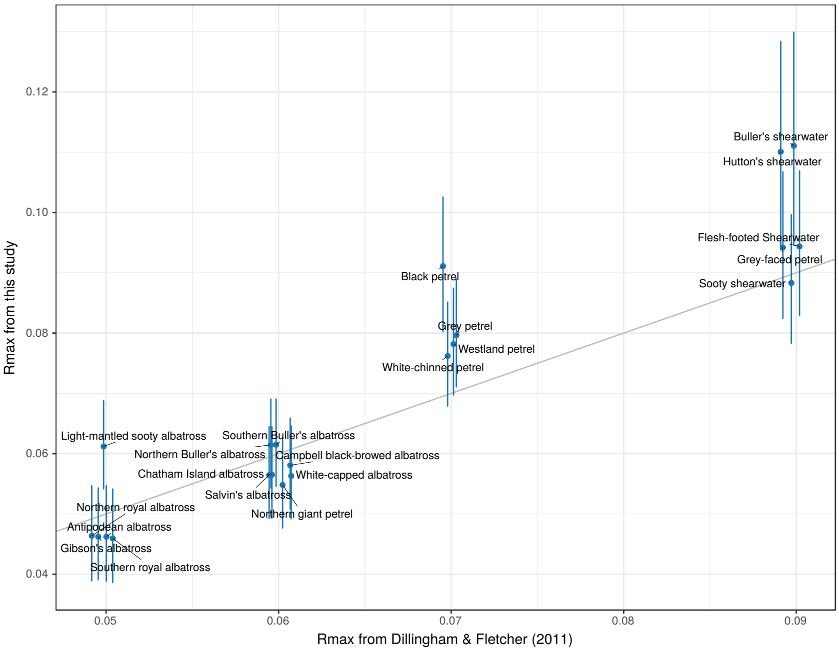

Figure 9: Comparison between the maximum net productivity rate r_{max} values estimated by Dillingham and Fletcher (2011) and the r_{max} values estimated in the current study. Points indicate the mean, and lines indicate the 95% credible interval of estimates from this study. The diagonal line marks the one-to-one relationship. Values from Dillingham and Fletcher (2011) were either 0.05, 0.06, 0.07, or 0.09, and are shown with a small random offset for legibility.

Observable captures were independently estimated in a seabird capture estimation, using a generalised linear modelling approach (Abraham & Richard 2017). Although the two studies used the same observer and fishing effort data, the modelling for the capture estimation did not use a spatially explicit overlap approach. Instead, estimates were based solely on observed capture rates, which were assumed to be constant within strata defined by area, fishery, year, and season. The seabird capture estimation used independent models for the eight most frequently caught species (or species groups, depending on the taxonomy used), whereas the risk assessment fit a single model to all the observer seabird capture data.

In general, there was broad agreement in the estimates of observable captures from the two modelling approaches, given the markedly different assumptions used (Figure 10). In some cases, however, the risk assessment underestimated the number of observable captures relative to the seabird capture estimation, involving species or species groups where the mean estimate of observable captures in this study was lower than the lower 2.5% credible level from the capture estimation: Salvin's albatross and other albatrosses in trawl fisheries; flesh-footed shearwater and grey petrel in bottom-longline fisheries; and flesh-footed shearwater in surface-longline fisheries. For Salvin's albatross, flesh-footed shearwater and grey petrel, the highest capture estimates associated with these fishing methods are in strata that were poorly observed. In all cases, however, the mean estimates of total observable captures from this study were lower than the mean estimates from the estimation modelling. For grey petrel and flesh-footed shearwater, the mean estimates from this study were 35% and 47% of the mean estimates from the estimation modelling, respectively. When the observable captures from this study are scaled up to match the mean estimated number of captures from the seabird capture estimation, then the median risk ratio for flesh-footed shearwater increases to 1.42, placing this species in the "very high risk" category.

Across all species groups and fishing methods where a comparison could be made, the distribution of the credible interval (taken as the ratio of the upper to the lower level) was smaller in the estimates from the risk assessment than in those from the capture estimation for 79% of the estimates (note that this comparison was undefined for one species-method that had a lower level of zero). The uncertainty estimated by the risk assessment was lower than the uncertainty from the capture estimation. This finding is likely due to the lower degrees of freedom in the risk assessment.

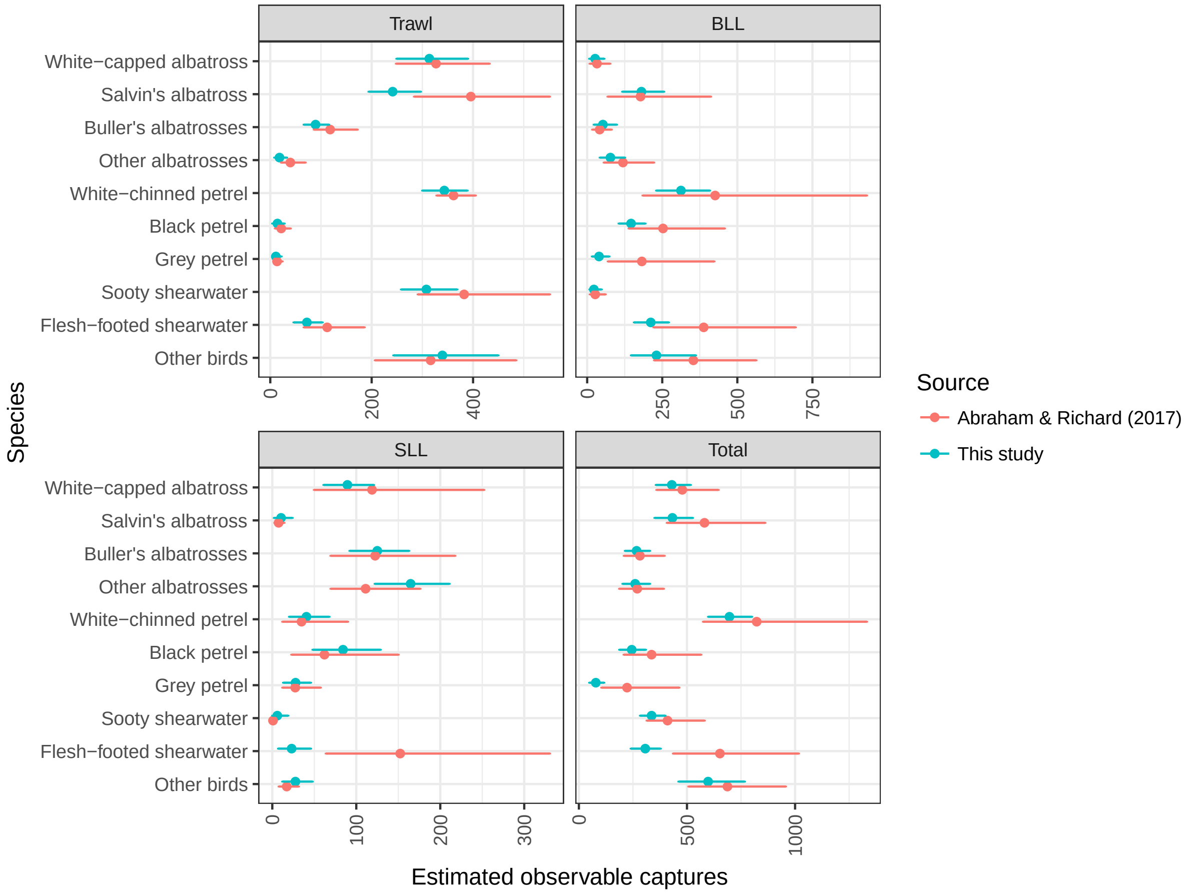

Figure 10: Comparison between observable captures estimated by this study and by Abraham and Richard (2017). Estimates are annual observable captures, averaged over the three years from 2012–13 to 2014–15, and are the total observable captures in all commercial trawl and longline fishing within the outer boundary of New Zealand's EEZ. The line indicates the 95% credible interval, and the dot indicates the mean of the posterior distribution of the estimates.

4.2 Species most at risk

Black petrel was the species the most at risk from commercial fisheries in New Zealand, with a median risk ratio of 1.15 (95% c.i.: 0.51–2.03), based on an estimated mean PST of 437 (95% c.i.: 220–834) individuals and mean annual potential fatalities of 468 (95% c.i.: 316–666) black petrel. The estimated annual potential fatalities of this species were mostly in the surface-longline fishery targeting bigeye tuna, inshore trawl fisheries, and bottom-longline fisheries targeting snapper and bluenose. These fisheries all have relatively low observer coverage, and so estimates of observable captures of black petrel are inherently uncertain (of all observed captures of black petrel, around one-third occurred during a single trip). The annual potential fatalities in inshore fisheries are associated with a high estimated cryptic mortality, with mean values over 20 individuals for medium-sized seabirds (see Appendix E). This level of cryptic mortality may be unrealistically high, and further studies are necessary.

If the risk ratio is larger than 1, fisheries-related fatalities may be sufficiently high to prevent the population from remaining (or increasing to) above half its carrying capacity. While the risk ranking of black petrel was estimated as "very high risk", the population trend of this species is unclear. For example, demographic modelling indicated an estimated population growth rate between -2.3% and 2.5% per year, depending on the estimated annual survival rate of juveniles. Assuming a juvenile survival rate of 88%, the population growth rate was estimated at -1.1% per year (Bell et al. 2014).

Furthermore, the population size of black petrel in New Zealand is not well known. The current study used the population size estimate of black petrel of 2750 (95% c.i.: 1600–5120) annual breeding pairs that was also used in the preceding risk assessment by Richard and Abraham (2015). In addition to this population estimate, the current risk assessment was repeated using an estimated population size of between 1400 and 1600 annual breeding pairs, based on recent survey data from Great Barrier and Little Barrier islands (Bell et al. 2016a, 2016b). Using this lower population estimate resulted in an increase in the risk ratio of black petrel to a median of 2.11 (95% c.i.: 1.63–2.58). Data from regular field surveys of breeding black petrel within a 35 ha area on Great Barrier Island (Bell et al. 2013b, Bell et al. 2016b), and from a recent survey of Little Barrier Island (Bell et al. 2016a), show that the number of breeding pairs varies widely between years. This variation reflects both the number of birds choosing to breed each year, changes in the population size, and uncertainty from the sampling process. Obtaining a population estimate from these survey data requires a demographic model. Ideally, this model would also include an estimate of black petrel that breed on Great Barrier Island outside the surveyed colony. At-sea counts of black petrel off the coast of South America outside the breeding season such as in Spear et al. (2005) and additional recoveries of tagged individuals caught in fisheries would also improve estimates of the black petrel population.

The species with the second highest risk ranking was Salvin's albatross, with a median risk ratio of 0.78 (95% c.i.: 0.51–1.09). In this assessment, the mean PST was estimated at 3598 (95% c.i.: 2709–4941) individuals, while the mean number of annual potential fatalities was 2778 (95% c.i.: 2028–3764), estimated from 328 observed captures, mainly in trawl fisheries. Of the estimated total annual potential fatalities of this species, 40% were in inshore trawl fisheries, but other fisheries with high estimated annual potential fatalities of Salvin's albatross included trawl fisheries targeting hoki, the fleet of small (less than 34 m length) bottom-longline vessels targeting ling, and trawl fisheries targeting middle-depth species and scampi.

Survey data of Salvin's albatross populations indicate different potential trends at different colonies. At Bounty Islands, where most of the population breeds, survey data indicate decreases in the annual number of breeding pairs, including a 30% decrease between 1997 and 2011 at Proclamation Island, and a 13% decrease between 2004 and 2011 at Depot Island (Sagar et al. 2015a). In contrast, recent aerial surveys across the Bounty Islands group indicated an increase from 31 786 to 39 995 annual breeding pairs between 2010 and 2013, including a doubling of the number of annual breeding pairs at Proclamation Island since the earlier survey (Baker et al. 2014). At Snares Islands (the Western Chain), ground counts indicated a stable population of Salvin's albatross between 2008 and 2014 (Sagar et al. 2015b). Inter-annual variability in the number of annual breeding pairs makes it difficult to ascertain changes in population size based on discrete surveys, suggesting that regular surveys are required to determine the status of the Salvin's albatross population. Providing an accurate population estimate of Salvin's albatross is also relevant in view of the conservation status of this species, which changed in 2013 from "nationally vulnerable" to "nationally critical", according to the New Zealand Threat Classification System (Robertson et al. 2017).

Another species with the upper bound of the estimated number of annual fatalities exceeding the PST was flesh-footed shearwater, which had the third highest risk ranking in the current assessment. The risk ratio for this species had an estimated median of 0.67 (95% c.i.: 0.39–1.15), while the mean PST was estimated at 1451 (95% c.i.: 1033–1998) individuals, and the mean number of annual potential fatalities was 987 (95% c.i.: 623–1561) individuals, estimated from 125 observed captures. Observed captures of this species included 68 and 49 captures in bottom-longline and trawl fisheries, respectively.

Flesh-footed shearwater populations in New Zealand are considered to be declining, and this notion is supported by recent population estimates from survey data (Taylor 2000, Baker et al. 2010, Waugh et al. 2013b). For example, the New Zealand population size is currently estimated at between 10 000 and 15 000 breeding pairs (Waugh et al. 2013b), compared with an earlier estimate of 25 000 to 50 000 pairs

(Taylor 2000). Owing to the population decline, this species was included in the threatened categories of the New Zealand Threat Classification System in 2012, and flesh-footed shearwater are currently classified as “nationally vulnerable” (Robertson et al. 2017).

4.3 Limitations of the seabird risk assessment

In the current risk assessment framework, cryptic mortality had a considerable influence on the estimated risk ratio. This impact was evident in the marked reduction in the risk ratios when fishery mortalities were included as the number of observable captures instead of annual potential fatalities (Table G-35). When cryptic mortality was not considered in the estimation, and the number of observable captures was used, the risk category decreased for 13 of the 16 seabird taxa that had non-negligible risk rankings; there were no populations in the “very high risk” category, and only one population in the “high risk” category. The most notable decrease was the risk ranking of New Zealand white-capped albatross, with a decrease from the “high risk” category to “negligible risk”.

Data on cryptic mortality are limited, and most of the information is from fisheries operating elsewhere. It is difficult to determine how adequate these data are to inform the current risk assessment of New Zealand fisheries; however, the occurrence of cryptic mortalities is well recognised, necessitating their inclusion in risk assessment frameworks. Further research on cryptic mortalities of seabirds and other protected species is needed to provide a better understanding of this type of fisheries interaction.

Estimation of seabird captures relies on observer data, and in many fisheries, particularly small-vessel inshore fisheries, observer coverage has consistently been low (less than 5%) (see Appendix G, Table G-22). If fisheries are poorly observed, it is possible that rare multiple-capture events have not been recorded, and this lack of records may downwardly bias the estimation of observable captures. An example is set-net fisheries, where the largest number of seabirds observed caught in a capture event is two individuals, but multiple captures are likely to occur. For example, a study of set-net captures of seabirds in Otago Harbour reported the capture of 20 spotted shags in a set net (Lalas 1991), multiple captures in a single set net with 50 dead Hutton’s shearwater were reported from Kaikoura (West & Imber 1985), and a net with nine Hutton’s and 29 fluttering shearwaters was also documented (Tarburton 1981). Similar to set-net fisheries, small-vessel longline and trawl fisheries have not been well observed. Increasing observer coverage in these fisheries would allow seabird captures to be more accurately estimated, and it is possible that quantitatively different interactions with seabirds are occurring in the unobserved parts of these fisheries.

There remain improvements to be made to the implementation of the risk assessment method. In particular:

1. In the current implementation, the overlap was calculated outside the model. Uncertainty in the population size was not included in the estimation of the annual potential fatalities. Ideally, the overlap would be calculated within the model, and the same samples from the population size would be used both for estimating the vulnerability, and for calculating the PBR. Including population size within the model would change the uncertainty in the vulnerability.

2. The use of adult survival in the Gilbert formula caused the population size to be underestimated when compared with demographic models that accounted for lower juvenile survival. Ideally the current juvenile survival would be estimated for each species, allowing a better estimate of the total population size.

3. Estimation of the vulnerability would be improved both by accounting for the number of birds that are within the New Zealand region (the effective population size; Ministry for Primary Industries 2016b, Chapter 3), and by accounting for the number of birds that are caught in New Zealand fisheries, but may be breeding elsewhere. Improvements to the underlying data, especially seabird distributions, are also required to fully realise the spatially explicit risk assessment method. More generally, however, the risk-assessment is a method that is suitable for species where there are few

data. Both the estimation of fatalities and the estimation of the PST rely on simple models that are idealisations of reality. While improving the implementation of the risk assessment is important, more detailed methods may be appropriate where data and resources permit.

The current risk assessment only considered the risk to seabird populations from commercial fisheries in New Zealand waters. Nevertheless, seabirds are exposed to a broad range of anthropogenic impacts, and some species might be in decline even when the mortality from New Zealand commercial fisheries is below the PST. Other fisheries impacts include mortalities in non-commercial fishing activities (Abraham et al. 2010, Miskelly et al. 2012). The only available estimate of incidental captures in recreational fisheries in New Zealand was over 11 000 birds annually in north-eastern New Zealand, with potentially 40 000 incidental captures throughout the entire country (Abraham et al. 2010). The latter estimate is higher than the number of annual potential fatalities in commercial trawl and longline fisheries estimated in the present study. Anthropogenic sources of mortality that pose a significant threat to seabird populations also include the introduction of exotic predators, light and chemical pollution, or climate change (Grémillet & Boulinier 2009, Croxall et al. 2012, Wilcox et al. 2015). These impacts were not considered here.

Another important consideration for the current risk assessment is that the distribution of seabird species breeding in New Zealand is frequently not restricted to this region. Many seabirds migrate after breeding in New Zealand, such as species that forage off the coast of Chile and Peru during the non-breeding season (e.g., Buller's albatross, Chatham Island albatross, Westland petrel), in eastern tropical Pacific Ocean waters (e.g., black petrel), or around South Africa (e.g., New Zealand white-capped albatross) (BirdLife International 2004). At these locations, they will interact with different fisheries, but these interactions and the concomitant risk have not been assessed. A global Southern Hemisphere seabird risk assessment is currently under way, and will provide some understanding of the risk of fisheries to seabirds from outside New Zealand waters.

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A APPENDIX A: DERIVATION OF UNCERTAINTIES IN DEMOGRAPHIC PARAMETERS

The current study relied on estimates of the demographic parameters of seabird populations, as data are limited. Seabird populations are often remote and difficult to access, and regular monitoring of a sufficient proportion of the total population is rare. Nevertheless, all estimates contain some level of uncertainty, and the latter can be considerable. Estimates in the literature are sometimes reported with their uncertainty, but this important information is frequently missing. To explicitly account for the uncertainty in all parameters in this risk assessment, every demographic estimate was assigned a standard deviation (s.d.), or a range when necessary, to match the uncertainties typically reported in the literature. The methods used for this approach depended on the demographic parameter.

An index of quality (poor, medium, or high) was assigned to each estimate when possible, based on the methodology used and the size of the sample from which the estimate was calculated. For example, the quality of estimates of survival rates was considered high when capture-mark-recapture modelling was used on a sample size of over 100 individuals. In contrast, the quality was qualified as poor, when the sample size was less than 50 individuals, with the survival estimate considered to be simply the ratio of banded birds returning alive to the breeding site to the total number of banded birds. When details of the methodology were not provided, e.g., when estimates were reported by a source and not the original publication of the study, we used the quality assessment of the citing source when possible, which was mostly for estimates from the ACAP website (Agreement on the Conservation of Albatrosses and Petrels; http://www.acap.aq). When it was not possible to assess the quality, it was assumed to be poor. In general, survival estimates were net estimates (including fisheries mortality), while for the calculation of r_{max}, they were assumed to be survival estimates under optimal conditions. The quality assessment of each parameter is provided with each value in the supplementary document.

When no uncertainty was reported in the literature, survival estimates were assigned a standard deviation of 0.01, 0.02, or 0.03 for estimates of high, medium, or poor quality, respectively. Estimates from capture-mark-recapture analysis are sometimes reported as a confidence interval. In this case, the mean was derived by calculating the logit of the mean (the average of the logit of the lower and upper limits of the confidence interval), which was then back-transformed. The standard deviation of the logit of the mean was calculated by dividing the difference between the logit of the upper limit and the logit of the lower limit, divided by 2×1.96. The standard deviation of the mean was then calculated using the delta method:

$$\text{s.d.}(\bar{S}) = \frac{\text{s.d.}(\text{logit}(\bar{S}))}{\bar{S}(1-\bar{S})} \tag{A-1}$$

Age at first reproduction and the number of breeding pairs were reported in the literature either as a minimum value only, or only as a mean. For age at first reproduction, when only a minimum was reported, the maximum was derived by multiplying the minimum by $5/3$, and when only a maximum was reported, the minimum was derived by multiplying the maximum by $3/5$. When only the minimum and the mean values were reported, the maximum was defined as the difference between twice the mean and the minimum. Similarly, when only the maximum and the mean values were reported, the minimum was defined as the difference between twice the mean and the maximum. When only the mean was reported, it was multiplied by $3/4$ to get the minimum, and by $5/4$ to get the maximum.

For the number of breeding pairs, when only the minimum value was reported in the literature, it was multiplied by three to obtain a maximum value. The minimum value was also reduced to 70% of its reported value to account for the possibility of a population decline since the value was derived (e.g., a reported minimum of 10 000 pairs was treated as between 7000 and 30 000 pairs). When only the maximum number of breeding pairs was reported, it was divided by five to obtain the minimum value, and it was multiplied by 1.2 to allow for a population increase. Calculation of the maximum and minimum values when only the mean and either the minimum or the maximum values were reported followed the approach used for age at first reproduction. When only the mean value was reported, a log-normal distribution was assumed, with a standard deviation set to 0.1, 0.2, or 0.3 for estimates of high, medium, or poor quality, respectively. When the uncertainty of the proportion of adults breeding in any given year was not reported, a standard deviation of 0.05 was used.

Whereas only one estimate of the number of breeding pairs was chosen during the data-preparation process, estimates of similar quality and similar age for adult survival and age at first reproduction were kept. When multiple estimates were available for the same parameter, the following rules were applied to combine them: for multiple pairs of minima and maxima (e.g., age at first reproduction of Fiordland crested penguin), the minimum and the maximum of the union of these ranges were taken; for multiple means and standard deviations (e.g., survival rate of northern giant petrel), pairs of minima and maxima were created by taking the lower and upper limits of the confidence intervals, defined as the mean ± 1.96 s.d., and by applying the previous rule.

A sample of 4000 values was calculated for each parameter and each taxon (see the distributions of the parameters used for calculating the PST in Table G-19). For estimates whose range was defined by the mean and the standard deviation, the sample was drawn from a normal distribution for the age at first reproduction, from a log-normal distribution for the number of breeding pairs, and from a normal distribution on the logit scale for the adult annual survival and the proportion of adults breeding in any given year. When only a minimum and a maximum were obtained, the age at first reproduction, the annual adult survival rate, and the proportion of adults breeding in a given year were assumed to be distributed uniformly between the minimum and the maximum, and the distribution of the number of breeding pairs was assumed to be uniform on the log scale between the minimum and the maximum.

B APPENDIX B: ALLOMETRIC MODELLING

The current risk assessment included allometric modelling to reduce variability in the estimates of age at first reproduction and of adult survival. These population parameters are used in the calculation of the population growth rate under optimal conditions, r_{max}. The population parameter adult survival is used to calculate the total population size from the number of annual breeding pairs, and also to estimate the maximum growth rate of each species, r_{max}. In the first case, adult survival should reflect the current survival rate in the current conditions that a species lives in, including human-caused mortality. In contrast, for calculating r_{max}, adult survival should reflect adult survival under optimal conditions, without human-caused mortality.

A single estimate of the adult survival rate was used in the previous seabird risk assessment, with estimates of the adult survival rate and the age at first reproduction being derived from field estimates. At the same time, a set of rules was applied to include uncertainty in the estimates when none was provided in the literature. Some values were adjusted following consultation with the Aquatic Environment Working Group or other expert panels, to provide a more adequate estimate of adult survival under optimal populations. Values of r_{max} in the preceding risk assessment were inconsistent for some species, considering that these species had a lower r_{max} value than larger species of the same taxonomic order.

B.1 Allometric modelling methods

The present risk assessment distinguished between the current (S_{curr}) and optimal (S_{opt}) adult annual survival rates. The optimal survival rate was assigned a higher value than the current value when the latter was deemed too low in view of the life history of the species. Age at first reproduction did not have the same variability as adult survival among taxa, and was assumed to be the same between the current and optimal values.

An allometric power relationship between body size and demographic parameters such as adult survival, age at first reproduction, and r_{max} was identified in previous studies (Blueweiss et al. 1978, Gaillard et al. 1989). Gaillard et al. (1989) quantified the relationship between body mass (M) and both age at first reproduction (A) and longevity (L) as $A \simeq M^{0.22 \pm 0.05}$ and $L \simeq M^{0.23 \pm 0.06}$.

Using the samples of values of age at first reproduction (A) and optimal adult annual survival rate S_{opt}, a power relationship was modelled between the body mass (M) and age at first reproduction (A), with the form $Y = \quad M^{\beta}$ (where Y is either the age at first reproduction A or the adult life expectancy, $L = -1/\log(S)$). The parameters A and L were assumed to follow a log-normal distribution.

The power coefficient, β, was constant across all taxa, but the intercept was allowed to vary with the taxonomic order and taxon. The effects of taxonomic order and of taxon were included as random effects in the intercept.

The model, for both A and L, was:

$$\begin{aligned} \log(Y) &\sim \text{Norm}(\log(\mu), \sigma), \\ \log(\mu) &= \log(\quad) + \beta \log(M) + \epsilon_{\text{order}} + \epsilon_{\text{species}}, \end{aligned}$$

where Y is either A or L, μ and σ are the mean and the standard deviation of Y (from the sample, not estimated in the model), is the intercept, β is the power coefficient of the allometric relationship, M is the body mass (in grams), and ϵ_{order} and $\epsilon_{\text{species}}$ are random effects of the taxonomic order and taxon, respectively (see Tables B-1 and B-2 for the estimated model parameters). A half-Cauchy prior with a scale of 3.2 was used for the standard deviation of both ϵ_{order} and $\epsilon_{\text{species}}$, which corresponds to an upper 95% credible limit of 80. A normal distribution with a mean of 0 and a standard deviation of 1000 was used as prior for the intercept and the power coefficient β.

The body mass for each taxon was sourced from the recent amniote life history database of birds, mammals, and reptiles (Myhrvold et al. 2015). This database provides a normalised and consolidated source of life-history parameters from peer-reviewed studies for birds, mammals, and reptiles. It currently contains data of 29 life-history parameters for 21 322 species, including 9802 bird species. A point estimate of body size was obtained for all 71 taxa included in the risk assessment by taking the average of body mass for males, females, and for unknown gender. No uncertainty in body mass was included in the analysis.

The model was fitted on the values of S_{opt} and A that were not obtained from proxy species. As a result, the modelled dataset included 28 estimates of annual adult survival, and 44 estimates of age at first reproduction.

The models were coded in the BUGS language (Spiegelhalter et al. 2003), and fitted using the software Just Another Gibbs Sampler (JAGS; Plummer 2013), using three chains, a burn-in period of 50 000 iterations, and taking samples every 100th iterations from a total of 20 000 iterations. The convergence of the Markov Chain Monte Carlo (MCMC) chains was visually assessed by examining the traces of the chains.

After fitting the two models (one each for age at first reproduction and adult life expectancy), a sample of 4000 values for both age at first reproduction and optimal annual adult survival were predicted for each taxon by using the taxonomic order and the body mass only (i.e., not including the species random effect, which represents the variability between studies and taxa due to differences in methodology and human-caused mortality).

B.2 Allometric modelling results

The age at first reproduction (A) and adult life expectancy (L) were linked to body mass via the relationships:

$$\begin{aligned} A &\simeq M^{0.25\pm0.04}, \\ L &\simeq M^{0.27\pm0.08}. \end{aligned}$$

These relationships closely compared to the findings of Gaillard et al. (1989), where:

$$\begin{aligned} A &\simeq M^{0.22\pm0.05}, \\ L &\simeq M^{0.23\pm0.06}. \end{aligned}$$

Table B-1: Summary of the estimated model parameters from a taxonomic and allometric model fitted on the relationship between body mass and age at first reproduction for the taxa considered in the seabird risk assessment.

Parameter	Mean	95% c.i.	s.d.
α	-0.424	-2.444–0.698	0.671
β	0.253	0.179–0.327	0.038
σ_{order}	0.452	0.321–0.588	0.068
σ_{species}	0.209	0.151–0.284	0.034

Table B-2: Summary of the estimated model parameters from a taxonomic and allometric model fitted on the relationship between body mass and adult life expectancy for the taxa considered in the seabird risk assessment.

Parameter	Mean	95% c.i.	s.d.
α	0.006	-1.579–1.528	0.772
β	0.272	0.118–0.425	0.077
σ_{order}	0.525	0.346–0.732	0.097
σ_{species}	0.192	0.011–0.457	0.117

From the fitted models, the age at first reproduction and annual adult survival rate were estimated for each taxon, based on the body mass, and omitting the species random effect (see Figure B-1 for the relationship between body mass and both age at first reproduction and adult survival rate).

The allometric modelling led to a decrease in age at first reproduction for 48 taxa and an increase for 23 taxa (Figure B-2; Table B-3). Nevertheless, for the eight species at “very high” and “high” risk, the value decreased for all but one species (Westland petrel), while the age at first reproduction remained the same for Gibson’s albatross. Similarly, estimating adult survival from the allometric models led to a decrease in the mean adult survival for 51 taxa and an increase for 19 taxa (Figure B-2; Table B-4), with a decrease of less than 3% for all species at “very high” and “high” risk.

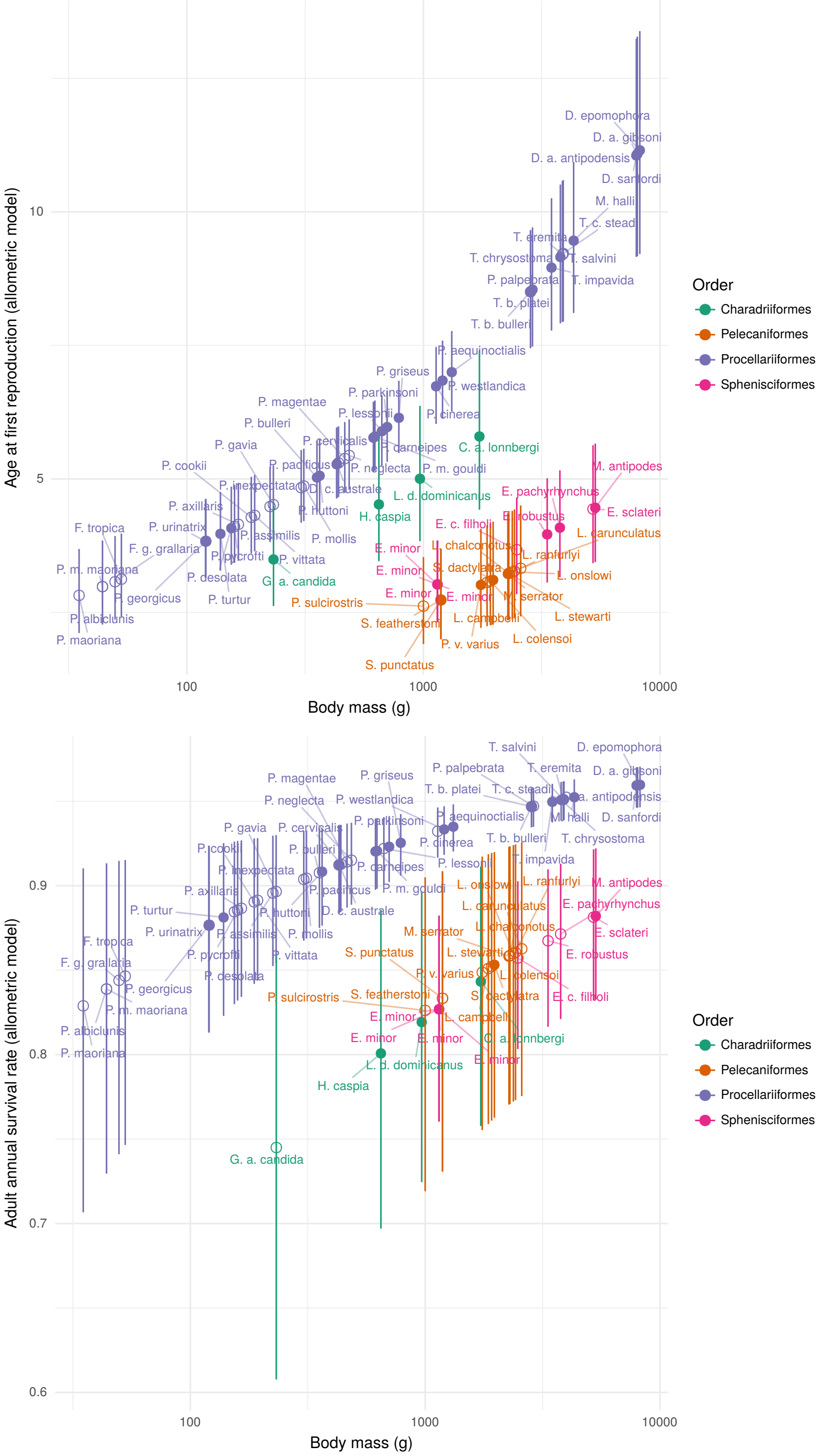


Figure B-1: Allometric and taxonomic relationship between body mass and both age at first reproduction and annual adult survival for each taxon considered in the seabird risk assessment (coloured by taxonomic order).

