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Risk of commercial fisheries to New Zealand seabird populations

New Zealand Aquatic Environment and Biodiversity Report No. 109

Y Richard Y, ER Abraham

Ministry for Primary Industries
Manatū Ahu Matua

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Y. Richard,
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EXECUTIVE SUMMARY

Richard Y.; Abraham, E.R. (2013). Risk of commercial fisheries to New Zealand seabird populations.

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This report presents a risk assessment of the effect of fishing-related mortalities on 70 of the seabird species that breed in the New Zealand region. The assessment covers all fishing by commercial trawl, bottom-longline, surface-longline, and set-net fisheries within New Zealand's Exclusive Economic Zone. The risk was defined as the ratio of the estimated annual number of fatalities of birds due to bycatch in fisheries to the Potential Biological Removal (PBR), which is an estimate of the number of seabirds that may be killed without causing the population to decline below half the carrying capacity. The risk ratio for each seabird species is an estimate of the ratio between the number of fatalities due to fisheries bycatch, and the PBR.

When estimating the PBR for each species, a recovery factor, f, should be specified. This recovery factor is typically between 0.1 and 0.5. It allows some protection against errors in estimating the PBR, and a lower value allows for a shorter recovery time for depleted populations. In this report, the risk ratio is calculated using PBR_1: the value of the PBR calculated with $f = 1$. The values of the recovery factor for each species will be specified at a later stage. When interpreting the risk ratio, it should be borne in mind that species with risk ratios less than one may still be considered at risk, depending on the value of the recovery factor.

Estimation of annual fatalities was based on seabird captures reported by observers between the 2006–07 and 2010–11 fishing years. From these captures, the total observable captures were estimated (the number of seabird captures that would have been reported had an observer been on every fishing vessel). Not all seabirds that are killed are brought on-board vessels, and the observable captures were multiplied by a factor to account for these cryptic mortalities. The cryptic multiplier varied between 1.30 and 8.66, depending on fishing method and seabird species.

This study replaces a previous seabird risk assessment that used a similar methodology. Demographic parameters and distributions were updated for some species, the methods used for estimating observable captures were changed, and calculation of the PBR was modified to include an additional calibration factor. Because of the number of methodological changes that were made, changes in risk between the two assessments should not be taken as being due to changes in the fisheries.

In total, there were 15 100 (95% c.i.: 13 600 – 16 600) estimated annual potential seabird fatalities across the four fishing methods. The highest number of annual potential fatalities were in trawl fisheries with 9870 (95% c.i.: 8560 – 11 300) estimated annual potential fatalities. There were a total of 3560 (95% c.i.: 3040 – 4150) annual potential fatalities in bottom-longline fisheries. Captures in surface-longline fisheries were lower, with a total of 1340 (95% c.i.: 1170 – 1570) annual potential fatalities of all seabirds. The estimated fatalities in set-net fisheries were relatively low, with a total of 317 (95% c.i.: 228 – 460) annual potential fatalities of all species. The estimates of these annual potential fatalities depend strongly on the assumptions that were made about the extent of the cryptic mortalities.

Six species had a median risk ratio above 1 or an upper 95% confidence limit above 2 and may be considered as at "Very high risk": black petrel, Salvin's albatross, flesh-footed shearwater, southern Buller's albatross, Chatham Island albatross, and New Zealand white-capped albatross. The risk ratio of black petrel was especially large, with a median of 19.9 (95% c.i.: 11.4 – 32.8), due to the combination of a high number of estimated annual potential fatalities (mean 1440; 95% c.i.: 1070 – 1900), and a low

PBR_1 (mean 74; 95% c.i.: 47 – 117). Fatalities of the species with high risk ratios were mainly in poorly observed small-vessel fisheries.

Four species had a median risk ratio above 0.3 or an upper 95% confidence limit above 1, and may be considered as at "High risk": northern Buller's albatross, Gibson's albatross, Cape petrel, and Antipodean albatross. Nine species had a median risk ratio above 0.1 or an upper 95% confidence limit above 0.3 ("Medium risk"), and another seven had an upper 95% confidence limit above 0.1 ("Low risk"). Among the 70 considered species, 45 had the upper 95% confidence limit of their risk ratio below 0.1, suggesting that commercial fisheries in New Zealand waters are unlikely to significantly impact the demography of these species.

The risk assessment methodology is not yet mature, and further improvements may be made in the future. Possible improvements include a better specification of the cryptic mortality. This improvement would require collection of data on cryptic mortality in New Zealand fisheries. While these kinds of data are difficult to collect, poor knowledge of cryptic mortality restricts understanding of the impacts of fisheries on seabird populations. For some species, the assessment could be extended to include fatalities in global fisheries, and to include broader impacts, such as bycatch in recreational fisheries. The risk assessment requires adequate observer data, and in small-vessel fisheries observer coverage remains low. Increasing observer coverage in these fisheries would greatly reduce the uncertainty associated with the current estimates of risk.

1. INTRODUCTION

Several studies have been carried out in recent years to assess the risk of commercial fisheries to seabirds that breed in the New Zealand region (Waugh et al. 2009, Rowe 2010, Dillingham & Fletcher 2011, Richard et al. 2011). The goal of these studies has been the identification of species whose populations may be adversely affected by fishing-related mortalities. A recently developed method for quantifying the risk to seabird populations from fishing compares the Potential Biological Removal (PBR; Wade 1998) to an estimate of fishing-related mortalities (Sharp et al. 2011). The PBR index (Wade 1998) 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.

For seabirds, the PBR may be estimated from simple demographic parameters (Dillingham & Fletcher 2011, Richard et al. 2011). Richard & Abraham (2013) recently showed that the PBR is typically overestimated, and recommended that an additional calibration factor, ρ, is included in the calculation of the PBR. This calibration corrects the approximations used in estimating the PBR. The calibration factor is required to adjust the estimated PBR, so that populations experiencing annual human-caused mortality at or below the PBR level will meet the management criterion of being able to remain above half the carrying capacity. The calibration factor varied between 0.17 and 0.61, depending on the seabird type. Calculation of the PBR for a seabird species requires specification of the recovery factor, f. This factor, with values typically between 0.1 and 0.5, protects against errors in the demographic estimates used to calculate the PBR, with lower values allowing for shorter recovery times. In this report, the recovery factor was set to $f = 1$, and appropriate values for each species will be determined at a later stage.

This report presents a risk assessment that was carried out for most of the seabird species that breed in the New Zealand region. The assessment followed the risk assessment framework initially developed by Sharp et al. (2011). In this report, the risk was defined as the ratio of the estimated annual number of bird fatalities due to fisheries bycatch to PBR_1, where PBR_1 is the PBR with $f = 1$. Accordingly, the risk ratio (RR) is expressed as the ratio of the annual potential fatalities (APF) to PBR_1:

$$\text{RR} = \text{APF}/\text{PBR}_1, \tag{1}$$

where the fatalities are from trawl, longline, and set-net fisheries within New Zealand's Exclusive Economic Zone. 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 included in captures reported by fisheries observers. The phrase "potential fatalities" is used to indicate the inherent uncertainty associated with estimating the cryptic fatalities.

A risk ratio larger than 1 indicates that the fishing-related fatalities in commercial fisheries exceed PBR_1, and the population will be at risk of not being able to remain above half its carrying capacity, regardless of the value chosen for the recovery factor. In contrast, a ratio less than 0.1 indicates that fishing-related fatalities may not be significantly impacting the population. For species with risk ratios between 0.1 and 1, an assessment of the risk will depend upon the choice of a value for the recovery factor.

This report presents an update of the assessment carried out by Richard et al. (2011), with several important modifications:

1. The assessment was extended to include additional seabird species: fluttering shearwater *Puffinus gavia*, little black shag *Phalacrocorax sulcirostris*, pied shag *Phalacrocorax varius varius*, and little blue penguin *Eudyptula minor*. Inclusion of the latter species encompassed four races of little penguin (northern, southern, white-flippered, and Chatham Island). In contrast, black-browed

albatross *Thalassarche melanophrys* was omitted from the assessment, due to the small number of pairs that breed in the New Zealand region. These amendments resulted in an increase in the number of populations assessed from 64 to 70.

2. The calculation of the PBR was modified to include the calibration factor, ρ.
3. The risk ratio was calculated using a PBR with $f = 1$.
4. Captures were estimated using a single model, so that the vulnerability was a product of a fisheries-related vulnerability and a species-group specific vulnerability.
5. Breeding and non-breeding bird distributions were considered to account for the seasonality in the distribution of species and fisheries.
6. Multipliers to account for cryptic mortality were re-calculated to include uncertainty in their estimation.
7. Captures were estimated using bycatch data from the period between 2006–07 and 2010–11.
8. Set-net fisheries were included.
9. Population sizes were updated for 14 species, and age at first reproduction, survival and the proportion of adults breeding was updated for 5 albatross species.
10. Spatial distributions were improved for 13 species.

This risk assessment is accompanied by another report that outlines the methodology for calculating the PBR (Richard & Abraham 2013), and supplementary information that provides detailed information on the demographic parameters and the distribution at sea used for the 70 seabird species included in the assessment. Due to the size of the supplementary information, it is produced as a separate document.

2. METHODS

2.1 Potential Biological Removal

The PBR may be estimated using the following expression (Richard & Abraham 2013):

$$\mathrm{PBR} = \frac{1}{2}\rho r_{\max}^{NL} N_{\min}^{G} f, \tag{2}$$

where ρ is a calibration factor (where ρ is between 0.17 and 0.61, depending on species type); $r_{\max}^{NL}$ is an estimate of the maximum growth rate, under optimal conditions (calculated following Niel & Lebreton (2005)); $N_{\min}^{G}$ is an estimate of the population size, calculated from a conservative estimate of the number of breeding pairs $N_{BP_{\min}}$ (Gilbert 2009); and f is a recovery factor designed so that the PBR is conservatively estimated, and so that populations can recover from a depleted state more rapidly.

The methods for calculating the PBR are detailed in Richard & Abraham (2013). The calculation of $r_{\max}^{NL}$ and $N_{\min}^{G}$ requires estimates of the adult survival, S; the age at first reproduction, A; the proportion of adults breeding in a year, P_B; and the number of breeding pairs $N_{\mathrm{BP}_{\min}}$. The growth rate is estimated by solving the following expressions (Niel & Lebreton 2005):

$$\lambda_{\max}^{NL} = \exp\left[\left(A + \frac{S_A}{\lambda_{\max}^{NL} - S_A}\right)^{-1}\right] \tag{3}$$

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

and the total population size may be estimated as follows (Gilbert 2009, Richard et al. 2011):

$$N^G = \frac{2N_{\text{BP}_{\text{min}}}}{P_B} S_A^{1-A}. \tag{5}$$

When calculating the PBR, uncertainty in the input parameters is carried through the calculation, so that the uncertainty in the risk ratio may also be calculated. To ensure that the population size used in calculating the PBR is conservative, the lower quartile of the distribution of breeding pairs was used ($N_{\text{BP}_{\text{min}}}$).

The calibration factor, ρ, is necessary to correct the approximations in the calculation of the maximum growth rate and total population size, and to ensure that the population goals are met in the presence of environmental stochasticity. The appropriate value for ρ depends on the species type (Table 1, Table 2).

Setting the recovery factor f for each species requires careful consideration of potential biases in the demographic estimates. For instance, when r^{NL}_{max} is calculated following Niel & Lebreton (2005), it may be overestimated if survival rates estimated from field data include a significant level of human-caused mortality, or if density-dependent factors lead to estimated survival rates markedly lower than the intrinsic natural survival. Setting f also needs to reflect management goals, as a more conservative approach and faster recovery rates may be desirable for threatened species. Richard & Abraham (2013) provide guidance on how to set f values in relation to different biases and according to desired recovery times. A recovery factor of 0.5 has been suggested as sufficient to allow for some bias in the demographic estimates (Wade 1998, Richard & Abraham 2013), and is the maximum value used in other risk assessment studies (e.g., Dillingham & Fletcher 2011, Richard et al. 2011). A recovery factor of $f = 0.1$ is the minimum value generally used in risk assessment studies. For the present study, determination of the f value for each species will be subsequently decided.

In the absence of definitive f values, the risk ratio was calculated with the recovery factor set at 1. Setting the recovery factor to $f = 1$ corresponds with the most optimistic scenario, when the demographic parameters are known to be accurate, and the population dynamics follow a logistic growth. In this case, risk ratios above 1 indicate that fisheries-induced fatalities are likely to exceed the ability of the population to remain above half its carrying capacity.

2.1.1 Data collation

Preparation of the previous seabird risk assessment (Richard et al. 2011) involved an extensive literature search for published estimates of the number of annual breeding pairs, the proportion of adults breeding in any given year, the annual adult survival rate, and the age at first reproduction for the seabird species concerned. The main sources of information were in the primary literature; published books on seabirds; grey literature; and 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). The current risk assessment followed the methods by Richard et al. (2011), and most of the parameters used were from this previous assessment. Where demographic estimates were not available, values from proxy species were used instead.

The chosen demographic parameters for the 70 study species are detailed in the supplementary information, including their associated uncertainty (if any), reference to their origin, and whether proxy species were used. A summary of the input demographic parameters used to calculate the maximum population growth rate, r^{NL}_{max}, and the total population size, N^G, is presented in Table A-1 of Appendix A. A summary of the estimated r^{NL}_{max} and total population size N^G for the calculation of the PBR for each species is presented in Table A-2 of Appendix A.

Table 1: Values for the calibration factor, ρ, for different species types, used for correcting the approximate calculation of the Potential Biological Removal (Richard & Abraham 2012a). (See Table 2 for the assignment of species to each species type.)

Species type	ρ
Antipodean albatross	0.37
Grey-headed albatross	0.43
Giant petrel	0.34
Black petrel	0.33
Flesh-footed shearwater	0.41
Fairy prion	0.32
Common diving petrel	0.17
Storm petrel	0.30
Erect-crested penguin	0.50
Yellow-eyed penguin	0.55
Shag	0.57
Caspian tern	0.61

In the current assessment, data on the population size were updated for 14 species (Table 3). A recent study on southern Buller's albatross provided new estimates of age at first reproduction, survival and proportion of adults breeding (Francis & Sagar 2012), which were also used for northern Buller's albatross. The age at first reproduction of this species was also used for white-capped, Salvin's, and Chatham Island albatrosses. Annual survival of Salvin's albatross was updated based on a recent study (Sagar et al. 2011), and was used as proxy for Chatham Island albatross. All other demographic parameters used here were the same as in Richard et al. (2011).

For the species (and the races of little blue penguin) that were new to this study, demographic parameters, such as estimates of the number of breeding pairs, were sourced following the methods in Richard et al. (2011).

The seabird taxonomy followed the recommendations of the Ornithological Society of New Zealand (Ornithological Society of New Zealand checklist committee 2010).

2.1.2 Uncertainties

Every estimate contains some level of uncertainty, which is often large. As seabird data are collected from colonies that are often remote and difficult to access, regular monitoring of a sufficient proportion of the total population is rare. 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, the PBR was calculated from samples of distributions of the parameters. This approach allowed for uncertainty in the risk ratio to be derived. For this purpose, every demographic estimate was assigned a standard deviation (s.d.), or a range when necessary, to match the uncertainties typically reported in the literature.

We assigned an index of quality (poor, medium, or high) 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

Table 2: Assignment of species to the species types (see Richard & Abraham (2013)) that were used to select a value for the correction factor ρ in the approximation of the Potential Biological Removal (see ρ values in Table 1).

Species	Species type
Gibson's albatross	Antipodean albatross
Antipodean albatross	Antipodean albatross
Southern royal albatross	Antipodean albatross
Northern royal albatross	Antipodean albatross
Campbell black-browed albatross	Grey-headed albatross
New Zealand white-capped albatross	Grey-headed albatross
Salvin's albatross	Grey-headed albatross
Chatham Island albatross	Grey-headed albatross
Grey-headed albatross	Grey-headed albatross
Southern Buller's albatross	Grey-headed albatross
Northern Buller's albatross	Grey-headed albatross
Light-mantled sooty albatross	Antipodean albatross
Northern giant petrel	Giant petrel
Grey petrel	Black petrel
Black petrel	Black petrel
Westland petrel	Black petrel
White-chinned petrel	Black petrel
Flesh-footed shearwater	Flesh-footed shearwater
Wedge-tailed shearwater	Flesh-footed shearwater
Buller's shearwater	Flesh-footed shearwater
Sooty shearwater	Flesh-footed shearwater
Fluttering shearwater	Flesh-footed shearwater
Hutton's shearwater	Flesh-footed shearwater
Little shearwater	Fairy prion
Cape petrel	Fairy prion
Fairy prion	Fairy prion
Antarctic prion	Fairy prion
Broad-billed prion	Fairy prion
Pycroft's petrel	Fairy prion
Cook's petrel	Fairy prion
Chatham petrel	Fairy prion
Mottled petrel	Fairy prion
White-naped petrel	Flesh-footed shearwater
Kermadec petrel	Flesh-footed shearwater
Grey-faced petrel	Flesh-footed shearwater
Chatham Island taiko	Flesh-footed shearwater
White-headed petrel	Flesh-footed shearwater
Soft-plumaged petrel	Fairy prion
Common diving petrel	Common diving petrel
South Georgian diving petrel	Common diving petrel
New Zealand white-faced storm petrel	Storm petrel
White-bellied storm petrel	Storm petrel
Black-bellied storm petrel	Storm petrel
Kermadec storm petrel	Storm petrel
New Zealand storm petrel	Storm petrel
Yellow-eyed penguin	Yellow-eyed penguin
Northern little penguin	Erect-crested penguin
White-flippered little penguin	Erect-crested penguin
Southern little penguin	Erect-crested penguin
Chatham Island little penguin	Erect-crested penguin
Western rockhopper penguin	Erect-crested penguin
Fiordland crested penguin	Erect-crested penguin
Snares crested penguin	Erect-crested penguin
Erect-crested penguin	Erect-crested penguin
Australasian gannet	Shag
Masked booby	Shag
Pied shag	Shag
Little black shag	Shag
New Zealand king shag	Shag
Stewart Island shag	Shag
Chatham Island shag	Shag
Bounty Island shag	Shag
Auckland Island shag	Shag
Campbell Island shag	Shag
Spotted shag	Shag
Pitt Island shag	Shag
Subantarctic skua	Shag
Southern black-backed gull	Caspian tern
Caspian tern	Caspian tern
White tern	Caspian tern

Table 3: Seabird population sizes that were updated from Richard et al. (2011) and used to calculate the Potential Biological Removal.

Species	Richard et al. (2011)	This study	Reference
NZ white-capped albatross	74 229–75 545 pairs	77 000 pairs	Birdlife International (2012)
Stewart Island shag	5000–8000 pairs	1800–2000 pairs	Birdlife International (2012)
Chatham Island taiko	120–150 individuals	17 pairs	Birdlife International (2012)
Chatham petrel	500 individuals	250 pairs	Birdlife International (2012)
White-chinned petrel	Maximum of 210 000 pairs	168 725 pairs	Birdlife International (2012)
Black petrel	1750 pairs	1059 pairs	Bell et al. (2011)
Spotted shag	35 000–150 000 individuals	10 000–30 000 pairs	Taylor (2000a)
Masked booby	Maximum of 1200 pairs	240 pairs	Veitch et al. (2004)
NZ king shag	650 individuals	102–126 pairs	Birdlife International (2012)
White tern	Maximum of 50 pairs	60–100 pairs	Taylor (2000a)
Campbell Island shag	8000 individuals	2000 pairs	Birdlife International (2012)
Chatham Island shag	540 individuals	357 pairs	Birdlife International (2012)
Bounty Island shag	620 individuals	120 pairs	Birdlife International (2012)
Auckland Island shag	2000 individuals	Minimum of 1366 pairs	Birdlife International (2012)

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 ACAP. When quality assessment could not be made, the quality was assumed to be poor.

When no uncertainty was reported in the literature, survival estimates were given a standard deviation of 0.01, 0.02, or 0.03 for estimates of good, 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:

$$\text{s.d.}(\bar{S}) = \frac{\text{s.d.}(\text{logit}(\bar{S}))}{\bar{S}(1-\bar{S})} \tag{6}$$

Age at first reproduction and the number of breeding pairs are reported either as a minimum value only, a maximum only, a minimum and a mean, a mean and a maximum, or only 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 the minimum and the mean only were reported, the maximum was defined as the difference between twice the mean and the minimum. Similarly, when the maximum and the mean only 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, it was multiplied by 3 to obtain a maximum value. The minimum was also reduced to 70% of its reported value to consider 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 5 to get 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 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 good, 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 grooming 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, the minimum and the maximum of the union of these ranges were taken; for multiple means and standard deviations, pairs of minima and maxima were created by taking the lower and upper limits of the confidence intervals (c.i.), defined as the mean ± 1.96 s.d., and by applying the previous rule.

A sample of 5000 values was calculated for each parameter and each species. 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.

2.2 Annual potential fatalities

2.2.1 Species distribution

Seabird spatial distribution maps were used for estimation of seabird captures. 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*, and white-capped albatross), 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 (*Fregetta* and New Zealand storm petrels, and masked booby). For the remaining species, two distribution maps were generated, with one map each for the breeding and non-breeding periods. This approach differed from the previous risk assessment (Richard et al. 2011), in which seasonality in the distribution of seabirds was not explicitly considered.

For seabird species with different seasonal distributions, two distribution layers were created, one for breeding birds and one for non-breeders. The density of breeders was assumed to decrease exponentially away from colonies. The location and size of colonies, and the exponential rate of decrease, were obtained from the literature (see Richard et al. 2011).

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 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 density maps by assigning a bird density to each layer. Following the choices used previously (Waugh et al. 2009, Richard et al. 2011), 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 summed to one across the region of the maps. Maps from Birdlife International are single-layer range maps, representing the range of a species at a global scale. Depending on the species, these maps were derived from at-sea observations, observer data and/or telemetry (GLS, GPS, Argos, and radio tracking). In these maps, the density of birds is equal to one within the species' range and equal to zero outside it. These maps were clipped to the latitude and longitude range used for the distributions, and normalised.

The distributions of breeders and non-breeders were normalised so the density summed to unity over the entire region. The distribution during the breeding season was obtained by adding the density of breeders and non-breeders, each multiplied by their relative population size. The latter was calculated from the ratios of the total population to the number of breeding pairs (N/N_{BP}; Table 4), estimated in Richard & Abraham (2013).

The number of breeders and non-breeders was a function of the number of annual breeding pairs using the following relationships:

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

where N^G is the total population size (see Equation 5), N_{BP} the number of annual breeding pairs, N_{B} the number of breeders, and N_{NB} the number of non-breeders.

For distributions outside the breeding season, the normalised density of non-breeders was multiplied by the total population size. Some migratory species leave New Zealand's Exclusive Economic Zone when they are not breeding, and their density for this non-breeding period was set to zero. These species included black petrel, Westland petrel, white-chinned petrel, flesh-footed shearwater, wedge-tailed shearwater, Buller's shearwater, sooty shearwater, Hutton's shearwater, Pycroft's petrel, Cook's petrel, Chatham petrel, mottled petrel, white-naped petrel, Chatham Island taiko, and New Zealand white-faced storm petrel.