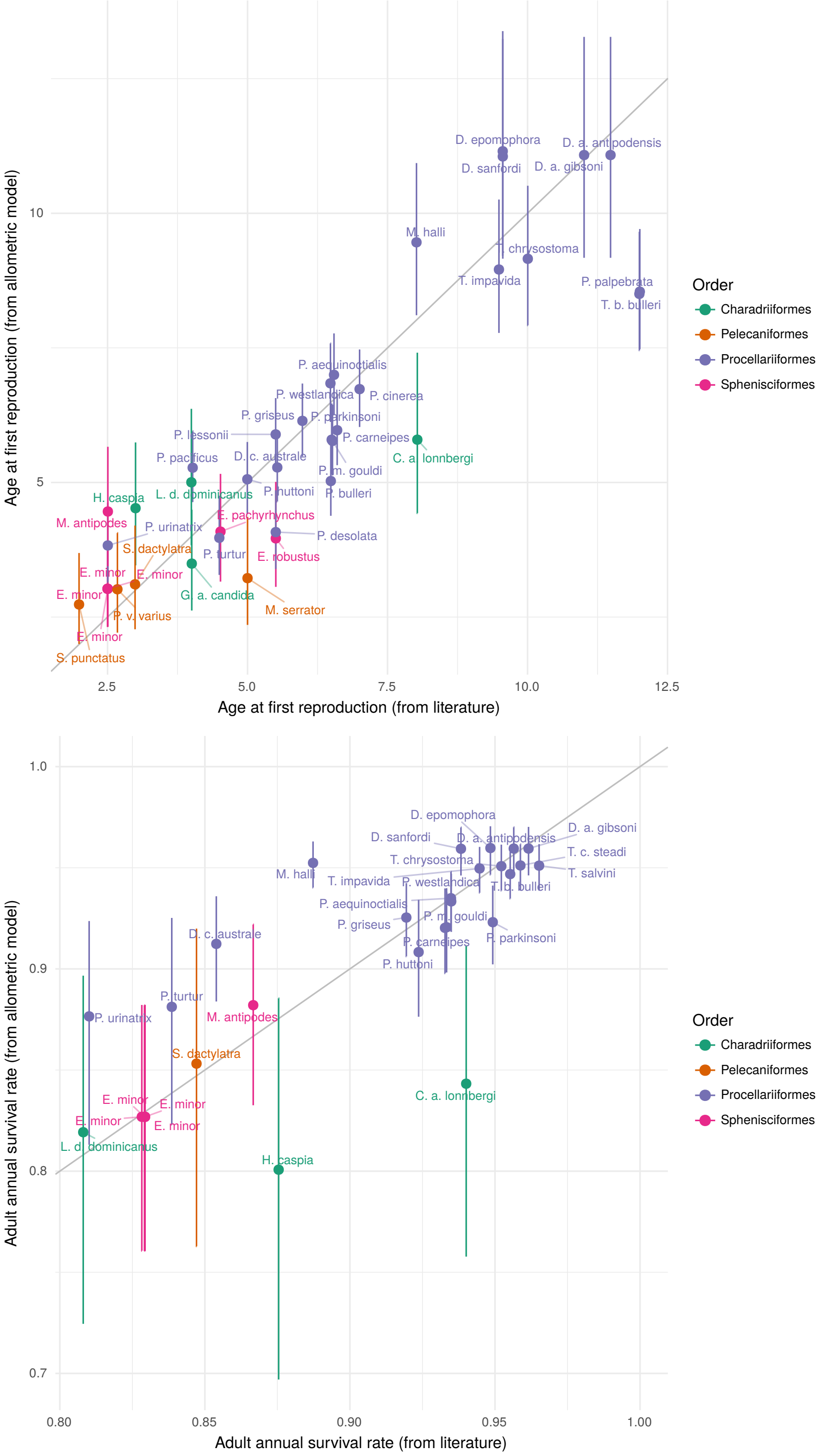


Figure B-2: Comparison of age at first reproduction and adult annual survival rate between estimates obtained from the literature and estimates from the allometric and taxonomic model, for each taxon used in the modelling (coloured by taxonomic order).

Table B-3: Estimates of age at first reproduction (mean value and 95% credible interval, c.i.) from the literature and from the allometric models. Change (%) indicates the difference in the mean value between both sources, coloured according to the maximum change (red shades for decreases; blue shades for increases). Seabird taxa are in decreasing order of median risk ratio in the updated base model. Asterisks indicate taxa included in the allometric modelling.

Taxon	From literature		Allometric model		Change (%)
	Mean	95% c.i.	Mean	95% c.i.	
* Black petrel	6.60	6.23–6.97	5.97	5.32–6.63	-9.5
Salvin's albatross	12.02	9.15–14.86	9.20	7.96–10.61	-23.4
* Flesh-footed shearwater	6.49	4.15–8.87	5.78	5.17–6.45	-10.9
* Westland petrel	6.50	4.11–8.87	6.85	6.12–7.58	5.4
* Southern Buller's albatross	12.03	9.15–14.85	8.52	7.50–9.61	-29.2
Chatham Island albatross	11.97	9.17–14.84	9.20	7.92–10.57	-23.2
NZ white-capped albatross	12.06	9.17–14.86	9.22	7.94–10.66	-23.5
* Gibson's albatross	11.00	10.06–11.96	11.10	9.20–13.21	0.9
Northern Buller's albatross	12.00	9.15–14.84	8.51	7.48–9.69	-29
* Antipodean albatross	11.51	10.07–12.92	11.10	9.15–13.36	-3.5
Otago shag	3.99	3.05–4.95	3.22	2.34–4.40	-19.4
* Northern giant petrel	7.97	6.09–9.88	9.46	8.18–10.91	18.6
* Spotted shag	2.00	1.05–2.95	2.72	1.98–3.70	36
* Yellow-eyed penguin	2.99	2.05–3.95	4.45	3.41–5.66	48.8
* Campbell black-browed albatross	9.52	6.18–12.80	8.96	7.77–10.28	-5.8
* White-chinned petrel	6.49	4.14–8.87	7.00	6.27–7.77	7.9
* Northern royal albatross	9.56	8.55–10.55	11.07	9.13–13.30	15.9
Foveaux shag	4.00	3.05–4.94	3.24	2.37–4.37	-18.9
* Grey petrel	7.00	5.10–8.90	6.74	6.02–7.49	-3.8
* Southern royal albatross	9.55	8.55–10.55	11.15	9.25–13.40	16.7
* Snares Cape petrel	5.53	3.15–7.88	5.28	4.67–5.96	-4.4
Little black shag	2.00	1.05–2.95	2.63	1.90–3.55	31.4
* Pied shag	2.67	2.03–3.30	3.02	2.20–4.11	13.2
* Grey-faced petrel	6.50	6.03–6.97	5.79	5.13–6.46	-10.9
Fluttering shearwater	5.01	4.05–5.95	4.51	3.84–5.25	-10.1
* Fiordland crested penguin	4.50	3.07–5.93	4.10	3.19–5.16	-8.9
* Sooty shearwater	6.00	5.06–6.95	6.14	5.51–6.80	2.3
* Grey-headed albatross	9.97	7.13–12.83	9.16	7.91–10.50	-8.1
* Common diving petrel	2.51	2.02–2.97	3.83	3.18–4.60	52.5
* Light-mantled sooty albatross	12.00	9.15–14.85	8.54	7.48–9.72	-28.9
* Hutton's shearwater	5.01	4.05–5.95	5.07	4.40–5.76	1
* Northern little penguin	2.50	2.03–2.98	3.03	2.32–3.86	20.9
* White-headed petrel	5.54	4.07–6.94	5.89	5.25–6.58	6.5
* Southern little penguin	2.51	2.03–2.97	3.03	2.32–3.84	20.8
NZ white-faced storm petrel	4.01	3.05–4.95	2.97	2.27–3.82	-25.9
* Australasian gannet	5.00	3.10–6.90	3.21	2.36–4.37	-35.7
* Buller's shearwater	6.53	4.13–8.86	5.03	4.36–5.74	-23
* Southern black-backed gull	4.00	3.06–4.95	5.00	3.84–6.34	25
* Fairy prion	4.49	4.03–4.97	3.98	3.27–4.77	-11.5
Little shearwater	4.99	4.05–5.94	4.49	3.81–5.26	-10
Black-bellied storm petrel	4.50	4.03–4.97	3.13	2.42–3.94	-30.6
Cook's petrel	6.50	6.03–6.98	4.28	3.58–5.04	-34.2
Broad-billed prion	4.50	4.02–4.98	4.32	3.64–5.08	-4
* Antarctic prion	5.50	5.02–5.97	4.08	3.42–4.87	-25.7
* Snares crested penguin	5.50	5.02–5.97	3.96	3.05–5.01	-28
Mottled petrel	6.50	6.03–6.97	4.83	4.21–5.51	-25.6
Auckland Island shag	4.02	3.05–4.96	3.09	2.26–4.17	-23.1
Bounty Island shag	4.00	3.05–4.95	3.28	2.35–4.41	-18.1
* Subantarctic skua	8.03	7.64–8.42	5.79	4.42–7.36	-27.9
* Caspian tern	2.99	2.05–3.95	4.51	3.44–5.71	51
Chatham Island shag	4.00	3.05–4.95	3.27	2.38–4.41	-18.3
Campbell Island shag	4.01	3.06–4.95	3.06	2.25–4.13	-23.6
* Chatham Island little penguin	2.50	2.02–2.97	3.02	2.29–3.86	20.8
* White-flippered little penguin	2.50	2.02–2.97	3.02	2.33–3.79	20.8
Eastern rockhopper penguin	4.49	3.09–5.91	3.68	2.83–4.65	-18.1
Erect-crested penguin	5.50	5.02–5.98	4.43	3.43–5.57	-19.4
White-bellied storm petrel	4.50	4.03–4.98	3.08	2.37–3.97	-31.7
* White tern	3.99	3.04–4.95	3.48	2.61–4.48	-12.9
South Georgian diving petrel	2.50	2.03–2.97	3.84	3.12–4.62	53.7
NZ king shag	4.00	3.05–4.96	3.32	2.41–4.55	-16.9
Kerm. storm petrel	4.00	3.05–4.95	2.99	2.29–3.84	-25.3
* Masked booby	2.99	2.04–3.95	3.12	2.29–4.23	4.4
NZ storm petrel	4.50	4.02–4.97	2.81	2.13–3.67	-37.5
Pitt Island shag	4.00	3.05–4.95	2.73	1.98–3.71	-31.6
Chatham petrel	6.51	6.03–6.98	4.14	3.45–4.91	-36.4
Chatham Island taiko	6.51	6.03–6.97	5.38	4.74–6.05	-17.4
Pycroft's petrel	6.50	6.02–6.98	4.11	3.43–4.88	-36.8
Soft-plumaged petrel	6.50	6.02–6.98	4.85	4.20–5.54	-25.3
* Wedge-tailed shearwater	3.99	3.06–4.95	5.28	4.63–5.96	32
Kerm. petrel	6.51	6.02–6.97	5.44	4.80–6.13	-16.4
White-naped petrel	6.50	6.03–6.98	5.30	4.66–5.98	-18.5

Table B-4: Estimates of adult annual survival rate (mean value and 95% credible interval, c.i.) from the literature and from the allometric models. Change (%) indicates the difference in the mean value between both sources, coloured according to the maximum change (red shades for decreases; blue shades for increases). Seabird taxa are in decreasing order of median risk ratio in the updated base case. Asterisks indicate taxa included in the allometric modelling.

Taxon	From literature		Allometric models		Change (%)
	Mean	95% c.i.	Mean	95% c.i.	
* Black petrel	0.95	0.93–0.97	0.92	0.90–0.94	-2.7
* Salvin's albatross	0.97	0.94–0.98	0.95	0.94–0.96	-1.5
* Flesh-footed shearwater	0.93	0.84–0.98	0.92	0.90–0.94	-1.2
* Westland petrel	0.95	0.92–0.97	0.93	0.92–0.95	-1.4
* Southern Buller's albatross	0.95	0.93–0.98	0.95	0.93–0.96	-0.9
Chatham Island albatross	0.97	0.94–0.98	0.95	0.94–0.96	-1.5
* NZ white-capped albatross	0.96	0.94–0.97	0.95	0.94–0.96	-0.8
* Gibson's albatross	0.96	0.94–0.98	0.96	0.95–0.97	-0.2
Northern Buller's albatross	0.95	0.93–0.98	0.95	0.94–0.96	-0.9
* Antipodean albatross	0.96	0.94–0.97	0.96	0.95–0.97	0.3
Otago shag	0.88	0.86–0.90	0.86	0.76–0.92	-2.3
* Northern giant petrel	0.89	0.81–0.96	0.95	0.94–0.96	7.5
Spotted shag	0.88	0.86–0.90	0.83	0.73–0.91	-5.1
* Yellow-eyed penguin	0.87	0.80–0.92	0.88	0.83–0.92	1.7
* Campbell black-browed albatross	0.94	0.93–0.96	0.95	0.94–0.96	0.6
* White-chinned petrel	0.94	0.90–0.97	0.94	0.92–0.95	0
* Northern royal albatross	0.94	0.91–0.97	0.96	0.95–0.97	2.2
Foveaux shag	0.88	0.86–0.90	0.86	0.77–0.92	-2.2
Grey petrel	0.94	0.90–0.97	0.93	0.92–0.95	-0.3
* Southern royal albatross	0.95	0.93–0.96	0.96	0.95–0.97	1.2
* Snares Cape petrel	0.85	0.78–0.93	0.91	0.88–0.94	6.7
Little black shag	0.88	0.86–0.90	0.83	0.72–0.91	-5.8
Pied shag	0.88	0.86–0.90	0.85	0.76–0.92	-3.3
* Grey-faced petrel	0.93	0.85–0.98	0.92	0.90–0.94	-1.3
Fluttering shearwater	0.92	0.89–0.96	0.90	0.85–0.93	-3
Fiordland crested penguin	0.84	0.82–0.86	0.87	0.82–0.91	3.7
* Sooty shearwater	0.92	0.86–0.98	0.93	0.91–0.94	0.6
* Grey-headed albatross	0.95	0.93–0.97	0.95	0.94–0.96	-0.2
* Common diving petrel	0.81	0.75–0.87	0.88	0.81–0.92	8.3
Light-mantled sooty albatross	0.97	0.96–0.98	0.95	0.94–0.96	-2.3
* Hutton's shearwater	0.92	0.89–0.96	0.91	0.88–0.93	-1.6
* Northern little penguin	0.83	0.79–0.87	0.83	0.76–0.88	-0.3
White-headed petrel	0.93	0.85–0.98	0.92	0.90–0.94	-1.2
* Southern little penguin	0.83	0.79–0.86	0.83	0.76–0.88	-0.2
NZ white-faced storm petrel	0.90	0.82–0.95	0.84	0.74–0.92	-6.2
Australasian gannet	0.93	0.84–0.98	0.86	0.77–0.92	-8
Buller's shearwater	0.92	0.84–0.96	0.91	0.88–0.93	-0.8
* Southern black-backed gull	0.81	0.74–0.86	0.82	0.73–0.90	1.5
* Fairy prion	0.84	0.78–0.89	0.88	0.82–0.92	5
Little shearwater	0.92	0.89–0.96	0.90	0.85–0.93	-3
Black-bellied storm petrel	0.90	0.82–0.95	0.84	0.74–0.91	-5.6
Cook's petrel	0.93	0.84–0.98	0.89	0.84–0.93	-4.6
Broad-billed prion	0.84	0.77–0.89	0.89	0.84–0.93	6.5
Antarctic prion	0.84	0.77–0.89	0.88	0.83–0.93	5.5
Snares crested penguin	0.84	0.82–0.86	0.87	0.82–0.91	3.4
Mottled petrel	0.93	0.85–0.98	0.90	0.87–0.93	-3.2
Auckland Island shag	0.88	0.86–0.90	0.85	0.76–0.92	-2.9
Bounty Island shag	0.88	0.86–0.90	0.86	0.77–0.93	-2
* Subantarctic skua	0.94	0.91–0.97	0.84	0.76–0.91	-10.3
* Caspian tern	0.88	0.82–0.93	0.80	0.70–0.88	-8.6
Chatham Island shag	0.88	0.86–0.90	0.86	0.77–0.92	-2.2
Campbell Island shag	0.88	0.86–0.90	0.85	0.76–0.92	-3.1
* Chatham Island little penguin	0.83	0.79–0.87	0.83	0.76–0.88	-0.2
* White-flippered little penguin	0.83	0.79–0.86	0.83	0.76–0.88	-0.3
Eastern rockhopper penguin	0.84	0.82–0.86	0.86	0.80–0.90	2
Erect-crested penguin	0.84	0.82–0.86	0.88	0.83–0.92	5.1
White-bellied storm petrel	0.90	0.82–0.95	0.84	0.74–0.92	-5.7
White tern	0.81	0.78–0.83	0.74	0.61–0.86	-7.4
South Georgian diving petrel	0.81	0.75–0.87	0.88	0.81–0.92	8.3
NZ king shag	0.88	0.86–0.90	0.86	0.78–0.93	-1.7
Kerm. storm petrel	0.90	0.82–0.94	0.84	0.74–0.92	-6.2
* Masked booby	0.85	0.78–0.90	0.85	0.76–0.92	0.7
NZ storm petrel	0.90	0.83–0.95	0.83	0.71–0.91	-7.5
Pitt Island shag	0.88	0.86–0.90	0.83	0.73–0.91	-5.1
Chatham petrel	0.93	0.84–0.98	0.89	0.84–0.93	-4.9
Chatham Island taiko	0.93	0.85–0.98	0.91	0.89–0.94	-1.9
Pycroft's petrel	0.93	0.85–0.98	0.89	0.83–0.93	-5
Soft-plumaged petrel	0.93	0.85–0.98	0.90	0.87–0.93	-3.1
Wedge-tailed shearwater	0.92	0.89–0.96	0.91	0.88–0.94	-1.2
Kerm. petrel	0.93	0.85–0.98	0.92	0.89–0.94	-2
White-naped petrel	0.93	0.85–0.98	0.91	0.88–0.94	-2.2

C APPENDIX C: AT-SEA DISTRIBUTION OF BLACK PETREL

Y. Richard & J. Zhang

Previous seabird risk assessments determined that black petrel was the species the most at risk from commercial fisheries in New Zealand (Richard & Abraham 2013c, 2015). Black petrel breeds predominantly on Great Barrier Island in Hauraki Gulf, where a long-term study of the species' demography has been conducted since the 1995–96 breeding season (Bell et al. 2016b). Since the 2012–13 breeding season, high-resolution GPS data loggers have been deployed on breeding birds to increase the understanding of the at-sea distribution of black petrel.

In view of the risk ranking of this species, the current risk assessment included an updated modelling approach to derive maps of the at-sea distribution of black petrel for each of the three recognised breeding periods. Two alternative models were used to predict the at-sea distribution of this species during the pre-egg laying, the incubation, and the chick-rearing periods. Previous predictions of the at-sea distribution of black petrel were based on tracking data, counts from observers on fishing vessels, and counts conducted during bird-watching tours (see also Abraham et al. 2015). These data limit the extent of the distribution maps to the spatial extent of fishing effort, owing to an effect of fishing method on the counts from observers, a requirement to scale the predicted black petrel density in each map cell by the relative fishing effort across fishing methods, and the type of model used (boosted regression trees). To address this limitation, the current study applied a new modelling approach to derive at-sea distribution maps of black petrel for the three breeding periods, pre-egg laying, incubation, and chick rearing.

In the preceding seabird risk assessment, the distribution of black petrel was modelled from tracking data of 15 GPS loggers (Richard & Abraham 2015). These loggers recorded the location of the birds every 15 minutes with high accuracy. In addition, the previous modelling included black petrel abundance data recorded at the back of fishing vessels by government observers, and also counts from bird watching tours (see also Abraham et al. 2015). These data were modelled using boosted regression trees (BRT; Elith et al. 2008), which incorporated environmental variables and the fishing method. To be comparable with counts by government observers or from bird watching tours, tracking data were converted to pseudo-counts, which are the number of GPS positions within map cells. The model related the counts to environmental variables so that the density of black petrel could be predicted in areas for which no count data were available. Nevertheless, as the attraction of birds to fishing vessels varies depending on the fishing method, the at-sea distribution of black petrel could only be derived for areas where fishing takes place.

To address this limitation, an alternative Bayesian generalised linear model was fitted to the same data. In contrast to the BRT model, the current model assumed a simple linear relationship between counts (log-transformed) and environmental variables, and did not consider potential interactions between variables. Also, fishing method was not considered, allowing predictions of the at-sea distribution of black petrel to be independent of fishing method. Although this model was simpler, the number of observed black petrel captures correlated adequately with the overlap between the at-sea distribution of black petrel predicted from the model and the observed fishing effort, for the pre-egg laying and incubation periods.

Another limitation of previous approaches was that pseudo-counts for tracking data did not account for GPS positions from one or multiple individuals. For example, two black petrel individuals could be foraging in the same area, which would be considered in the models to be an area twice as attractive than an area where only one individual forages. Also, due to the small number of tracks, the effect of habitat on the pseudo-counts could be inflated if one individual spent a significant amount of time at a single location. To address these limitations, the individual movement process was modelled, and the at-sea distribution was then predicted from a large number of simulations of individuals tracks, instead of converting GPS track data to pseudo-counts.

The analysis of animal movement using high-resolution location data has been an active field of study in the last 20 years. Among the state-of-the-art techniques, state-space models (SSMs; Patterson et al. 2008) and step-selection functions (SSFs; Thurfjell et al. 2014) relate environmental variables to movement processes in different ways. In SSMs, movement patterns consist of regular steps described from the turning angle and speed, and the state of the individual at time $t+1$, i.e., the spatial location and behavioural mode, is predicted as a function of the state at time t, with the transition probability being a function of environmental parameters. The behavioural mode may include for example a "resident" mode, characterised by slow, tortuous movements, and a "transit" mode, characterised by fast, straight movements. In comparison, SSFs do not include behavioural modes, but the spatial location at $t + 1$ is chosen among alternative steps offered to the individual at its location, based on associated environmental attributes. In SSFs, the alternatives are calculated from each location, of the same length as the observed step.

For both types of model, a distribution map may be derived by simulating a large number of animal tracks, with each step being predicted by the model. For SSMs, the behavioural mode, predicted at each step according to local environmental variables, defines the turning angle and step length from which the next location can be drawn. Nevertheless, this movement process cannot reflect the attraction to or avoidance of specific environmental features. For example, existing tracking data of black petrel suggest that they avoid shallow waters, but prefer foraging along the continental shelf break. This foraging cannot be captured by a "resident" or "transit" behavioural mode only. In contrast, using SSFs, each step is chosen according to the attributes available around individuals, and habitat preferences may be explicitly predicted. Nevertheless, SSFs require a step length that is not explicitly included in the model.

A combination of both approaches was developed to take advantage of their respective strengths. First, an SSM was fitted to the tracking data, allowing the characterisation of the behavioural modes and of their associated step length. Once fitted, the behavioural mode of each observed movement step was extracted from the model. Then, for each behavioural mode, SSFs were fitted to all the steps of the given mode to determine how environmental variables influenced the choice of observed steps relative to possible alternatives. After model fitting, tracks were simulated by first predicting the behavioural mode at each step from the local environmental variables, and a step length was drawn randomly according to the selected mode. This length was used to draw 12 alternative steps, equally spaced around the current location. After extracting the covariates of the alternative locations, the next location was chosen among the alternatives by the SSF of the given behavioural mode.

C.0.1 Black petrel modelling data

The tracking data consisted of 5233 GPS locations (longitude and latitude) recorded from 31 individuals. Since the earlier study of the overlap between black petrel and commercial fisheries (Abraham et al. 2015), data from another 16 GPS loggers deployed in January and February 2014 have been recovered. These data were included in the present analysis and included a total of 22 days, with over 96% of the locations recorded between 28 January and 11 February 2014. This period corresponds with the beginning of the guard and chick rearing breeding periods. As the location records had an accuracy of up to 1 metre, no corrections were made for positional errors. Individual trips to sea were identified by splitting the tracks when two successive locations were separated by more than 150 minutes, after removing points that were on land (i.e., at the colony).

The covariates considered in the SSM model were the number of steps from the start of the trip, time of day (transformed as cosine and sine), depth of the sea floor, shortest distance over water to Great Barrier Island, shortest distance to the coastline (not considering other islands), slope of the sea floor, chlorophyll-a surface concentration, sea-surface temperature and its anomaly, sea-surface height anomaly, wind direction and strength (as zonal and meridional components), and the geostrophic velocity anomaly (also as zonal and meridional components). Bathymetry data were obtained from NIWA (Charting Around New Zealand (CANZ) 2008). The shortest distance over water to Great Barrier Island and the bathymetry slope were computed using GRASS 7 (Neteler et al. 2012). The chlorophyll-a surface concentration was sourced from the daily reprocessed level-4 GlobalColour OSS15 product (from http://marine.copernicus.eu). Sea-surface temperature and its anomaly were sourced from the daily near-real-time level-4 OSTIA product (from http://marine.copernicus.eu). Sea-surface height anomaly was sourced from the daily reprocessed level-4 SL-TAC product (from http://marine.copernicus.eu). Wind data were sourced from the daily CCMP Wind Vector Analysis product (available at http://www.remss.com). The geostrophic velocity anomaly data were sourced from the delayed-time MSLA-UV product (available at http://www.aviso.altimetry.fr).

All spatial covariates were converted to raster grids of 0.2° resolution extending from 163° and 190° of longitude, and between -41° and -25° of latitude.

C.0.2 State-space model

The SSM was fitted using the moveHMM package (Michelot et al. 2016) for the statistical software R (R Core Team 2015), via Hidden Markov Models (Patterson et al. 2009, Langrock et al. 2012). All covariates except the number of steps were standardised by their mean and standard deviation prior to analysis. The turning angle was expressed relative to the angle to Great Barrier Island to capture the behaviour of birds departing the colony and returning to it. Four states were assumed in the model, to include these two behavioural states, as well as the resident and transit behaviours when at sea, away from the colony.

The model requires initial parameters for the distribution of step lengths and turning angles for each of the four states. A gamma distribution was assumed for step lengths, with a mean of 0.1, 2.0, 7.0, and 7.0 km, and a standard deviation of 0.05, 1.0, 2.0, and 2.0, for the four states. For turning angles (in radians), a von Mises distribution was assumed with a mean of 0 for states 1–3, and π for state 4, and a kappa of 1 for all four states. The covariates were entered in the model as an additive linear function.

After fitting the model, the most probable state for each movement step was reconstructed using the Viterbi algorithm, with the *viterbi* function of the moveHMM package.

C.0.3 Step-selection functions

A conditional logistic regression was performed for each state, fitting the SSFs to all movement steps of the same state, as predicted from the SSM. The analysis was carried out in R using the *clogit* function of the *survival* package.

In addition to the covariates used in the SSM, the independent variables also considered in the SSF model were three types of turning angle: absolute, relative to Great Barrier Island, and relative to the shortest path over water to Great Barrier Island. All angles entered the model as both sine and cosine components. A boolean variable indicating whether the depth was shallower than 150 m or deeper was also included. The number of steps from the start of the trip and the time of the day were not included, as they are irrelevant in comparing the chosen steps with their available alternatives.

For the SSFs, the shortest distance over water, sea-floor depth, and the shortest distance to the coastline were log-transformed, and all covariates were standardised by their mean and standard deviation.

A backward stepwise regression was carried out for each model, based on the Akaike Information Criterion (AIC; Akaike 1976), to remove the covariates that do not explain the movement choices of individual birds.

C.0.4 Tracks simulation

After fitting the SSM and SSFs, 5000 tracks of black petrel movement at sea were simulated, starting from Great Barrier Island.

The *simData* function from the moveHMM R package was modified so that the starting point of each track could be specified and to include the SSFs in the movement process. For each simulated track, the process is outlined below.

One date was first drawn randomly from the set of 22 dates of the GPS tracking data. This step defined the values of the time-varying environmental covariates in the landscape (e.g., sea-surface temperature, sea-surface height anomaly). The length of the track to be simulated, as a number of steps, was drawn randomly between 500 and 2000.

All tracks started at sea on the north-eastern side of Great Barrier Island, with an initial angle of 45° (from the west-east direction). According to GPS data, this direction is taken by black petrels leaving the colony. The initial state was set to the behaviour state leaving, as identified by the SSM. A step length was drawn randomly from the distribution defined by the covariates at the location, parameterised by the SSM. Twelve alternative steps were created, regularly distributed on a circle around the location, with a radius equal to the step length. The SSF model corresponding with the current behavioural state was used to calculate a choice probability for each of the alternative points based on their covariates, and the chosen step was drawn for these probabilities. From the covariates at the new location and the previous state, a new behavioural state was drawn from the SSM.

The process was repeated until the total number of steps initially drawn for the track was reached, or once the simulated individual returned to Great Barrier Island.

Once all the simulations were performed, the at-sea distribution map was derived by summing the number of simulated locations within each cell of the same grid used for the covariates.

This map was used in the risk assessment only for the guard and chick-rearing period, as the tracking data only covered this period. For the pre-egg laying and incubation periods, the maps derived from the generalised linear model (presented previously) were used.

Similar to the other species, the at-sea distribution maps of black petrel were normalised prior to the risk assessment analysis, so that the density summed to one across the region.

C.1 Black petrel at-sea distribution maps

The updated at-sea distribution for each of the three periods of the breeding season revealed differences in the distribution of this species over time (Figure C-3). The distribution was more concentrated around Great Barrier Island as the breeding season progressed. This finding was expected as chicks require frequent feeding after hatching, and foraging trips of parents become shorter (Weimerskirch et al. 1993, Berrow et al. 2000).

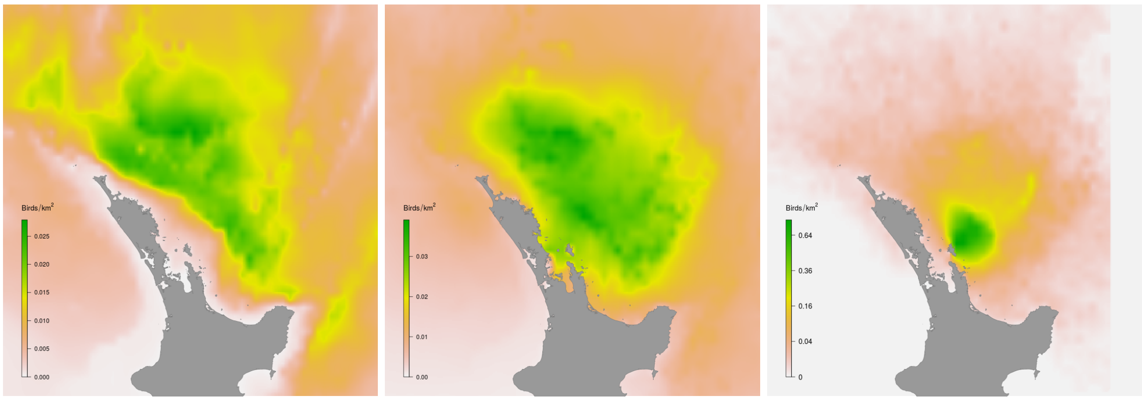

(a) Pre-egg laying **(b) Incubation** **(c) Chick rearing**

Figure C-3: Distribution of black petrel during the three recognised breeding periods: pre-egg laying (October to November), incubation (December to January), and guard and chick rearing (February to May).

The results of the SSM and the step selection function SSF models illustrate the different behaviours of black petrel (Table C-5 and Table C-6). In the SSM, state 4 represented black petrel behaviour of leaving the Great Barrier Island colony, at a high speed (mean speed of 29.8 km/h) and in a direction of movement away from Great Barrier Island (mean turning angles of 3.01 radians, or 172°, relative to the bearing to Great Barrier Island). State 3 represents the behaviour of returning to the colony, also fast (mean speed of 25.6 km/h), but in a direction towards the colony (mean turning angle of 0.19 radians, or 11° relative to the bearing to Great Barrier Island). States 1 and 2 represent two behavioural states of foraging at sea, with state 1 reflecting birds resting on water (speed almost zero), and state 2 reflecting birds flying at relatively slow speed (mean speed of 9 km/h).

The SSF model coefficients were consistent with the expected movement behaviour of the different states (Table C-6 and Figure C-4). In all four states, the birds tended to move in a straight direction, especially when leaving (state 4) and returning to the colony (state 3). When leaving the colony, birds tended to move away from the coast and Great Barrier Island, but towards the island when returning (Figure C-4). Habitat variables had a relatively small effect in explaining these movements.

Table C-5: Step length and turning angle for the four states considered to represent black petrel movement behaviour, estimated from the state-space model. Step length is expressed in kilometres (including standard deviation, s.d.), with a step duration of 15 minutes. Turning angle is expressed in radians, relative to the bearing to Great Barrier Island (e.g., angle of 0 is movements towards Great Barrier Island, angle of 3.14 (π) is movements away from the island).

State	Step length		Turning angle	
	Mean	s.d.	Mean	Concentration
State 1	0.24	0.15	-1.16	0.35
State 2	2.23	1.77	-1.19	0.11
State 3	6.40	2.25	-0.19	1.85
State 4	7.45	2.58	3.01	2.49

Table C-6: Summary of the parameter coefficients in each of the four step selection function models corresponding with the four identified behavioural states of moving black petrel identified by a state-space model. Shown are the mean, standard deviation (s.d.), and p value ($= 0.05$). Slope, slope of the ocean floor; shallow, less than 300 m water depth; distance to coast, minimum Euclidean distance to coastline; distance to GBI, minimum distance over sea to Great Barrier Island (GBI); chl-a, sea-surface chlorophyll-a concentration; θ_{turn}, turning angle; θ_{GBI}, turning angle relative to GBI; θ_{return}, turning angle relative to angle to return to GBI over sea; GV (u, v), geostrophic velocity anomaly (zonal and meridional components); SSH, sea-surface height; SST: sea-surface temperature; u', v', zonal and meridional components relative to movement direction.