New information, including expert knowledge, was incorporated into the distribution maps when it had become available since the previous assessment (Richard et al. 2011). Species for which distributions were amended were Gibson's and Antipodean albatrosses, Chatham albatross, Hutton's and

Table 4: Ratio of the total population N^G to the number of breeding pairs N_{BP} for various species types, based on the simulations of seabird population dynamics (Richard & Abraham 2013).

Species type	N^G/N_{BP}
Biennial breeding albatrosses	8.5
Partially biennial albatrosses	8.0
Annual breeding albatrosses	7.5
Biennial breeding petrels	6.0
Diving petrels	3.5
Other procellariiformes	5.0
Two-egg clutch size or more	5.0

fluttering shearwater, grey-faced petrel, king, spotted, Stewart, Pitt, Chatham and pied shags, and blue penguin. The distribution maps created for each species are available in the supplementary information accompanying this report.

2.2.2 Estimation of observable captures

The total number of captures was estimated using data on seabird captures reported by Ministry for Primary Industries observers. When they are on-board commercial fishing vessels, observers 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 the Ministry for Primary Industries. These data are currently housed in the Centralised Observer Database (COD). Extraction and grooming of fisheries and seabird capture data followed the methods described by Abraham et al. (2013), with data encompassing the period from 2006–07 to 2010–11. Non-fishing related captures, such as birds colliding with the superstructure of the vessels or landing on the deck, were identified by the capture method code and observer comments, and were excluded from the data set.

In addition to the observer data, fishing effort data were required for the estimation of total captures. Records of all fishing events made during commercial bottom-longline, surface-longline, trawl, and set-net fishing were obtained, covering the period from the 2006–07 to the 2010–11 fishing year. Data were extracted from the *warehou* database (Ministry of Fisheries 2008), 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 line sets for bottom- and surface-longline fisheries, and the net length (in metres) for set-net fisheries.

Fishing effort was assigned to fishery groups based on fisher-reported information (see Table 5), as in previous assessments (Waugh et al. 2009, Richard et al. 2011). 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 a processor or a fresher type; and if it was a processor type, whether or not it had a meal plant on board (as in Richard et al. 2011). The target species groups followed those defined in assessments of protected species bycatch (e.g., Abraham et al. 2010b), with the exception that trawl fishing targeting hoki, hake, and ling was included with trawl fishing targeting other middle-depth species. In addition, set-net fishing was also included here. For each fishery group, data on fishing effort, observer effort and observer coverage were collated for the assessment period between 2006–07 and 2010–11 (see data summary in Table 6).

The risk assessment was carried out for 70 distinct seabird species or populations (Table 7). As in Richard et al. (2011), seabirds were aggregated into species groups to improve the estimation of potential fatalities for species with small populations. Grouping species assumes that the species within the same group interacted similarly with fisheries. For shearwaters, *Procellaria* petrels, and albatrosses, different species groupings were used for set-net fisheries compared with other fisheries. Captures of these species were not frequently observed in set-net fisheries, and grouping them into broader groups helped to better constrain the estimated captures. The different groups used for set-net fisheries were: small albatrosses and giant petrel (*Thallassarche* and *Macronectes* species); great albatrosses (*Diomedea* and *Phoebetria* species); *Procellaria* petrels (*Procellaria* species); and shearwaters (*Puffinus* species).

The number of annual potential fatalities in Richard et al. (2011) was estimated independently for each species and fishery group, leading to poorly constrained estimates in strata when few fishing events were observed. Vulnerability to capture can be better constrained by recognising that it is a function of both the species group and the fishery type. Some species have a tendency to be more attracted to fishing vessels

Table 5: Fishery groups used for the assignment of fishing effort (SBW - southern blue whiting; SQU - squid; SCI - scampi; SNA - snapper).

Method	Fishery group	Description
Trawl	Small inshore	Targeting inshore species (other than flatfish), or targeting middle-depth species (principally hoki, hake, or ling) on vessels less than 28 m length.
	SBW	Targeting southern blue whiting.
	SCI	Targeting scampi.
	Mackerel	Targeting mackerel (primarily jack mackerel species).
	SQU	Targeting squid.
	Flatfish	Targeting flatfish species.
	Large trawler (no meal plant)	Targeting middle-depth species, vessel longer than 28 m, with freezer but without meal plant.
	Large trawler (with meal plant)	Targeting middle-depth species, vessel longer than 28 m, with freezer and meal plant.
	Large fresher	Targeting middle depth species, vessel longer than 28 m, with no processing on board, and so no freezer.
	Deepwater	Targeting deepwater species (principally orange roughy or oreos).
Bottom longline (BLL)	Bluenose	Targeting bluenose, and vessel less than 34 m.
	SNA	Targeting snapper, and vessel less than 34 m.
	Small	Not targeting snapper or bluenose, and vessel less than 34 m.
	Large	Vessel 34 m or longer.
Surface longline (SLL)	Small	Vessel less than 45 m long.
	Large	Vessel 45 m or longer.
Set net	Set net	All set-net fishing.

than others, 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 intercept) allows the estimation of vulnerability in poorly observed fisheries and/or for rare species to be informed by the vulnerability from better observed fisheries and/or common species. To reflect differences in operations relating to fishing gear types, and in the different units of fishing effort, a separate model was fitted for each method (trawl, bottom longline, surface longline, and set net).

For trawl, surface-longline, and bottom-longline methods, the model of observable captures for each fishing method was defined as:

$$C_{gs} \sim \text{Poisson}(\mu_{gs}) \quad (7)$$

$$\mu_{gs} = v_0 v_g v_s O_{gs} \varepsilon_{gs}, \quad (8)$$

where C_{gs} is the number of annual observable captures of the species group s in the fishery group g, μ_{gs} is the mean number of observable captures of species group s in the fishery group g, v_g is the overall vulnerability of seabirds in the fishery group g (reflecting that some fisheries tend to attract more birds than others), v_s is the vulnerability of the species group, s (reflecting that some birds have a tendency to be more attracted to fishing vessels than others). The overlap O_{gs} between the species group s and the fishery group g, is the product of the fishing effort and the bird density at each fishing event, summed over all fishing events, and ε_{gs} the error associated with the combination of species group, s, and the fishing group, g. The intercept, v_0, is taken as the vulnerability of white-chinned petrel in deepwater trawl fisheries for the trawl model, in large bottom-longline fisheries for the bottom-longline model, and in large surface-longline fisheries for the surface-longline model. The vulnerabilies v_s and v_g were fixed to 1 for this species and these fisheries taken as base cases. Vulnerabilities in other groups (species or fisheries) were expressed relative to these base cases.

Table 6: Summary of fishing effort and observer effort and coverage by fishery group for the period between 2006–07 and 2010–11 (SBW - southern blue whiting). Effort data include the number of tows (trawl fisheries), the number of sets (longline fisheries), and kilometres of net (set-net fisheries), and are not comparable between methods.

Method	Fishery group	Effort	Observed	Coverage (%)
Trawl	Small inshore	203 093	7 329	3.6
	SBW	4 920	1 677	34.1
	Scampi	22 609	2 173	9.6
	Mackerel	11 816	3 789	32.1
	Squid	22 009	6 357	28.9
	Flatfish	97 029	1 165	1.2
	Large processor	23 689	4 052	17.1
	Large meal	37 165	8 797	23.7
	Large fresher	10 863	839	7.7
	Deepwater	30 415	10 746	35.3
BLL	Bluenose	20 832	204	1.0
	Snapper	31 054	504	1.6
	Small	31 480	581	1.8
	Large	9 918	1 443	14.5
SLL	Small	11 953	832	7.0
	Large	1 104	854	77.4
Set net	Set net	110 212	1 612	1.5

The error, ε_{gs}, was defined as a random effect following a log-normal distribution with mean one and a gamma-distributed standard error, with a prior of rate and shape 0.001. The vulnerabilities v_g and v_s had a log-normal prior, with a mean 0 and standard deviation of 16 on the normal scale. These priors were defined to be vague, and re-running the models with different values showed that the impact of these choices on the posterior distribution of the parameters was minimal.

Because set-net fisheries were aggregated into a single fishery group, the mean number of captures in the model was simply

$$C_s \sim \text{Poisson}(\mu_s) \tag{9}$$

$$\mu_s = v_s O_s. \tag{10}$$

The vulnerability, v_s, had a uniformly distributed prior, with range 0 to 0.1, after verification that changing this upper bound had a minimal influence on the parameters' posterior distributions.

For each combination of species group and fishery group, the observed fishing events were aggregated by summing the observed captures and by summing the overlap over all fishing events. The model, run for each fishing method, was coded in the BUGS language (Spiegelhalter et al. 2003), and fitted using Markov Chain Monte Carlo (MCMC) methods with the software JAGS (Plummer 2005). A burn-in period of three million iterations was used, with the posterior samples taken from five million iterations, thinned by sampling every 500 values.

The models were assessed for convergence using the test of Heidelberger & Welch (1983), implemented in the CODA package for the R statistical analysis system (Plummer et al. 2006). The fit of the models to the data was assessed by testing whether the observed captures of each species in each fishery group fell within the credible intervals predicted by the models. The vulnerabilities were taken as samples of 5000 values from the posterior distribution of the models parameters. The number of observable captures was

Table 7: Species considered in the assessment of risk of commercial fisheries to seabirds breeding in New Zealand, and their grouping in the models for estimating their vulnerability in set nets and in other fisheries (trawling and longlining).

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

estimated in non-observed fishing events. This number represents the number of captures that would have been observed if observers had been present on all fishing vessels. The number of observable captures in the non-observed fishing events was calculated by applying the fitted models in Equations 7–10 to the non-observed overlap for each fishing method. The total annual number of observable captures was then obtained by adding the captures in observed fishing events to the estimated number of observable captures in the non-observed fishing events; this sum was then divided by five, the number of years covered by the data, to get the average annual number of observable captures.

The proportion of overlap observed for each species was calculated as the ratio of the total overlap at the observed fishing events (the product of the seabird density and the fishing effort, summed over the fishing events) to the total overlap at all fishing events. In many cases, the proportion of the overlap observed was low (less than 10%).

The data used for estimating the observable captures, i.e., the number of observed captures of each species and the proportion of overlap observed between the different species and fisheries, are summarised in Appendix A, Table A-3.

2.2.3 Potential seabird fatalities

Observer bycatch records may under-represent the total number of fishing-related seabird mortalities, as seabirds involved in fatal interactions with commercial fisheries may not necessarily be captured by fishers or recorded by observers. In longline fisheries, birds can become hooked during sets, but may not be retained when gear is hauled, so that they are not brought on-board the fishing vessel (Brothers et al. 2010). In trawl fisheries, birds may get caught in nets, but may also be fatally injured by the impact with trawl warps while flying ("aerial warp strike", *sensu* Sharp et al. 2011), or become entangled by warps on the water and subsequently drown ("surface warp strike"; Watkins et al. 2008). These cryptic mortalities are not included in the number of observable captures, so that the latter potentially underestimates the total number of fatalities.

There is limited information available to help quantify cryptic mortalities. For surface-longline fisheries, a 15-year study counted the number of seabirds that were caught when lines were set, and found that only half of the bodies, 85 of a total 176, were retrieved during line hauling (Brothers et al. 2010). For trawl fisheries, 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. Abraham (2010) provide estimates of the number of warp strikes per observed capture, using 7266 observations of warp strikes recorded in New Zealand trawl fisheries between the 2004–2005 and 2008–2009 fishing years.

From the values provided in these studies, cryptic mortality multipliers were calculated. These multipliers give the number of potential fatalities as a multiple of the number of observable captures. A summary of the cryptic mortality multipliers depending on the fishing method and species type is presented in Table 8, and details of their calculations in Appendix B. The estimation of cryptic mortality multipliers used by Richard et al. (2011) was revised to include uncertainty, and was updated with new data. The uncertainty is limited to statistical uncertainty from the underlying data sources and does not include uncertainty associated with extrapolating from results obtained in different fisheries, and in different jurisdictions.

There are no data available regarding cryptic mortality in bottom-longline fisheries, and we assumed the same amount of cryptic mortality in both surface- and bottom-longline fisheries. In trawl fisheries, the amount of cryptic mortality due to interactions with nets was based on expert knowledge, agreed at a

New Zealand National Plan of Action Risk Assessment workshop (held in February 2009). Because no data exist on cryptic mortality in set-net fisheries to allow for 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.

Table 8: Mean and 95% confidence interval of the number of potential seabird fatalities per observed capture in longline and trawl fisheries for each species type (Large: albatrosses, giant petrels, skuas; small fast-flying: large petrels and shearwaters; small slow-flying: small petrels, prions, storm petrels, diving petrels, small shearwaters; small diving: shags, penguins, gannets and boobies).

Fishery	Species type	Mean	95% c.i.
Bottom & surface longline	All	2.08	1.79–2.44
Trawl	Large	8.66	5.67–12.78
	Small fast-flying	3.78	1.91–7.87
	Small slow-flying	3.29	1.74–6.62
	Small diving	1.30	1.10–1.70

2.3 Sensitivity

In order to understand the relative importance of different sources of uncertainty in the risk ratio, a sensitivity analysis was carried out. For a range of input parameters, the sensitivity of uncertainty in the risk ratio was determined by setting the value of the parameter to its mean value. The resulting reduction in the 95% confidence interval of the risk ratio was then determined. Using this method the sensitivity to the uncertainty in the following parameters was determined: proportion of breeders (P_B); age at first breeding (A); adult survival (S_A); number of breeding pairs (N_{BP}); cryptic mortality multiplier; observable captures in set-net fisheries; observable captures in surface-longline fisheries; observable captures in bottom-longline fisheries; and observable captures in trawl fisheries.

3. RESULTS

3.1 Overall risk

Comparison of the estimated PBR, annual potential fatalities, and the resulting risk ratio across all species clearly identified those species that were most at risk (Table 9, Figure 1). There were two species with a probability of over 95% of the risk ratio exceeding 1 when the recovery factor f was set to 1, with black petrel having the highest risk ratio (median: 19.9; 95% c.i.: 11.4 – 32.8), followed by Salvin's albatross (median: 2.88; 95% c.i.: 1.47 – 5.41). The risk ratio of black petrel was particularly high, due to the high number of estimated annual potential fatalities (median: 1440; 95% c.i.: 1070 – 1900), paired with a relatively low PBR_1 (mean: 74; 95% c.i.: 47 – 117).

Another four species may be classified as at "Very high risk", having a risk ratio with a median above 1 or with the upper 95% confidence limit above 2: flesh-footed shearwater, southern Buller's albatross, Chatham Island albatross, and New Zealand white-capped albatross.

Four species had a median risk ratio above 0.3 or the upper 95% confidence limit above 1 and may be classified as at "High risk": northern Buller's albatross, Gibson's albatross, Cape petrel, and Antipodean albatross.

The risk ratio of nine species had a median above 0.1 or the upper 95% confidence limit above 0.3 and may be classified at “Medium risk”: northern and southern royal albatrosses, Westland petrel, northern giant petrel, white-chinned petrel, spotted shag, Campbell black-browed albatross, grey petrel, and the mainland population of yellow-eyed penguin (assuming that all fisheries-related mortalities are of the mainland population).

Another seven species had an upper 95% confidence limit of the risk ratio above 0.1 and may be classified as at “Low risk”: little black shag, yellow-eyed penguin (when merging the mainland population with the subantarctic one), Kermadec storm petrel, pied shag, Stewart Island shag, New Zealand king shag, and New Zealand storm petrel.

Of the 70 species considered, 45 species had an upper 95% confidence limit below 0.1. All these species, mostly small procellariiformes and coastal seabirds, had a probability of a risk ratio exceeding 1 of less than 5%, and the risk of commercial fisheries to these species in New Zealand may be considered as negligible. None of the four *Procellaria* petrels and only two of the 12 considered albatross species fell into this low-risk category.

The species with a mean of over 1000 annual potential fatalities were black petrel, Salvin’s albatross, white-chinned petrel, New Zealand white-capped albatross, and sooty shearwater. These species have all been frequently reported as bycatch by observers (Abraham et al. 2013, Ramm 2012).

Median risk ratios are presented in Table 9 and were used as the key indicator of risk. The median values are generally lower than the mean risk ratios (Figure 1; Table A-14, Appendix A), due to extended right-hand tails in the posterior distributions. In most cases, however, the mean and median values were similar.

3.2 Annual potential fatalities by fishery

Annual potential fatalities were estimated for each fishing method, and these estimates are presented in Appendix A, for trawl fisheries (Tables A-4, A-5), bottom-longline fisheries (Table A-6), and surface-longline fisheries (Table A-7). Estimates for set-net fisheries are included in the comparison across fishing methods (Table A-8).

In total, there were 15 100 (95% c.i.: 13 600 – 16 600) estimated annual potential seabird fatalities across the four fishing methods (Table A-8). The highest number of annual potential fatalities was in trawl fisheries with 9870 (95% c.i.: 8560 – 11 300) estimated seabird fatalities. These fatalities were mainly of albatross, *Procellaria* petrels, and large shearwater species. Species with over 1000 estimated fatalities in trawl fisheries were New Zealand white-capped albatross, Salvin’s albatross, white-chinned petrel, and sooty shearwater. Spotted shag had an estimated 681 (95% c.i.: 444 – 991) annual potential fatalities in trawl fisheries. Almost all of these fatalities were in trawl fisheries targeting flatfish (Tables A-4 and A-5).

Mean estimated annual potential fatalities exceeded 1000 birds in scampi, squid, large-processor, small-inshore, and flatfish trawl fisheries. Fewer than 200 birds were estimated to be killed annually in each of southern blue whiting, deepwater, mackerel, and large-fresher trawl fisheries.

In bottom-longline fisheries, there were a total of 3560 (95% c.i.: 3040 – 4150) estimated annual potential fatalities (Table A-8). The species with the highest number of estimated fatalities in these fisheries was black petrel with 1340 (95% c.i.: 980 – 1780) annual potential fatalities. These fatalities were in snapper, bluenose, and other small-vessel bottom-longline fisheries (Table A-6). Species with over 100 estimated

Table 9: Potential Biological Removal (PBR_1, i.e., with a recovery factor $f = 1$), total annual potential fatalities (APF) in trawl, longline, and set-net fisheries, risk ratio with $f = 1$ ($RR = APF/PBR_1$), and the probability that $APF > PBR$ with $f = 1$, $f = 0.5$, and $f = 0.1$ (P_1, $P_{0.5}$, and $P_{0.1}$ respectively). Species are ordered in decreasing order of the median risk ratio. 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. Species names are coloured according to their risk category. Red: risk ratio with a median over 1 or upper 95% confidence 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.

	PBR_1		APF		Risk ratio		P_1	$P_{0.5}$	$P_{0.1}$
	Mean	95% c.i.	Mean	95% c.i.	Median	95% c.i.			
Black petrel	74	47-117	1 440	1 070-1 900	19.90	11.40-32.80	100.00	100.00	100.00
Salvin's albatross	975	521-1 740	2 690	2 100-3 420	2.88	1.47-5.41	99.80	100.00	100.00
Flesh-footed shearwater	590	288-1 200	780	523-1 090	1.41	0.59-2.94	80.60	99.00	100.00
Southern Buller's albatross	513	270-831	663	520-839	1.32	0.75-2.58	79.20	100.00	100.00
Chatham Island albatross	159	94-264	205	136-316	1.30	0.68-2.59	78.20	99.70	100.00
NZ white-capped albatross	4 040	908-9 840	2 830	2 080-3 790	0.78	0.28-3.13	36.20	76.70	100.00
Northern Buller's albatross	617	325-1000	418	312-560	0.69	0.38-1.36	17.20	82.30	100.00
Gibson's albatross	260	132-425	121	86-164	0.48	0.25-1.00	2.52	45.40	100.00
Cape petrel	840	283-1 890	254	175-361	0.33	0.12-0.93	1.74	23.30	99.10
Antipodean albatross	295	203-419	89	63-121	0.30	0.18-0.49	0.00	2.06	100.00
Northern royal albatross	396	164-782	108	72-160	0.29	0.12-0.70	0.30	11.70	99.50
Southern royal albatross	441	302-630	116	82-160	0.27	0.16-0.43	0.00	0.30	100.00
Westland petrel	241	142-384	63	28-129	0.25	0.10-0.66	0.10	7.68	97.90
Northern giant petrel	217	66-486	47	18-103	0.23	0.06-0.85	1.44	13.60	87.40
White-chinned petrel	7 920	3 280-15 800	1 670	1 210-2 330	0.22	0.10-0.53	0.04	3.54	97.10
Spotted shag	3 780	1 730-7 570	745	485-1 100	0.21	0.09-0.48	0.00	1.64	94.60
Campbell black-browed albatross	1 020	514-1 830	192	111-324	0.19	0.08-0.44	0.00	1.12	94.00
Yellow-eyed penguin (mainland)	184	122-272	35	19-56	0.19	0.09-0.37	0.00	0.06	96.00
Grey petrel	2 170	1 010-3 900	247	169-364	0.12	0.06-0.27	0.00	0.00	65.10
Little black shag	120	67-216	8	5-14	0.07	0.03-0.15	0.00	0.00	18.00
Yellow-eyed penguin	537	352-805	35	19-56	0.07	0.03-0.12	0.00	0.00	10.20
Kermadec storm petrel	4	1-9	0	0-0	0.06	0.02-0.18	0.00	0.00	25.70
Pied shag	172	75-329	10	3-24	0.06	0.01-0.20	0.00	0.02	22.50
Stewart Island shag	269	218-334	13	3-29	0.04	0.01-0.11	0.00	0.00	4.44
NZ king shag	16	13-20	1	0-4	0.04	0.00-0.24	0.00	0.12	12.10
Light-mantled sooty albatross	237	167-319	7	2-20	0.02	0.01-0.09	0.00	0.00	1.94
Chatham petrel	11	5-26	0	0-1	0.02	0.00-0.10	0.00	0.00	2.30
Grey-headed albatross	333	157-613	6	1-20	0.01	0.00-0.07	0.00	0.00	0.76
Australasian gannet	4 190	1 500-9 770	62	7-222	0.01	0.00-0.07	0.00	0.00	1.12
Fiordland crested penguin	488	255-866	6	1-17	0.01	0.00-0.04	0.00	0.00	0.02
Soft-plumaged petrel	171	32-553	1	0-3	0.01	0.00-0.05	0.00	0.00	0.04
Grey-faced petrel	14 000	6 290-31 200	108	51-207	0.01	0.00-0.02	0.00	0.00	0.00
Cook's petrel	2 430	1 140-5 500	17	6-35	0.01	0.00-0.02	0.00	0.00	0.00
Pycroft's petrel	109	48-241	1	0-2	0.01	0.00-0.02	0.00	0.00	0.00
Northern little penguin	1 360	869-2 000	9	2-23	0.01	0.00-0.02	0.00	0.00	0.00
Sooty shearwater	348 000	115 000-751 000	1 760	1 260-2 480	0.01	0.00-0.02	0.00	0.00	0.00
Fluttering shearwater	5 220	1 240-13 700	19	5-54	0.00	0.00-0.02	0.00	0.00	0.00
White-flippered little penguin	421	263-657	2	0-4	0.00	0.00-0.01	0.00	0.00	0.00
Mottled petrel	15 300	7 040-33 500	45	17-98	0.00	0.00-0.01	0.00	0.00	0.00
Southern little penguin	1 360	864-2 030	3	1-9	0.00	0.00-0.01	0.00	0.00	0.00
Hutton's shearwater	6 370	3 490-10 600	15	4-36	0.00	0.00-0.01	0.00	0.00	0.00
Black-bellied storm petrel	4 550	2 410-8 220	8	2-17	0.00	0.00-0.00	0.00	0.00	0.00
Snares crested penguin	4 910	2 520-8 800	8	2-19	0.00	0.00-0.00	0.00	0.00	0.00
White-headed petrel	18 500	6 760-44 000	23	11-41	0.00	0.00-0.00	0.00	0.00	0.00
Chatham Island little penguin	1 350	856-2 030	3	0-14	0.00	0.00-0.01	0.00	0.00	0.00
Common diving petrel	64 600	19 400-152 000	36	15-77	0.00	0.00-0.00	0.00	0.00	0.00
Buller's shearwater	14 800	5 530-33 800	10	2-32	0.00	0.00-0.00	0.00	0.00	0.00
Kermadec petrel	336	153-752	0	0-1	0.00	0.00-0.00	0.00	0.00	0.00
Little shearwater	7 800	4 090-13 200	4	1-10	0.00	0.00-0.00	0.00	0.00	0.00
NZ white-faced storm petrel	105 000	38 800-226 000	45	12-111	0.00	0.00-0.00	0.00	0.00	0.00
Western rockhopper penguin	7 510	5 580-9 990	3	1-8	0.00	0.00-0.00	0.00	0.00	0.00
Southern black-backed gull	371 000	148 000-751 000	94	25-231	0.00	0.00-0.00	0.00	0.00	0.00
Antarctic prion	40 100	9 230-110 000	5	2-10	0.00	0.00-0.00	0.00	0.00	0.00
Fairy prion	159 000	62 800-330 000	22	7-56	0.00	0.00-0.00	0.00	0.00	0.00
Erect-crested penguin	12 600	10 200-15 600	2	0-5	0.00	0.00-0.00	0.00	0.00	0.00
Broad-billed prion	106 000	48 700-201 000	11	4-26	0.00	0.00-0.00	0.00	0.00	0.00
NZ storm petrel	16	1-64	0	0-0	0.00	0.00-0.12	0.00	0.00	3.56
Chatham Island taiko	1	0-2	0	0-0	0.00	0.00-0.00	0.00	0.00	1.90
Chatham Island shag	51	38-68	0	0-4	0.00	0.00-0.08	0.00	0.00	1.56
Pitt Island shag	100	51-178	1	0-6	0.00	0.00-0.06	0.00	0.00	0.98
South Georgian diving petrel	5	2-8	0	0-0	0.00	0.00-0.00	0.00	0.00	0.02
Bounty Island shag	17	11-26	0	0-0	0.00	0.00-0.02	0.00	0.00	0.02
Wedge-tailed shearwater	4 120	2 720-5 760	0	0-0	0.00	0.00-0.00	0.00	0.00	0.00
White-naped petrel	2 990	1 060-7 410	0	0-0	0.00	0.00-0.00	0.00	0.00	0.00
White-bellied storm petrel	66	29-131	0	0-0	0.00	0.00-0.00	0.00	0.00	0.00
Masked booby	46	26-76	0	0-0	0.00	0.00-0.01	0.00	0.00	0.00
Auckland Island shag	305	132-581	0	0-1	0.00	0.00-0.00	0.00	0.00	0.00
Campbell Island shag	298	153-534	0	0-0	0.00	0.00-0.00	0.00	0.00	0.00
Subantarctic skua	31	19-45	0	0-0	0.00	0.00-0.01	0.00	0.00	0.00
Caspian tern	176	92-299	0	0-1	0.00	0.00-0.00	0.00	0.00	0.00
White tern	18	13-26	0	0-0	0.00	0.00-0.00	0.00	0.00	0.00