Parameter	State 1			State 2			State 3			State 4		
	Mean	s.d.	p	Mean	s.d.	p	Mean	s.d.	p	Mean	s.d.	p
Slope							0.29	0.09	0.002	0.22	0.09	0.019
Shallow	-0.49	0.24	0.042									
Distance to coast										-0.48	0.25	0.062
Distance to GBI	-3.15	1.52	0.038							1.12	0.65	0.086
Chl-a	-0.53	0.31	0.084				-0.34	0.13	0.007	-0.37	0.15	0.013
θ_{turn} (cos)	1.29	0.05	0.000	0.92	0.04	0.000	1.55	0.06	0.000	1.93	0.08	0.000
θ_{turn} (sin)							0.08	0.05	0.110	0.34	0.05	0.000
θ_{return} (cos)	-0.46	0.23	0.049									
θ_{return} (sin)	0.58	0.22	0.010	0.25	0.14	0.074	-0.28	0.18	0.115			
θ_{GBI} (cos)	0.43	0.24	0.070				1.20	0.06	0.000	-1.55	0.08	0.000
θ_{GBI} (sin)	0.37	0.22	0.097	0.20	0.14	0.151	-0.60	0.19	0.002			
GV anomaly (u)							0.32	0.14	0.021	-0.56	0.16	0.000
GV anomaly (v)										-0.30	0.15	0.041
SSH anomaly										-0.33	0.19	0.078
SST anomaly							-0.29	0.18	0.113			
Wind (u')							0.22	0.05	0.000	-0.15	0.05	0.004
Wind (v')	-0.31	0.06	0.000				-0.33	0.05	0.000	0.18	0.06	0.004

Overall, the predicted density of black petrel from the simulated paths correlated adequately with the

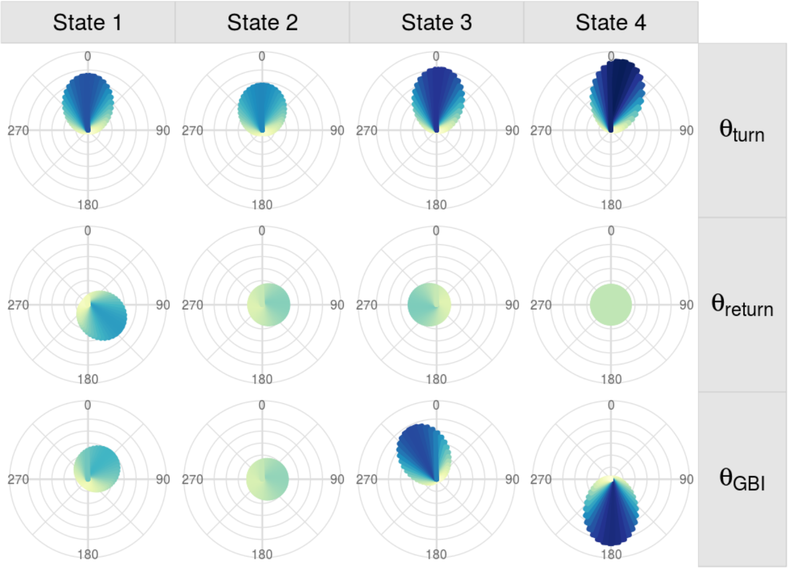
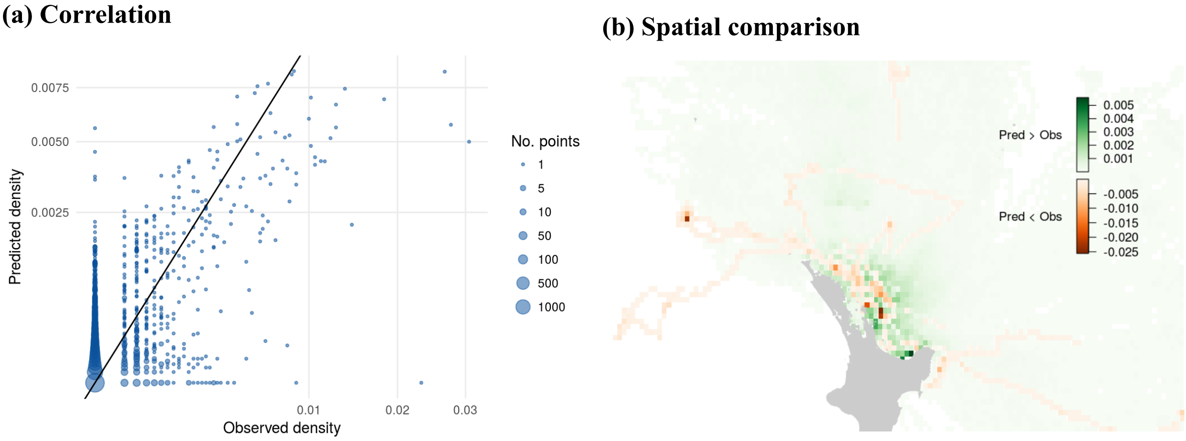


Figure C-4: Directionality in movement preferences of black petrel, in each of the four states of black petrel behaviour, as estimated by step selection function models. Movement preferences included: θ_{turn}, turning angle; θ_{return}, turning angle relative to angle to return to Great Barrier Island (GBI) over sea; θ_{GBI}, turning angle relative to GBI. The colour shows the intensity in directionality.

density of observed GPS positions (Figure C-5). Owing to the small number of GPS tracks, the observed densities were sensitive to the movements of single birds. For example, an individual bird spending a significant amount of time at a single location increases the density at that location without representing the typical distribution of the species. These high observed densities were underestimated by the simulations (Figure C-5).


(a) Correlation

(b) Spatial comparison

Figure C-5: Comparison of the number of movement points in each map cell between the observed Global Positioning System tracks and the simulated paths of black petrel movement. Shown are (a) the correlation of the standardised number of movement points in each map cell between observations and predictions (black line indicates 1:1 relationship), and (b) the spatial difference between the predicted and observed standardised densities.

D APPENDIX D: CALIBRATION OF THE PST

D.1 Demographic constraints

For the PST calculation, the total population size N was calculated from the current age at first reproduction A and adult annual survival rate S_{curr} using Gilbert (2009)'s formula, and the maximum net productivity rate r_{max} was estimated from the age at first reproduction and adult annual survival rate obtained from an allometric model (A_{tax} and S_{tax}, respectively), using the formula from Niel and Lebreton (2005).

An earlier study (Richard & Abraham 2013a) tested the accuracy of this approach by simulating the population dynamics of 12 seabird taxa, representing the range of taxa considered in the risk assessment. In the earlier study, however, the same age at first reproduction and adult annual survival rate were used for both N and r_{max}. A range of values was considered for each of the demographic parameters under optimal conditions (egg, immature, and adult survival rates, proportion of adults breeding, age at first reproduction, clutch size) and of the parameters defining the ecological context (population size, carrying capacity level, strength of density dependence, gender and age capture bias, amount of environmental stochasticity). Because random independent draws of the demographic parameters led to an unrealistic range of r_{max} values (from negative values to growth rates recorded in insects), the demographic parameters were resampled so that r_{max} was constrained between bounds defined for each taxon, and rules were added so that egg and immature survival rates were lower than adult survival rates.

For each draw of the simulation parameters, N, r_{max}, and the critical mortality level were known. The latter represents the amount of human-caused mortality that the population could sustain while remaining above half its carrying capacity with a 95% probability after 200 years. The estimates N^G, $r_{\text{max}}^{\text{NL}}$, and the resulting PST calculated from the approach using formulae by Gilbert (2009) and Niel and Lebreton (2005) were then compared with their respective "true" value. A single correction factor, ρ, was provided for each taxon, including all three corrections of N^G, $r_{\text{max}}^{\text{NL}}$, and PST, to ensure that the PST meets the long-term goal of the population remaining above half its carrying capacity with a 95% probability, in absence of knowledge of the demographic and ecological context. This correction factor, ρ, varied between 0.17 for diving petrels to 0.61 for species demographically similar to Caspian tern. This outcome was considered to indicate that a correction factor was needed in the seabird risk assessment to adjust the PST (Richard & Abraham 2015).

The calculation of the correction factor assumed that all sets of the sampled parameters were biologically possible. A study by Niel and Lebreton (2005), however, found that the product of the logarithm of the maximum annual population growth rate λ_{max} and the mean optimal generation length T_{opt} was approximately 1 across all considered species (Niel & Lebreton 2005, Dillingham et al. 2016) (Figure D-6). This allometric relationship was not considered when drawing the values of the demographic parameters in the early risk assessment methods by Richard and Abraham (2013a). Assuming a constant adult survival rate and fecundity after the age at first reproduction, T_{opt} can be calculated from λ_{max}, the optimal adult annual survival rate (S_{opt}), and the age at first reproduction (A_{opt}) (Equation D-2; Niel & Lebreton 2005):

$$T_{\text{opt}} = A_{\text{opt}} + \frac{S_{\text{opt}}}{\lambda_{\text{max}} - S_{\text{opt}}}. \tag{D-2}$$

There was a strong relationship between the product $\log(\lambda_{\text{max}})T_{\text{opt}}$ calculated from the values of λ_{max}, S_{opt}, and A_{opt} used in simulations in the early risk assessment methods (Richard & Abraham 2013a) and the values of the overall correction of the PST (ρ), mostly determined by the difference between r_{max} and $r_{\text{max}}^{\text{NL}}$, calculated using the formula by Niel and Lebreton (2005) (Figure D-7).

In a revision of the assumptions underlying the sampled populations used in the early risk assessment methods (Richard & Abraham 2013a), demographic samples were obtained by drawing values of the demographic parameters so that the product $\log(\lambda_{\text{max}})T_{\text{opt}}$ approximates 1, without constraining r_{max}. In an iterative approach, a value of adult annual survival rate was first drawn from a logit-normal distribution so that the 95% credible limits were matched to bounds (specified in Table D-7). The ranges considered

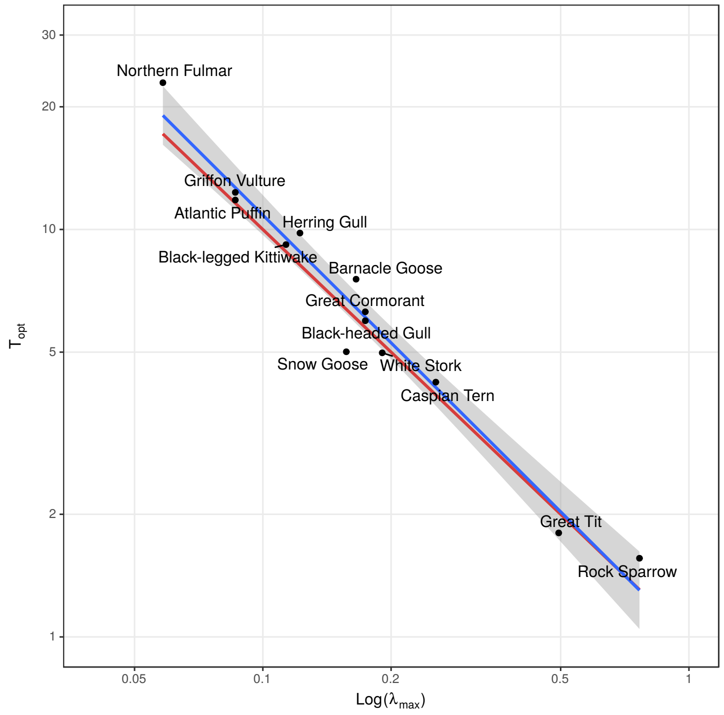
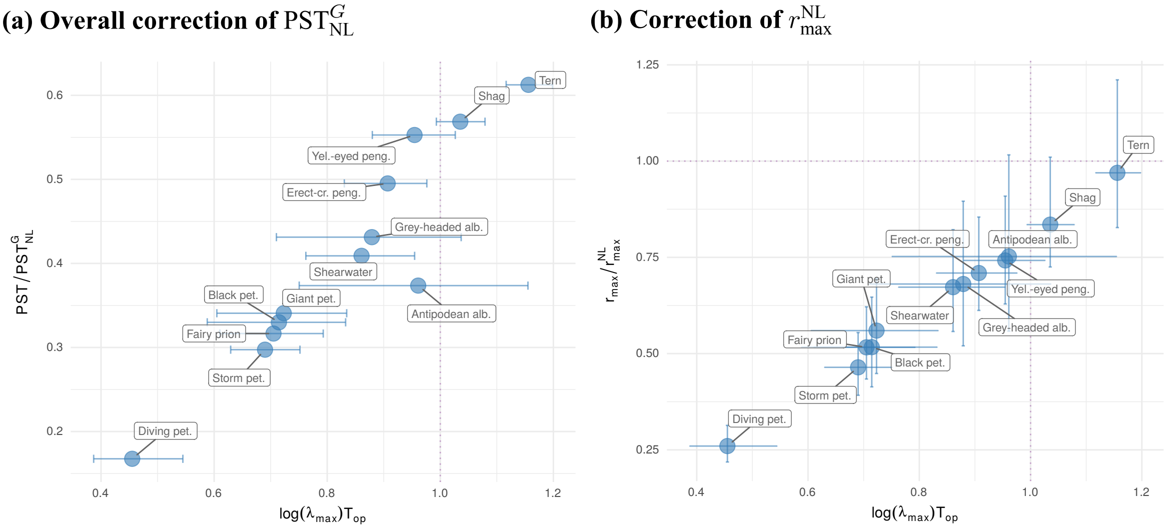


Figure D-6: Relationship between the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length T_{opt}, for 13 bird species with widely varying life-histories (data from Niel & Lebreton 2005). The red line is the relationship $T_{\text{opt}} = 1/\log(\lambda_{\text{max}})$, the blue line and the shading indicate the mean and standard error of best fit through the data, from a linear regression. The fitted line has a slope of -1.04 ± 0.06, and an intercept of -0.01 ± 0.11.


(a) Overall correction of PST^G_{NL}

(b) Correction of $r^{\text{NL}}_{\text{max}}$

Figure D-7: Relationship between the demographic invariant, $\log(\lambda_{\text{max}})T_{\text{opt}}$ on the correction factors for (a) the Population Sustainability Threshold PST^G_{NL} and (b) the maximum net productivity rate $r^{\text{NL}}_{\text{max}}$ (NL: estimated following Niel and Lebreton (2005); G: estimated following Gilbert (2009)). The product of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length T_{opt} was calculated from the demographic samples by Richard and Abraham (2013a).

for adult survival were slightly increased compared with the early risk assessment methods by Richard and Abraham (2013a) to increase the sample acceptance rate. The annual survival rate of juveniles (birds after fledging and before first reproduction) was then drawn by multiplying the adult survival rate by a random variable representing the ratio of juvenile survival to adult survival. This variable was drawn from a logit-normal distribution with a mean of 0.92, and a coefficient of variation of 0.03, resulting in a 95% c.i. of 0.85–0.96. Similarly, the egg survival rate was defined relative to adult survival, and calculated by multiplying the adult survival by a random variable following a logit-normal distribution with a mean of 0.8 and a coefficient of variation of 0.03. The only exception was penguins, for which the mean egg survival was set to 0.5, and with a coefficient of variation of 0.03, as penguins lay two eggs but often lose one (Heber et al. 2008, Miskelly 2013). This approach resulted in a 95% c.i. of 0.47–0.53 for penguins, and 0.75–0.84 for other species. Age at first reproduction was drawn randomly from the mean (specified in Table D-7), plus or minus one year. The probability of breeding was drawn from a logit-normal distribution (with a mean as specified in Table D-7) and a standard deviation of 0.05 (e.g., for a mean of 0.8, the 95% c.i. is 0.68–0.88). The sample of demographic parameters was finally accepted only if the product $\log(\lambda_\text{max})T_\text{opt}$ (calculated using Equation D-2) was within 1.00±0.03, and the process was repeated until 2000 samples were obtained for each taxon.

Table D-7: Base parameters used to draw samples of demographic variables for 12 seabird taxa breeding in New Zealand. Demographic variables included clutch size (number of eggs), optimal age at first reproduction A (years), optimal adult annual survival rate S_A (minimum and maximum), and probability of adult breeding P_B.

Taxon	Clutch size	A	S_{A_min}	S_{A_max}	P_B
Antipodean albatross	1	11	0.95	0.98	0.55
Grey-headed albatross	1	10	0.94	0.97	0.55
Giant petrel	1	7	0.88	0.95	0.80
Black petrel	1	5	0.90	0.95	0.73
Flesh-footed shearwater	1	6	0.90	0.95	0.70
Fairy prion	1	4	0.82	0.93	0.80
Common diving-petrel	1	2	0.85	0.93	0.80
Storm petrel	1	3	0.80	0.92	0.80
Shag	2	3	0.85	0.91	0.75
Erect-crested penguin	2	3	0.85	0.91	0.70
Yellow-eyed penguin	2	3	0.85	0.92	0.60
Caspian tern	2	3	0.87	0.91	0.80

D.1.1 Adjustment of the total population size

The demographic samples were constrained so that $\log(\lambda_\text{max})T_\text{opt} \simeq 1$, and the proportion of adults in the population was then calculated for each sample, from the stable age distribution obtained from the dominant eigenvector of a simple population matrix having $a - 1$ classes for immature birds before the age at first reproduction a, and a single class for adults (Figure D-8). The stable age distribution was calculated using the *popbio* library (Stubben & Milligan 2007) for the software R (R Development Core Team 2008). The Gilbert estimate of the proportion of adults in the population was calculated for each sample, from the adult survival rate S_A and the age at first reproduction A, as S_A^{1-A} (Gilbert 2009). The correction factor, g, for the population size was obtained for each taxon from the ratio between the proportion of adults calculated using the population matrix and the Gilbert estimate.

D.1.2 Adjustment of the maximum net productivity rate r_max

The maximum net productivity rate r_max was calculated from the constrained demographic samples by calculating the dominant eigenvalue of the population matrix minus one (Caswell 2001). In parallel, the estimate r_max^NL was calculated using the formula by Niel and Lebreton (2005). The correction factor for

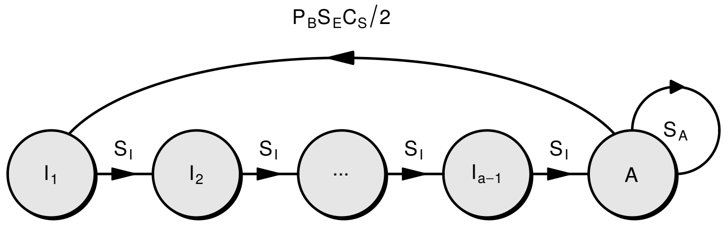


Figure D-8: Diagram of the population model used to calculate the stable proportion of adults in the population and the long-term population growth rate. I_x: Immature of age x; A: Adult; S_I: Immature annual survival rate; S_A: Adult annual survival rate; a: age at first reproduction; P_B: probability of adult breeding; S_E: egg survival rate; C_S: clutch size.

r_{max} was obtained for each taxon from the ratio $r_{\text{max}}/r_{\text{max}}^{\text{NL}}$.

D.1.3 Adjustment of the PST to the critical human-caused mortality limit

From the simulations of population dynamics in the early risk assessment methods (Richard & Abraham 2013a), the ratio between the critical human-caused mortality limit (MM), and $\text{PST}_{\text{NL}}^{G}$, calculated using $r_{\text{max}}^{\text{NL}}$ following Niel and Lebreton (2005) and N^G, the total population size following Gilbert (2009), was calculated for each sample. For each of the 12 example taxa, ρ was calculated as the 5th percentile of the ratio $MM/\text{PST}_{\text{NL}}^{G}$, so that $\rho\text{PST}_{\text{NL}}^{G}$ exceeds MM with a 95% probability. The factor, ρ, included corrections to $r_{\text{max}}^{\text{NL}}$ and N^G, as well as allowing for environmental stochasticity.

The calibration was repeated with the corrected r_{max} and population size N. A new correction factor, ϕ, was introduced and derived so that the PST ($0.5\phi r_{\text{max}}N$) exceeded the critical human-caused mortality limit with a 95% probability.

D.2 Outcome of the PST corrections

The alternative demographic samples were constrained so that the product of the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length $T_{\text{opt}} \simeq 1$ showed some variability across seabird groups (see summaries in Tables D-8 and D-9). Although not constrained in these samples, the resulting r_{max} values were similar to published values (Dillingham & Fletcher 2011), with a mean between 0.04 and 0.05 for albatrosses and between 0.07 and 0.09 for large petrels.

Using the constrained demographic samples, the ratio $r_{\text{max}}/r_{\text{max}}^{\text{NL}}$ was close to 1 (Table D-10), with the uncertainty in the ratio being solely determined by the deviation from the perfect relationship $\log(\lambda_{\text{max}})T_{\text{opt}} = 1$ (Figure D-9). This finding suggests that the formula by Niel and Lebreton (2005) does not need correction when $\log(\lambda_{\text{max}})T_{\text{opt}} = 1$, when adult survival and age at first reproduction are known and optimal.

The correction of the total population size, when calculated using the formula by Gilbert (2009), varied across taxa, from a mean of 1.26 (95% c.i.: 1.19–1.35) for diving petrels to 1.77 (95% c.i.: 1.65–1.91) for large albatrosses (Table D-10). This correction factor was determined by the age structure of the population (Figure D-10), because of the assumption in the methods of a constant survival rate among age classes.

Table D-8: Adult, immature, and egg annual survival rates from demographic samples that were constrained so that the product of the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length $T_{\text{opt}} \simeq 1$ for different seabird groups.

Taxon	Adult		Immature		Egg	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Large albatrosses	0.975	0.967–0.982	0.917	0.893–0.936	0.781	0.736–0.823
Small albatrosses	0.969	0.962–0.975	0.921	0.900–0.939	0.780	0.734–0.823
Giant petrel	0.952	0.944–0.962	0.898	0.869–0.919	0.766	0.722–0.804
Black petrel	0.950	0.942–0.959	0.892	0.860–0.916	0.766	0.722–0.804
Shearwaters	0.953	0.945–0.962	0.901	0.873–0.921	0.769	0.726–0.809
Prions	0.945	0.935–0.955	0.883	0.845–0.909	0.762	0.720–0.800
Diving petrels	0.942	0.934–0.952	0.878	0.834–0.908	0.763	0.720–0.800
Storm petrels	0.943	0.935–0.952	0.879	0.836–0.909	0.762	0.720–0.800
Shags	0.894	0.878–0.911	0.826	0.773–0.861	0.717	0.678–0.755
Small penguins	0.920	0.907–0.932	0.861	0.818–0.891	0.540	0.489–0.590
Large penguins	0.933	0.920–0.945	0.873	0.834–0.904	0.535	0.482–0.589
Terns	0.893	0.877–0.907	0.822	0.770–0.857	0.714	0.672–0.753

Table D-9: Probability of adults breeding, age at first reproduction, and the maximum net productivity rate r_{max} from demographic samples that were constrained so that the product of the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length $T_{\text{opt}} \simeq 1$ for different seabird groups.

Taxon	Probability of breeding		Age at first reproduction		r_{max}	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Large albatrosses	0.566	0.475–0.658	10.8	10–12	0.040	0.033–0.046
Small albatrosses	0.587	0.502–0.671	9.6	9–11	0.046	0.040–0.052
Giant petrel	0.818	0.729–0.890	6.6	6–8	0.071	0.057–0.081
Black petrel	0.765	0.685–0.836	4.5	4–6	0.094	0.072–0.109
Shearwaters	0.734	0.645–0.809	5.5	5–7	0.080	0.063–0.091
Prions	0.824	0.730–0.895	3.6	3–5	0.118	0.085–0.141
Diving petrels	0.837	0.755–0.902	2.5	2–3	0.158	0.125–0.192
Storm petrels	0.832	0.746–0.900	2.8	2–4	0.147	0.102–0.191
Shags	0.764	0.679–0.840	2.5	2–4	0.212	0.131–0.264
Small penguins	0.763	0.691–0.829	2.4	2–4	0.187	0.119–0.227
Large penguins	0.669	0.588–0.742	2.6	2–4	0.164	0.108–0.211
Terns	0.800	0.707–0.880	2.7	2–4	0.205	0.132–0.269

Table D-10: Correction factors for the maximum net productivity rate r_{max}, population size N^G, and Population Sustainability Threshold PST, from demographic samples that were constrained so that the product of the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length $T_{\text{opt}} \simeq 1$ for different seabird groups.

Taxon	Correction of r_{max}		Correction of N^G, g		Correction of PST (ϕ)
	Mean	95% c.i.	Mean	95% c.i.	
Large albatrosses	1.00	0.955–1.046	1.77	1.652–1.908	0.50
Small albatrosses	0.99	0.956–1.044	1.69	1.595–1.806	0.50
Giant petrel	0.99	0.955–1.045	1.63	1.537–1.753	0.53
Black petrel	0.99	0.949–1.049	1.45	1.380–1.590	0.54
Shearwaters	0.99	0.952–1.045	1.51	1.443–1.636	0.52
Prions	0.99	0.945–1.053	1.39	1.304–1.540	0.55
Diving petrels	0.98	0.933–1.057	1.26	1.186–1.351	0.58
Storm petrels	0.98	0.935–1.056	1.29	1.185–1.449	0.54
Shags	1.00	0.947–1.052	1.37	1.258–1.598	0.51
Small penguins	0.98	0.940–1.048	1.29	1.215–1.482	0.53
Large penguins	0.98	0.936–1.047	1.30	1.196–1.471	0.52
Terns	1.00	0.951–1.055	1.40	1.265–1.626	0.49

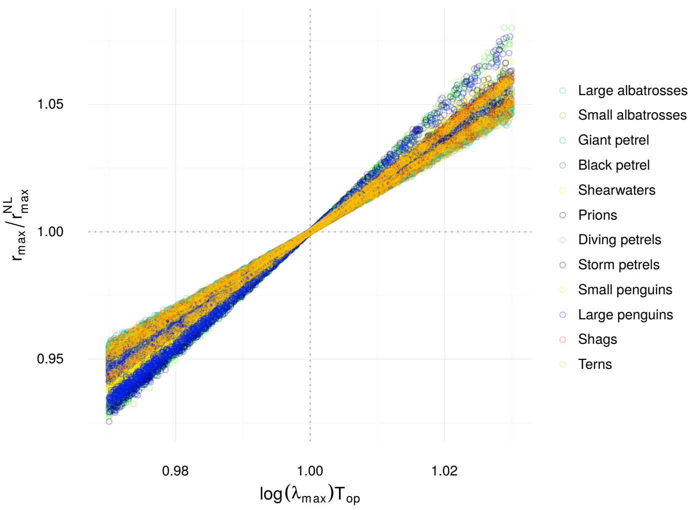


Figure D-9: Effect of the deviation from 1 for the product of the logarithm of the maximum annual population growth rate $\log(\lambda_{\text{max}})$ and the optimal generation length T_{opt} in the constrained demographic samples on the correction of the maximum net productivity rate r_{max} for different seabird groups (NL: estimated following Niel and Lebreton (2005)).

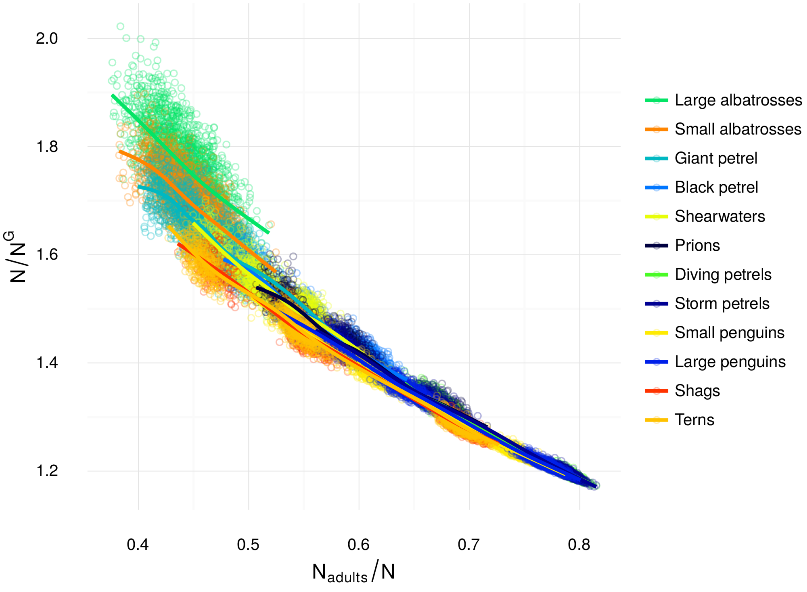


Figure D-10: Effect of the proportion of adults in the population on the correction of the total population size when calculated using the formula by Gilbert (2009) for different seabird groups.

The correction factor ϕ ensures that the estimated PST remains above the critical human-caused mortality limit with a 5% probability, and the value for this factor was approximately 0.5 for all considered taxa (Table D-10). It varied from 0.49 for terns to 0.58 for diving petrels. There was no clear relationship with taxonomy, and a value of 0.5 was chosen for all taxa. Among samples, the variations of the ratio of the critical human-caused mortality limit to $\mathrm{PST}^{G}_{\mathrm{NL}}$ was determined by the amount of environmental stochasticity (Figure D-11). This outcome was expected, as the probability of the PST exceeding the critical human-caused mortality limit depends on the variability of the population.

A correction of ϕ of 0.5 halves $\mathrm{PST}^{G}_{\mathrm{NL}}$ and, therefore, doubles the risk ratio, independently of the correction of population size or r_{max}. Nevertheless, the product of the correction factors for $r^{\mathrm{NL}}_{\mathrm{max}}$, N^{G}, and PST indicates a lower correction than the ρ factor used in Richard and Abraham (2015) (Table D-11). This change in correction factor corresponded with decreases of around 15% for shags, terns and penguins, around 50% for albatrosses and larger petrels, to over 70% for diving petrels.

Table D-11: Comparison of the Population Sustainability Threshold (PST) correction factor used in Richard and Abraham (2015) (ρ), the product of the correction factor for the calculation of the total population size, for r_{max}, and for the PST as obtained with alternative demographic samples (combined corrections). Also shown is the product of the correction of the total population size and $\phi = 0.5$ (combined, suggested corrections).

Taxon	ρ	Combined corrections		Combined suggested corrections	
		Mean	95% c.i.	Mean	95% c.i.
Large albatrosses	0.37	0.88	0.80–0.97	0.88	0.83–0.95
Small albatrosses	0.43	0.84	0.77–0.92	0.84	0.80–0.90
Giant petrel	0.34	0.86	0.79–0.95	0.81	0.77–0.88
Black petrel	0.33	0.77	0.71–0.86	0.73	0.69–0.80
Shearwaters	0.41	0.79	0.73–0.87	0.76	0.72–0.82
Prions	0.32	0.75	0.68–0.86	0.69	0.65–0.77
Diving petrels	0.17	0.71	0.64–0.81	0.63	0.59–0.68
Storm petrels	0.30	0.69	0.60–0.80	0.65	0.59–0.72
Shags	0.57	0.70	0.61–0.83	0.68	0.63–0.80
Small penguins	0.50	0.67	0.61–0.78	0.65	0.61–0.74
Large penguins	0.55	0.66	0.59–0.77	0.65	0.60–0.74
Terns	0.61	0.69	0.59–0.81	0.70	0.63–0.81

The simulations of the earlier risk assessment method (Richard & Abraham 2013a) were used to calculate ϕ, even though the demographic parameters were not constrained by the relationship $\log(\lambda_{\mathrm{max}})T_{\mathrm{opt}} \simeq 1$; deviations from this allometric relationship do not have an effect on ϕ. A simple regression of $\mathrm{MM}/\mathrm{PST}^{G}_{\mathrm{NL}}$ against $\log(\lambda_{\mathrm{max}})T_{\mathrm{opt}}$ for each considered taxon was performed, and the R^2, the proportion of variance explained by the model, was less than 0.05 for all species.

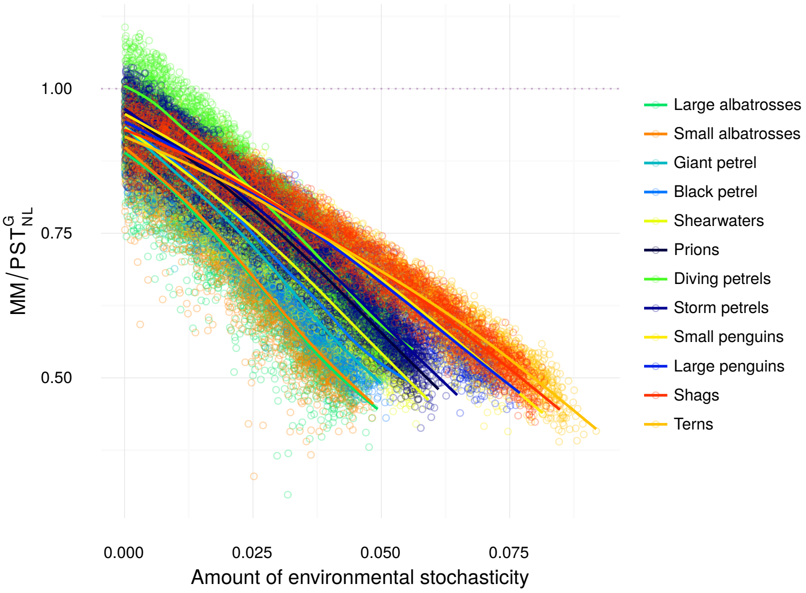


Figure D-11: Effect of the amount of environmental stochasticity on the correction factor ϕ of the Population Sustainability Threshold $\mathrm{PST}^{G}_{\mathrm{NL}}$ so that $\phi\mathrm{PST}^{G}_{\mathrm{NL}}$ exceeds the critical human-caused mortality limit with a probability of 5% for seabird populations. The amount of environmental stochasticity was defined as the standard deviation of the annual survival rate of chicks, immatures, and adults.

E APPENDIX E: ESTIMATION OF CRYPTIC MORTALITIES

Not all seabirds that are killed during fishing operations are recorded by observers, even when observers are on-board a vessel. For example, birds may be killed but not brought on-board the fishing vessel, and observers may also not record captures if they are off duty or in an area of the vessel where captures are not visible.

These cryptic fatalities are not included in the number of observable captures, but need to be included in the assessment of the risk to seabirds from fishing. The current risk assessment process included multipliers for cryptic mortalities ("cryptic multipliers") in the estimation of observable captures. The cryptic multipliers were derived from a number of data sources, as there are limited data available to support the quantification of cryptic mortalities.