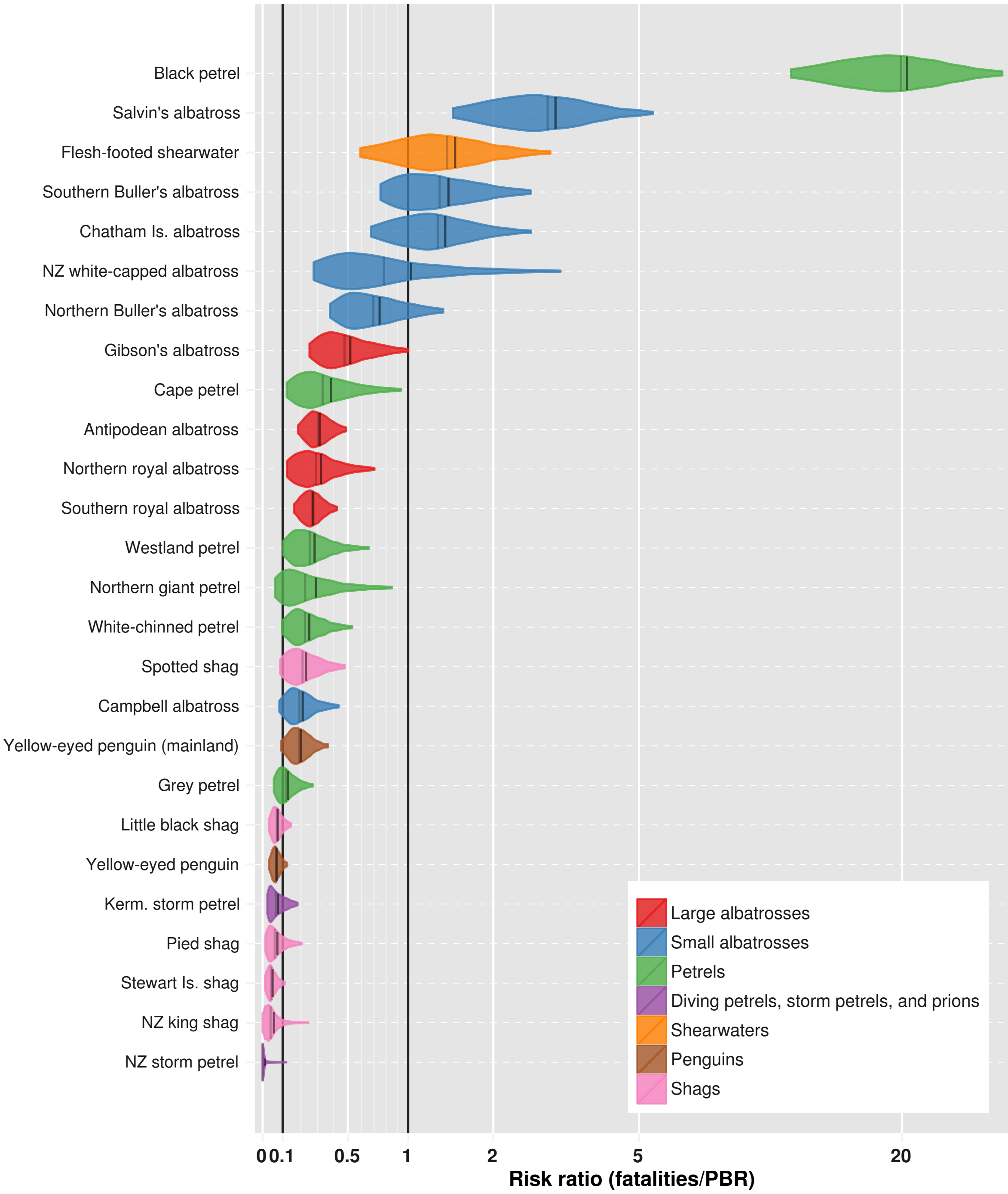

Figure 1: Risk ratio (total annual potential fatalities/Potential Biological Removal, PBR) with the recovery factor f set at 1 for each of the 70 studied species. The risk ratio is displayed on a logarithmic scale, with the threshold of the number of potential bird fatalities equaling the PBR with $f = 0.1$ and $f = 1$ indicated by the two vertical black lines, and the distribution of the risk ratios within their 95% confidence interval indicated by the coloured shapes, including the mean risk ratio (solid black line), and median (grey line). Seabird species are listed in decreasing order of the median risk ratio. Species with a risk ratio of almost zero were not included (95% upper limit with $f = 1$ less than 0.1). 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.

annual potential fatalities in bottom-longline fisheries included flesh-footed shearwater, with 519 (95% c.i.: 313 – 742) estimated fatalities, primarily in snapper bottom-longline fisheries; Salvin's albatross, with 427 (95% c.i.: 287 – 614) estimated fatalities, primarily in small-vessel bottom-longline fisheries; and Chatham albatross, with 158 (95% c.i.: 95 – 261) estimated fatalities, also primarily in small-vessel bottom-longline fisheries.

Annual potential fatalities in surface-longline fisheries were lower, with a total of 1340 (95% c.i.: 1170 – 1570) estimated annual potential fatalities across all seabird species (Table A-8). Over 80% of the mean estimated annual potential fatalities were in small-vessel surface-longline fisheries (Table A-7). Species with over 100 estimated fatalities included northern and southern Buller's albatross (mean annual potential fatalities 242; 95% c.i.: 170 – 343, and 106; 95% c.i.: 87 – 127, respectively), New Zealand white-capped albatross (mean 178; 95% c.i.: 122 – 240), and Gibson's albatross (mean 103; 95% c.i.: 71 – 143).

Set-net fisheries were also included in the risk assessment, and estimated fatalities in these fisheries were relatively low, with a total of 317 (95% c.i.: 228 – 460) annual potential fatalities across all species (Table A-8). Although the total estimate was low, for some species, the highest number of estimated annual potential fatalities occurred in set-net fisheries. In particular, there were 32 (95% c.i.: 17 – 49) estimated annual potential fatalities of yellow-eyed penguin, and 50 (95% c.i.: 2 – 175) estimated annual potential fatalities of Australasian gannet in set-net fisheries.

3.3 Vulnerabilities

As part of the estimation of the total observable captures in trawl and longline fisheries, the vulnerability was estimated as the product of a constant, v_0, multiplied by a species-group vulnerability, v_s, and a fisheries-group vulnerability, v_g (Equation 7). The species-group vulnerabilities had high uncertainty and varied widely across the different species and fisheries (Tables A-9 to A-11). Correlations between the model parameters made the uncertainties on the individual vulnerabilities higher than the uncertainties on the estimated observable captures. In cases where there was little overlap between the species distribution and the fishing method (such as for yellow-eyed penguin in surface-longline fisheries), the calculation of the vulnerability was poorly constrained, resulting in high apparent vulnerability, but no estimated observable captures, and hence no actual risk.

The species-group vulnerabilities were estimated relative to the vulnerability of white-chinned petrel (which was set to 1 as the base case; Table A-9). In trawl fisheries, the species with the highest relative mean vulnerability was Cape petrel, followed by Salvin's albatross and black petrel. In bottom-longline fisheries the species with the highest mean vulnerabilities were black petrel, Cape petrel, flesh-footed shearwater, Campbell black-browed albatross, Chatham albatross, and Salvin's albatross. In surface-longline fisheries, the species with the highest mean vulnerabilities were yellow-eyed penguin, Buller's albatrosses, group-foraging shags, black petrel, and great albatrosses. For surface-longline fisheries, the high apparent vulnerability of yellow-eyed penguin and shags resulted from the very low overlap between their distributions and observed fishing, and may not be indicative of actual risk. For shags, this high mean vulnerability resulted in estimated potential fatalities of spotted shag with a high uncertainty: a mean of 17, but with a 95% c.i. of 0 to 175 annual potential fatalities (Table A-7).