The total number of potential fatalities, F, is calculated as the sum of observable captures, C, and unobservable or cryptic fatalities, U:

$$F = C + U. \tag{E-3}$$

Some of the observable captures, C, involve birds that were released alive. The probability that a captured bird was released alive, p_{alive}, varied across species groups and fishery groups (see below, and Section 2.3.4).

Cryptic multipliers, $M = F/C$, were estimated separately for longline and trawl fisheries, following previous risk assessments. The number of total fatalities was expressed as the product of the cryptic multiplier and the number of observable captures. Cryptic multipliers were estimated separately for longline and trawl fisheries. For longline fisheries, a single cryptic multiplier was estimated for all taxa, whereas for trawl fisheries, different multipliers were estimated for five different species groups (large albatrosses, mollymawks and giant petrel, medium-sized seabirds, small-sized seabirds, and diving seabirds), and for nine fishery groups. Because no data exist on cryptic mortality in set-net fisheries to allow the estimation of a multiplier, the number of annual potential fatalities was assumed to be equal to the estimated number of observable captures in these fisheries.

E.1 Cryptic multiplier for longline fisheries

A multi-year study conducted in Australia compared the number of individual birds hooked during the set and haul processes with observed captures that were subsequently recorded (Brothers et al. 2010). This study revealed that of 176 seabirds observed caught on hooks, only 85 carcasses were retrieved. These values were used here to deduce the probability distribution of capturing a bird in longline fisheries, given it was caught on the line, from the likelihood of the binomial distribution:

$$\mathcal{L} = \frac{n!}{k!(n-k)!} p^k (1-p)^{n-k}, \tag{E-4}$$

where n is the number of birds observed hooked, k is the number of retrieved carcasses, and p is the probability of a bird being retrieved on-board, given that it was hooked. The cryptic multiplier for longline fisheries is then $M = 1/p$. Using $n = 176$ and $k = 85$ in Equation E-4 led to a mean of M of 2.08, with a 95% credible interval of 1.79 to 2.43.

This distribution was used for all seabird taxa and all surface-longline fisheries. Each sample of estimated observable captures was multiplied by a sample from this distribution to estimate the total annual potential fatalities. In the absence of other information, the same distribution for the cryptic multiplier was used for bottom-longline fisheries. The uncertainly was the statistical uncertainty associated with the study by Brothers et al. (2010). Structural uncertainty associated with applying these values to different fisheries, impacting a different assemblage of seabird species, was not considered.

E.2 Cryptic multiplier for trawl fisheries

To estimate total fatalities in trawl fisheries, three types of seabird-trawler interactions were considered:

- Net entanglement. Birds that become entrapped or entangled in the net during shooting or hauling gear.

- Surface warp strike. Birds resting or hovering on the surface of the water that are overtaken and potentially entangled or drowned by a moving warp line, or that are struck by warp movement arising from the lateral movement of the vessel.

- Aerial warp strike. Flying birds that collide with the warp.

The number of fatalities per observed fishing event can then be defined as:

$$\begin{aligned} F_{tot} &= F_{net} + F_{surf} + F_{air} \quad &\text{(E-5)} \\ &= C_{net}M_{net} + C_{surf}M_{surf} + C_{air}M_{air} \quad &\text{(E-6)} \end{aligned}$$

where F_{net}, F_{surf}, and F_{air} are the total fatalities in the net, due to surface warp strikes and aerial warp strikes respectively, C_{net}, C_{surf}, and C_{air} the corresponding observed captures, and M_{net}, M_{surf}, and M_{air}, the corresponding cryptic multipliers.

To determine the relationship between captures and fatalities, different probabilities were estimated (illustrated in Figure E-12). Uncertainties were estimated by drawing 5000 samples from a probability distribution for the underlying data. When the data were given as a number of interactions in a number of trials, a binomial distribution was assumed (Equation E-4). When estimated proportions were reported as a mean and 95% confidence interval (e.g., the number of strikes per capture), a log-normal distribution was assumed and defined to match the 95% confidence interval. From a mean μ and a standard deviation σ, mortality rates were assumed to follow a beta distribution, with its two shape parameters and β defined using the equations (Samaranayaka & Fletcher 2010):

$$= \mu \left(\frac{\mu(1-\mu)}{\sigma^2} - 1 \right), \tag{E-7}$$

$$\beta = \frac{(1-\mu)}{\mu}. \tag{E-8}$$

E.2.1 Net entanglement

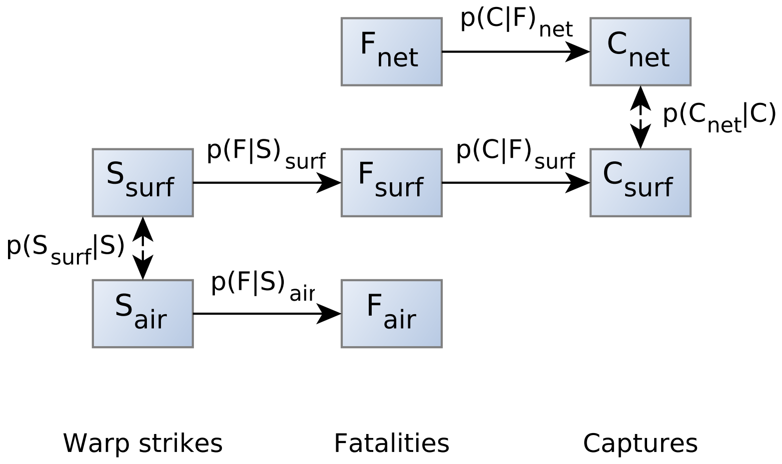
Net entanglements can occur either when shooting or hauling the net, with the majority of net captures occurring during hauling. Birds can become enmeshed in the trawl wings during setting, trapped inside the net as it closes (i.e., primarily diving species) or trapped on the outside of the net as the mesh tightens and closes during hauling. In the latter instance, birds may be released alive. In this analysis, these live captures were treated as fatalities as long-term impacts resulting from the capture are unknown. Cryptic net fatalities U_{net} arise when birds become entangled in the trawl wings during setting or on the outside of the net during hauling, but subsequently fall off and are not recorded. Cryptic net fatalities also include birds caught inside the net that are subsequently lost through the slack mesh during the haul.

In preparation of a previous risk assessment (Richard et al. 2011), it was agreed that the number of cryptic net fatalities, U_{net}, is likely to be lower than the number of observable captures, C_{net}. A ratio of cryptic to observable captures of $U_{net}/C_{net} = 0.3$ was used in the earlier assessment by Richard et al. (2011). To consider uncertainty around this ratio, we assumed that U_{net}/C_{net} followed a log-normal distribution with a 95% confidence interval of 0.1 to 0.7, and mean of 0.3. This range was not based on data.

The total number of fatalities due to net entanglements is the sum of observed and unobserved fatalities, therefore

$$M_{net} = F_{net}/C_{net} = 1 + U_{net}/C_{net}. \tag{E-9}$$

Figure E-12: Diagram of the parameters and processes involving seabird fatalities in trawl fisheries. Seabirds can be struck by warps either on the surface of the water, S_{surf}, or when flying, S_{air}. These warp strikes can lead to fatalities (F_{surf}, F_{air}). Fatalities of seabirds can also occur from their entanglement or capture in nets, F_{net}. Captures of seabirds recovered on-board the fishing vessel were assumed to be only from interactions with the net, C_{net}, or from surface warp strikes, C_{surf}.



E.2.2 Warp strikes

Limited data for estimating cryptic mortality from warp strikes are provided by two studies. Watkins et al. (2008) provide data on the number of warp strikes and subsequent fatalities, based on 190 hours of dedicated observations in the South African deepwater hake fishery in 2004 and 2005. Another study by Abraham (2010) provides estimates of the number of warp strikes per observed capture, using 7266 observations of warp strikes collected in New Zealand trawl fisheries in the fishing years between 2004–05 and 2008–09.

To relate observed warp captures to estimated warp fatalities, it is first necessary to distinguish between types of warp interactions and species- or guild-specific differences likely to affect the outcome of warp-bird interactions.

Seabird taxa were categorised according to their size and their diving behaviour (diving seabirds are assumed to not be affected by collisions with warps while at the surface) (Table 1). The species types were: large albatrosses (*Diomedea* species), mollymawks (*Thalassarche* and *Phoebetria* species) and giant petrel, diving seabirds (penguins, shags, boobies, and gannets), medium-sized seabirds (non-diving seabirds and non-albatross seabirds at least larger than white-naped petrel), and small seabirds (other seabirds like Cape petrel and smaller).

Due to behavioural and anatomical differences affecting warp-bird interactions, estimates of warp strike parameters were calculated independently for large versus small seabirds. Small birds were further differentiated into “fast-flying”, “slow-flying”, or “diving” species, with distinct assumptions about their relative susceptibilities to different kinds of capture. In general, fast-flying birds are larger than slow-flying birds; they are slower to accelerate from the surface of the water, turn less quickly, and may fly with considerable forward momentum. Diving birds (shags and penguins) do not forage while flying and were assumed to be killed only in the net.

E.2.3 Surface warp strikes

The total cryptic fatalities from surface warp strikes are:

$$F_{surf} = C_{surf} + U_{surf}. \tag{E-10}$$

Surface warp strikes occur when birds resting or hovering on the surface of the water are overtaken by the moving warp, or struck by warp movement arising from lateral movement of the vessel. Watkins et al. (2008) report that surface warp strike rates are strongly correlated with large swell conditions due to the resulting erratic movement of the warps relative to resting seabirds. Surface strikes leading to capture or fatality occur primarily when bird wings become entangled, and they are dragged underwater by the force of the water passing over the warp. Birds dragged underwater may resurface, or they may drown. Drowned birds may subsequently fall off the warp during the setting and hauling processes (U_{surf}); alternatively, they may be impaled on a sprag (loose warp splice) or pulled all the way to the trawl door, and subsequently retrieved (i.e., C_{surf}). Non-lethal warp captures are not observed.

Large birds such as albatrosses are particularly susceptible to being dragged underwater by surface warp strikes, because they habitually sit or hover on the surface with their wings spread; when struck from behind by a moving warp, the wing tends to wrap around the warp leading to entanglement. In contrast, because small birds habitually sit on the water with their wings closed, they are seldom entangled in the warps, and only very rarely observed as warp captures. Both fast-flying and slow-flying small birds were assumed to be susceptible to surface warp capture; the lower susceptibility of the slow-flying birds was expected to be reflected in lower observed capture rates. In contrast, diving birds (penguins and shags) were assumed not to be captured or killed in warp interactions; all diving bird fatalities were assumed to occur in the net, with no cryptic surface or aerial warp fatalities ($U^{fast}_{surf} = U^{fast}_{air} = 0$).

The probability that a bird hit by the warp (aerial or surface strike) is recovered on-board the vessel is the product of the probability of entanglement (or impalement; F) given the strike (S) and the probability that the bird is recovered (C) given it gets entangled (or impaled). In mathematical terms,

$$p(C|S) \quad = \quad p(C|F)p(F|S). \tag{E-11}$$

Assuming that fatal aerial warp strikes do not result in captures ($C_{air} = 0$), the number of fatalities from surface warp strikes per warp capture (F_{surf}/C_{warp}) is the probability that a surface warp strike is fatal, $p(F_{surf}|S_{surf})$, times the number of surface warp strikes per warp capture (S_{surf}/C_{warp}). In the earlier studies, Abraham (2010) found that for large birds, there were an estimated 244 (95% c.i.: 190–330) warp strikes for each capture (S_{warp}/C_{warp}); Watkins et al. (2008) report that of a total 376 observed strikes, 139 were surface warp strikes for large birds, leading to the mean probability that a strike is at the surface, $p(S_{surf}|S_{warp})$, of 0.37 (95% c.i.: 0.32–0.42). The ratio S_{surf}/C_{warp} was then estimated to be 93.63 (95% c.i.: 68.66–123.89). Watkins et al. (2008) also report that 24 fatalities were observed following 139 surface warp strikes, resulting in a probability of observing a fatality from a surface warp strike of 0.18 (95% c.i.: 0.12–0.24).

The same authors reported that 16 albatrosses were seen dragged under the water without resurfacing, so that their fate was unknown. The fatalities of large albatrosses, mollymawks, and giant petrel, following the observed surface warp strikes were then estimated to be 26.86 (95% c.i.: 24–30), and the probability of a surface warp strike being fatal was estimated as 0.2 (95% c.i.: 0.14–0.27). From the product of $p(F_{surf}|S_{surf})$ and S_{surf}/C_{warp}, the number of fatalities per surface warp capture, F_{surf}/C_{warp}, was estimated to be 18.4 (95% c.i.: 11.23–27.82).

For small birds, there were an estimated 6440 (95% c.i.: 3400–20 000) strikes per warp capture (Abraham 2010). There were 124 surface warp strikes out of 615 observed strikes, and they resulted in 6 fatalities (and 10 that were unsure) (Watkins et al. 2008). Repeating the calculations, the mean number of small-bird fatalities per surface warp capture, F_{surf}/C_{warp}, was estimated to be 112.47 (95% c.i.: 28.9–294.82). This estimate was used for small and medium-sized taxa.

E.2.4 Aerial warp strikes

Aerial warp strikes occur when flying birds collide with the moving warps. Aerial strikes are defined as any heavy contact between the bird and the warp, sufficient to deflect the bird's flight trajectory; wing contacts are only included if they occur above the wrist (Abraham 2010), coinciding with the definition of "heavy" collisions used by Watkins et al. (2008).

Because impacts occur primarily on the front surface of the wings, aerial strikes do not result in entanglement in the warp, and captures on warps due to aerial strikes can be assumed to be non-existent. Fatalities from aerial strikes are only cryptic, and thus a multiplier cannot be defined relative to aerial captures. Nevertheless, as in the previous analysis of surface warp strikes, the number of aerial strikes can be estimated relative to the number of surface strikes; the latter is estimated relative to the number of warp captures.

The number of fatalities due to aerial strikes per warp capture, F_{air}/C_{warp}, is the probability that an aerial warp strike is fatal, $p(F_{air}|S_{air})$, times the number of aerial strikes per warp capture, S_{air}/C_{warp}.

Aerial strike fatality is expected to arise primarily from damage to wing bones or tendons, but empirical data to estimate the subsequent fatality rate among affected birds are not currently available. Watkins et al. (2008) report that aerial strikes "usually had little apparent impact on birds" and recorded only one confirmed broken wing for a small fast-flying bird (white-chinned petrel) in 728 observed heavy collisions. Fatality rates for aerial warp strikes are thought to be low (e.g., 0 to 5%), and expected to be highest for large birds, and moderate for small, fast-flying birds, which may collide under their own forward momentum; they are expected to be low for small, slow-flying birds, which have a minimal forward momentum and for which strikes are more likely to arise from the lateral movement of the warp itself. For small diving birds, it was assumed that there are no cryptic warp fatalities, i.e., $F_{air} = 0$. It is important to note, however, that without dedicated efforts to assess the post-collision status of affected birds, any conclusion about associated fatality rates is highly speculative. We assumed that the fatality rate due to aerial warp strikes, $p(F_{air}|S_{air})$, followed a beta distribution, with a coefficient of variation of 0.2, and we applied the following mean fatality rate estimates previously proposed by Sharp et al. (2011) (see Richard et al. 2011): 2% for large birds, 1% for small, fast-flying birds, and 0.5% for small, slow-flying birds.

The ratio S_{air}/C_{warp} is the number of warp strikes per warp capture, S_{warp}/C_{warp}, times the proportion of aerial strikes among warp strikes, $p(S_{air}|S_{warp}) = 1 - p(S_{surf}|S_{warp})$, as calculated in the analysis of surface warp strikes above. Using this ratio led to the number of fatalities due to aerial strike per observed capture of 3.18 (95% c.i.: 1.88–4.96) for large birds, 72.17 (95% c.i.: 24.4–168.38) for medium-sized seabirds, and 37.02 (95% c.i.: 12.74–86.9) for small-sized seabirds. These estimates are speculative.

E.3 Estimation of total fatalities in trawl fisheries

The total number of fatalities in trawl fisheries, F_{trawl}, is the number of fatalities due to entanglements in the net, F_{net}, due to surface warp strikes, F_{surf}, and due to aerial warp strikes, F_{air}. Following the previous calculations,

$$\begin{aligned}
F_{trawl} &= F_{net} + F_{surf} + F_{air} && \text{(E-12)}\\
&= M_{net}C_{net} + (M_{surf} + M_{air})C_{warp} && \text{(E-13)}\\
&= M_{net}p(C_{net}|C_{trawl}) + (M_{surf} + M_{air})(1 - p(C_{net}|C_{trawl}))C_{trawl}, && \text{(E-14)}
\end{aligned}$$

where $p(C_{net}|C_{trawl})$ is the proportion of trawl captures that are retrieved in the net. This proportion can be estimated as observers in New Zealand trawl fisheries record whether captured birds were retrieved in the net or on the warps. The proportion of warp versus net captures varied among trawl fishery groups and species groups. For example, the proportion of observed net versus warp captures of mollymawks and giant petrel recorded in the net varied from approximately 7% in small inshore trawl fisheries to 80% in trawl fisheries targeting squid (Table E-12).

Table E-12: Number of seabirds recorded caught on warps or in the net, in trawl fisheries, between the fishing years 2006–07 and 2014–15. Shown are the total number of captures and the proportion of captures recorded in the net.

Fishery	Large albatrosses		Mollymawks & giant petrel		Medium-sized seabirds		Small-sized seabirds		Diving seabirds	
	Total	%(net)	Total	%(net)	Total	%(net)	Total	%(net)	Total	%(net)
Small inshore $<$ 17 m	0		7	0.0	9	100.0	0		32	100
Small inshore 17 to 28 m	0		55	7.3	33	87.9	0		0	
Southern blue whiting	1	100	19	26.3	36	100.0	3	100	0	
Scampi	0		44	63.6	134	100.0	2	100	0	
Mackerel	0		18	88.9	34	97.1	3	100	0	
Squid	5	100	481	79.6	1 359	99.6	11	100	0	
Large processor	4	75	464	69.8	548	99.1	25	76	0	
Large fresher	0		5	20.0	0		0		0	
Deepwater	1	0	17	5.9	3	100.0	2	50	0	

From the number of observed captures occurring in the net, the proportion of net or warp captures p_{net} for each fishing group and species group was estimated using a simple Bayesian binomial and logistic regression model (Table E-13).

In the model, the number of observed net captures C'_{net} was a binomial draw from the total number of observed captures C'_{tot} in the net or on warps, of species group s in the fishery group g, with probability p_{net}. The logit of p_{net} for each fishery group and species group was the addition of a fishery group effect β_{g} and a species group effect β_{s}:

$$C'_{\text{net}} \sim Binom(p_{\text{net}}, C'_{\text{tot}}), \tag{E-15}$$

$$\text{logit}(p_{\text{net}}) = \beta_{\text{g}} + \beta_{\text{s}}. \tag{E-16}$$

A normally-distributed uninformative prior was used for β_{g} and β_{s} (mean of 0 and standard deviation of 10 000). The model was run with three chains, a burn-in period of 150 000 iterations, and the posterior distributions drawn from 10 000 iterations, keeping a sample value every 10 iterations.

This model structure was selected during preliminary analyses, when a combination of alternative models was tested. In these models, a time effect was considered, with the period 2006–07 to 2014–15 split into three periods of three years. Alternative splits of all trawl fisheries were also tested, into inshore and other trawls, or into inshore, low-vulnerability fisheries (mackerel, scampi, deepwater, large fresher trawls), and other trawls. Interactions between the fishery group, the species group, and time period were also tested.

The models were compared using the Bayesian leave-one-out cross validation measure (LOO; Vehtari et al. 2016a, 2016b). The LOO measure estimates the error in point-wise out-of-sample predictions from the model. A lower LOO measure indicates a more accurate model. Here, the model with the lowest LOO score was the additive model of an effect of the seabird risk assessment fishery groups and of the species group, without time variation.

From the parameters involving seabird fatalities in trawl fisheries (summarised in Table E-14), and from Equation E-14, the number of fatalities in trawl fisheries relative to the number of observable captures was estimated for each seabird group (Table 11).

After fitting the best model, the posterior distributions of the probability p_{net} were used to derive the cryptic multiplier for each trawl fishery group and species type (Table E-15).

To allow cryptic mortalities to be estimated in trawl fisheries, the following simplifying assumptions were made:

- all bird captures on warps result in mortality, and only captures in the net include live captures;
- all bird captures on warps are only due to surface warp strikes;

Table E-13: Proportion of seabird captures in net or on warps in trawl fisheries that occurred in net (p_{net}), as estimated by a generalised linear model fitted to seabird captures observed between 2006–07 and 2014–15. Shown are the mean, 95% credible interval (c.i.), and the posterior distribution between 0 and 1.

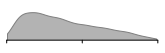
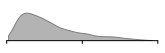
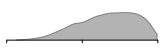
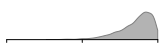
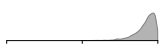
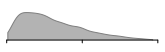
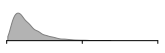
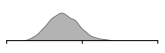
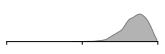
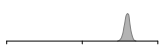
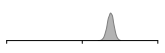
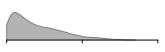
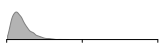
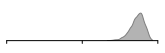
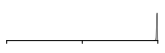
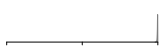
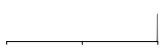
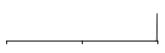
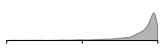
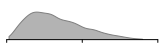
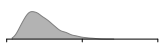
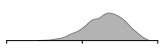
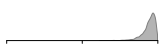
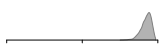
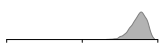
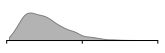
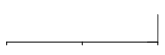
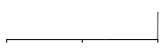
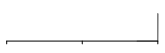
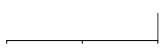
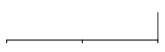
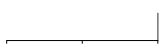
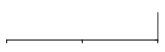
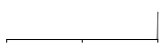
Species type	Fishery	p_{net}		Posterior
		Mean	95% c.i.	
Large albatrosses	Small inshore < 17m	0.37	0.05–0.87	
	Small inshore < 28m	0.28	0.05–0.76	
	Southern blue whiting	0.67	0.28–0.96	
	Scampi	0.85	0.57–0.99	
	Mackerel	0.94	0.75–1.00	
	Squid	0.92	0.74–0.99	
	Large processor	0.87	0.62–0.99	
	Large fresher	0.43	0.02–0.94	
	Deepwater	0.30	0.04–0.77	
Mollymawks & giant petrel	Small inshore < 17m	0.14	0.03–0.38	
	Small inshore < 28m	0.08	0.03–0.14	
	Southern blue whiting	0.38	0.20–0.58	
	Scampi	0.66	0.52–0.79	
	Mackerel	0.85	0.68–0.97	
	Squid	0.80	0.76–0.83	
	Large processor	0.69	0.64–0.73	
	Large fresher	0.20	0.01–0.60	
	Deepwater	0.10	0.02–0.24	
Medium-sized seabirds	Small inshore < 17m	0.89	0.70–0.98	
	Small inshore < 28m	0.86	0.76–0.94	
	Southern blue whiting	0.98	0.95–0.99	
	Scampi	0.99	0.99–1.00	
	Mackerel	1.00	0.99–1.00	
	Squid	1.00	0.99–1.00	
	Large processor	0.99	0.99–1.00	
	Large fresher	0.88	0.37–0.99	
	Deepwater	0.86	0.63–0.97	
Small-sized seabirds	Small inshore < 17m	0.33	0.06–0.73	
	Small inshore < 28m	0.23	0.08–0.48	
	Southern blue whiting	0.65	0.40–0.87	
	Scampi	0.86	0.70–0.96	
	Mackerel	0.94	0.83–0.99	
	Squid	0.92	0.85–0.97	
	Large processor	0.87	0.75–0.95	
	Large fresher	0.40	0.02–0.87	
	Deepwater	0.25	0.05–0.58	
Diving seabirds	Small inshore < 17m	1.00	1.00–1.00	
	Small inshore < 28m	1.00	1.00–1.00	
	Southern blue whiting	1.00	1.00–1.00	
	Scampi	1.00	1.00–1.00	
	Mackerel	1.00	1.00–1.00	
	Squid	1.00	1.00–1.00	
	Large processor	1.00	1.00–1.00	
	Large fresher	1.00	1.00–1.00	
	Deepwater	1.00	1.00–1.00	

Table E-14: Transition probabilities (%; mean and 95% credible interval, c.i.) for the calculation of cryptic mortality of seabirds in trawl fisheries for different types of birds. C, observed captures; F, fatalities; S, warp strike; indices $surf$, air, and net refer to surface and air warp strikes and net entanglement or captures; "all" includes large, small slow-flying, small fast-flying, and small diving seabirds.

Transition probability	Seabird type	Mean	95% c.i.
$p(C\|F)_{surf}$	Large	5.73	3.59–8.91
	Medium & small	1.29	0.35–3.50
$p(F\|S)_{surf}$	Large	524.74	370.79–735.55
	Medium & small	1 924.07	912.37–4 004.51
$p(F\|S)_{air}$	Large	5 212.10	3 502.64–7 585.58
	Medium-sized	10 452.45	6 937.71–15 714.09
	Small-sized	20 714.57	14 018.83–30 413.36
$p(S_{surf}\|S)$	Large	37.00	32.39–41.75
	Medium & small	20.28	17.24–23.46
$p(C\|F)_{net}$	All	77.86	59.00–90.78

- small diving birds are killed only in the net;
- the mortality rate for surface warp strikes in New Zealand trawl fisheries can be approximated by applying the mortality rate observed in South African deepwater hake fisheries.

Table E-15: Cryptic multipliers (mean and 95% credible interval, c.i.) used to relate annual potential fatalities (APF) to the number of observable captures, by seabird species group and fishery group (BLL, bottom longlining; SLL, surface longlining; SN, set netting).

Method	Species group	Fishery group	Cryptic multiplier	
			Mean	95% c.i.
Trawl	Large albatrosses	Small inshore < 17 m	14.26	4.13–25.54
		Small inshore < 28 m	15.86	5.89–26.14
		Southern blue whiting	8.08	2.15–17.98
		Scampi	4.29	1.50–10.38
		Mackerel	2.54	1.28–6.60
		Squid	2.98	1.36–6.98
		Large processor	3.96	1.49–9.45
		Large fresher	12.90	2.46–25.86
		Deepwater	15.37	5.29–25.94
	Mollymawks & giant petrel	Small inshore < 17 m	18.82	11.19–28.38
		Small inshore < 28 m	19.97	12.79–29.62
		Southern blue whiting	13.99	8.09–21.90
		Scampi	8.14	4.71–12.93
		Mackerel	4.46	1.86–8.89
		Squid	5.41	3.70–7.70
		Large processor	7.65	5.10–11.13
		Large fresher	17.66	8.23–28.31
		Deepwater	19.64	12.20–29.65
	Medium-sized seabirds	Small inshore < 17 m	20.65	3.36–72.28
		Small inshore < 28 m	25.45	7.14–64.46
		Southern blue whiting	5.41	2.04–13.71
		Scampi	2.48	1.48–4.70
		Mackerel	1.74	1.24–2.93
		Squid	1.88	1.36–2.85
		Large processor	2.34	1.49–4.15
		Large fresher	24.80	2.14–131.48
		Deepwater	26.68	5.13–90.02
	Small-sized seabirds	Small inshore < 17 m	101.00	22.90–274.06
		Small inshore < 28 m	115.79	34.13–295.48
		Southern blue whiting	52.75	11.95–151.80
		Scampi	22.55	5.22–67.98
		Mackerel	9.94	2.11–33.84
		Squid	12.67	3.46–35.43
		Large processor	20.34	5.13–59.17
		Large fresher	90.33	14.96–263.72
		Deepwater	111.69	30.84–281.37
	Diving seabirds	All trawl	1.30	1.10–1.69
BLL	All seabirds	All BLL	2.08	1.79–2.43
SLL	All seabirds	All SLL	2.08	1.79–2.43
SN	All seabirds	All SN	1.00	1.00–1.00

F APPENDIX F: ESTIMATION OF LIVE RELEASES

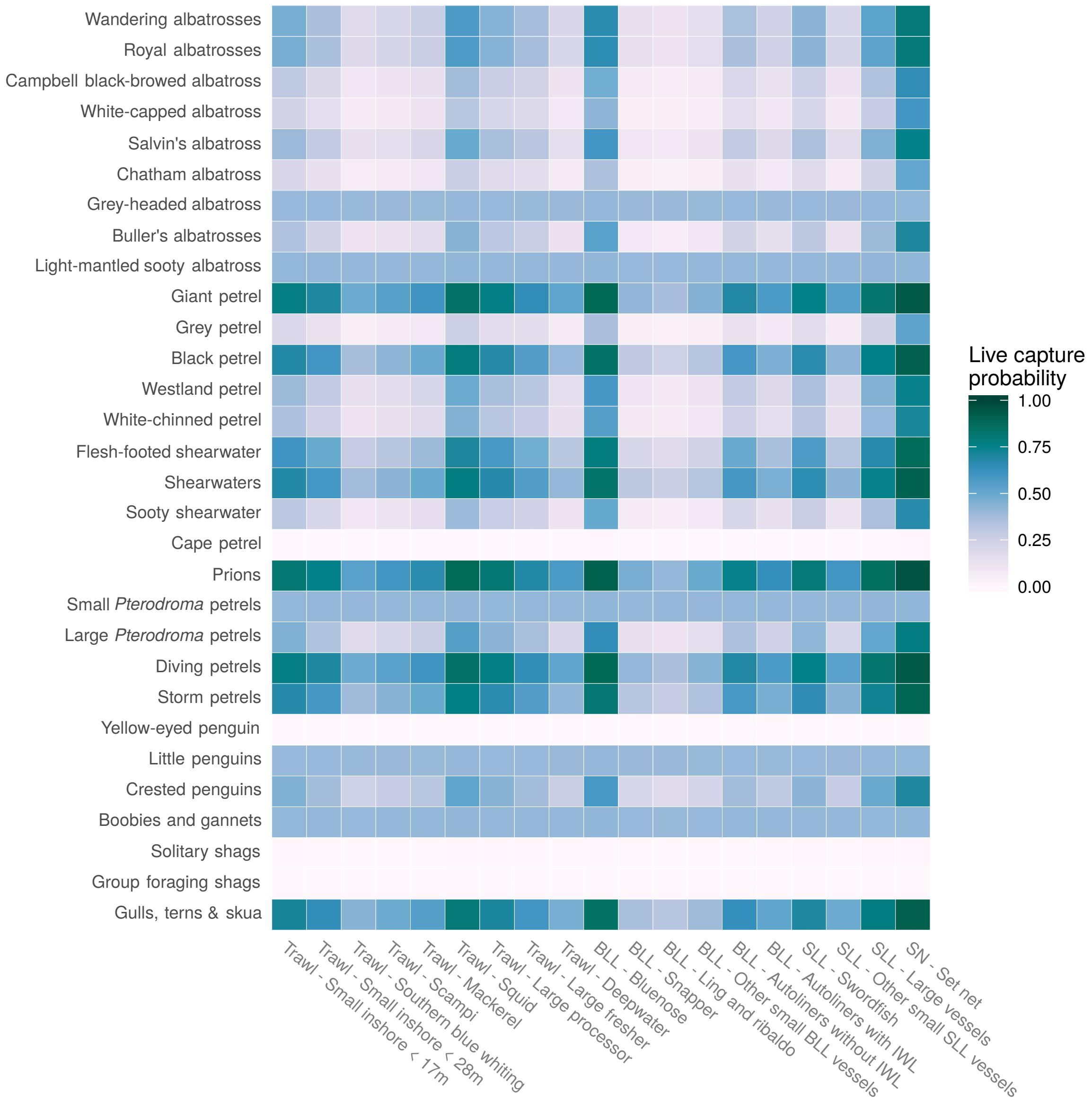


Figure F-13: Mean probability that a seabird is released alive estimated in the model, by species and fishery group, summarised from the posterior distributions after model fitting. Fishery groups including trawl, bottom-longline (BLL), surface-longline (SLL) and set-net (SN) fisheries. (The uncertainty associated with the parameters is not shown.)

G APPENDIX G: SUMMARY TABLES

G.1 Updates of demographic parameters

Table G-16: Updates to the number of annual breeding pairs for seabird species included in the current risk assessment.

Species	Previous data	Updated data	Reference
Chatham Island shag	357	355	Debski et al. (2012)
Chatham Island albatross	5 247	5 245	Fraser et al. (2011)
Salvin's albatross	33 000–41 000	41 004–41 958	Baker et al. (2014, 2015)
Snares crested penguin	30 000	24 666–30 672	Hiscock and Chilvers (2016)
Flesh-footed shearwater	20 000–200 000	100 000–500 000	Waugh et al. (2013a)
King shag	102–126	187	Schuckard et al. (2015)
Northern giant petrel	2 567	2 140–3 140	I. Debski, pers. comm.
Buller's shear water	200 000	300 000–400 000	Waugh et al. (2013a)
Grey petrel	50 000	32 000–73 000	Bell et al. (2013a)
Westland petrel	4 000	2 954–5 137	Wood and Otley (2013)
Flesh-footed shearwater	10 000	10 000–15 000	Waugh et al. (2013a)
Hutton's shearwater	94 000	114 000	Waugh et al. (2013a)
White-chinned petrel	168 725	204 725–368 125	Rexer-Huber et al. 2016, Sommer et al. 2011
Pitt Island shag	669	388	Debski et al. (2012)
Cook's petrel	50 000–60 000	216 000–419 000	Rayner et al. (2007), Rayner et al. (2008)
Little shearwater	100 000–220 000	115 000–210 000	Waugh et al. (2013a)
Wedge-tailed shearwater	52 500–60 000	50 000	Waugh et al. (2013a)
Antarctic prion	100 000–1 million	350 000–1 million	Jamieson et al. (2016)
Fairy prion	min. 1 million	point estimate of 1.5 million	Jamieson et al. (2016)
Broad-billed prion	1 million	350 000	Jamieson et al. (2016)
Yellow-eyed penguin	1 700–2 420	1 450–1 890	Ellenberg and Mattern (2012)
Otago shag	2 075–2 485 (for Stewart Is. shag)	1 230–1 400	Lalas & Perriman, unpubl. data
Foveaux shag	2 075–2 485 (for Stewart Is. shag)	840–1 080	Lalas & Perriman, unpubl. data

Table G-17: Updates to the adult annual survival rate and age at first reproduction (AFR) for seabird species included in the current risk assessment.