The vulnerability calculation for set-net fisheries was different, as there was only a single fishing group, resulting in a single vulnerability value for each species group (Table A-10). The species with the highest vulnerabilities in set-net fisheries were Cape petrel and yellow-eyed penguin.

Species vulnerabilities were estimated with reference to the value of the spatial overlap, which in turn depended on the estimated total population size. For Cape petrel, captures were observed in areas with very low overlap, which led to high estimated vulnerability. This outcome could be due to the presence in New Zealand waters of individuals breeding outside the New Zealand region, not included in our estimate of population size.

As a consequence of high uncertainties, problems of low overlap increasing apparent vulnerabilities, and the dependence on population and distribution estimates, direct comparisons of the species-group vulnerabilities are difficult to make and should be interpreted with caution.

The fisheries-group vulnerabilities had less uncertainty than the species-group vulnerabilities (Table A-11). For trawl fisheries, the fisheries-group vulnerabilities were estimated relative to deepwater trawl fisheries. The highest vulnerability values were in a group of trawl fisheries that included large processor, large meal, southern blue whiting, scampi, and squid trawls, with mean vulnerability values between 3 and 6. A second group had mean vulnerabilities around 1 (deepwater trawl and mackerel trawl), and the large fresher trawl group had a mean vulnerability of 0.2. There was no apparent difference in vulnerability between large vessels with or without a meal plant, but large freshers (which do not discharge processing waste), had a markedly lower vulnerability.

In bottom-longline fisheries, the small-vessel group had the highest vulnerability, followed by the bluenose and large-vessel groups, whereas the snapper group had the lowest vulnerability, although none of these differences were significant (Table A-11). There were only two surface-longline groups, with small vessels having a higher vulnerability than the large-vessel group, but the difference was not significant.

3.4 Sensitivity

For around one-third of the species, the uncertainty in the risk ratio is most sensitive to uncertainty in bottom-longline fatalities (Table 10). For most species, the uncertainty is higher in bluenose, snapper, or other small-vessel bottom-longline fisheries than in the large-vessel bottom-longline fisheries (see Table A-6). For many species, increased observer coverage in small-vessel bottom-longline fisheries would reduce the uncertainty in the risk ratio. For many other species, the uncertainty in the risk ratio is most sensitive to uncertainty in the number of breeding pairs and to uncertainty in adult survival.

For nine of the 12 species that are most at risk, the uncertainty in the risk ratio is most sensitive to uncertainty in adult survival (Figure 2). Many of the species that are most at risk are long-lived. For long

Table 10: Number and proportion of seabird species for which the uncertainty in the risk ratio is most sensitive to the uncertainty in the corresponding parameter.

Parameter	Number	Proportion (%)
Bottom-longline captures	22	33.8
Number of breeding pairs	16	24.6
Adult survival	13	20.0
Set-net fatalities	6	9.2
Surface-longline fatalities	5	7.7
Trawl fatalities	3	4.6
Age at first reproduction	0	0.0
Cryptic multiplier	0	0.0
Probability of breeding	0	0.0

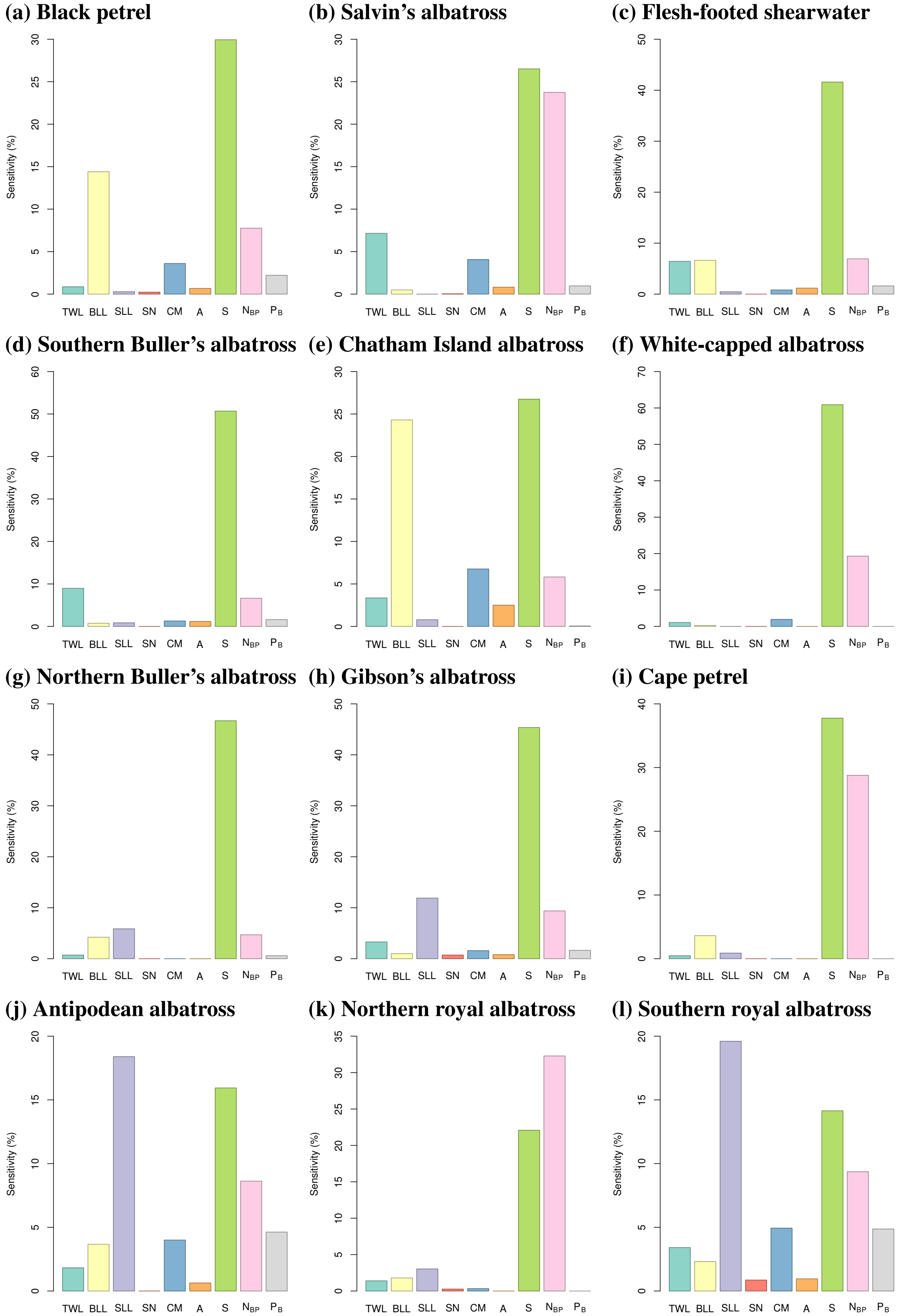

Figure 2: Sensitivity of the uncertainty in the risk ratio for the 12 seabird species with the highest risk ratio. For each seabird type, the sensitivity to the uncertainty in the following parameters is considered: annual potential fatalities in trawl, bottom-longline, surface-longline and set-net fisheries (TWL, BLL, SLL, SN, respectively); the cryptic multipliers (CM); age at first reproduction (A); adult survival (S_A); the number of annual breeding pairs (N_{BP}); and the proportion of adults breeding (P_{B}). The sensitivity is defined as the percentage of reduction in the 95% confidence interval of the risk ratio that occurs when the parameter is set to its arithmetic mean.

lived species, adult survival is high, and small changes in survival rates have a relatively large effect on the population.

For all the species in the risk assessment, the sensitivity analysis allows the source of uncertainty in the risk ratio to be explored (see Table A-17). This analysis may be used to prioritise further research, where reducing the uncertainty in the risk ratio would help resolve the risk status of the species. The sensitivity analysis helps to understand uncertainty in the risk ratio, but is not suited for identifying the most effective way of reducing the risk.

4. DISCUSSION

4.1 Species most at risk

The risk of commercial fisheries to seabirds was defined as the ratio of the estimated number of annual potential fatalities to the PBR. The PBR value is dependent on the multiplicative recovery factor, f. Previous studies assigned values between 0.1 and 0.5, based on the IUCN status of the species concerned (e.g., Richard et al. 2011, Dillingham & Fletcher 2011). In this study, however, the risk was calculated using a recovery factor of $f = 1$, which must be considered during interpretation of the risk values. The group of species identified as being most at risk included (in this order) black petrel, Salvin's albatross, flesh-footed shearwater, southern Buller's albatross, Chatham Island albatross, and New Zealand white-capped albatross. All these species had a risk ratio with a median above 1 or an upper 95% confidence limit above 2, and may be categorised as at "Very high risk".

These species are discussed in more detail below.

4.1.1 Black petrel

The species found to be the most at risk from commercial fisheries within New Zealand's Exclusive Economic Zone was black petrel (Table 9), with annual potential fatalities in bottom-longline, surface-longline, and inshore trawl fisheries (Tables A-4 to A-8). This species was also identified as being the most at risk in the previous seabird risk assessment (Richard et al. 2011).

Based on an estimated total number of annual potential fatalities of 1440 (95% c.i. 1070 – 1900) and a PBR_1 of 74 (95% c.i. 47 – 117), the median risk ratio for black petrel was estimated to be 19.9 (95% c.i. 11.4 – 32.8). This estimate was considerably higher than the previous mean risk ratio of 3.34 (95% c.i. 1.78 – 5.57) (Richard et al. 2011, back-calculated to $f = 1$). The increase in the risk ratio was partly due to a decrease in PBR_1, from a mean of 331 (95% c.i.: 216 – 512) to a mean of 74 (95% c.i.: 47 – 117). There were two reasons for this decrease, including a lower population estimate and the inclusion of a calibration factor in the updated calculation of the PBR for black petrel. The population estimate used here was 1059 breeding pairs, based on a recent survey (Bell et al. 2011), compared with the estimate of 1750 breeding pairs used in the previous assessment (Richard et al. 2011). Furthermore, it was found by Richard & Abraham (2013) that the estimated PBR needed to be corrected by multiplying by a calibration factor of 0.33.

Another reason for the increase in the risk ratio for this species was an increase in the number of annual potential fatalities, from a mean of 1060 (95% c.i.: 725 – 1520) to a mean of 1440 (95% c.i.: 1080 – 1900). This increase was due to a higher observed capture rate in the two most recent fishing years, 2009–10 and 2010–11. Observed captures in 2009–10 included a single bottom-longline trip that caught 27 black petrel (Abraham et al. 2013). As a sensitivity analysis, we estimated the number of annual potential fatalities without including the data from this trip. Although the exclusion of this trip reduced the risk ratio by almost 50%, the median risk ratio remained high at 10.39 (95 % c.i. 5.71 – 18.13).

Without including cryptic mortalities, the estimated mean number of observable black petrel captures was 693 (95% c.i. 522–884), exceeding PBR_1 (Table A-15). As an assessment of this value, simple ratio methods were used to estimate the observable captures of this species in bottom-longline fisheries. Over the 5-year study period, observer coverage in snapper and bluenose bottom-longline target fisheries was 1.7% and 0.9%, respectively, and there were a total of 23 and 19 observed black petrel captures in these fisheries. Based on these observer data, ratio estimated annual observable captures were 271 (calculated as $23/(5 \times 0.017)$) estimated black petrel captures in snapper bottom-longline fisheries, and 422 (calculated as $19/(5 \times 0.009)$) captures in bluenose bottom-longline fisheries per year. Both these values were well above the PBR_1 of 74. The total of around 700 captures was similar to estimated 500 observable black-petrel captures in these fisheries (from Table A-6, allowing for a cryptic mortality multiplier of around 2). The high estimated captures of black petrel are not due to a peculiarity of the statistical model.

This risk assessment only included commercial trawl, longline, and set-net fisheries in New Zealand's Exclusive Economic Zone. During the breeding season, black petrel forage in north-eastern New Zealand waters, where they may interact with recreational fisheries. Based on limited interview data, there were estimated to be potentially around 10 000 captures of seabirds by recreational fishers annually in this region (Abraham et al. 2010a), and some of these captures may result in black petrel fatalities. Moreover, black petrel migrate to the eastern Pacific Ocean during the non-breeding season, where they interact with other fisheries.

The population trend of this species is unclear. Data from random transect surveys of the Great Barrier Island colony, conducted in 2004–05 and 2009–10, suggested an apparent population decline of 22% over 5 years (Bell et al. 2011). Census grid data, however, did not confirm this decline. Summarising all population data, Bell et al. (2011) concluded that it is likely that the mean rate of change of the black petrel population has not exceeded 2% per year, that the direction of change is uncertain, may differ across years, but that the population is most likely to be in decline.

4.1.2 Salvin's albatross

Salvin's albatross are endemic to New Zealand, where they breed on Bounty Islands and the western chain of Snares Islands, with a total population of approximately 32 000 annual breeding pairs concentrated on Bounty Islands (Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2010). This species was caught in a range of fisheries in New Zealand waters, mainly by small inshore trawlers, large processor trawlers (with or without meal plants), trawlers targeting scampi, and small-bottom longliners (Tables A-4 to A-8). There were 150 observed captures over the 5-year reporting period, and there were estimated to be 2690 (95% c.i. 2100 – 3420) annual potential fatalities. With a PBR_1 estimated to be 975 (95% c.i. 521–1740), the median risk ratio with $f = 1$ was 2.88 (95% c.i. 1.47–5.41). Although the number of annual potential fatalities was lower than in the previous assessment (Richard et al. 2011), the estimated risk ratio was higher (see Tables A-13 and A-14) due to the inclusion of the calibration factor in the updated calculation of the PBR.

Of the 150 observed Salvin's albatross captures between 2006–07 and 2010–11, 147 occurred during the breeding season, with only three observed captures outside the breeding season (Table A-16). In contrast, a comparatively large number of annual potential fatalities was estimated for the non-breeding period, with a mean of 627 (95% c.i.: 453 – 855) compared with a mean of 2060 (95% c.i.: 1510 – 2750) during the breeding season. The reason for this discrepancy was the low observed overlap with small-vessel inshore trawling (0.5%) outside the breeding season, compared with observed overlap of 2.5% during the breeding season. Nevertheless, the estimated number of potential annual fatalities exceeded PBR_1 for this species, even when only considering the estimated number of annual potential fatalities for the breeding season.

Salvin's albatross is classified as "Vulnerable" by the IUCN (IUCN 2012) because of its restricted breeding range. The overall population trend is unclear, owing to different methodologies used to survey populations at different times. Recent surveys of the smaller Snares Islands population showed an apparent decline of almost 8% over the three years between 2008 and 2010 (Sagar et al. 2011).

4.1.3 Flesh-footed shearwater

The third species identified in the present study as most at risk of commercial fisheries in New Zealand was flesh-footed shearwater. There were 124 observed captures in the fishing years between 2006–07 and 2010–11, with most fatalities occurring in bottom-longline fisheries targeting snapper, and trawl fisheries targeting scampi (Tables A-4 to A-8; Table A-3). All of these captures were during the breeding season (Table A-16), as this species migrates to the North Pacific Ocean during winter.

The total number of annual fatalities was estimated to be 780 (95% c.i. 523 – 1090), which was lower than the mean 1380 (95% c.i.: 1080 – 1770) annual potential fatalities estimated by Richard et al. (2011). The annual potential fatalities exceeded the PBR_1 of 590 (95% c.i. 288 – 1200). The median risk ratio for this species was 1.41 (95% c.i. 0.59 – 2.94), an increase from the previous risk ratio (mean 1.25; 95% c.i.: 0.54 – 0.54) in Richard et al. (2011). This increase was due to a lower PBR, resulting from the inclusion of the calibration factor ($\rho = 0.41$) in the updated PBR calculation.

In addition to commercial fisheries, flesh-footed shearwater are also caught in recreational fisheries. Flesh-footed shearwater forage in the north-eastern New Zealand region, where fatalities of this species have been linked to captures in recreational fisheries (Abraham et al. 2010a). Recent anecdotal evidence also implicated recreational fisheries in the capture of this species, with carcasses washed ashore in apparently good condition, but with recreational fishing hooks inside, or suffering from trauma such as broken wings, crushed skulls and stab wounds (A. Tennyson, pers. comm.). The extent of the recreational fisheries bycatch remains unknown.

Approximately 10 000 pairs of flesh-footed shearwater breed annually on eight New Zealand islands (Baker et al. 2010). This recent population estimate is considerably lower than a previous estimate of between 25 000 and 50 000 breeding pairs in New Zealand (Taylor 2000b). A large flesh-footed shearwater population also breeds on Lord Howe Island, eastern Australia. It is possible that some of the birds caught in New Zealand originate from Lord Howe Island, which would lead to an overestimation of the risk. It is important to note, however, that the flesh-footed shearwater population on Lord Howe Island is declining (Priddel et al. 2006). The IUCN status of this species is assessed as "Least Concern" (IUCN 2012).

4.1.4 Southern Buller's albatross

Southern Buller's albatross are endemic to New Zealand and breed only on Snares and Solander islands, with a population of almost 14 000 annual breeding pairs. This species was classified as "Near-Threatened" by the IUCN, although this assessment did not distinguish it from northern Buller's albatross (IUCN 2012). This species has shown a long-term population increase, although a declining survival rate has been suggested in recent years (Francis & Sagar 2012).

The median risk ratio with $f = 1$ was estimated as 1.32 (95% c.i. 0.75 – 2.58) for this species, from a total estimated number of annual fatalities of 663 (95% c.i. 520 – 839) and a PBR_1 of 513 (95% c.i. 270 – 831). Fatalities were estimated to occur mainly in large-vessel processor trawl fisheries (with and without meal plants), and in trawl fisheries targeting squid.

4.1.5 Chatham Island albatross

Chatham Island albatross are endemic to New Zealand, and breed only on The Pyramid, Chatham Islands, with a population of over 5200 annual pairs. The species' IUCN status was previously "Critically Endangered", which was downgraded to "Vulnerable" in 2010, because the population has been stable over time (IUCN 2012).

For Chatham Island albatross, the median risk ratio with $f = 1$ was estimated to be 1.3 (95% c.i. 0.68 – 2.59), from a total number of annual fatalities estimated to be 205 (95% c.i. 136 – 316) and a PBR_1 of 159 (95% c.i. 94 – 264). Fatalities were estimated to occur mainly in small bottom-longline fisheries. Although the risk ratio is high, there is no evidence of a population decline for this species.

The risk ratio increased from a mean of 0.81 (95% c.i.: 0.34 – 2.28) previously (when calculated with $f = 1$; Table A-14), owing to a lower PBR (Table A-12), which resulted from the multiplication with the calibration factor ($\rho = 0.43$). The survival rate that was used in this study was higher, increasing from 86.8% in Richard et al. (2011) to 96.7% here. The previous estimate was unusually low for an albatross species, and we used the survival rate for the closely related Salvin's albatross to better approximate natural survival (without human-caused mortality). As a consequence, the estimated maximum growth rate for Chatham Island albatross decreased following Niel & Lebreton (2005), resulting in a large decrease in PBR_1, from a mean of 1240 (95% c.i.: 918 – 1720) to 159 (95% c.i.: 94 – 264). However, the increase in the risk ratio was relatively small, due to lower estimated annual potential fatalities, which decreased from a mean of 980 (95% c.i.: 463 – 2680) to 205 (95% c.i.: 136 – 316). The large number of potential fatalities estimated in Richard et al. (2011) was due to the lack of constraint in the estimation of vulnerabilities, and the low observer coverage in fisheries around the Chatham Islands.

4.1.6 New Zealand white-capped albatross

New Zealand white-capped albatross are endemic to New Zealand, and breed mainly in Antipodes and Auckland islands, with 77 000 annual breeding pairs. Their median risk ratio with $f = 1$ was estimated to be 0.78 (95% c.i. 0.28 – 3.13), from a total number of annual fatalities estimated to be 2830 (95% c.i. 2080 – 3790) and a PBR_1 of 4040 (95% c.i. 908 – 9840). Fatalities occurred mainly in small-vessel inshore trawl fisheries and in trawl fisheries targeting squid.

The risk ratio increased from the previous assessment, from a mean of 0.33 (95% c.i.: 0.2 – 0.53). This increase was mainly due to a lower PBR (from a mean of 16 700; 95% c.i.: 9700 – 25 300), because of the multiplication by the calibration factor $\rho = 0.43$, and an updated estimate of annual survival (Francis 2012). The uncertainty in this recent estimate of annual survival was large (95% c.i.: 90.7 – 99.5%), and drove the large uncertainty in the risk ratio estimated here.

A recent aerial survey conducted over 5 years indicated a possible decrease of the Auckland Islands population, from 117 000 annual breeding pairs in 2006 to 77 000 in 2010 (Baker et al. 2011). In this assessment, we used the most recent low value of 77 000 annual breeding pairs. It is possible, however, that this apparent decrease was due to random year-to-year variation in the number of birds returning to breed. A recent modelling study concluded that the population status of white-capped albatross was uncertain, and that the decline recorded in the aerial survey was inconsistent with adult survival rates (Francis 2012).

White-capped albatross species are frequently caught in New Zealand commercial fisheries (Abraham et al. 2013). They are also caught in fisheries in South Africa and in the southern Indian Ocean, with an estimate of around 8 000 individuals killed in the Southern Ocean each year (Baker et al. 2007). This study only included cryptic mortality in some fisheries, and so this value may be a considerable underestimate of global fatalities. Fatalities outside of the New Zealand region are not considered in this risk assessment.

Since the introduction of mandatory warp mitigation in 2006, there has been a decrease in the number of white-capped albatross killed in the New Zealand squid fishery (Abraham et al. 2013). The highest number of potential fatalities are in small-vessel trawl fisheries, however, and no warp mitigation is required in these fisheries.

4.2 Other species

4.2.1 Northern Buller's albatross

Northern Buller's albatross are endemic to New Zealand, breeding mainly in the Chatham Islands region, with a population of over 16 000 pairs annually. This species is classified as "Near-Threatened" by the IUCN, although it is not considered distinct from southern Buller's albatross (IUCN 2012).

The median risk ratio with $f = 1$ was estimated to be 0.69 (95% c.i. 0.38 – 1.36), from a mean number of annual fatalities estimated to be 418 (95% c.i. 312 – 560) and a mean PBR_1 of 617 (95% c.i. 325 – 1000). Fatalities were estimated to occur mainly in small surface-longline fisheries.

Although there are no published data available regarding the population trend of this species, it is considered stable (Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2012). Further research is necessary to assess the current population status.