Parameter	Species	Previous data	Updated data	Reference
Survival	Westland petrel	90–97%	91.8–97.5%	Waugh et al. (2015)
	Flesh-footed shearwater	94%	93.1–94%	Barbraud et al. (2014)
	Black petrel	95%	92.7%	Bell et al. (2016b)
AFR	Yellow-eyed penguin	2–3 years	2–4 years	Ellenberg and Mattern (2012)

Table G-18: Updates to the breeding period for seabird species included in the current risk assessment.

Species	Previous data	Updated data
Salvin's albatross	Ending in March	Ending in April
Southern Buller's albatross	January to September	December to August
White-chinned petrel	Starting in October	Starting in November
Sooty shearwater	Starting in October	Starting in November
Flesh-footed shearwater	Starting in October	Starting in September
Common diving petrel	September to March	March to January
Soft-plumaged petrel	Starting in August	Starting in September
White-headed petrel	November to June	August to May

G.2 Population Sustainability Threshold parameters

Table G-19: Description of the distribution of the processed parameters used for the calculation of the Population Sustainability Threshold (PST) for 71 seabird taxa to assess the risk of commercial fisheries. S_{curr}, S_{opt}: current and optimal adult annual survival rate, respectively; A: current age at first reproduction; P_B: proportion of adults breeding; N_{BP}: annual breeding pairs. $\mathcal{U}$: uniform distribution; Log-$\mathcal{U}$: uniform distribution on the logarithmic scale; Logit-$\mathcal{N}$: normal distribution on the logit scale; Log-$\mathcal{N}$: normal distribution on the logarithmic scale. "Posterior distribution" indicates a distribution obtained from the posterior distribution of external studies (see Section 2, Methods). μ, σ: mean and standard deviation on the natural scale (not transformed); s: standard deviation on the transformed scale (log or logit). Taxon names were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk.

Taxon		S_{curr}		S_{opt}		A		P_B		N_{BP}
Gibson's albatross	$\mathcal{U}$	0.938 – 0.985	$\mathcal{U}$	0.938 – 0.985	$\mathcal{U}$	10.00 – 12.00	Logit-$\mathcal{N}$	μ=0.600; σ=0.05	Log-$\mathcal{N}$	μ= 4 792; s=0.1
Antipodean albatross	Logit-$\mathcal{N}$	μ=0.957; σ=0.007	Logit-$\mathcal{N}$	μ=0.957; σ=0.007	$\mathcal{U}$	10.00 – 13.00	Logit-$\mathcal{N}$	μ=0.600; σ=0.05	Log-$\mathcal{N}$	μ= 3 320; s=0.1
Southern royal albatross	Logit-$\mathcal{N}$	μ=0.949; σ=0.008	Logit-$\mathcal{N}$	μ=0.949; σ=0.008	$\mathcal{U}$	8.50 – 10.60	Logit-$\mathcal{N}$	μ=0.600; σ=0.05	Log-$\mathcal{N}$	μ= 7 886; s=0.1
Northern royal albatross	$\mathcal{U}$	0.908 – 0.969	$\mathcal{U}$	0.908 – 0.969	$\mathcal{U}$	8.50 – 10.60	Logit-$\mathcal{N}$	μ=0.610; σ=0.05	Log-$\mathcal{N}$	μ= 5 832; s=0.3
Campbell albatross	Logit-$\mathcal{N}$	μ=0.945; σ=0.007	Logit-$\mathcal{N}$	μ=0.945; σ=0.007	$\mathcal{U}$	6.00 – 13.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 21 000; s=0.3
NZ white-capped albatross	Logit-$\mathcal{N}$	μ=0.960; σ=0.010	Logit-$\mathcal{N}$	μ=0.960; σ=0.010	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.680; σ=0.05	-	Posterior distribution
Salvin's albatross	Logit-$\mathcal{N}$	μ=0.967; σ=0.010	Logit-$\mathcal{N}$	μ=0.967; σ=0.010	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	41 004 – 41 958
Chatham Island albatross	Logit-$\mathcal{N}$	μ=0.967; σ=0.010	Logit-$\mathcal{N}$	μ=0.967; σ=0.010	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 5 245; s=0.1
Grey-headed albatross	Logit-$\mathcal{N}$	μ=0.953; σ=0.009	Logit-$\mathcal{N}$	μ=0.953; σ=0.009	$\mathcal{U}$	7.00 – 13.00	Logit-$\mathcal{N}$	μ=0.750; σ=0.05	Log-$\mathcal{N}$	μ= 6 600; s=0.3
Southern Buller's albatross	$\mathcal{U}$	0.930 – 0.980	$\mathcal{U}$	0.930 – 0.980	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 13 625; s=0.1
Northern Buller's albatross	$\mathcal{U}$	0.930 – 0.980	$\mathcal{U}$	0.930 – 0.980	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 16 346; s=0.1
Light-mantled sooty albatross	$\mathcal{U}$	0.960 – 0.980	$\mathcal{U}$	0.960 – 0.980	$\mathcal{U}$	9.00 – 15.00	Logit-$\mathcal{N}$	μ=0.600; σ=0.05	Log-$\mathcal{U}$	6 770 – 6 900
Northern giant petrel	$\mathcal{U}$	0.808 – 0.965	$\mathcal{U}$	0.808 – 0.965	$\mathcal{U}$	6.00 – 10.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	2 140 – 3 140
Grey petrel	$\mathcal{U}$	0.900 – 0.970	$\mathcal{U}$	0.900 – 0.970	$\mathcal{U}$	5.00 – 9.00	Logit-$\mathcal{N}$	μ=0.800; σ=0.05	Log-$\mathcal{U}$	32 000 – 73 000
Black petrel	Logit-$\mathcal{N}$	μ=0.927; σ=0.012	Logit-$\mathcal{N}$	μ=0.950; σ=0.010	$\mathcal{U}$	6.21 – 6.99	Logit-$\mathcal{N}$	μ=0.800; σ=0.05	-	Posterior distribution
Westland petrel	$\mathcal{U}$	0.918 – 0.975	$\mathcal{U}$	0.918 – 0.975	$\mathcal{U}$	4.00 – 9.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	2 954 – 5 137
White-chinned petrel	$\mathcal{U}$	0.900 – 0.970	$\mathcal{U}$	0.900 – 0.970	$\mathcal{U}$	4.00 – 9.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	204 725 – 368 125
Flesh-footed shearwater	$\mathcal{U}$	0.931 – 0.940	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	4.00 – 9.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	10 000 – 15 000
Wedge-tailed shearwater	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 50 000; s=0.3
Buller's shearwater	Logit-$\mathcal{N}$	μ=0.920; σ=0.030	Logit-$\mathcal{N}$	μ=0.920; σ=0.030	$\mathcal{U}$	4.00 – 9.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	300 000 – 400 000
Sooty shearwater	$\mathcal{U}$	0.860 – 0.979	$\mathcal{U}$	0.860 – 0.979	$\mathcal{U}$	5.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ=5 000 000; s=0.3
Fluttering shearwater	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	4.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	100 000 – 500 000
Hutton's shearwater	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	4.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 114 000; s=0.2
Little shearwater	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	0.889 – 0.958	$\mathcal{U}$	4.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	115 000 – 210 000
Snares Cape petrel	$\mathcal{U}$	0.771 – 0.939	$\mathcal{U}$	0.771 – 0.939	$\mathcal{U}$	3.00 – 8.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 8 420; s=0.3
Fairy prion	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	$\mathcal{U}$	4.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ=1 500 000; s=0.1
Antarctic prion	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	$\mathcal{U}$	5.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	350 000 – 1 000 000
Broad-billed prion	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	Logit-$\mathcal{N}$	μ=0.840; σ=0.030	$\mathcal{U}$	4.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 350 000; s=0.1
Pycroft's petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	2 000 – 3 000
Cook's petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	216 000 – 419 000
Chatham petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 250; s=0.2
Mottled petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	300 000 – 400 000
White-naped petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 50 000; s=0.3
Kerm. petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	5 000 – 7 000
Grey-faced petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	200 000 – 300 000
Chatham Island taiko	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 17; s=0.1
White-headed petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	4.00 – 7.00	Logit-$\mathcal{N}$	μ=0.600; σ=0.05	Log-$\mathcal{N}$	μ= 200 000; s=0.3
Soft-plumaged petrel	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	6.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	1 000 – 9 999
Common diving petrel	$\mathcal{U}$	0.750 – 0.870	$\mathcal{U}$	0.750 – 0.870	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	300 000 – 2 150 000
South Georgian diving petrel	$\mathcal{U}$	0.750 – 0.870	$\mathcal{U}$	0.750 – 0.870	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 64; s=0.3
NZ white-faced storm petrel	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	700 000 – 3 000 000
White-bellied storm petrel	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	$\mathcal{U}$	4.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 1 000; s=0.3
Black-bellied storm petrel	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	$\mathcal{U}$	4.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	50 000 – 100 000
Kerm. storm petrel	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	20 – 120
NZ storm petrel	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	Logit-$\mathcal{N}$	μ=0.900; σ=0.030	$\mathcal{U}$	4.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	20 – 1 000
Yellow-eyed penguin	Logit-$\mathcal{N}$	μ=0.870; σ=0.030	Logit-$\mathcal{N}$	μ=0.870; σ=0.030	$\mathcal{U}$	2.00 – 4.00	Logit-$\mathcal{N}$	μ=0.688; σ=0.05	Log-$\mathcal{U}$	1 450 – 1 890
Northern little penguin	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	5 000 – 10 000
White-flippered little penguin	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 2 200; s=0.2
Southern little penguin	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	5 000 – 10 000
Chatham Island little penguin	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	Logit-$\mathcal{N}$	μ=0.830; σ=0.020	$\mathcal{U}$	2.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	5 000 – 10 000
Eastern rockhopper penguin	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	$\mathcal{U}$	3.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	38 961 – 58 500
Fiordland crested penguin	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	$\mathcal{U}$	3.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 3 000; s=0.3
Snares crested penguin	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	$\mathcal{U}$	5.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	24 666 – 30 672
Erect-crested penguin	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	Logit-$\mathcal{N}$	μ=0.840; σ=0.011	$\mathcal{U}$	5.00 – 6.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	77 000 – 85 000
Australasian gannet	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	Logit-$\mathcal{N}$	μ=0.940; σ=0.030	$\mathcal{U}$	3.00 – 7.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 46 004; s=0.3
Masked booby	Logit-$\mathcal{N}$	μ=0.850; σ=0.030	Logit-$\mathcal{N}$	μ=0.850; σ=0.030	$\mathcal{U}$	2.00 – 4.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 240; s=0.2
Pied shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	2.00 – 3.33	Logit-$\mathcal{N}$	μ=1.000; σ=0.00	Log-$\mathcal{N}$	μ= 6 400; s=0.1
Little black shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	1.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 1 500; s=0.3
NZ king shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 187; s=0.1
Otago shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	1 230 – 1 400
Foveaux shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	840 – 1 080
Chatham Island shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 355; s=0.1
Bounty Island shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 120; s=0.2
Auckland Island shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	956 – 4 098
Campbell Island shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 2 000; s=0.3
Spotted shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	1.00 – 3.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	10 000 – 30 000
Pitt Island shag	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	0.859 – 0.897	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 388; s=0.1
Subantarctic skua	$\mathcal{U}$	0.910 – 0.970	$\mathcal{U}$	0.910 – 0.970	$\mathcal{U}$	7.62 – 8.44	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	450 – 470
Southern black-backed gull	Logit-$\mathcal{N}$	μ=0.810; σ=0.030	Logit-$\mathcal{N}$	μ=0.810; σ=0.030	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	700 000 – 3 000 000
Caspian tern	$\mathcal{U}$	0.816 – 0.937	$\mathcal{U}$	0.816 – 0.937	$\mathcal{U}$	2.00 – 4.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{N}$	μ= 1 000; s=0.2
White tern	$\mathcal{U}$	0.780 – 0.830	$\mathcal{U}$	0.780 – 0.830	$\mathcal{U}$	3.00 – 5.00	Logit-$\mathcal{N}$	μ=0.900; σ=0.05	Log-$\mathcal{U}$	60 – 100

Table G-20: Summary of demographic parameters (mean and 95% credible interval, c.i.) for each seabird taxon, used for the calculation of the Population Sustainability Threshold (PST), including current and optimal adult annual survival rate (S_{curr} and S_{opt}, respectively), current age at first reproduction (A), the proportion of adults breeding (P_B), and the number of annual breeding pairs (N_{BP}), rounded to three significant digits. Taxon names were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk.

Taxon	S_{curr}		S_{opt}		A		P_B		N_{BP}	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	0.96	0.94–0.98	0.96	0.94–0.98	11.00	10.06–11.96	0.60	0.50–0.69	4 811	3 944–5 824
Antipodean albatross	0.96	0.94–0.97	0.96	0.94–0.97	11.51	10.07–12.92	0.60	0.50–0.69	3 326	2 686–4 045
Southern royal albatross	0.95	0.93–0.96	0.95	0.93–0.96	9.55	8.55–10.55	0.60	0.50–0.69	7 926	6 538–9 489
Northern royal albatross	0.94	0.91–0.97	0.94	0.91–0.97	9.56	8.55–10.55	0.61	0.51–0.70	6 053	3 193–10 457
Campbell albatross	0.94	0.93–0.96	0.94	0.93–0.96	9.52	6.18–12.80	0.89	0.75–0.96	22 023	11 824–38 256
NZ white-capped albatross	0.96	0.94–0.98	0.96	0.94–0.98	12.06	9.17–14.86	0.68	0.57–0.77	95 701	85 350–106 338
Salvin's albatross	0.97	0.94–0.98	0.97	0.94–0.98	12.02	9.15–14.86	0.89	0.75–0.96	41 472	41 024–41 932
Chatham Island albatross	0.97	0.94–0.98	0.97	0.94–0.98	11.97	9.17–14.84	0.89	0.75–0.96	5 278	4 299–6 400
Grey-headed albatross	0.95	0.93–0.97	0.95	0.93–0.97	9.97	7.13–12.83	0.75	0.64–0.84	6 901	3 709–11 764
Southern Buller's albatross	0.95	0.93–0.98	0.95	0.93–0.98	12.03	9.15–14.85	0.89	0.75–0.96	13 705	11 142–16 631
Northern Buller's albatross	0.96	0.93–0.98	0.96	0.93–0.98	12.00	9.15–14.84	0.89	0.75–0.96	16 396	13 330–19 999
Light-mantled sooty albatross	0.97	0.96–0.98	0.97	0.96–0.98	12.00	9.15–14.85	0.60	0.50–0.69	6 835	6 773–6 897
Northern giant petrel	0.89	0.81–0.96	0.89	0.81–0.96	7.97	6.09–9.88	0.89	0.74–0.96	2 612	2 164–3 114
Grey petrel	0.94	0.90–0.97	0.93	0.90–0.97	7.00	5.10–8.90	0.79	0.69–0.88	49 711	32 726–71 394
Black petrel	0.93	0.90–0.95	0.95	0.93–0.97	6.60	6.23–6.97	0.79	0.69–0.88	4 627	1 972–9 777
Westland petrel	0.95	0.92–0.97	0.95	0.92–0.97	6.50	4.11–8.87	0.89	0.75–0.96	3 942	2 998–5 056
White-chinned petrel	0.94	0.90–0.97	0.94	0.90–0.97	6.49	4.14–8.87	0.89	0.76–0.96	279 323	207 698–362 489
Flesh-footed shearwater	0.94	0.93–0.94	0.93	0.84–0.98	6.49	4.15–8.87	0.89	0.75–0.96	12 331	10 119–14 861
Wedge-tailed shearwater	0.92	0.89–0.96	0.92	0.89–0.96	3.99	3.06–4.95	0.89	0.76–0.96	52 077	28 207–92 005
Buller's shearwater	0.91	0.84–0.96	0.92	0.84–0.96	6.53	4.13–8.86	0.89	0.75–0.96	347 254	302 394–396 707
Sooty shearwater	0.92	0.86–0.98	0.92	0.86–0.98	6.00	5.06–6.95	0.89	0.75–0.96	5 226 984	2 738 657–9 073 574
Fluttering shearwater	0.92	0.89–0.96	0.92	0.89–0.96	5.01	4.05–5.95	0.89	0.76–0.96	249 814	104 342–483 229
Hutton's shearwater	0.92	0.89–0.96	0.92	0.89–0.96	5.01	4.05–5.95	0.89	0.76–0.96	116 079	77 298–167 205
Little shearwater	0.92	0.89–0.96	0.92	0.89–0.96	4.99	4.05–5.94	0.89	0.75–0.96	157 593	116 753–206 950
Snares Cape petrel	0.86	0.78–0.93	0.86	0.78–0.93	5.53	3.15–7.88	0.89	0.75–0.96	8 851	4 854–15 284
Fairy prion	0.84	0.77–0.89	0.84	0.78–0.89	4.49	4.03–4.97	0.89	0.75–0.96	1 508 306	1 244 366–1 827 095
Antarctic prion	0.84	0.77–0.89	0.84	0.77–0.89	5.50	5.02–5.97	0.89	0.75–0.96	617 585	358 377–972 068
Broad-billed prion	0.84	0.77–0.89	0.84	0.77–0.89	4.50	4.02–4.98	0.89	0.75–0.96	352 025	285 135–428 792
Pycroft's petrel	0.93	0.85–0.98	0.93	0.85–0.98	6.50	6.02–6.98	0.89	0.75–0.96	2 464	2 022–2 969
Cook's petrel	0.93	0.84–0.98	0.93	0.84–0.98	6.50	6.03–6.98	0.89	0.76–0.96	307 337	219 812–411 786
Chatham petrel	0.93	0.85–0.98	0.93	0.84–0.98	6.51	6.03–6.98	0.89	0.76–0.96	255	170–367
Mottled petrel	0.93	0.85–0.98	0.93	0.85–0.98	6.50	6.03–6.97	0.89	0.76–0.96	347 838	302 612–396 689
White-naped petrel	0.93	0.85–0.98	0.93	0.85–0.98	6.50	6.03–6.98	0.89	0.75–0.96	52 431	28 118–88 899
Kerm. petrel	0.93	0.85–0.98	0.93	0.85–0.98	6.51	6.02–6.97	0.89	0.76–0.96	5 953	5 053–6 944
Grey-faced petrel	0.93	0.84–0.98	0.93	0.85–0.98	6.50	6.03–6.97	0.89	0.74–0.96	246 495	201 789–296 842
Chatham Island taiko	0.93	0.85–0.98	0.93	0.85–0.98	6.51	6.03–6.97	0.89	0.75–0.96	17	14–21
White-headed petrel	0.93	0.85–0.98	0.93	0.85–0.98	5.54	4.07–6.94	0.60	0.50–0.69	210 469	111 504–371 004
Soft-plumaged petrel	0.93	0.85–0.98	0.93	0.85–0.98	6.50	6.02–6.98	0.89	0.75–0.96	3 913	1 067–9 444
Common diving petrel	0.81	0.75–0.87	0.81	0.75–0.87	2.51	2.02–2.97	0.89	0.74–0.96	939 125	313 653–2 064 341
South Georgian diving petrel	0.81	0.75–0.87	0.81	0.75–0.87	2.50	2.03–2.97	0.89	0.76–0.96	67	36–114
NZ white-faced storm petrel	0.90	0.83–0.94	0.90	0.82–0.95	4.01	3.05–4.95	0.89	0.76–0.96	1 586 529	724 592–2 905 677
White-bellied storm petrel	0.90	0.82–0.95	0.90	0.82–0.95	4.50	4.03–4.98	0.89	0.75–0.96	1 052	555–1 818
Black-bellied storm petrel	0.90	0.83–0.95	0.90	0.82–0.95	4.50	4.03–4.97	0.89	0.75–0.96	72 299	50 860–98 237
Kerm. storm petrel	0.90	0.82–0.95	0.90	0.82–0.95	4.00	3.05–4.95	0.89	0.76–0.96	55	21–115
NZ storm petrel	0.90	0.82–0.95	0.90	0.83–0.95	4.50	4.02–4.97	0.89	0.75–0.96	247	22–898
Yellow-eyed penguin	0.87	0.80–0.92	0.87	0.80–0.92	2.99	2.05–3.95	0.68	0.58–0.78	1 660	1 459–1 877
Northern little penguin	0.83	0.79–0.87	0.83	0.79–0.87	2.50	2.03–2.98	0.89	0.75–0.96	7 221	5 084–9 847
White-flippered little penguin	0.83	0.79–0.86	0.83	0.79–0.87	2.50	2.02–2.97	0.89	0.75–0.96	2 243	1 474–3 290
Southern little penguin	0.83	0.79–0.87	0.83	0.79–0.87	2.51	2.03–2.97	0.89	0.76–0.96	7 223	5 095–9 838
Chatham Island little penguin	0.83	0.79–0.87	0.83	0.79–0.87	2.50	2.02–2.97	0.89	0.75–0.97	7 230	5 075–9 829
Eastern rockhopper penguin	0.84	0.82–0.86	0.84	0.82–0.86	4.49	3.09–5.91	0.89	0.76–0.96	48 248	39 355–57 955
Fiordland crested penguin	0.84	0.82–0.86	0.84	0.82–0.86	4.50	3.07–5.93	0.89	0.75–0.97	3 158	1 661–5 437
Snares crested penguin	0.84	0.82–0.86	0.84	0.82–0.86	5.50	5.02–5.97	0.89	0.76–0.96	27 503	24 791–30 493
Erect-crested penguin	0.84	0.82–0.86	0.84	0.82–0.86	5.50	5.02–5.98	0.89	0.75–0.96	81 015	77 181–84 785
Australasian gannet	0.93	0.85–0.98	0.93	0.84–0.98	5.00	3.10–6.90	0.89	0.76–0.96	48 460	26 040–84 111
Masked booby	0.85	0.78–0.90	0.85	0.78–0.90	2.99	2.04–3.95	0.89	0.76–0.96	245	162–358
Pied shag	0.88	0.86–0.90	0.88	0.86–0.90	2.67	2.03–3.30	1.00	1.00–1.00	6 426	5 284–7 757
Little black shag	0.88	0.86–0.90	0.88	0.86–0.90	2.00	1.05–2.95	0.89	0.75–0.96	1 573	835–2 768
NZ king shag	0.88	0.86–0.90	0.88	0.86–0.90	4.00	3.05–4.96	0.89	0.75–0.97	188	153–227
Otago shag	0.88	0.86–0.90	0.88	0.86–0.90	3.99	3.05–4.95	0.89	0.76–0.96	1 313	1 234–1 396
Foveaux shag	0.88	0.86–0.90	0.88	0.86–0.90	4.00	3.05–4.94	0.89	0.74–0.96	955	845–1 073
Chatham Island shag	0.88	0.86–0.90	0.88	0.86–0.90	4.00	3.05–4.95	0.89	0.76–0.97	357	292–433
Bounty Island shag	0.88	0.86–0.90	0.88	0.86–0.90	4.00	3.05–4.95	0.89	0.75–0.96	123	81–180
Auckland Island shag	0.88	0.86–0.90	0.88	0.86–0.90	4.02	3.05–4.96	0.89	0.75–0.96	2 147	990–3 948
Campbell Island shag	0.88	0.86–0.90	0.88	0.86–0.90	4.01	3.06–4.95	0.89	0.75–0.96	2 112	1 099–3 655
Spotted shag	0.88	0.86–0.90	0.88	0.86–0.90	2.00	1.05–2.95	0.89	0.75–0.96	18 197	10 305–29 220
Pitt Island shag	0.88	0.86–0.90	0.88	0.86–0.90	4.00	3.05–4.95	0.89	0.75–0.96	391	319–475
Subantarctic skua	0.94	0.91–0.97	0.94	0.91–0.97	8.03	7.64–8.42	0.89	0.75–0.97	460	451–470
Southern black-backed gull	0.81	0.74–0.86	0.81	0.75–0.86	4.00	3.06–4.95	0.89	0.75–0.97	1 567 135	728 011–2 895 563
Caspian tern	0.88	0.82–0.93	0.88	0.82–0.93	2.99	2.05–3.95	0.89	0.75–0.96	1 020	692–1 477
White tern	0.81	0.78–0.83	0.80	0.78–0.83	3.99	3.04–4.95	0.89	0.76–0.96	78	61–99

Table G-21: Summary of the input parameters to the calculation of the Population Sustainability Threshold (PST) for seabird taxa breeding in New Zealand, including the total population size (in individuals; N) and the estimated maximum growth rate $r_{\max}$ (mean and 95% credible interval, c.i.); $r_{\max}$ was rounded to three significant digits. Taxon names were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk.

Taxon	Population size, N		Maximum growth rate, $r_{\max}$	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	42 900	29 600–62 800	0.046	0.039–0.054
Antipodean albatross	31 500	22 900–42 600	0.046	0.039–0.055
Southern royal albatross	73 800	54 100–98 000	0.046	0.039–0.054
Northern royal albatross	61 800	30 400–114 000	0.046	0.039–0.055
Campbell black-browed albatross	136 000	70 700–246 000	0.058	0.051–0.066
NZ white-capped albatross	775 000	563 000–1 080 000	0.056	0.049–0.065
Salvin's albatross	255 000	202 000–344 000	0.056	0.049–0.065
Chatham Island albatross	30 100	21 600–43 000	0.056	0.049–0.064
Grey-headed albatross	49 000	25 400–86 700	0.057	0.050–0.065
Southern Buller's albatross	89 100	60 100–140 000	0.061	0.055–0.069
Northern Buller's albatross	106 000	70 500–167 000	0.061	0.054–0.069
Light-mantled sooty albatross	56 800	44 700–72 000	0.061	0.054–0.069
Northern giant petrel	24 500	11 700–58 400	0.055	0.048–0.063
Grey petrel	278 000	163 000–455 000	0.080	0.071–0.089
Black petrel	19 200	9 630–36 700	0.091	0.080–0.103
Westland petrel	17 900	12 200–26 300	0.078	0.070–0.087
White-chinned petrel	1 340 000	865 000–2 130 000	0.076	0.068–0.085
Flesh-footed shearwater	61 500	44 900–82 700	0.094	0.083–0.107
Wedge-tailed shearwater	226 000	120 000–391 000	0.105	0.090–0.121
Buller's shearwater	2 020 000	1 280 000–3 630 000	0.111	0.095–0.130
Sooty shearwater	27 900 000	13 300 000–55 500 000	0.088	0.078–0.100
Fluttering shearwater	1 150 000	496 000–2 260 000	0.126	0.104–0.152
Hutton's shearwater	547 000	344 000–824 000	0.110	0.094–0.128
Little shearwater	688 000	466 000–1 010 000	0.127	0.104–0.152
Snares Cape petrel	61 000	23 100–151 000	0.105	0.090–0.121
Fairy prion	8 940 000	6 260 000–13 000 000	0.147	0.117–0.183
Antarctic prion	4 320 000	2 270 000–7 810 000	0.142	0.115–0.175
Broad-billed prion	2 080 000	1 430 000–3 010 000	0.133	0.109–0.162
Pycroft's petrel	11 700	7 480–19 900	0.141	0.113–0.173
Cook's petrel	1 470 000	859 000–2 610 000	0.135	0.110–0.163
Chatham petrel	1 190	674–2 120	0.140	0.113–0.171
Mottled petrel	1 640 000	1 100 000–2 620 000	0.116	0.098–0.137
White-naped petrel	268 000	129 000–519 000	0.104	0.090–0.121
Kerm. petrel	30 800	20 700–51 300	0.101	0.087–0.116
Grey-faced petrel	1 270 000	834 000–2 070 000	0.094	0.082–0.107
Chatham Island taiko	88	58–142	0.103	0.088–0.118
White-headed petrel	1 480 000	727 000–2 840 000	0.093	0.081–0.105
Soft-plumaged petrel	17 300	4 790–44 600	0.116	0.098–0.136
Common diving petrel	3 520 000	1 290 000–7 840 000	0.154	0.121–0.191
South Georgian diving petrel	263	135–470	0.154	0.121–0.193
NZ white-faced storm petrel	6 300 000	2 790 000–12 100 000	0.210	0.150–0.286
White-bellied storm petrel	4 580	2 240–8 560	0.202	0.147–0.272
Black-bellied storm petrel	314 000	198 000–489 000	0.199	0.146–0.266
Kerm. storm petrel	216	85–470	0.210	0.151–0.281
NZ storm petrel	896	107–3 290	0.227	0.162–0.314
Yellow-eyed penguin	8 510	6 160–11 700	0.135	0.105–0.171
Northern little penguin	28 000	18 900–40 400	0.216	0.165–0.280
White-flippered little penguin	8 630	5 520–13 100	0.216	0.167–0.276
Southern little penguin	28 200	18 600–41 400	0.216	0.165–0.277
Chatham Island little penguin	28 000	18 600–41 400	0.216	0.165–0.279
Eastern rockhopper penguin	262 000	175 000–387 000	0.170	0.132–0.217
Fiordland crested penguin	17 000	8 470–31 300	0.149	0.116–0.187
Snares crested penguin	177 000	138 000–231 000	0.155	0.121–0.197
Erect-crested penguin	525 000	419 000–667 000	0.135	0.107–0.171
Australasian gannet	200 000	97 600–380 000	0.189	0.133–0.260
Masked booby	1 060	645–1 690	0.196	0.138–0.271
Pied shag	21 800	17 000–28 500	0.205	0.142–0.286
Little black shag	5 510	2 800–9 820	0.245	0.169–0.349
NZ king shag	861	621–1 190	0.182	0.129–0.253
Otago shag	6 020	4 690–7 830	0.189	0.133–0.259
Foveaux shag	4 420	3 330–5 900	0.187	0.130–0.259
Chatham Island shag	1 620	1 180–2 200	0.186	0.132–0.259
Bounty Island shag	562	350–856	0.185	0.128–0.259
Auckland Island shag	9 530	4 450–18 000	0.199	0.140–0.274
Campbell Island shag	9 770	4 980–17 500	0.201	0.143–0.277
Spotted shag	63 600	34 900–108 000	0.233	0.160–0.330
Pitt Island shag	1 790	1 310–2 460	0.233	0.159–0.326
Subantarctic skua	2 220	1 640–3 120	0.120	0.092–0.156
Southern black-backed gull	9 400 000	4 030 000–19 200 000	0.142	0.108–0.181
Caspian tern	4 220	2 570–6 670	0.161	0.120–0.211
White tern	480	311–717	0.221	0.161–0.297

G.3 Observed captures and effort

Table G-22: Number of observed seabird captures (C), live captures (Live), and the proportion of overlap observed (P) with trawl, bottom-longline (BLL), surface-longline (SLL), and set-net fisheries between 2006–07 and 2014–15. Taxon names were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk.

Species	Trawl			BLL			SLL			Set net		
	C	Live	P (%)	C	Live	P (%)	C	Live	P (%)	C	Live	P (%)
Gibson's albatross	1	0	13.10	0	0	3.00	31	6	15.10	0	0	2.90
Antipodean albatross	0	0	11.60	0	0	3.50	27	12	10.20	0	0	2.70
Southern royal albatross	10	3	17.60	4	3	4.90	3	1	13.40	0	0	2.90
Northern royal albatross	0	0	10.20	0	0	3.30	1	0	10.50	0	0	4.10
Campbell black-browed albatross	12	2	22.20	4	1	9.50	24	5	12.80	0	0	4.00
NZ white-capped albatross	623	178	17.80	3	2	3.40	106	13	12.30	0	0	2.70
Salvin's albatross	290	95	12.20	31	2	3.50	7	0	6.80	0	0	3.10
Chatham Island albatross	10	1	17.90	14	1	3.40	0	0	4.40	0	0	2.50
Grey-headed albatross	0	0	16.20	0	0	4.30	0	0	14.40	0	0	3.40
Southern Buller's albatross	237	58	15.10	11	6	2.70	278	115	49.00	0	0	7.20
Northern Buller's albatross	1	0	13.80	0	0	1.70	0	0	4.60	0	0	1.50
Light-mantled sooty albatross	0	0	16.60	0	0	4.30	0	0	17.10	0	0	3.50
Northern giant petrel	10	6	14.90	2	2	3.50	0	0	12.70	0	0	2.50
Grey petrel	48	9	15.30	11	0	5.00	31	0	13.30	0	0	2.10
Black petrel	8	5	6.10	62	29	4.00	21	11	2.90	0	0	0.20
Westland petrel	23	9	12.10	2	0	2.00	6	0	8.00	3	3	2.10
White-chinned petrel	1 190	490	15.70	87	7	4.20	29	0	15.70	0	0	4.00
Flesh-footed shearwater	49	14	5.80	68	19	3.30	7	6	3.80	1	0	0.30
Wedge-tailed shearwater	0	0	55.50	0	0	0.00	0	0	45.90	0	0	0.00
Buller's shearwater	0	0	7.30	10	3	2.30	0	0	10.20	0	0	2.20
Sooty shearwater	896	302	13.60	14	0	3.70	2	1	13.80	11	9	7.00
Fluttering shearwater	0	0	3.90	7	3	3.20	0	0	10.10	2	1	0.00
Hutton's shearwater	0	0	3.80	0	0	2.00	0	0	4.00	0	0	6.40
Little shearwater	0	0	9.20	0	0	2.00	0	0	11.70	0	0	0.50
Snares Cape petrel	3	0	20.90	0	0	3.60	0	0	12.90	0	0	6.50
Fairy prion	9	6	5.90	0	0	0.70	0	0	13.10	0	0	1.50
Antarctic prion	24	22	29.30	0	0	4.10	0	0	8.40	0	0	3.30
Broad-billed prion	0	0	15.00	0	0	1.20	0	0	12.60	0	0	2.70
Pycroft's petrel	0	0	5.80	0	0	4.10	0	0	3.50	0	0	0.00
Cook's petrel	0	0	4.50	0	0	3.40	0	0	4.90	0	0	0.30
Chatham petrel	0	0	16.10	0	0	0.60	0	0	0.00	0	0	0.00
Mottled petrel	0	0	8.10	0	0	6.40	0	0	27.90	0	0	11.10
White-naped petrel	0	0		0	0	0.00	0	0	26.50	0	0	0.00
Kerm. petrel	0	0	9.00	0	0	2.30	0	0	12.00	0	0	1.90
Grey-faced petrel	3	3	6.30	6	0	2.20	5	0	7.10	0	0	1.00
Chatham Island taiko	0	0	20.10	0	0	2.10	0	0	0.00	0	0	0.00
White-headed petrel	1	1	20.80	0	0	4.70	0	0	11.50	0	0	3.10
Soft-plumaged petrel	0	0	11.70	0	0	4.20	0	0	11.70	0	0	2.90
Common diving petrel	16	12	5.80	0	0	3.30	0	0	13.60	0	0	4.70
South Georgian diving petrel	0	0	6.10	0	0	7.50	0	0	0.00	0	0	13.00
NZ white-faced storm petrel	5	3	14.10	0	0	0.70	0	0	5.10	0	0	0.80
White-bellied storm petrel	0	0	36.40	0	0	1.30	0	0	10.90	0	0	0.00
Black-bellied storm petrel	2	1	11.10	0	0	2.90	0	0	11.50	0	0	2.70
Kerm. storm petrel	0	0	100.00	0	0	0.00	0	0	14.70	0	0	0.00
NZ storm petrel	0	0	5.60	0	0	2.40	0	0	6.60	0	0	0.20
Yellow-eyed penguin	0	0	3.40	0	0	2.10	0	0		9	0	5.30
Northern little penguin	0	0	3.80	0	0	2.20	0	0	4.80	0	0	1.90
White-flippered little penguin	0	0	5.60	0	0	4.40	0	0		0	0	1.90
Southern little penguin	0	0	4.10	0	0	1.40	0	0	8.30	0	0	7.20
Chatham Island little penguin	0	0	15.30	0	0	1.00	0	0		0	0	0.00
Eastern rockhopper penguin	0	0	26.90	0	0	17.40	0	0	29.30	0	0	5.10
Fiordland crested penguin	0	0	4.40	0	0	0.20	0	0	10.30	1	0	10.10
Snares crested penguin	0	0	26.10	0	0	5.70	0	0	33.50	0	0	8.20
Erect-crested penguin	0	0	33.80	0	0	16.80	0	0	0.00	0	0	0.00
Australasian gannet	0	0	3.50	0	0	2.70	0	0	5.80	0	0	0.40
Masked booby	0	0	11.70	0	0	2.90	0	0	12.60	0	0	2.60
Pied shag	0	0	1.90	0	0	2.50	0	0	1.20	1	0	1.40
Little black shag	0	0	1.80	0	0	2.50	0	0	0.10	0	0	0.60
NZ king shag	0	0	0.70	0	0	0.00	0	0		0	0	3.80
Otago shag	0	0	1.40	0	0	0.00	0	0		2	0	5.80
Foveaux shag	0	0	0.90	0	0	0.20	0	0		0	0	8.90
Chatham Island shag	0	0	1.50	0	0	1.00	0	0		0	0	
Bounty Island shag	0	0	62.10	0	0	21.60	0	0		0	0	
Auckland Island shag	0	0	29.40	0	0	100.00	0	0		0	0	0.00
Campbell Island shag	0	0		0	0		0	0		0	0	
Spotted shag	32	0	1.60	0	0	2.80	0	0	1.50	3	0	1.90
Pitt Island shag	0	0	0.50	0	0	0.90	0	0		0	0	
Subantarctic skua	0	0	10.50	0	0	0.60	0	0	12.80	0	0	6.30
Southern black-backed gull	0	0	1.90	8	3	2.50	0	0	2.30	0	0	2.10
Caspian tern	0	0	2.20	0	0	2.40	0	0	3.40	0	0	2.30
White tern	0	0	9.00	0	0	2.00	0	0	9.80	0	0	1.80

G.4 Vulnerabilities

Table G-23: Vulnerability of seabirds to capture in trawl fisheries, distinguished by fishery group. Fishery groups distinguished vessel size classes (small inshore <17 m and 17 to 28 m, all other vessels ≥ 28 m length), target species, and the presence of a processor plant. Seabirds are listed in species groups used in the estimation of vulnerability.

Species group	Small inshore < 17m		Small inshore < 28m		Southern blue whiting		Scampi		Mackerel		Squid		Large processor		Large fresher		Deepwater	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Black petrel	0.66	0.02–3.07	1.15	0.27–2.93	2.81	0.00–21.35	0.17	0.01–0.57	0.09	0.00–0.46	0.81	0.00–5.62	0.3	0.00–1.56	0.17	0.00–1.28	0.4	0.00–2.57
Salvin’s albatross	0.08	0.00–0.41	4.77	2.66–7.73	3.12	1.37–5.86	3.89	1.97–6.68	0.04	0.00–0.14	0.22	0.09–0.42	3.02	1.98–4.39	0.08	0.00–0.53	1.31	0.64–2.29
Buller’s albatrosses	0.03	0.00–0.16	0.12	0.01–0.43	6.88	0.07–36.01	0.39	0.12–0.85	0.08	0.02–0.21	0.32	0.20–0.47	0.65	0.42–0.96	0.03	0.00–0.20	0.03	0.00–0.11
Chatham albatross	0.14	0.00–1.05	0.26	0.00–1.99	0.42	0.00–3.04	0.07	0.00–0.41	0.05	0.00–0.37	0.71	0.02–3.06	0.16	0.03–0.40	0.07	0.00–0.59	0.57	0.19–1.25
Campbell albatross	0.07	0.00–0.45	0.09	0.00–0.54	0.05	0.01–0.15	0.11	0.01–0.42	0.02	0.00–0.15	0.01	0.00–0.03	0.17	0.07–0.33	0.06	0.00–0.49	0.04	0.00–0.21
White-capped albatross	0.57	0.20–1.19	1.2	0.66–1.99	0.03	0.00–0.16	0.15	0.07–0.29	0.1	0.04–0.22	0.46	0.31–0.64	0.38	0.25–0.55	0.57	0.14–1.40	0.01	0.00–0.05
Flesh-footed shearwater	0.26	0.04–0.78	0.21	0.06–0.51	0.65	0.00–4.56	0.15	0.07–0.28	0.01	0.00–0.03	0.18	0.00–1.19	0.05	0.00–0.19	0.04	0.00–0.24	0.07	0.00–0.42
Westland petrel	0.05	0.00–0.31	0.32	0.04–1.00	0.39	0.00–3.09	0.04	0.00–0.19	0.02	0.00–0.06	0.11	0.00–0.70	0.06	0.03–0.11	0.04	0.00–0.31	0.1	0.00–0.73
Giant petrel	0.08	0.00–0.67	0.15	0.00–1.02	0.12	0.00–0.78	0.38	0.01–1.69	0.03	0.00–0.18	0.04	0.00–0.23	0.68	0.26–1.35	0.05	0.00–0.41	0.18	0.01–0.69
Grey petrel	0.04	0.00–0.23	0.04	0.00–0.22	0.91	0.31–2.10	0.02	0.00–0.09	0.01	0.00–0.03	0.01	0.00–0.04	0.02	0.00–0.05	0.04	0.00–0.27	0.06	0.00–0.24
Wandering albatrosses	0.04	0.00–0.28	0.06	0.00–0.41	0.05	0.00–0.33	0.04	0.00–0.20	0.01	0.00–0.07	0.01	0.00–0.06	0.01	0.00–0.05	0.03	0.00–0.18	0.1	0.00–0.41
Royal albatrosses	0.02	0.00–0.12	0.02	0.00–0.16	0.05	0.00–0.20	0.01	0.00–0.07	0	0.00–0.02	0.06	0.02–0.14	0.01	0.00–0.05	0.01	0.00–0.08	0.05	0.00–0.18
White-chinned petrel	0.02	0.00–0.10	0.01	0.00–0.04	0.01	0.00–0.05	0.35	0.18–0.61	0.06	0.03–0.10	0.34	0.23–0.49	0.15	0.09–0.23	0.01	0.00–0.05	0.01	0.00–0.03
Yellow-eyed penguin	0	0.00–0.01	0.01	0.00–0.04	0.08	0.00–0.56	0.03	0.00–0.23	0	0.00–0.03	0.01	0.00–0.03	0	0.00–0.02	0.01	0.00–0.04	0.05	0.00–0.37
Cape petrel	0.01	0.00–0.08	0.03	0.00–0.26	0.05	0.00–0.34	0.03	0.00–0.19	0	0.00–0.03	0	0.00–0.02	0.08	0.01–0.29	0.01	0.00–0.04	0.02	0.00–0.19
Grey-headed albatross	0	0.00–0.04	0.01	0.00–0.10	0.01	0.00–0.08	0.01	0.00–0.08	0	0.00–0.02	0	0.00–0.03	0.01	0.00–0.04	0.01	0.00–0.05	0.01	0.00–0.06
Group foraging shags	0.01	0.01–0.02	0	0.00–0.00	0.02	0.00–0.18	0.01	0.00–0.04	0	0.00–0.03	0	0.00–0.02	0	0.00–0.01	0	0.00–0.00	0.01	0.00–0.05
LM sooty albatross	0	0.00–0.04	0.01	0.00–0.08	0.01	0.00–0.07	0.01	0.00–0.06	0	0.00–0.02	0	0.00–0.02	0	0.00–0.03	0	0.00–0.02	0.01	0.00–0.06
Solitary shags	0	0.00–0.00	0	0.00–0.00	0.01	0.00–0.09	0	0.00–0.02	0	0.00–0.01	0.01	0.00–0.05	0	0.00–0.02	0	0.00–0.01	0	0.00–0.04
Sooty shearwater	0	0.00–0.00	0.01	0.00–0.02	0	0.00–0.02	0.01	0.01–0.02	0	0.00–0.00	0	0.00–0.01	0	0.00–0.01	0	0.00–0.00	0	0.00–0.02
Storm petrels	0	0.00–0.02	0	0.00–0.02	0.01	0.00–0.05	0	0.00–0.01	0	0.00–0.02	0.03	0.00–0.09	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01
Diving petrels	0	0.00–0.01	0.01	0.00–0.04	0	0.00–0.02	0	0.00–0.01	0	0.00–0.01	0.01	0.00–0.01	0	0.00–0.01	0	0.00–0.00	0	0.00–0.02
Large *Pterodroma* petrels	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Crested penguins	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Shearwaters	0	0.00–0.00	0	0.00–0.00	0	0.00–0.02	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01
Little penguins	0	0.00–0.00	0	0.00–0.00	0	0.00–0.02	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Boobies and gannets	0	0.00–0.00	0	0.00–0.00	0	0.00–0.02	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Prions	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Small *Pterodroma* petrels	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Gulls, terns & skua	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00

Table G-24: Vulnerability of seabirds to capture in bottom-longline (BLL) fisheries, distinguished by fishery group. Fishery groups distinguished small vessels (<34 m length) by target species, and large vessels (≥34 m length) by the use of integrated weight line (IWL). Seabirds are listed in species groups used in the estimation of vulnerability.

Species group	Bluenose		Snapper		Ling and ribaldo		Other small BLL vessels		Large vessels without IWL		Large vessels with IWL	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Black petrel	4.87	2.97–7.32	1.22	0.80–1.73	0.72	0.01–4.21	2.67	1.09–4.92	1.51	0.00–11.56	0.68	0.00–5.14
Salvin's albatross	0.16	0.00–0.91	0.05	0.00–0.24	5.93	3.76–8.68	0.32	0.03–1.04	0.56	0.12–1.38	0.03	0.00–0.14
Buller's albatrosses	0.27	0.05–0.64	0.03	0.00–0.17	0.43	0.14–0.89	0.07	0.00–0.32	0.4	0.09–0.99	0.03	0.00–0.18
Chatham albatross	0.08	0.00–0.48	0.13	0.00–0.91	2.59	1.30–4.33	0.19	0.00–1.10	0.33	0.04–0.99	0.04	0.00–0.23
Campbell albatross	2.83	0.17–9.59	0.08	0.00–0.53	0.16	0.00–0.91	1.08	0.04–4.46	0.2	0.00–1.35	0.04	0.00–0.12
White-capped albatross	0.04	0.00–0.21	0.01	0.00–0.06	0.17	0.04–0.41	0.04	0.00–0.18	0.04	0.00–0.18	0.01	0.00–0.04
Flesh-footed shearwater	0.03	0.00–0.15	0.15	0.11–0.20	0.08	0.00–0.41	1	0.56–1.60	0.22	0.00–1.52	0.11	0.00–0.90
Westland petrel	0.11	0.00–0.80	0.04	0.00–0.27	0.31	0.01–1.15	0.39	0.02–1.45	0.13	0.00–0.81	0.06	0.00–0.41
Giant petrel	0.1	0.00–0.71	0.46	0.01–2.10	0.11	0.00–0.65	0.8	0.02–3.39	0.09	0.00–0.54	0.04	0.00–0.31
Grey petrel	0.06	0.00–0.44	0.03	0.00–0.15	1.04	0.39–2.10	0.07	0.00–0.37	0.94	0.24–2.19	0.03	0.00–0.09
Wandering albatrosses	0.07	0.00–0.52	0.05	0.00–0.33	0.07	0.00–0.45	0.12	0.00–0.80	0.07	0.00–0.44	0.02	0.00–0.16
Royal albatrosses	0.03	0.00–0.18	0.02	0.00–0.13	0.09	0.00–0.31	0.04	0.00–0.25	0.02	0.00–0.14	0.11	0.02–0.30
White-chinned petrel	0.14	0.01–0.43	0.01	0.00–0.03	1.71	1.13–2.42	0.02	0.00–0.08	1.71	1.07–2.50	0.17	0.10–0.26
Yellow-eyed penguin	0.03	0.00–0.23	0.05	0.00–0.30	0.06	0.00–0.45	0.1	0.00–0.83	0.08	0.00–0.62	0.02	0.00–0.12
Cape petrel	0.02	0.00–0.14	0.01	0.00–0.09	0.03	0.00–0.23	0.03	0.00–0.24	0.03	0.00–0.20	0.01	0.00–0.06
Grey-headed albatross	0.01	0.00–0.09	0.01	0.00–0.05	0.02	0.00–0.18	0.03	0.00–0.21	0.02	0.00–0.16	0	0.00–0.03
Group foraging shags	0.01	0.00–0.05	0	0.00–0.00	0.01	0.00–0.09	0.01	0.00–0.05	0.03	0.00–0.18	0	0.00–0.02
LM sooty albatross	0.01	0.00–0.06	0.01	0.00–0.04	0.02	0.00–0.15	0.02	0.00–0.15	0.01	0.00–0.11	0	0.00–0.05
Solitary shags	0	0.00–0.04	0	0.00–0.00	0.01	0.00–0.06	0	0.00–0.04	0.02	0.00–0.12	0	0.00–0.02
Sooty shearwater	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.01	0	0.00–0.01
Storm petrels	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.02	0	0.00–0.01
Diving petrels	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.01	0	0.00–0.01	0	0.00–0.00
Large *Pterodroma* petrels	0	0.00–0.01	0	0.00–0.00	0	0.00–0.01	0.03	0.01–0.06	0	0.00–0.01	0	0.00–0.00
Crested penguins	0	0.00–0.01	0	0.00–0.01	0	0.00–0.03	0	0.00–0.03	0	0.00–0.02	0	0.00–0.01
Shearwaters	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00
Little penguins	0	0.00–0.01	0	0.00–0.00	0	0.00–0.01	0	0.00–0.01	0	0.00–0.01	0	0.00–0.00
Boobies and gannets	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.01	0	0.00–0.01	0	0.00–0.00
Prions	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Small *Pterodroma* petrels	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00
Gulls, terns & skua	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.00	0	0.00–0.01	0	0.00–0.00

Table G-25: Vulnerability of seabirds to capture in surface-longline (SLL) fisheries, distinguished by fishery group. Fishery groups distinguished small vessels (<45 m length) by target species, and large vessels (≥45 m length). Seabirds are listed in species groups used in the estimation of vulnerability.

Species group	Swordfish		Other small SLL vessels		Large vessels	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Black petrel	1.48	0.24–3.82	3.47	2.05–5.31	8.1	0.02–65.08
Salvin's albatross	0.78	0.02–3.58	1.23	0.36–2.62	0.88	0.20–2.12
Buller's albatrosses	0.76	0.01–3.75	10.82	7.89–14.16	7.68	5.89–9.82
Chatham albatross	3.01	0.01–22.27	0.6	0.01–3.20	2.73	0.00–20.14
Campbell albatross	11.98	2.18–30.98	10.66	6.01–16.76	1.38	0.36–3.11
White-capped albatross	0.62	0.10–1.69	1.58	1.12–2.13	1.09	0.76–1.49
Flesh-footed shearwater	0.56	0.04–1.78	0.4	0.15–0.77	1.88	0.00–15.79
Westland petrel	0.5	0.01–2.60	0.88	0.24–1.94	0.57	0.08–1.55
Giant petrel	1.18	0.01–7.55	0.31	0.00–1.61	0.17	0.00–0.88
Grey petrel	2.74	0.57–6.80	1.44	0.75–2.36	0.86	0.46–1.40
Wandering albatrosses	108.04	70.92–152.82	10.15	6.39–14.84	0.98	0.36–2.00
Royal albatrosses	0.32	0.00–1.96	0.78	0.21–1.81	0.04	0.00–0.21
White-chinned petrel	1.74	0.73–3.16	0.26	0.10–0.48	0.12	0.06–0.20
Yellow-eyed penguin	0.73	0.00–5.68	0.59	0.00–4.66	0.31	0.00–2.50
Cape petrel	0.18	0.00–1.36	0.06	0.00–0.38	0.03	0.00–0.21
Grey-headed albatross	0.14	0.00–1.19	0.06	0.00–0.48	0.02	0.00–0.18
Group foraging shags	0.22	0.00–1.58	0.11	0.00–0.93	0.08	0.00–0.71
LM sooty albatross	0.1	0.00–0.88	0.04	0.00–0.30	0.02	0.00–0.13
Solitary shags	0.09	0.00–0.70	0.06	0.00–0.57	0.04	0.00–0.30
Sooty shearwater	0.01	0.00–0.04	0	0.00–0.01	0	0.00–0.00
Storm petrels	0.01	0.00–0.07	0.01	0.00–0.03	0.01	0.00–0.04
Diving petrels	0.01	0.00–0.04	0	0.00–0.01	0	0.00–0.00
Large *Pterodroma* petrels	0.03	0.00–0.10	0.01	0.00–0.01	0	0.00–0.01
Crested penguins	0.03	0.00–0.24	0.01	0.00–0.12	0.01	0.00–0.04
Shearwaters	0	0.00–0.03	0	0.00–0.01	0	0.00–0.01
Little penguins	0.01	0.00–0.08	0	0.00–0.03	0.01	0.00–0.04
Boobies and gannets	0.01	0.00–0.07	0	0.00–0.02	0	0.00–0.03
Prions	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00
Small *Pterodroma* petrels	0	0.00–0.01	0	0.00–0.00	0	0.00–0.00
Gulls, terns & skua	0	0.00–0.01	0	0.00–0.01	0	0.00–0.01

Table G-26: Vulnerability of seabirds to capture in set-net fisheries. Seabirds are listed in species groups used in the estimation of vulnerability (including lower and upper credible limit).

Species group	Set net	
	Mean	95% c.i.
Black petrel	0.1	0.00–0.70
Salvin's albatross	0.01	0.00–0.03
Buller's albatrosses	0	0.00–0.01
Chatham albatross	0.03	0.00–0.22
Campbell albatross	0.01	0.00–0.04
White-capped albatross	0	0.00–0.01
Flesh-footed shearwater	0.02	0.00–0.07
Westland petrel	0.08	0.01–0.20
Giant petrel	0.01	0.00–0.10
Grey petrel	0	0.00–0.03
Wandering albatrosses	0.01	0.00–0.04
Royal albatrosses	0	0.00–0.01
White-chinned petrel	0	0.00–0.00
Yellow-eyed penguin	0.07	0.03–0.13
Cape petrel	0	0.00–0.01
Grey-headed albatross	0	0.00–0.01
Group foraging shags	0	0.00–0.00
LM sooty albatross	0	0.00–0.01
Solitary shags	0	0.00–0.00
Sooty shearwater	0	0.00–0.00
Storm petrels	0	0.00–0.00
Diving petrels	0	0.00–0.00
Large *Pterodroma* petrels	0	0.00–0.00
Crested penguins	0	0.00–0.00
Shearwaters	0	0.00–0.00
Little penguins	0	0.00–0.00
Boobies and gannets	0	0.00–0.00
Prions	0	0.00–0.00
Small *Pterodroma* petrels	0	0.00–0.00
Gulls, terns & skua	0	0.00–0.00

G.5 Annual potential fatalities by target fisheries

Table G-27: Estimated number of annual potential fatalities (APF) in different trawl fisheries (see definition of target fisheries in Richard & Abraham 2013b; SBW, southern blue whiting). Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits. Fisheries are sorted by decreasing order of the mean total APF. [Continued on next page.]

Species	Inshore trawl		Hoki trawl		Flatfish trawl		Middle depth trawl	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	4	0–24	1	0–4	2	0–11	1	0–5
Antipodean albatross	3	0–18	0	0–3	1	0–10	1	0–4
Southern royal albatross	2	0–14	1	0–4	1	0–8	0	0–3
Northern royal albatross	6	0–38	2	0–8	3	0–22	2	0–8
Campbell black-browed albatross	13	0–61	20	6–39	9	0–57	6	0–19
NZ white-capped albatross	**1 680**	995–2 620	451	311–624	**599**	291–1 090	348	217–531
Salvin's albatross	**1 090**	596–1 810	**437**	268–674	105	54–186	**306**	196–453
Chatham Island albatross	6	0–38	8	1–21	1	0–8	3	0–12
Grey-headed albatross	1	0–6	0	0–2	0	0–2	0	0–2
Southern Buller's albatross	**44**	4–142	**195**	118–299	25	1–106	61	33–99
Northern Buller's albatross	25	2–83	54	29–86	1	0–6	24	11–41
Light-mantled sooty albatross	1	0–6	0	0–2	0	0–3	0	0–2
Northern giant petrel	**4**	0–27	**11**	1–27	1	0–11	3	0–10
Grey petrel	16	0–73	4	0–11	7	0–44	3	0–12
Black petrel	**95**	22–242	4	0–13	0	0–2	3	0–11
Westland petrel	**62**	8–186	**25**	8–52	**21**	2–65	**13**	1–40
White-chinned petrel	34	2–133	158	84–265	33	1–148	37	18–65
Flesh-footed shearwater	**445**	153–951	12	3–31	14	1–42	13	3–30
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	4	0–22	0	0–3	1	0–7	1	0–4
Sooty shearwater	786	240–1 920	115	65–188	39	10–99	163	82–300
Fluttering shearwater	22	0–124	1	0–5	0	0–2	0	0–1
Hutton's shearwater	5	0–32	1	0–8	3	0–19	3	0–17
Little shearwater	0	0–3	0	0–1	0	0–1	0	0–1
Snares Cape petrel	4	0–32	5	0–18	1	0–9	3	0–10
Fairy prion	52	0–321	15	1–51	17	0–114	20	1–96
Antarctic prion	1	0–8	1	0–6	0	0–3	0	0–2
Broad-billed prion	1	0–10	1	0–5	0	0–3	1	0–4
Pycroft's petrel	0	0–1	0	0–0	0	0–0	0	0–0
Cook's petrel	10	0–66	0	0–1	0	0–1	0	0–1
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	3	0–22	0	0–2	2	0–14	1	0–4
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	69	9–218	3	0–10	1	0–7	3	0–12
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	6	0–20	0	0–2	1	0–4	1	0–4
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	193	6–921	13	1–38	34	1–168	17	1–67
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	13	0–91	2	0–10	1	0–8	8	0–51
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	1	0–9	0	0–2	0	0–4	0	0–2
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–1	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	2	0–9	0	0–1	2	0–10	1	0–4
Northern little penguin	0	0–3	0	0–1	0	0–1	0	0–1
White-flippered little penguin	0	0–1	0	0–0	0	0–1	0	0–1
Southern little penguin	0	0–2	0	0–1	0	0–3	0	0–1
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–1	0	0–1	0	0–1	0	0–0
Fiordland crested penguin	0	0–3	0	0–1	0	0–1	0	0–1
Snares crested penguin	0	0–1	0	0–1	0	0–1	0	0–1
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	1	0–8	0	0–1	0	0–3	0	0–1
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	2	0–8	0	0–2	1	0–7	0	0–1
Little black shag	0	0–3	0	0–1	0	0–3	0	0–1
NZ king shag	0	0–1	0	0–0	0	0–1	0	0–1
Otago shag	3	0–8	0	0–0	**37**	20–58	0	0–1
Foveaux shag	1	0–3	0	0–0	7	2–13	0	0–0
Chatham Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	70	41–107	1	0–5	**226**	141–334	6	2–12
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	16	0–74	1	0–6	11	0–61	2	0–9
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
All birds	4 800	3 140–7 080	1 540	1 140–2 050	1 210	804–1 820	1 060	777–1 410

Table G-27: [Continued]

Species	Scampi trawl		Squid trawl		Deepwater trawl		Ling trawl	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson’s albatross	1	0–4	0	0–1	1	0–6	0	0–1
Antipodean albatross	0	0–4	0	0–1	1	0–5	0	0–1
Southern royal albatross	0	0–3	2	0–6	1	0–4	0	0–1
Northern royal albatross	1	0–6	1	0–4	2	0–7	0	0–1
Campbell black-browed albatross	7	0–28	1	0–3	1	0–4	2	0–6
NZ white-capped albatross	89	36–170	303	186–452	3	0–13	62	37–93
Salvin’s albatross	**283**	141–492	7	1–15	83	37–149	40	22–60
Chatham Island albatross	3	0–16	1	0–3	**28**	8–63	0	0–2
Grey-headed albatross	0	0–2	0	0–1	0	0–1	0	0–1
Southern Buller’s albatross	10	2–25	66	34–109	1	0–4	6	2–14
Northern Buller’s albatross	53	16–117	0	0–1	5	0–18	0	0–1
Light-mantled sooty albatross	0	0–2	0	0–1	0	0–1	0	0–1
Northern giant petrel	5	0–23	0	0–1	3	0–12	1	0–3
Grey petrel	1	0–6	0	0–2	3	0–14	0	0–3
Black petrel	6	0–24	0	0–1	3	0–23	0	0–2
Westland petrel	1	0–4	0	0–1	1	0–10	2	0–8
White-chinned petrel	166	79–297	220	127–343	2	0–13	9	3–17
Flesh-footed shearwater	49	20–96	0	0–1	3	0–19	3	0–9
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller’s shearwater	0	0–3	0	0–1	0	0–4	0	0–1
Sooty shearwater	87	39–160	150	87–237	36	3–130	22	10–38
Fluttering shearwater	3	0–21	0	0–1	0	0–1	0	0–1
Hutton’s shearwater	0	0–1	0	0–0	3	0–19	0	0–0
Little shearwater	0	0–1	0	0–0	0	0–1	0	0–0
Snares Cape petrel	0	0–3	0	0–2	0	0–4	2	0–7
Fairy prion	1	0–4	1	0–5	1	0–5	0	0–2
Antarctic prion	0	0–4	16	1–51	0	0–2	0	0–2
Broad-billed prion	1	0–4	1	0–3	1	0–8	0	0–1
Pycroft’s petrel	0	0–0	0	0–0	0	0–0	0	0–0
Cook’s petrel	1	0–6	0	0–0	0	0–2	0	0–1
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–2	0	0–1	0	0–1
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	0	0–3	0	0–0	1	0–6	1	0–3
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–2	0	0–2	0	0–2	0	0–1
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	3	0–19	5	0–18	12	0–55	22	2–87
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	4	0–24	0	0–2	43	3–161	0	0–2
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–1	1	0–4	0	0–1	0	0–0
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–1	0	0–0	0	0–0
Northern little penguin	0	0–1	0	0–0	0	0–0	0	0–0
White-flippered little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–1	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–1	0	0–0	0	0–0	0	0–0
Fiordland crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0	0	0–1
Erect-crested penguin	0	0–2	0	0–1	0	0–0	0	0–0
Australasian gannet	0	0–2	0	0–0	0	0–1	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–1	0	0–0	0	0–0	0	0–0
Little black shag	0	0–0	0	0–0	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0	0	0–0	0	0–0
Otago shag	0	0–0	0	0–0	0	0–0	0	0–0
Foveaux shag	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–1	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	0	0–0	0	0–0	0	0–0	0	0–1
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–2	0	0–1	0	0–3	0	0–1
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
All birds	777	489–1 150	775	561–1 020	237	120–433	174	121–252

[Continued on next page.]

Table G-27: [Continued]

Species	Hake trawl		SBW trawl		Jack mackerel trawl	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson’s albatross	0	0–1	0	0–1	0	0–1
Antipodean albatross	0	0–0	0	0–1	0	0–1
Southern royal albatross	0	0–1	1	0–6	0	0–1
Northern royal albatross	0	0–1	0	0–1	0	0–1
Campbell black-browed albatross	1	0–3	6	0–18	0	0–2
NZ white-capped albatross	49	29–72	1	0–6	13	3–32
Salvin’s albatross	15	7–27	35	13–69	1	0–5
Chatham Island albatross	0	0–1	0	0–1	0	0–1
Grey-headed albatross	0	0–0	0	0–1	0	0–0
Southern Buller’s albatross	8	2–17	0	0–3	3	0–11
Northern Buller’s albatross	0	0–1	1	0–5	0	0–2
Light-mantled sooty albatross	0	0–0	0	0–1	0	0–0
Northern giant petrel	1	0–2	0	0–2	0	0–1
Grey petrel	0	0–2	33	10–79	0	0–1
Black petrel	0	0–0	0	0–0	0	0–1
Westland petrel	3	0–9	0	0–1	0	0–2
White-chinned petrel	7	2–14	0	0–2	11	4–22
Flesh-footed shearwater	0	0–0	0	0–0	0	0–1
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0
Buller’s shearwater	0	0–0	0	0–0	0	0–1
Sooty shearwater	4	1–9	0	0–1	2	0–7
Fluttering shearwater	0	0–0	0	0–1	0	0–0
Hutton’s shearwater	0	0–0	0	0–0	0	0–1
Little shearwater	0	0–0	0	0–0	0	0–0
Snares Cape petrel	1	0–6	0	0–1	0	0–1
Fairy prion	0	0–1	0	0–2	2	0–9
Antarctic prion	0	0–1	0	0–1	0	0–1
Broad-billed prion	0	0–1	0	0–1	0	0–0
Pycroft’s petrel	0	0–0	0	0–0	0	0–0
Cook’s petrel	0	0–0	0	0–0	0	0–0
Chatham petrel	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0
Grey-faced petrel	0	0–1	0	0–0	0	0–1
Chatham Island taiko	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–1	0	0–2	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0
Common diving petrel	0	0–2	0	0–4	1	0–5
South Georgian diving petrel	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	0	0–0	1	0–6
White-bellied storm petrel	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–1	0	0–1
Kerm. storm petrel	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–0	0	0–1
Northern little penguin	0	0–0	0	0–0	0	0–0
White-flippered little penguin	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0	0	0–0
Fiordland crested penguin	0	0–0	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–1	0	0–0
Australasian gannet	0	0–0	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0
Pied shag	0	0–0	0	0–0	0	0–0
Little black shag	0	0–0	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0	0	0–0
Otago shag	0	0–0	0	0–0	0	0–0
Foveaux shag	0	0–0	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0
Spotted shag	0	0–0	0	0–0	0	0–0
Pitt Island shag	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0
All birds	91	62–124	80	41–140	38	19–65

Table G-28: Estimated number of annual potential fatalities (APF) in bottom-longline (BLL) fisheries (see definition of target fisheries in Richard & Abraham 2013b; cut-off length for vessel size classes was 34 m). Cells were coloured according to the associated risk category as defined in the “National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries” (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits. Fisheries are sorted by decreasing order of the mean total APF. [Continued on next page.]

Species	Small ling BLL		Snapper BLL		Minor BLL		Hapuka BLL	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson’s albatross	1	0–7	1	0–5	1	0–5	1	0–6
Antipodean albatross	1	0–6	0	0–2	0	0–3	1	0–5
Southern royal albatross	1	0–6	0	0–3	0	0–2	0	0–3
Northern royal albatross	6	0–23	0	0–3	1	0–6	2	0–10
Campbell black-browed albatross	3	0–18	1	0–8	6	0–25	7	0–30
NZ white-capped albatross	38	7–91	3	0–17	5	0–18	4	0–20
Salvin’s albatross	**317**	194–472	3	0–13	19	7–39	9	0–31
Chatham Island albatross	**88**	41–151	1	0–5	4	0–16	**7**	0–41
Grey-headed albatross	0	0–2	0	0–1	0	0–1	0	0–1
Southern Buller’s albatross	25	6–53	0	0–0	2	0–6	2	0–8
Northern Buller’s albatross	36	10–77	2	0–13	6	0–20	11	0–53
Light-mantled sooty albatross	0	0–2	0	0–1	0	0–1	0	0–1
Northern giant petrel	1	0–8	3	0–17	4	0–17	**9**	0–40
Grey petrel	58	20–122	2	0–11	3	0–11	2	0–10
Black petrel	2	0–10	**91**	51–141	16	4–33	**27**	9–56
Westland petrel	**11**	0–43	2	0–11	5	0–20	5	0–19
White-chinned petrel	450	292–639	2	0–10	19	9–33	3	0–14
Flesh-footed shearwater	4	0–19	**268**	178–375	61	30–104	57	28–97
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller’s shearwater	0	0–3	9	2–18	1	0–3	1	0–3
Sooty shearwater	4	0–22	2	0–12	11	0–36	8	0–29
Fluttering shearwater	1	0–6	97	44–171	12	2–34	0	0–2
Hutton’s shearwater	1	0–7	2	0–6	2	0–6	0	0–1
Little shearwater	0	0–1	4	0–9	0	0–1	0	0–1
Snares Cape petrel	0	0–4	0	0–3	0	0–2	0	0–2
Fairy prion	2	0–11	1	0–4	10	0–58	4	0–26
Antarctic prion	0	0–1	0	0–2	0	0–1	0	0–1
Broad-billed prion	1	0–7	0	0–1	1	0–5	2	0–14
Pycroft’s petrel	0	0–0	0	0–0	0	0–0	0	0–0
Cook’s petrel	0	0–2	1	0–8	0	0–2	0	0–2
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–2	0	0–0	0	0–0	0	0–1
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	2	0–12	2	0–11	25	7–54	22	6–49
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–2	0	0–1	4	0–9	4	0–10
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	3	0–18	2	0–13	2	0–14	6	0–32
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	15	0–92	1	0–8	10	0–48	29	0–151
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–1	0	0–1	0	0–0	0	0–0
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	0	0–4	0	0–0	1	0–6	0	0–2
Northern little penguin	0	0–2	0	0–3	0	0–1	0	0–1
White-flippered little penguin	0	0–1	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–2	0	0–0	0	0–0	0	0–1
Chatham Island little penguin	0	0–2	0	0–0	0	0–1	0	0–3
Eastern rockhopper penguin	0	0–1	0	0–0	0	0–1	0	0–1
Fiordland crested penguin	2	0–15	0	0–0	0	0–1	1	0–7
Snares crested penguin	0	0–2	0	0–0	0	0–1	0	0–1
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–4	1	0–5	0	0–2	0	0–3
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	1	0–4	1	0–7	1	0–5	0	0–2
Little black shag	0	0–1	0	0–3	0	0–2	0	0–1
NZ king shag	0	0–0	0	0–0	0	0–1	0	0–1
Otago shag	0	0–0	0	0–0	0	0–1	0	0–0
Foveaux shag	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island shag	0	0–1	0	0–0	0	0–1	0	0–2
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	3	0–26	2	0–12	2	0–16	2	0–12
Pitt Island shag	0	0–0	0	0–0	0	0–1	0	0–2
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	4	0–28	18	3–48	20	4–47	11	2–28
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
All birds	1 090	809–1 410	523	385–681	254	170–364	238	140–398

Table G-28: [Continued]

Species	Large ling BLL		Bluenose BLL	
	Mean	95% c.i.	Mean	95% c.i.
Gibson’s albatross	0	0–2	0	0–2
Antipodean albatross	0	0–2	0	0–2
Southern royal albatross	1	0–4	0	0–1
Northern royal albatross	1	0–5	0	0–2
Campbell black-browed albatross	2	0–7	9	0–35
NZ white-capped albatross	2	0–8	2	0–14
Salvin’s albatross	8	1–20	2	0–14
Chatham Island albatross	5	0–15	0	0–3
Grey-headed albatross	0	0–1	0	0–0
Southern Buller’s albatross	4	0–12	1	0–4
Northern Buller’s albatross	6	0–16	7	0–19
Light-mantled sooty albatross	0	0–1	0	0–0
Northern giant petrel	0	0–3	0	0–2
Grey petrel	14	2–33	1	0–8
Black petrel	0	0–1	**82**	19–172
Westland petrel	0	0–2	1	0–6
White-chinned petrel	128	76–191	11	0–37
Flesh-footed shearwater	0	0–2	2	0–11
Wedge-tailed shearwater	0	0–0	0	0–0
Buller’s shearwater	0	0–2	0	0–2
Sooty shearwater	18	7–34	1	0–6
Fluttering shearwater	0	0–0	1	0–5
Hutton’s shearwater	0	0–0	0	0–1
Little shearwater	0	0–0	0	0–0
Snares Cape petrel	0	0–1	0	0–1
Fairy prion	0	0–1	0	0–1
Antarctic prion	0	0–1	0	0–1
Broad-billed prion	0	0–1	0	0–2
Pycroft’s petrel	0	0–0	0	0–0
Cook’s petrel	0	0–0	0	0–2
Chatham petrel	0	0–0	0	0–0
Mottled petrel	0	0–2	0	0–0
White-naped petrel	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0
Grey-faced petrel	0	0–1	1	0–6
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	0	0–1	0	0–1
Soft-plumaged petrel	0	0–0	0	0–0
Common diving petrel	1	0–8	0	0–4
South Georgian diving petrel	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–4	1	0–6
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	0	0–1	0	0–0
Kerm. storm petrel	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–0
Northern little penguin	0	0–0	0	0–1
White-flippered little penguin	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–1	0	0–0
Fiordland crested penguin	0	0–0	0	0–0
Snares crested penguin	0	0–1	0	0–0
Erect-crested penguin	0	0–2	0	0–0
Australasian gannet	0	0–0	0	0–1
Masked booby	0	0–0	0	0–0
Pied shag	0	0–0	0	0–1
Little black shag	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0
Otago shag	0	0–0	0	0–0
Foveaux shag	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0
Spotted shag	0	0–0	0	0–1
Pitt Island shag	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	0	0–2	0	0–3
Caspian tern	0	0–0	0	0–0
White tern	0	0–0	0	0–0
All birds	192	130–268	125	49–223

Table G-29: Estimated number of annual potential fatalities (APF) in surface-longline (SLL) fisheries (see definition of target fisheries in Richard & Abraham 2013b; cut-off length for vessel size classes was 45 m; STN: southern bluefin tuna). Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Fisheries are sorted by decreasing order of the mean total APF. [Continued on next page.]

Species	Bigeye SLL		Small STN SLL		Swordfish SLL		Large STN SLL	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	18	8–31	**37**	19–59	**96**	50–157	1	0–3
Antipodean albatross	9	3–17	17	8–30	**37**	17–61	0	0–1
Southern royal albatross	2	0–7	3	0–9	0	0–3	0	0–1
Northern royal albatross	2	0–6	3	0–9	0	0–3	0	0–0
Campbell black-browed albatross	20	9–35	29	14–50	10	1–26	0	0–2
NZ white-capped albatross	61	38–89	95	61–132	11	1–31	8	3–16
Salvin's albatross	11	2–25	6	0–14	3	0–13	0	0–2
Chatham Island albatross	1	0–4	0	0–3	1	0–4	0	0–0
Grey-headed albatross	0	0–1	0	0–1	0	0–1	0	0–0
Southern Buller's albatross	1	0–3	52	33–75	1	0–4	19	9–31
Northern Buller's albatross	**111**	76–153	50	30–72	2	0–11	0	0–0
Light-mantled sooty albatross	0	0–1	0	0–1	0	0–1	0	0–0
Northern giant petrel	0	0–2	0	0–3	0	0–3	0	0–1
Grey petrel	14	5–26	25	11–44	13	1–34	2	0–6
Black petrel	**121**	59–204	0	0–2	**13**	1–39	0	0–0
Westland petrel	2	0–7	**15**	3–37	2	0–12	0	0–2
White-chinned petrel	13	3–26	16	4–33	43	15–86	2	0–5
Flesh-footed shearwater	26	8–55	1	0–4	11	0–39	0	0–0
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	0	0–3	0	0–2	0	0–3	0	0–0
Sooty shearwater	2	0–9	1	0–6	8	0–29	0	0–1
Fluttering shearwater	0	0–1	0	0–1	0	0–1	0	0–0
Hutton's shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Little shearwater	0	0–1	0	0–1	0	0–0	0	0–0
Snares Cape petrel	0	0–2	0	0–2	0	0–3	0	0–0
Fairy prion	0	0–1	0	0–2	0	0–2	0	0–0
Antarctic prion	0	0–1	0	0–1	0	0–1	0	0–0
Broad-billed prion	0	0–1	0	0–1	0	0–1	0	0–0
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0
Cook's petrel	1	0–4	0	0–0	0	0–4	0	0–0
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	4	0–11	4	0–12	7	0–23	0	0–0
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–2	0	0–2	1	0–4	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	1	0–4	0	0–3	1	0–4	0	0–0
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	1	0–4	0	0–1	1	0–5	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–1	0	0–1	0	0–1	0	0–0
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–0	0	0–0	0	0–0
Northern little penguin	0	0–1	0	0–1	0	0–1	0	0–0
White-flippered little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–1	0	0–1	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–1	0	0–0	0	0–0
Fiordland crested penguin	0	0–0	0	0–1	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–2	0	0–1	0	0–3	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–1	0	0–0	0	0–1	0	0–0
Little black shag	0	0–0	0	0–0	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0	0	0–0	0	0–0
Otago shag	0	0–0	0	0–0	0	0–0	0	0–0
Foveaux shag	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	0	0–0	0	0–1	0	0–3	0	0–0
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–3	0	0–2	0	0–3	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
All birds	422	318–548	359	277–450	262	170–372	33	19–49

Table G-29: [Continued]

Species	Minor surface SLL		Albacore SLL	
	Mean	95% c.i.	Mean	95% c.i.
Gibson’s albatross	1	0–3	0	0–1
Antipodean albatross	1	0–3	0	0–1
Southern royal albatross	0	0–1	0	0–0
Northern royal albatross	0	0–1	0	0–0
Campbell black-browed albatross	1	0–2	0	0–1
NZ white-capped albatross	2	0–5	0	0–2
Salvin’s albatross	0	0–2	0	0–1
Chatham Island albatross	0	0–1	0	0–0
Grey-headed albatross	0	0–0	0	0–0
Southern Buller’s albatross	0	0–2	0	0–0
Northern Buller’s albatross	3	0–7	1	0–3
Light-mantled sooty albatross	0	0–0	0	0–0
Northern giant petrel	0	0–0	0	0–0
Grey petrel	1	0–2	0	0–1
Black petrel	0	0–1	0	0–1
Westland petrel	0	0–1	0	0–0
White-chinned petrel	0	0–2	0	0–1
Flesh-footed shearwater	0	0–1	0	0–1
Wedge-tailed shearwater	0	0–0	0	0–0
Buller’s shearwater	0	0–0	0	0–0
Sooty shearwater	0	0–1	0	0–0
Fluttering shearwater	0	0–0	0	0–0
Hutton’s shearwater	0	0–0	0	0–0
Little shearwater	0	0–0	0	0–0
Snares Cape petrel	0	0–0	0	0–0
Fairy prion	0	0–0	0	0–0
Antarctic prion	0	0–0	0	0–0
Broad-billed prion	0	0–0	0	0–0
Pycroft’s petrel	0	0–0	0	0–0
Cook’s petrel	0	0–0	0	0–0
Chatham petrel	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0
Grey-faced petrel	0	0–1	0	0–0
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	0	0–0	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0
Common diving petrel	0	0–0	0	0–0
South Georgian diving petrel	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	0	0–0
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–0
Kerm. storm petrel	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–0
Northern little penguin	0	0–0	0	0–0
White-flippered little penguin	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0
Fiordland crested penguin	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0
Australasian gannet	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0
Pied shag	0	0–0	0	0–0
Little black shag	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0
Otago shag	0	0–0	0	0–0
Foveaux shag	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0
Spotted shag	0	0–0	0	0–0
Pitt Island shag	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	0	0–1	0	0–0
Caspian tern	0	0–0	0	0–0
White tern	0	0–0	0	0–0
All birds	9	4–16	2	0–5

Table G-30: Estimated number of annual potential fatalities (APF) in set-net (SN) fisheries, by target species. Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Fisheries are sorted by decreasing order of the mean total APF.

Species	Shark SN		Flatfish SN		Minor SN		Grey mullet SN	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	0	0–1	0	0–1	0	0–1	0	0–0
Antipodean albatross	0	0–1	0	0–1	0	0–1	0	0–0
Southern royal albatross	0	0–1	0	0–0	0	0–0	0	0–0
Northern royal albatross	0	0–1	0	0–1	0	0–1	0	0–0
Campbell black-browed albatross	0	0–2	0	0–1	0	0–1	0	0–0
NZ white-capped albatross	1	0–3	0	0–3	0	0–2	0	0–1
Salvin's albatross	1	0–3	0	0–2	0	0–2	0	0–1
Chatham Island albatross	0	0–1	0	0–1	0	0–1	0	0–0
Grey-headed albatross	0	0–0	0	0–0	0	0–0	0	0–0
Southern Buller's albatross	0	0–3	0	0–1	0	0–1	0	0–0
Northern Buller's albatross	0	0–1	0	0–1	0	0–1	0	0–0
Light-mantled sooty albatross	0	0–0	0	0–0	0	0–0	0	0–0
Northern giant petrel	0	0–1	0	0–1	0	0–1	0	0–0
Grey petrel	0	0–3	0	0–2	0	0–2	0	0–1
Black petrel	0	0–3	1	0–6	1	0–5	0	0–2
Westland petrel	3	0–9	3	0–9	2	0–6	0	0–2
White-chinned petrel	0	0–3	0	0–1	0	0–1	0	0–0
Flesh-footed shearwater	3	0–15	8	0–34	4	0–18	1	0–6
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	0	0–1	0	0–0	0	0–0	0	0–0
Sooty shearwater	9	1–20	1	0–3	3	0–8	0	0–1
Fluttering shearwater	0	0–1	2	0–7	0	0–2	0	0–0
Hutton's shearwater	1	0–5	0	0–0	1	0–3	0	0–0
Little shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Snares Cape petrel	0	0–1	0	0–0	0	0–0	0	0–0
Fairy prion	1	0–4	0	0–0	0	0–2	0	0–0
Antarctic prion	0	0–0	0	0–0	0	0–0	0	0–0
Broad-billed prion	0	0–0	0	0–0	0	0–0	0	0–0
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0
Cook's petrel	0	0–1	0	0–1	0	0–1	0	0–0
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–1	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	0	0–2	0	0–2	0	0–2	0	0–1
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–1	0	0–0	0	0–0	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	0	0–3	0	0–1	0	0–1	0	0–0
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–1	0	0–3	0	0–1	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	**12**	4–25	2	0–6	3	0–8	0	0–0
Northern little penguin	0	0–1	0	0–1	0	0–1	0	0–0
White-flippered little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–1	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0
Fiordland crested penguin	0	0–2	0	0–0	0	0–1	0	0–0
Snares crested penguin	0	0–1	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–2	0	0–2	0	0–1	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	1	0–5	2	0–7	1	0–4	0	0–2
Little black shag	0	0–3	1	0–4	0	0–2	0	0–2
NZ king shag	0	0–0	0	0–0	0	0–1	0	0–0
Otago shag	0	0–2	0	0–0	0	0–0	0	0–0
Foveaux shag	0	0–1	0	0–0	0	0–1	0	0–0
Chatham Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	6	1–16	10	2–22	4	0–11	1	0–5
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–3	0	0–3	0	0–2	0	0–1
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
All birds	42	24–65	31	13–62	21	9–39	4	0–11

Table G-31: Estimated number of annual potential fatalities (APF) in trawl, surface-longline (SLL), bottom-longline (BLL), and set-net (SN) fisheries. Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits.

Species	Trawl		BLL		SLL		SN		All	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	10	0–43	4	0–16	**153**	96–223	0	0–2	**166**	106–242
Antipodean albatross	8	0–34	3	0–12	**64**	38–96	0	0–2	**74**	45–115
Southern royal albatross	9	1–29	3	0–10	6	0–15	0	0–1	19	6–41
Northern royal albatross	**18**	2–74	10	1–32	6	0–15	0	0–2	**34**	10–92
Campbell black-browed albatross	**64**	22–167	28	5–78	60	32–97	0	0–3	**153**	88–264
NZ white-capped albatross	**3 600**	2 460–5 130	54	15–115	176	122–241	1	0–7	**3 830**	2 690–5 380
Salvin's albatross	**2 400**	1 670–3 380	**358**	223–529	20	5–43	1	0–6	**2 780**	2 030–3 760
Chatham Island albatross	**49**	18–103	**104**	50–184	1	0–8	0	0–2	**155**	89–246
Grey-headed albatross	2	0–12	1	0–4	0	0–3	0	0–1	3	0–15
Southern Buller's albatross	**421**	270–637	33	12–63	73	49–101	1	0–4	**528**	371–745
Northern Buller's albatross	**163**	95–255	68	26–133	**166**	115–227	0	0–1	**397**	294–523
Light-mantled sooty albatross	2	0–12	1	0–4	0	0–3	0	0–1	3	0–15
Northern giant petrel	**28**	7–73	**18**	1–61	1	0–6	0	0–2	**47**	14–112
Grey petrel	68	23–174	80	34–147	55	28–90	1	0–5	203	123–340
Black petrel	**113**	31–274	**218**	128–329	**135**	70–223	2	0–14	**468**	316–666
Westland petrel	**128**	29–349	**24**	3–66	**20**	5–46	7	0–23	**180**	67–407
White-chinned petrel	678	473–967	612	431–827	74	37–125	1	0–4	1 360	1 080–1 720
Flesh-footed shearwater	**540**	216–1 100	**392**	274–528	38	13–77	17	0–69	**987**	623–1 560
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	7	0–34	10	3–21	1	0–5	0	0–1	18	6–47
Sooty shearwater	1 400	728–2 740	44	17–94	11	1–33	12	2–27	1 470	790–2 810
Fluttering shearwater	26	0–135	111	54–187	0	0–2	2	0–9	140	68–272
Hutton's shearwater	15	0–74	5	1–13	0	0–1	2	0–6	22	4–80
Little shearwater	1	0–5	4	1–10	0	0–1	0	0–0	5	1–12
Snares Cape petrel	17	1–70	1	0–9	1	0–5	0	0–1	19	2–74
Fairy prion	109	10–553	16	0–86	1	0–4	1	0–5	127	15–566
Antarctic prion	21	4–58	1	0–3	0	0–2	0	0–1	22	4–60
Broad-billed prion	6	0–22	4	0–21	0	0–2	0	0–0	11	1–35
Pycroft's petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–1
Cook's petrel	11	0–69	2	0–10	1	0–7	0	0–2	14	0–76
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	6	0–39	0	0–3	0	0–1	0	0–1	7	0–41
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–1	0	0–1	0	0–0	0	0–0	0	0–1
Grey-faced petrel	78	12–244	52	16–106	15	3–35	1	0–5	146	57–321
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	9	1–28	8	1–18	1	0–5	0	0–1	19	6–40
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	300	35–1 220	15	1–57	2	0–8	1	0–4	317	46–1 250
South Georgian diving petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–1
NZ white-faced storm petrel	73	11–242	57	3–227	1	0–7	1	0–4	131	28–376
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	3	0–15	0	0–2	0	0–2	0	0–1	4	0–15
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–1
Yellow-eyed penguin	5	0–19	1	0–11	0	0–0	**18**	6–34	**23**	8–47
Northern little penguin	1	0–4	1	0–5	0	0–2	0	0–1	2	0–8
White-flippered little penguin	0	0–2	0	0–1	0	0–0	0	0–0	0	0–3
Southern little penguin	1	0–5	0	0–2	0	0–1	0	0–1	1	0–7
Chatham Island little penguin	0	0–1	1	0–5	0	0–0	0	0–0	1	0–5
Eastern rockhopper penguin	0	0–2	0	0–2	0	0–1	0	0–0	1	0–3
Fiordland crested penguin	1	0–5	3	0–22	0	0–1	0	0–2	4	0–23
Snares crested penguin	0	0–2	0	0–3	0	0–1	0	0–1	1	0–4
Erect-crested penguin	0	0–2	0	0–2	0	0–0	0	0–0	1	0–3
Australasian gannet	2	0–10	2	0–10	1	0–5	0	0–3	5	0–20
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	3	0–14	3	0–13	0	0–1	4	0–16	9	0–29
Little black shag	1	0–5	1	0–5	0	0–0	2	0–7	3	0–11
NZ king shag	0	0–2	0	0–2	0	0–0	0	0–1	0	0–3
Otago shag	**41**	22–63	0	0–1	0	0–0	0	0–2	**41**	22–64
Foveaux shag	7	2–14	0	0–0	0	0–0	0	0–2	8	2–15
Chatham Island shag	0	0–0	0	0–3	0	0–0	0	0–0	0	0–3
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–1	0	0–0	0	0–0	0	0–0	0	0–1
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	**303**	190–447	10	0–45	0	0–3	21	5–48	**335**	215–484
Pitt Island shag	0	0–0	0	0–2	0	0–0	0	0–0	0	0–2
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	31	1–136	54	19–109	1	0–6	1	0–6	87	29–200
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–1
White tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
All birds	10 800	8 390–13 800	2 420	1 930–2 950	1 090	868–1 340	98	55–166	14 400	11 900–17 500

Table G-32: Comparison of population productivity indices estimated as the Potential Biological Removal index (PBR_{ρ}) in the previous risk assessment (before updates; Richard & Abraham 2015) and as the Population Sustainability Threshold (PST) in the current assessment (after updates). Taxon names were coloured according to the associated risk categories as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits.

Taxon	Before updates		After updates	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	181	98–281	496	331–736
Antipodean albatross	136	98–187	364	251–513
Southern royal albatross	387	280–530	848	596–1 170
Northern royal albatross	259	134–423	716	342–1 360
Campbell black-browed albatross	673	437–937	1 980	1 010–3 590
NZ white-capped albatross	4 040	2 620–6 320	10 900	7 630–15 800
Salvin's albatross	1 020	638–1 650	3 600	2 710–4 940
Chatham Island albatross	139	85–228	425	296–623
Grey-headed albatross	221	130–328	695	349–1 250
Southern Buller's albatross	449	246–701	1 370	901–2 160
Northern Buller's albatross	540	296–845	1 630	1 050–2 570
Light-mantled sooty albatross	236	167–315	869	666–1 120
Northern giant petrel	164	57–352	336	159–805
Grey petrel	2 150	1 220–3 200	5 530	3 220–9 140
Black petrel	100	60–147	437	220–834
Westland petrel	157	89–234	350	234–520
White-chinned petrel	5 200	2 670–8 170	25 600	16 300–41 100
Flesh-footed shearwater	514	233–1 140	1 450	1 030–2 000
Wedge-tailed shearwater	3 900	2 580–5 460	5 930	3 120–10 500
Buller's shearwater	9 730	4 580–19 400	56 000	34 500–103 000
Sooty shearwater	230 000	93 500–410 000	617 000	291 000–1 240 000
Fluttering shearwater	1 800	1 040–2 850	36 100	15 100–72 700
Hutton's shearwater	4 880	3 060–7 040	15 000	9 300–23 400
Little shearwater	5 700	3 690–8 100	21 800	14 100–33 100
Snares Cape petrel	564	231–1 110	1 600	602–4 030
Fairy prion	85 000	53 700–133 000	329 000	214 000–506 000
Antarctic prion	13 900	7 940–24 200	154 000	77 200–289 000
Broad-billed prion	69 800	41 000–110 000	69 100	45 700–105 000
Pycroft's petrel	93	43–208	412	246–723
Cook's petrel	2 250	1 070–4 960	49 400	27 400–89 300
Chatham petrel	9	4–19	42	23–76
Mottled petrel	13 800	6 370–29 800	47 700	30 400–77 600
White-naped petrel	2 000	863–4 590	7 010	3 320–13 800
Kerm. petrel	298	140–666	781	511–1 320
Grey-faced petrel	11 900	5 540–26 300	29 900	19 200–49 500
Chatham Island taiko	1	0–2	2	1–4
White-headed petrel	12 300	5 390–25 300	34 300	16 600–66 100
Soft-plumaged petrel	60	25–133	499	137–1 280
Common diving petrel	26 600	17 300–38 900	135 000	47 800–309 000
South Georgian diving petrel	3	2–4	10	5–18
NZ white-faced storm petrel	55 900	32 400–92 400	332 000	137 000–669 000
White-bellied storm petrel	44	24–74	232	105–458
Black-bellied storm petrel	3 440	2 150–5 560	15 600	8 850–25 700
Kerm. storm petrel	2	1–3	11	4–25
NZ storm petrel	2	1–4	51	6–192
Yellow-eyed penguin	465	321–659	287	191–425
Northern little penguin	1 020	799–1 310	1 510	934–2 330
White-flippered little penguin	324	231–426	466	275–737
Southern little penguin	1 020	793–1 310	1 520	918–2 380
Chatham Island little penguin	1 020	794–1 310	1 510	935–2 390
Eastern rockhopper penguin	6 400	5 280–7 880	11 100	6 800–17 500
Fiordland crested penguin	322	210–427	636	295–1 230
Snares crested penguin	3 220	2 090–4 280	6 840	4 770–9 620
Erect-crested penguin	12 100	9 990–14 900	17 800	12 600–24 600
Australasian gannet	2 730	1 210–5 450	9 440	4 240–19 300
Masked booby	35	23–51	52	28–89
Pied shag	830	671–1 010	1 120	702–1 680
Little black shag	215	123–366	338	153–655
NZ king shag	15	12–18	39	24–61
Otago shag	301	244–369	285	182–425
Foveaux shag		N/A		N/A
Chatham Island shag	45	35–56	76	46–116
Bounty Island shag	13	10–17	26	14–44
Auckland Island shag	163	122–216	473	198–952
Campbell Island shag	196	128–261	492	230–944
Spotted shag	2 400	1 580–3 890	3 710	1 780–6 900
Pitt Island shag	66	43–89	104	61–161
Subantarctic skua	30	19–44	67	44–100
Southern black-backed gull	197 000	129 000–294 000	334 000	137 000–703 000
Caspian tern	135	79–201	170	96–282
White tern	15	12–19	26	15–43

Table G-33: Comparison of the total number of annual potential fatalities in trawl and longline fisheries estimated in the previous risk assessment (before updates; Richard & Abraham 2015) and in the current assessment (after updates). Values were rounded to two significant digits. Taxon names were coloured according to the associated risk categories as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits.

Taxon	Before updates		After updates	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	223	161–303	166	106–242
Antipodean albatross	123	86–175	74	45–115
Southern royal albatross	39	20–71	19	6–41
Northern royal albatross	52	20–120	34	10–92
Campbell black-browed albatross	214	121–362	153	88–264
NZ white-capped albatross	4 420	2 800–6 620	3 830	2 690–5 380
Salvin's albatross	3 480	2 250–5 200	2 780	2 030–3 760
Chatham Island albatross	128	70–226	155	89–246
Grey-headed albatross	5	0–24	3	0–15
Southern Buller's albatross	812	557–1 190	528	371–745
Northern Buller's albatross	549	410–727	397	294–523
Light-mantled sooty albatross	11	1–39	3	0–15
Northern giant petrel	37	9–98	47	14–112
Grey petrel	178	109–279	203	123–340
Black petrel	1 130	840–1 490	468	316–666
Westland petrel	88	37–183	180	67–407
White-chinned petrel	1 450	916–2 560	1 360	1 080–1 720
Flesh-footed shearwater	696	473–991	987	623–1 560
Wedge-tailed shearwater	0	0–0	0	0–0
Buller's shearwater	10	1–34	18	6–47
Sooty shearwater	1 350	738–2 600	1 470	790–2 810
Fluttering shearwater	25	3–89	140	68–272
Hutton's shearwater	18	5–50	22	4–80
Little shearwater	2	0–8	5	1–12
Snares Cape petrel	50	26–89	19	2–74
Fairy prion	41	10–123	127	15–566
Antarctic prion	3	0–7	22	4–60
Broad-billed prion	14	2–66	11	1–35
Pycroft's petrel	1	0–2	0	0–1
Cook's petrel	16	6–33	14	0–76
Chatham petrel	1	0–2	0	0–0
Mottled petrel	46	18–91	7	0–41
White-naped petrel	0	0–0	0	0–0
Kerm. petrel	0	0–1	0	0–1
Grey-faced petrel	101	43–187	146	57–321
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	14	5–27	19	6–40
Soft-plumaged petrel	0	0–1	0	0–0
Common diving petrel	34	9–102	317	46–1 250
South Georgian diving petrel	0	0–0	0	0–1
NZ white-faced storm petrel	51	8–219	131	28–376
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	2	0–7	4	0–15
Kerm. storm petrel	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–1
Yellow-eyed penguin	44	17–91	23	8–47
Northern little penguin	7	1–21	2	0–8
White-flippered little penguin	1	0–5	0	0–3
Southern little penguin	3	0–11	1	0–7
Chatham Island little penguin	2	0–18	1	0–5
Eastern rockhopper penguin	3	0–12	1	0–3
Fiordland crested penguin	12	0–73	4	0–23
Snares crested penguin	4	0–20	1	0–4
Erect-crested penguin	1	0–3	1	0–3
Australasian gannet	41	3–129	5	0–20
Masked booby	0	0–0	0	0–0
Pied shag	31	5–78	9	0–29
Little black shag	9	1–23	3	0–11
NZ king shag	0	0–2	0	0–3
Otago shag	91	58–139	41	22–64
Foveaux shag		N/A		N/A
Chatham Island shag	0	0–2	0	0–3
Bounty Island shag	0	0–0	0	0–0
Auckland Island shag	0	0–1	0	0–1
Campbell Island shag	0	0–0	0	0–0
Spotted shag	425	285–628	335	215–484
Pitt Island shag	0	0–3	0	0–2
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	94	27–215	87	29–200
Caspian tern	0	0–0	0	0–1
White tern	0	0–0	0	0–0

Table G-34: Comparison of the risk ratio estimated in the previous risk assessment (before updates; Richard & Abraham 2015) and in the current assessment (after updates). Cells were coloured according to the associated risk categories as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk.

Taxon	Before updates		After updates	
	Median	95% c.i.	Median	95% c.i.
Gibson's albatross	**1.256**	0.691–2.485	**0.337**	0.186–0.586
Antipodean albatross	**0.894**	0.556–1.474	**0.202**	0.110–0.356
Southern royal albatross	**0.096**	0.047–0.204	0.020	0.007–0.053
Northern royal albatross	**0.186**	0.066–0.591	**0.043**	0.012–0.163
Campbell black-browed albatross	**0.306**	0.162–0.626	**0.077**	0.035–0.183
NZ white-capped albatross	**1.100**	0.587–1.968	**0.353**	0.208–0.577
Salvin's albatross	**3.440**	1.818–6.504	**0.779**	0.509–1.095
Chatham Island albatross	**0.906**	0.418–1.901	**0.362**	0.183–0.657
Grey-headed albatross	**0.011**	0.000–0.123	0.002	0.000–0.026
Southern Buller's albatross	**1.819**	0.970–3.671	**0.392**	0.219–0.664
Northern Buller's albatross	**1.025**	0.579–1.998	**0.253**	0.141–0.405
Light-mantled sooty albatross	**0.033**	0.005–0.174	0.001	0.000–0.018
Northern giant petrel	**0.218**	0.046–0.963	**0.138**	0.033–0.468
Grey petrel	**0.083**	0.043–0.170	0.037	0.018–0.076
Black petrel	**11.336**	6.853–19.814	**1.152**	0.505–2.032
Westland petrel	**0.531**	0.214–1.375	**0.476**	0.180–1.186
White-chinned petrel	**0.278**	0.136–0.641	0.055	0.032–0.089
Flesh-footed shearwater	**1.500**	0.565–3.356	**0.669**	0.391–1.153
Wedge-tailed shearwater	0.000	0.000–0.000	0.000	0.000–0.000
Buller's shearwater	0.001	0.000–0.005	0.000	0.000–0.001
Sooty shearwater	0.006	0.002–0.018	0.002	0.001–0.006
Fluttering shearwater	0.010	0.002–0.055	0.004	0.001–0.011
Hutton's shearwater	0.003	0.001–0.011	0.001	0.000–0.006
Little shearwater	0.000	0.000–0.001	0.000	0.000–0.001
Snares Cape petrel	**0.093**	0.035–0.253	0.010	0.001–0.064
Fairy prion	0.000	0.000–0.002	0.000	0.000–0.002
Antarctic prion	0.000	0.000–0.001	0.000	0.000–0.000
Broad-billed prion	0.000	0.000–0.001	0.000	0.000–0.001
Pycroft's petrel	0.006	0.000–0.028	0.000	0.000–0.003
Cook's petrel	0.007	0.002–0.021	0.000	0.000–0.002
Chatham petrel	**0.069**	0.000–0.323	0.000	0.000–0.000
Mottled petrel	0.003	0.001–0.009	0.000	0.000–0.001
White-naped petrel	0.000	0.000–0.000	0.000	0.000–0.000
Kerm. petrel	0.000	0.000–0.003	0.000	0.000–0.002
Grey-faced petrel	0.009	0.003–0.023	0.005	0.002–0.012
Chatham Island taiko	**0.000**	0.000–0.356	0.000	0.000–0.000
White-headed petrel	0.001	0.000–0.003	0.001	0.000–0.002
Soft-plumaged petrel	0.007	0.000–0.036	0.000	0.000–0.000
Common diving petrel	0.001	0.000–0.004	0.002	0.000–0.013
South Georgian diving petrel	0.000	0.000–0.000	0.000	0.000–0.065
NZ white-faced storm petrel	0.001	0.000–0.004	0.000	0.000–0.002
White-bellied storm petrel	0.000	0.000–0.000	0.000	0.000–0.000
Black-bellied storm petrel	0.001	0.000–0.002	0.000	0.000–0.001
Kerm. storm petrel	0.000	0.000–0.000	0.000	0.000–0.000
NZ storm petrel	**0.000**	0.000–0.294	0.000	0.000–0.040
Yellow-eyed penguin	**0.080**	0.034–0.211	**0.078**	0.027–0.185
Northern little penguin	0.005	0.001–0.022	0.001	0.000–0.006
White-flippered little penguin	0.003	0.000–0.017	0.000	0.000–0.006
Southern little penguin	0.002	0.000–0.011	0.000	0.000–0.005
Chatham Island little penguin	0.001	0.000–0.019	0.000	0.000–0.004
Eastern rockhopper penguin	0.000	0.000–0.002	0.000	0.000–0.000
Fiordland crested penguin	**0.015**	0.001–0.236	0.003	0.000–0.042
Snares crested penguin	0.001	0.000–0.007	0.000	0.000–0.001
Erect-crested penguin	0.000	0.000–0.000	0.000	0.000–0.000
Australasian gannet	0.012	0.001–0.063	0.000	0.000–0.003
Masked booby	0.000	0.000–0.010	0.000	0.000–0.000
Pied shag	0.033	0.006–0.097	0.007	0.000–0.029
Little black shag	**0.036**	0.005–0.128	0.008	0.000–0.043
NZ king shag	**0.000**	0.000–0.106	0.000	0.000–0.074
Otago shag	**0.297**	0.186–0.485	**0.144**	0.070–0.279
Foveaux shag		N/A		N/A
Chatham Island shag	0.000	0.000–0.043	0.000	0.000–0.040
Bounty Island shag	0.000	0.000–0.000	0.000	0.000–0.000
Auckland Island shag	0.000	0.000–0.009	0.000	0.000–0.002
Campbell Island shag	0.000	0.000–0.000	0.000	0.000–0.000
Spotted shag	**0.183**	0.095–0.321	**0.093**	0.043–0.203
Pitt Island shag	0.000	0.000–0.045	0.000	0.000–0.025
Subantarctic skua	0.000	0.000–0.000	0.000	0.000–0.000
Southern black-backed gull	0.000	0.000–0.001	0.000	0.000–0.001
Caspian tern	0.000	0.000–0.004	0.000	0.000–0.005
White tern	0.000	0.000–0.000	0.000	0.000–0.000

G.6 Effect of cryptic mortality

Table G-35: Comparison of the estimated risk ratio for 71 seabird taxa, with and without the inclusion of cryptic mortality in the estimation. Shown are the median and 95% credible interval (c.i.) of the risk ratios, when fishery mortalities are either considered as the annual number of observable captures (i.e., without cryptic mortality) or as the annual potential fatalities (i.e., with cryptic mortality). Median values were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits.

Taxon	No cryptic mortality		With cryptic mortality	
	Median	95% c.i.	Median	95% c.i.
Black petrel	**0.609**	0.284–1.137	**1.152**	0.505–2.032
Salvin's albatross	**0.122**	0.084–0.166	**0.779**	0.509–1.095
Flesh-footed shearwater	**0.234**	0.154–0.36	**0.669**	0.391–1.153
Westland petrel	**0.148**	0.069–0.287	**0.476**	0.18–1.186
Southern Buller's albatross	**0.094**	0.054–0.146	**0.392**	0.219–0.664
Chatham Island albatross	**0.13**	0.061–0.247	**0.362**	0.183–0.657
NZ white-capped albatross	0.04	0.026–0.059	**0.353**	0.208–0.577
Gibson's albatross	**0.189**	0.111–0.311	**0.337**	0.186–0.586
Northern Buller's albatross	**0.091**	0.051–0.148	**0.253**	0.141–0.405
Antipodean albatross	**0.109**	0.061–0.188	**0.202**	0.11–0.356
Yellow-eyed penguin (mainland)	**0.072**	0.025–0.165	**0.185**	0.066–0.447
Otago shag	**0.112**	0.056–0.213	**0.144**	0.07–0.279
Northern giant petrel	**0.047**	0.01–0.18	**0.138**	0.033–0.468
Spotted shag	**0.073**	0.033–0.157	**0.093**	0.043–0.203
Yellow-eyed penguin	**0.072**	0.025–0.165	**0.078**	0.027–0.185
Campbell black-browed albatross	0.028	0.012–0.063	**0.077**	0.035–0.183
White-chinned petrel	0.028	0.017–0.044	0.055	0.032–0.089
Northern royal albatross	0.015	0.003–0.048	**0.043**	0.012–0.163
Foveaux shag	0.028	0.007–0.067	0.037	0.01–0.084
Grey petrel	0.015	0.007–0.029	0.037	0.018–0.076
Southern royal albatross	0.008	0.002–0.019	0.02	0.007–0.053
Snares Cape petrel	0.001	0–0.007	0.01	0.001–0.064
Little black shag	0.006	0–0.037	0.008	0–0.043
Pied shag	0.005	0–0.023	0.007	0–0.029
Grey-faced petrel	0.001	0.001–0.003	0.005	0.002–0.012
Fluttering shearwater	0.002	0.001–0.005	0.004	0.001–0.011
Fiordland crested penguin	0.002	0–0.025	0.003	0–0.042
Grey-headed albatross	0	0–0.008	0.002	0–0.026
Common diving petrel	0	0–0.001	0.002	0–0.013
Sooty shearwater	0.001	0–0.001	0.002	0.001–0.006
Northern little penguin	0.001	0–0.005	0.001	0–0.006
Light-mantled sooty albatross	0	0–0.005	0.001	0–0.018
Hutton's shearwater	0	0–0.001	0.001	0–0.006
White-headed petrel	0	0–0.001	0.001	0–0.002
Auckland Island shag	0	0–0.002	0	0–0.002
Bounty Island shag	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0.005
Chatham Island shag	0	0–0.024	0	0–0.04
Campbell Island shag	0	0–0	0	0–0
Chatham Island little penguin	0	0–0.002	0	0–0.004
Southern little penguin	0	0–0.004	0	0–0.005
White-flippered little penguin	0	0–0.006	0	0–0.006
Eastern rockhopper penguin	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0
Snares crested penguin	0	0–0.001	0	0–0.001
Black-bellied storm petrel	0	0–0	0	0–0.001
White-bellied storm petrel	0	0–0	0	0–0
White tern	0	0–0	0	0–0
South Georgian diving petrel	0	0–0	0	0–0.065
NZ king shag	0	0–0.057	0	0–0.074
Kerm. storm petrel	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0
Australasian gannet	0	0–0.002	0	0–0.003
NZ storm petrel	0	0–0	0	0–0.04
Buller's shearwater	0	0–0	0	0–0.001
Pitt Island shag	0	0–0.016	0	0–0.025
Chatham petrel	0	0–0	0	0–0
Cook's petrel	0	0–0	0	0–0.002
Chatham Island taiko	0	0–0	0	0–0
Pycroft's petrel	0	0–0	0	0–0.003
Soft-plumaged petrel	0	0–0	0	0–0
Little shearwater	0	0–0	0	0–0.001
Wedge-tailed shearwater	0	0–0	0	0–0
Kerm. petrel	0	0–0.001	0	0–0.002
Antarctic prion	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0.001	0	0–0.002
Southern black-backed gull	0	0–0	0	0–0.001
Fairy prion	0	0–0	0	0–0.002
Mottled petrel	0	0–0	0	0–0.001
Broad-billed prion	0	0–0	0	0–0.001

Table G-36: Sources of the uncertainty in the risk ratio for the 72 seabird populations included in the current risk assessment. Values are percentage decrease in the 95% credible interval of the risk ratio for each parameter, when fixed to the mean independently of each other. Parameters included age at first reproduction A and adult survival rate S (from the literature or from taxonomic analysis), the number of annual breeding pairs N_{BP}, the proportion of adults breeding in a year P_{B}, and annual potential fatalities (APF) in trawl, surface-longline (SLL), bottom-longline (BLL), and set-net (SN) fisheries. Only taxa with a non-zero risk are shown. Taxon names were coloured according to their risk category. Red: risk ratio with a median over 1 or upper 95% credible limit (u.c.l.) over 2; dark orange: median over 0.3 or u.c.l. over 1; light orange: median over 0.1 or u.c.l. over 0.3; yellow: u.c.l. over 0.1.

Taxon	A_{lit}	A_{tax}	S_{lit}	S_{tax}	N_{BP}	P_{B}	APF			
							Trawl	SLL	BLL	SN
Black petrel	0	0	0	1	33	0	0	0	0	0
Salvin's albatross	10	5	14	1	0	0	26	4	5	4
Flesh-footed shearwater	6	1	0	3	0	1	36	2	2	2
Westland petrel	1	1	0	1	1	0	52	1	4	0
Southern Buller's albatross	3	1	15	2	7	2	24	1	1	0
Chatham Island albatross	2	2	0	3	9	2	12	3	28	1
New Zealand white-capped albatross	4	1	15	2	3	4	33	2	3	3
Gibson's albatross	1	3	10	3	4	7	5	28	5	4
Northern Buller's albatross	2	1	19	0	8	2	7	4	3	0
Antipodean albatross	1	2	1	2	9	4	11	29	4	1
Yellow-eyed penguin (mainland)	2	2	1	4	1	3	15	3	9	28
Otago shag	5	9	7	7	4	4	50	8	11	11
Northern giant petrel	3	1	18	3	5	2	24	1	17	3
Spotted shag	1	4	0	9	31	0	19	5	4	6
Yellow-eyed penguin	2	2	0	3	4	2	14	2	11	29
Campbell black-browed albatross	0	0	0	0	27	0	19	5	5	0
White-chinned petrel	9	1	11	0	19	6	9	2	6	2
Northern royal albatross	1	2	9	0	17	2	39	3	13	3
Foveaux shag	2	5	1	7	6	0	58	6	4	7
Grey petrel	0	0	0	0	21	0	17	4	9	0
Southern royal albatross	1	1	7	2	3	5	41	11	11	3
Snares Cape petrel	2	0	15	1	25	10	54	1	2	0
Little black shag	0	0	1	3	12	5	12	0	11	29
Pied shag	2	0	0	1	3	2	22	2	21	26
Grey-faced petrel	0	0	14	2	0	3	46	0	8	0
Fluttering shearwater	0	0	8	1	44	0	14	1	14	0
Fiordland crested penguin	4	0	0	0	25	21	2	2	66	0
Sooty shearwater	2	1	11	2	26	0	31	2	0	2
Grey-headed albatross	0	1	4	4	14	1	54	9	16	3
Common diving petrel	3	3	0	5	30	7	57	3	2	2
Light-mantled sooty albatross	2	0	0	0	0	0	61	2	12	0
Hutton's shearwater	0	0	4	2	10	0	69	0	1	0
Northern little penguin	0	0	3	0	6	0	22	9	31	3
White-headed petrel	1	1	8	1	23	5	29	2	14	1
Southern little penguin	1	0	9	2	17	5	46	4	15	1
New Zealand white-faced storm petrel	0	0	0	2	24	2	22	0	21	0
Australasian gannet	0	0	5	1	12	4	25	5	27	5
Buller's shearwater	4	1	9	0	4	0	40	2	12	1
Southern black-backed gull	0	2	0	2	23	0	26	5	18	1
Fairy prion	0	4	0	0	5	0	76	0	3	0
Little shearwater	0	0	2	2	11	0	13	3	42	2
Black-bellied storm petrel	2	0	11	2	1	3	68	2	0	3
Cook's petrel	1	1	11	0	20	0	73	3	5	1
Broad-billed prion	3	0	8	2	5	7	32	1	33	0
Antarctic prion	1	2	6	1	15	2	55	2	3	2
Snares crested penguin	2	0	0	3	5	3	24	4	33	10
Mottled petrel	2	0	0	0	11	0	81	2	5	1
Auckland Island shag	0	0	2	0	12	10	91	0	0	0
Caspian tern	0	1	8	0	0	5	33	1	97	4
Chatham Island shag	0	4	5	1	0	0	4	2	90	0
Chatham Island little penguin	0	0	0	0	9	9	5	0	64	0
White-flippered little penguin	4	4	8	3	17	4	49	4	15	7
Eastern rockhopper penguin	1	3	0	1	0	0	22	7	26	4
Erect-crested penguin	0	2	0	0	3	0	23	1	32	0
South Georgian diving petrel	2	4	98	7	100	100	94	3	5	0
New Zealand king shag	0	1	0	2	0	0	20	0	26	3
New Zealand storm petrel	0	0	0	0	54	0	75	12	5	0
Pitt Island shag	0	0	0	1	0	8	0	0	91	0
Pycroft's petrel	0	0	8	1	9	4	94	2	2	1
Kermadec petrel	0	1	9	3	3	1	9	4	25	1

G.7 Effect of updates

Table G-37: Comparison of risk ratios between model versions used to estimate the risk of commercial fisheries to seabirds. New base case is the current model including all updates, compared with the current model including all updates except individual ones. Omitted updates included current population sustainability threshold (PST) corrections, separate cryptic multipliers (k) for different trawl fishery groups, use of the total population size in the estimation of the PST, data up to the 2014–15 fishing year, using allometric relationships to estimate demographic parameters, updated demography and fishery groups, constraining the number of annual potential fatalities (APF), considering live captures, using an updated map (2015) of the at-sea distribution of black petrel, and considering changes in vulnerability over time. N_{min}, lower quartile of the population size. Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits. [Continued on next page.]

Species	New base case		Previous PST correction		Single trawl CM		Use of Nmin in PST		Data up to 2012–13	
	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.
Black petrel	**1.15**	0.51–2.03	**1.75**	0.77–3.08	**0.98**	0.43–1.93	**1.63**	1.08–2.24	**1.42**	0.68–2.2
Salvin's albatross	**0.78**	0.51–1.09	**1.53**	1–2.12	**0.53**	0.33–0.8	**0.82**	0.54–1.14	**0.89**	0.59–1.24
Flesh-footed shearwater	**0.67**	0.39–1.15	**1.23**	0.72–2.12	**0.43**	0.27–0.67	**0.77**	0.49–1.23	**0.5**	0.25–1.1
Southern Buller's albatross	**0.39**	0.22–0.66	**0.77**	0.43–1.3	**0.36**	0.2–0.61	**0.46**	0.26–0.73	**0.44**	0.24–0.74
Westland petrel	**0.48**	0.18–1.19	**1.05**	0.4–2.62	**0.28**	0.13–0.61	**0.56**	0.23–1.32	**0.25**	0.09–0.74
Gibson's albatross	**0.34**	0.19–0.59	**0.8**	0.44–1.35	**0.34**	0.18–0.58	**0.4**	0.22–0.65	**0.34**	0.18–0.6
NZ white-capped albatross	**0.35**	0.21–0.58	**0.69**	0.41–1.12	**0.2**	0.11–0.32	**0.4**	0.25–0.63	**0.46**	0.27–0.74
Chatham Island albatross	**0.36**	0.18–0.66	**0.71**	0.36–1.28	**0.31**	0.15–0.57	**0.42**	0.21–0.71	**0.34**	0.18–0.67
Northern Buller's albatross	**0.25**	0.14–0.41	**0.5**	0.28–0.79	**0.23**	0.13–0.38	**0.29**	0.17–0.45	**0.29**	0.16–0.48
Antipodean albatross	**0.2**	0.11–0.36	**0.48**	0.26–0.83	**0.2**	0.11–0.34	**0.24**	0.14–0.4	**0.23**	0.13–0.41
Yellow-eyed penguin (mainland)	**0.18**	0.07–0.45		0.08–0.51	**0.17**	0.06–0.42	**0.22**	0.08–0.5	**0.23**	0.08–0.57
Otago shag	**0.14**	0.07–0.28	**0.17**	0.09–0.33	**0.15**	0.08–0.29	**0.16**	0.08–0.29	**0.16**	0.08–0.31
Northern giant petrel	**0.14**	0.03–0.47	**0.33**	0.08–1.11	**0.12**	0.03–0.39	**0.16**	0.04–0.53	**0.1**	0.02–0.4
Spotted shag	**0.09**	0.04–0.2	**0.11**	0.05–0.24	**0.1**	0.05–0.22	**0.13**	0.07–0.24	**0.11**	0.05–0.24
Campbell black-browed albatross	**0.08**	0.04–0.18	**0.15**	0.07–0.36	**0.07**	0.03–0.15	**0.11**	0.06–0.23	**0.1**	0.05–0.25
Yellow-eyed penguin	**0.08**	0.03–0.19	**0.09**	0.03–0.21	**0.07**	0.02–0.17	**0.09**	0.03–0.2	**0.1**	0.04–0.24
White-chinned petrel	0.05	0.03–0.09	**0.12**	0.07–0.19	**0.06**	0.03–0.11	0.07	0.04–0.1	0.04	0.02–0.08
Northern royal albatross	**0.04**	0.01–0.16	**0.1**	0.03–0.38	**0.04**	0.01–0.13	**0.06**	0.02–0.21	**0.04**	0.01–0.16
Grey petrel	0.04	0.02–0.08	**0.08**	0.04–0.17	0.03	0.02–0.06	0.05	0.03–0.09	0.04	0.02–0.1
Foveaux shag	0.04	0.01–0.08	0.04	0.01–0.1	0.04	0.01–0.09	0.04	0.01–0.1	0.04	0.01–0.09
Southern royal albatross	0.02	0.01–0.05	**0.05**	0.02–0.13	0.02	0.01–0.05	0.02	0.01–0.06	0.02	0.01–0.06
Snares Cape petrel	0.01	0–0.06	**0.02**	0–0.14	0	0–0.01	0.01	0–0.09	0.01	0–0.09
Little black shag	0.01	0–0.04	0.01	0–0.05	0.01	0–0.04	0.01	0–0.06	0.01	0–0.06
Pied shag	0.01	0–0.03	0.01	0–0.03	0.01	0–0.03	0.01	0–0.03	0.01	0–0.04
Grey-faced petrel	0	0–0.01	0.01	0–0.02	0	0–0.01	0.01	0–0.01	0	0–0.01
Fluttering shearwater	0	0–0.01	0.01	0–0.02	0	0–0.01	0.01	0–0.02	0	0–0.02
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Light-mantled sooty albatross	0	0–0.02	0	0–0.04	0	0–0.01	0	0–0.02	0	0–0.02
Fiordland crested penguin	0	0–0.04	0	0–0.06	0	0–0.05	0	0–0.06	0	0–0.05
Sooty shearwater	0	0–0.01	0	0–0.01	0	0–0	0	0–0.01	0	0–0.01
Grey-headed albatross	0	0–0.03	0	0–0.05	0	0–0.02	0	0–0.04	0	0–0.03
Common diving petrel	0	0–0.01	0.01	0–0.05	0	0–0	0	0–0.02	0	0–0.01
Hutton's shearwater	0	0–0.01	0	0–0.01	0	0–0	0	0–0.01	0	0–0.01
Cook's petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Northern little penguin	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Pycroft's petrel	0	0–0	0	0–0.01	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0.01	0	0–0	0	0–0.01	0	0–0.01
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Little shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Fairy prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-flippered little penguin	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Antarctic prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Broad-billed prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0.01	0	0–0.01	0	0–0	0	0–0.01	0	0–0.01
Chatham Island shag	0	0–0.04	0	0–0.05	0	0–0.04	0	0–0.04	0	0–0.04
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
South Georgian diving petrel	0	0–0.07	**0**	0–0.24	0	0–0	**0**	0–0.14	0	0–0
NZ king shag	0	0–0.07	0	0–0.09	0	0–0.08	0	0–0.08	**0**	0–0.12
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0.04	0	0–0.09	0	0–0	**0**	0–0.12	0	0–0.05
Pitt Island shag	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.03
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0

Table G-37: [Continued]

Species	Without allometric relationship		Previous demography and groups		No APF constraint		No live captures		2015 black petrel map	
	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.
Black petrel	**1.45**	0.62–2.62	**1.23**	0.53–2.27	**1.31**	0.55–3.2	**1.4**	0.69–2.16	**1.26**	0.56–2.09
Salvin’s albatross	**1.08**	0.7–1.55	**0.88**	0.58–1.24	**0.9**	0.55–1.41	**0.86**	0.57–1.17	**0.78**	0.51–1.1
Flesh-footed shearwater	**0.8**	0.43–1.52	**0.73**	0.36–1.28	**0.72**	0.4–1.41	**0.82**	0.49–1.31	**0.66**	0.39–1.16
Southern Buller’s albatross	**0.54**	0.3–0.93	**0.45**	0.25–0.74	**0.41**	0.22–0.7	**0.46**	0.26–0.74	**0.39**	0.22–0.67
Westland petrel	**0.5**	0.19–1.28	**0.4**	0.14–1.29	**0.53**	0.19–1.81	**0.53**	0.21–1.2	**0.46**	0.18–1.16
Gibson’s albatross	**0.35**	0.18–0.65	**0.34**	0.18–0.58	**0.34**	0.19–0.59	**0.41**	0.24–0.67	**0.34**	0.18–0.58
NZ white-capped albatross	**0.45**	0.28–0.74	**0.4**	0.23–0.66	**0.37**	0.22–0.6	**0.38**	0.23–0.62	**0.35**	0.21–0.56
Chatham Island albatross	**0.5**	0.25–0.93	**0.37**	0.18–0.67	**0.37**	0.19–0.71	**0.37**	0.19–0.66	**0.36**	0.18–0.65
Northern Buller’s albatross	**0.34**	0.19–0.59	**0.26**	0.15–0.43	**0.26**	0.14–0.42	**0.27**	0.16–0.45	**0.25**	0.14–0.41
Antipodean albatross	**0.2**	0.11–0.35	**0.2**	0.11–0.36	**0.2**	0.11–0.36	**0.24**	0.14–0.42	**0.2**	0.11–0.35
Yellow-eyed penguin (mainland)	**0.13**	0.05–0.3	**0.17**	0.06–0.4	**0.18**	0.06–0.45	**0.18**	0.06–0.45	**0.18**	0.06–0.44
Otago shag	**0.18**	0.1–0.31	**0.17**	0.09–0.32	**0.15**	0.07–0.27	**0.14**	0.07–0.28	**0.14**	0.07–0.27
Northern giant petrel	**0.09**	0.02–0.32	**0.14**	0.03–0.53	**0.15**	0.04–0.48	**0.2**	0.05–0.61	**0.14**	0.03–0.45
Spotted shag	**0.08**	0.03–0.17	**0.1**	0.04–0.21	**0.09**	0.04–0.2	**0.09**	0.04–0.2	**0.09**	0.04–0.2
Campbell black-browed albatross	**0.08**	0.04–0.18	**0.08**	0.03–0.2	**0.08**	0.03–0.2	**0.08**	0.04–0.2	**0.08**	0.03–0.18
Yellow-eyed penguin	**0.05**	0.02–0.13	**0.06**	0.02–0.14	**0.08**	0.02–0.19	**0.08**	0.03–0.19	**0.08**	0.03–0.19
White-chinned petrel	0.05	0.03–0.09	**0.08**	0.04–0.17	0.06	0.03–0.09	0.06	0.04–0.1	0.05	0.03–0.09
Northern royal albatross	**0.03**	0.01–0.13	**0.05**	0.01–0.17	**0.04**	0.01–0.16	**0.05**	0.01–0.18	**0.04**	0.01–0.15
Grey petrel	0.04	0.02–0.08	0.03	0.02–0.07	0.04	0.02–0.08	0.04	0.02–0.08	0.04	0.02–0.08
Foveaux shag	0.05	0.01–0.1	0.04	0.01–0.1	0.04	0.01–0.08	0.04	0.01–0.08	0.04	0.01–0.08
Southern royal albatross	0.02	0.01–0.04	0.02	0.01–0.05	0.02	0.01–0.05	0.02	0.01–0.06	0.02	0.01–0.05
Snares Cape petrel	0.01	0–0.05	0.01	0–0.07	0.01	0–0.06	0.01	0–0.06	0.01	0–0.06
Little black shag	0.01	0–0.04	0.01	0–0.04	0.01	0–0.05	0.01	0–0.04	0.01	0–0.05
Pied shag	0.01	0–0.03	0.01	0–0.03	0.01	0–0.03	0.01	0–0.03	0.01	0–0.03
Grey-faced petrel	0.01	0–0.02	0.01	0–0.03	0	0–0.01	0.01	0–0.01	0	0–0.01
Fluttering shearwater	0	0–0.01	0.01	0–0.04	0	0–0.01	0	0–0.01	0	0–0.01
Chatham petrel	0	0–0	0	0–0.05	0	0–0	0	0–0	0	0–0
Light-mantled sooty albatross	0	0–0.03	0	0–0.02	0	0–0.02	0	0–0.02	0	0–0.02
Fiordland crested penguin	0	0–0.04	0	0–0.03	0	0–0.03	0	0–0.04	0	0–0.03
Sooty shearwater	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Grey-headed albatross	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.02
Common diving petrel	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.02	0	0–0.01
Hutton’s shearwater	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Cook’s petrel	0	0–0	0.01	0–0.04	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–0.01	0	0–0	0	0–0	0	0–0	0	0–0
Northern little penguin	0	0–0	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Pycroft’s petrel	0	0–0.01	0	0–0.02	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0.01	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0	0	0–0	0	0–0.01	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0.01	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller’s shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Little shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Fairy prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-flippered little penguin	0	0–0	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Antarctic prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Broad-billed prion	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Chatham Island shag	0	0–0.05	0	0–0.05	0	0–0.04	0	0–0.04	0	0–0.04
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
South Georgian diving petrel	0	0–0.03	0	0–0	0	0–0.08	0	0–0.09	0	0–0
NZ king shag	0	0–0.09	**0**	0–0.1	0	0–0.08	0	0–0.07	0	0–0.08
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0.07	0	0–0.04	0	0–0.04	0	0–0.06	0	0–0.04
Pitt Island shag	0	0–0.04	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.03
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0

Table G-37: [Continued]

Species	Constant vulnerability	
	Median	95% c.i.
Black petrel	**1.15**	0.5–2.05
Salvin’s albatross	**0.77**	0.49–1.08
Flesh-footed shearwater	**0.66**	0.38–1.17
Southern Buller’s albatross	**0.37**	0.21–0.64
Westland petrel	**0.46**	0.17–1.18
Gibson’s albatross	**0.33**	0.18–0.58
NZ white-capped albatross	**0.35**	0.2–0.56
Chatham Island albatross	**0.35**	0.18–0.64
Northern Buller’s albatross	**0.25**	0.14–0.4
Antipodean albatross	**0.2**	0.11–0.36
Yellow-eyed penguin (mainland)	**0.18**	0.06–0.43
Otago shag	**0.14**	0.07–0.28
Northern giant petrel	**0.13**	0.03–0.46
Spotted shag	**0.09**	0.04–0.21
Campbell black-browed albatross	**0.07**	0.03–0.18
Yellow-eyed penguin	**0.08**	0.03–0.18
White-chinned petrel	0.05	0.03–0.09
Northern royal albatross	**0.04**	0.01–0.16
Grey petrel	0.04	0.02–0.08
Foveaux shag	0.04	0.01–0.08
Southern royal albatross	0.02	0.01–0.05
Snares Cape petrel	0.01	0–0.05
Little black shag	0.01	0–0.04
Pied shag	0.01	0–0.03
Grey-faced petrel	0	0–0.01
Fluttering shearwater	0	0–0.01
Chatham petrel	0	0–0
Light-mantled sooty albatross	0	0–0.02
Fiordland crested penguin	0	0–0.03
Sooty shearwater	0	0–0.01
Grey-headed albatross	0	0–0.02
Common diving petrel	0	0–0.01
Hutton’s shearwater	0	0–0.01
Cook’s petrel	0	0–0
Australasian gannet	0	0–0
Northern little penguin	0	0–0.01
Pycroft’s petrel	0	0–0
White-headed petrel	0	0–0
Mottled petrel	0	0–0
Southern little penguin	0	0–0
Soft-plumaged petrel	0	0–0
NZ white-faced storm petrel	0	0–0
Buller’s shearwater	0	0–0
Southern black-backed gull	0	0–0
Little shearwater	0	0–0
Fairy prion	0	0–0
Black-bellied storm petrel	0	0–0
White-flippered little penguin	0	0–0.01
Antarctic prion	0	0–0
Broad-billed prion	0	0–0
Snares crested penguin	0	0–0
Chatham Island little penguin	0	0–0
Eastern rockhopper penguin	0	0–0
Erect-crested penguin	0	0–0
Auckland Island shag	0	0–0
Bounty Island shag	0	0–0
Subantarctic skua	0	0–0
Caspian tern	0	0–0.01
Chatham Island shag	0	0–0.03
Campbell Island shag	0	0–0
White-bellied storm petrel	0	0–0
White tern	0	0–0
South Georgian diving petrel	0	0–0
NZ king shag	0	0–0.08
Kerm. storm petrel	0	0–0
Masked booby	0	0–0
NZ storm petrel	0	0–0.03
Pitt Island shag	0	0–0.02
Chatham Island taiko	0	0–0
Wedge-tailed shearwater	0	0–0
Kerm. petrel	0	0–0
White-naped petrel	0	0–0

G.8 Sensitivities

Table G-38: Comparison of risk ratios between model versions used to estimate the risk of commercial fisheries to seabirds, based on different data. New base case is the current model including all updates, compared with the current model including data to 2010–11 only, recent population data for yellow-eyed penguin (YEP), or recent New Zealand population data for black petrel (BPE; Bell et al. 2016a, Bell et al. (2016b)). Cells were coloured according to the associated risk category as defined in the "National Plan of Action – 2013 to reduce the incidental catch of seabirds in New Zealand fisheries" (Ministry for Primary Industries 2013): Red: very high risk; dark orange: high risk; light orange: medium risk; yellow: low risk. Numbers were rounded to three significant digits.

Species	New base case		Data up to 2010–11		Recent data YEP		Recent data BPE	
	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.	Median	95% c.i.
Black petrel	**1.15**	0.51–2.03	**1.51**	0.73–2.27	**1.16**	0.5–2.05	**2.11**	1.63–2.58
Salvin's albatross	**0.78**	0.51–1.09	**0.88**	0.58–1.22	**0.78**	0.52–1.1	**0.78**	0.51–1.1
Flesh-footed shearwater	**0.67**	0.39–1.15	**0.44**	0.23–1.01	**0.67**	0.39–1.2	**0.61**	0.36–1.08
Southern Buller's albatross	**0.39**	0.22–0.66	**0.34**	0.18–0.59	**0.39**	0.21–0.66	**0.39**	0.21–0.66
Westland petrel	**0.48**	0.18–1.19	**0.24**	0.08–0.72	**0.49**	0.18–1.19	**0.42**	0.16–1.09
Gibson's albatross	**0.34**	0.19–0.59	**0.26**	0.14–0.45	**0.34**	0.18–0.58	**0.33**	0.18–0.57
NZ white-capped albatross	**0.35**	0.21–0.58	**0.32**	0.19–0.56	**0.35**	0.21–0.57	**0.36**	0.22–0.58
Chatham Island albatross	**0.36**	0.18–0.66	**0.4**	0.2–0.72	**0.36**	0.19–0.65	**0.35**	0.18–0.66
Northern Buller's albatross	**0.25**	0.14–0.41	**0.25**	0.14–0.41	**0.25**	0.14–0.4	**0.24**	0.14–0.41
Antipodean albatross	**0.2**	0.11–0.36	**0.2**	0.11–0.34	**0.2**	0.11–0.35	**0.19**	0.11–0.35
Yellow-eyed penguin (mainland)	**0.18**	0.07–0.45	**0.24**	0.09–0.61	**0.36**	0.12–0.9	**0.18**	0.06–0.43
Otago shag	**0.14**	0.07–0.28	**0.21**	0.1–0.39	**0.14**	0.07–0.28	**0.15**	0.07–0.28
Northern giant petrel	**0.14**	0.03–0.47	**0.12**	0.02–0.42	**0.14**	0.03–0.44	**0.14**	0.03–0.43
Spotted shag	**0.09**	0.04–0.2	**0.15**	0.07–0.33	**0.09**	0.04–0.2	**0.1**	0.04–0.21
Campbell black-browed albatross	**0.08**	0.04–0.18	**0.09**	0.04–0.25	**0.08**	0.03–0.19	**0.08**	0.03–0.18
Yellow-eyed penguin	**0.08**	0.03–0.19	**0.1**	0.04–0.25	**0.09**	0.03–0.23	**0.08**	0.03–0.18
White-chinned petrel	0.05	0.03–0.09	0.04	0.02–0.07	0.05	0.03–0.09	0.05	0.03–0.09
Northern royal albatross	**0.04**	0.01–0.16	0.01	0–0.05	**0.04**	0.01–0.16	**0.04**	0.01–0.15
Grey petrel	0.04	0.02–0.08	0.04	0.02–0.09	0.04	0.02–0.08	0.04	0.02–0.07
Foveaux shag	0.04	0.01–0.08	**0.05**	0.02–0.11	0.04	0.01–0.08	0.04	0.01–0.08
Southern royal albatross	0.02	0.01–0.05	0.01	0–0.02	0.02	0.01–0.05	0.02	0.01–0.05
Snares Cape petrel	0.01	0–0.06	0	0–0.02	0.01	0–0.06	0.01	0–0.06
Little black shag	0.01	0–0.04	0.01	0–0.07	0.01	0–0.04	0.01	0–0.04
Pied shag	0.01	0–0.03	0.01	0–0.05	0.01	0–0.03	0.01	0–0.03
Grey-faced petrel	0	0–0.01	0.01	0–0.01	0	0–0.01	0	0–0.01
Fluttering shearwater	0	0–0.01	0	0–0.02	0	0–0.01	0	0–0.01
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0
Light-mantled sooty albatross	0	0–0.02	0	0–0.02	0	0–0.02	0	0–0.02
Fiordland crested penguin	0	0–0.04	0	0–0.04	0	0–0.04	0	0–0.04
Sooty shearwater	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Grey-headed albatross	0	0–0.03	0	0–0.03	0	0–0.02	0	0–0.02
Common diving petrel	0	0–0.01	0	0–0	0	0–0.01	0	0–0.01
Hutton's shearwater	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Cook's petrel	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–0	0	0–0.01	0	0–0	0	0–0
Northern little penguin	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–0	0	0–0	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–0.01	0	0–0	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	0	0–0	0	0–0	0	0–0	0	0–0
Little shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Fairy prion	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
White-flippered little penguin	0	0–0.01	0	0–0.01	0	0–0.01	0	0–0.01
Antarctic prion	0	0–0	0	0–0	0	0–0	0	0–0
Broad-billed prion	0	0–0	0	0–0	0	0–0	0	0–0
Snares crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0
Eastern rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0.01	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0.01	0	0–0	0	0–0	0	0–0.01
Chatham Island shag	0	0–0.04	0	0–0.04	0	0–0.04	0	0–0.04
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
White tern	0	0–0	0	0–0	0	0–0	0	0–0
South Georgian diving petrel	0	0–0.07	0	0–0	0	0–0.07	0	0–0.08
NZ king shag	0	0–0.07	**0**	0–0.13	0	0–0.08	0	0–0.07
Kerm. storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0.04	0	0–0.04	0	0–0.04	0	0–0.04
Pitt Island shag	0	0–0.03	0	0–0.03	0	0–0.03	0	0–0.02
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0