4.2.2 Gibson's albatross

Gibson's albatross have a total population of less than 6000 pairs, breeding only on Auckland Islands (Walker & Elliott 1999). Gibson's albatross are not recognised as separate species to wandering albatross by the IUCN, which classified the latter as "Vulnerable" (IUCN 2012). From 22 captures observed in the fishing period between 2006–07 and 2010–11, it was estimate that 121 (95% c.i. 86 – 164) birds were potentially killed annually, mainly by small-vessel surface longline fisheries (Tables A-4 to A-8).

The mean PBR_1 was estimated to be 260 (95% c.i. 132 – 425), which resulted in a median risk ratio of 0.48 (95% c.i. 0.25 – 1). The probability was less than 5% (2.52%) that the estimated annual potential fatalities exceed PBR_1 for Gibson's albatross. Similar to flesh-footed shearwater and Salvin's albatross, this risk ratio was higher than that derived by Richard et al. (2011) (Table A-14), despite lower annual potential fatalities (Table A-13), as the PBR_1 was lower.

A recent analysis of 21 years of data (mark-recapture, nest-based, and counts of breeders) of the Gibson's albatross population on Adam Island indicated a population decline of 5.8% per year since 2004, following a decline in survival rates, breeding probability, and breeding success (Francis et al. 2011).

4.2.3 Yellow-eyed penguin

Yellow-eyed penguin are one of the species that have most of their risk associated with set-net fisheries. There were 7 captures of yellow-eyed penguin in set-net fisheries reported by fisheries observers over the 5-year period. Earlier captures of yellow-eyed penguin in set-net fisheries were reviewed by Darby & Dawson (2000).

Yellow-eyed penguin had an estimated 32 (95% c.i.: 17 – 49) mean annual potential fatalities in set-net fisheries, which was less than the mean PBR of 537 (95% c.i.: 352 – 805). However, the largest population of yellow-eyed penguin is in the subantarctic islands, where their distribution is unlikely to overlap with set-net fisheries. Also, all observed captures were along the mainland coast. It is possible that the fishing-related mortality may impact the smaller population in Otago and Southland, even though the overall assessment was that the species is not at risk from fishing. By assuming a mainland population of 600 – 800 annual pairs (Ursula Ellenberg, Yellow-eyed penguin Trust, pers. comm.), the mean PBR of this population was estimated to 184 (95% c.i.: 122 – 272), and by assuming that all annual potential fatalities were of this population, the median risk to the mainland population more than doubled to 0.19 (95% c.i.: 0.09 – 0.37) when calculated with a recovery factor $f = 1$. For this population, the probability that annual potential fatalities exceeded the PBR was estimated to be 0%, 0.06%, and 96%, when $f = 1$, 0.5, and 0.1, respectively. Depending on the choice of f value, this population may be at risk from fishing-related mortalities. Yellow-eyed penguin are classified as endangered by the IUCN (International Union for Conservation of Nature (IUCN) 2010). If the previous method for allocating the recovery factor was used, then the recovery factor would be set to 0.2 for endangered species (Richard et al. 2011). In this case, the Stewart Island and mainland population of yellow-eyed penguin would have a median risk-ratio close to 1.

4.3 Comparison with previous work

This study replaces the previous risk assessment of commercial fisheries to New Zealand seabird species (Richard et al. 2011). It used an improved methodology for calculating the PBR, updated distribution information, and additional bycatch data. Because of the changes in methodology between the two assessments, changes in the risk cannot be attributed to changes in the fisheries management. For fisheries monitoring purposes, methods that estimate time-series of seabird bycatch, but with less taxonomic resolution, are more useful (Abraham et al. 2013).

Most of the demographic parameters used here were the same as those used previously. The number of breeding pairs was updated for 14 species, with 11 other changes in age at first reproduction, survival and proportion of adults breeding for 5 albatross species. Comparisons with the previous seabird risk assessment (Table A-12) were made possible by back-calculating the values of PBR_1 of Richard et al. (2011). The resulting PBR_1 values were typically lower in the present study than previously, owing to the inclusion of the calibration factor and the changes in some of the demographic parameters. The only exceptions were PBR_1 values for Chatham, Auckland, and Pitt Island shags, and for white tern. For these species, PBR_1 values were higher than previous ones, based on increases in their population sizes used in the updated estimates.

In the present assessment, the mean number of annual potential fatalities decreased for most species compared with previous estimates (Table A-13). The main reason for these decreases was the change in the calculation of the vulnerabilities, which typically caused a decrease in the estimated number of captures in poorly observed fisheries. For example, the mean number of annual potential fatalities in small inshore trawl fisheries was estimated as 7110 (95% c.i.: 4290 – 12 600) in Richard et al. (2011), but reduced to 2650 (95% c.i.: 1850 – 3650) in the current study. In contrast, the mean number of annual potential fatalities was estimated as 1150 (95% c.i.: 772 – 1740) in the well-observed large-vessel processor trawl fishery (Richard et al. 2011), and was estimated as 1190 (95% c.i.: 929 – 1510) here. In addition, the current assessment included data from the most recent five years, including the 2009–10 and 2010–11 fishing years. As there was increased observer coverage of inshore and small-vessel fisheries in recent fishing years, these observer data helped to reduce the uncertainty in the estimated captures in inshore fisheries.

The only species whose annual potential fatalities increased in the current study were black petrel, from 1060 (95% c.i.: 725 – 1520) to 1440 (95% c.i.: 1080 – 1900) fatalities; white-chinned petrel, from 1640 (95% c.i.: 1450 – 1920) to 1670 (95% c.i.: 1210 – 2330) fatalities; and yellow-eyed penguin, from 20 (95% c.i.: 3 – 61) to 35 (95% c.i.: 19 – 56) fatalities. The increase in estimated black petrel fatalities followed an increase in observed captures in 2009–10 and 2010–11, not included in the previous risk assessment. White-chinned petrel had increased observed capture rates 2010–11 in trawl and bottom-longline fisheries (Abraham et al. 2013), whereas the increase in estimated potential fatalities of yellow-eyed penguin was due to the inclusion of set-net fisheries in the current study.

In the previous risk assessment, there were a number of “low information” species that were identified as being at high risk. For example, high-risk species previously included grey-headed albatross and light-mantled sooty albatross; however, in the current study, the risk for these two species decreased markedly. This decrease was due to the change in the model used to estimate vulnerabilities. Light-mantled sooty albatross were not caught in well-observed fisheries, and the current model of observable captures was able to infer that they are, therefore, less likely to be caught in poorly observed fisheries.

Although both the PBR and the estimated annual potential fatalities tended to be lower than in the previous assessment, the risk ratios were typically similar (Table A-14). There were only five species whose $f = 1$ risk ratios increased (Salvin’s albatross, southern Buller’s albatross, northern Buller’s albatross, black petrel, and Kermadec storm petrel) so that the mean values of the two assessments were outside the 95% confidence intervals. The increase in risk for these species was primarily due to a decrease in the PBR (Table A-12), while for black petrel the increase was also associated with an increase in the estimated annual potential fatalities (Table A-13). There were nine species whose risk ratios significantly decreased (Campbell black-browed albatross, grey-headed albatross, light-mantled sooty albatross, northern giant petrel, Westland petrel, Hutton’s shearwater, Fiordland crested penguin, New Zealand king shag, and Stewart Island shag). The decreases were due to decreases in the estimated annual potential fatalities (Table A-13). The decreased fatalities resulted from more constraint on estimated captures in inshore fisheries, more constraint on the vulnerability of infrequently caught species, and from changes in the distributions resulting in less overlap with fisheries. Because of the methodological differences between the assessments, the changes cannot be interpreted as being due to changes in fishing practice.

The inclusion of set-net fisheries in this risk assessment had little effect on the overall outcome for most species, as these fisheries were not associated with a large number of mortalities. As expected, this fishing method caused the greatest risk to inshore species, mainly penguins and shags. The highest number of potential fatalities in set-net fisheries involved Australasian gannet, spotted shag, yellow-eyed penguin, and Cape petrel. No cryptic mortality was included in the assessment of set-net fisheries, as there was no relevant research that could be used to estimate its magnitude.

Data from other studies allow validation of different aspects of the current risk assessment. For example, estimates of observable captures in New Zealand waters in the 2010–2011 fishing-year are available for New Zealand white-capped albatross, sooty shearwater, white-chinned petrel, and as a total for all seabirds (Abraham et al. 2013). The estimates of observable captures derived in the current study were comparable with these estimates, except for white-chinned petrel (Table 11). The estimate for this species was lower in this study, as it was an annual average over a 5-year period. In contrast, the estimate by Abraham et al. (2013) was for the most recent fishing year only, and estimated captures of white-chinned petrel have increased over the 5-year period. For example, the mean number of observable captures for this species in 2008–2009 was 601 (95% c.i.: 253 – 1590) (Abraham & Thompson 2011), which is comparable to the estimate in this study (mean 546; 95% c.i.: 466 – 664).

Table 11: Estimates of annual observable captures in commercial fisheries in New Zealand waters for three seabird species and for all seabirds in 2010–11, as estimated in the present risk assessment and in Abraham et al. (2013).

	This study		Abraham et al. (2012)	
Species	Mean	95% c.i.	Mean	95% c.i.
New Zealand white-capped albatross	391	337 – 452	441	319 – 589
Sooty shearwater	519	459 – 592	560	372 – 834
White-chinned petrel	546	466 – 664	996	704 – 1 420
All birds	4 540	4 200 – 4 880	4 930	4 120 – 5 960

In this study, the PBR was calculated using the methods from Richard & Abraham (2013). Independent calculations of the PBR were made earlier by Dillingham & Fletcher (2011) for 22 albatrosses and petrel species (Table A-12), using typical values for the demographic estimates. In most cases, the PBR values they estimated were close to those determined in the previous risk assessment by Richard et al. (2011), and were higher than the PBR values estimated here (taking $f = 1$ in both cases). The reason for this difference was that Dillingham & Fletcher (2011) estimated r_{max} using the method of Niel & Lebreton (2005), without using the calibration factor, ρ, recommended by Richard & Abraham (2013).

4.4 Future directions

The Potential Biological Removal (PBR) approach was used to assess the risk of fishing-related mortalities to many of the seabird species that breed within New Zealand waters. This risk assessment required calculation of the PBR from demographic data, and estimation of the bycatch of individual seabird species in a range of trawl, bottom-longline, surface-longline, and set-net fisheries. This report presents the most comprehensive seabird risk assessment carried out to date, applying a consistent methodology to 70 seabird species, and considering all fishing by four fishing methods in New Zealand waters over the most recent 5-year period. The methodology for estimating risk was improved relative to the previous assessment (Richard et al. 2011). In particular, the method for estimating the PBR was calibrated; we considered seasonality in species and fisheries distributions; the vulnerabilities to capture were better constrained; and set-net fisheries were included in the analysis. Despite these improvements, the seabird risk assessment is by no means mature. It is likely that the methodology will continue to be updated and modified, as our understanding of seabird distributions and demography improves, and as our knowledge of seabird interactions with fisheries continues to increase.

To provide a full risk assessment, the PBR needs to be compared with the total annual human-caused mortality, not only mortality from commercial fishing within the New Zealand region. Other anthropogenic factors affect seabirds, and some species might be in decline even when the mortality from New Zealand commercial fisheries is below the PBR. For example, some species may be caught in recreational fisheries, and very little is known about these impacts (Abraham et al. 2010a). Many New Zealand seabirds forage outside the New Zealand region, and their captures by foreign fisheries were not included in this analysis. For instance, some species 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) (Agreement on the Conservation of Albatrosses and Petrels (ACAP) 2012). Captures of birds from New Zealand colonies that occur outside the New Zealand region result in an underestimate of the total risk. On the other hand, bird captures in the New Zealand region of species that breed elsewhere tend to overestimate the risk. Although it would not be straightforward, a global assessment, and a consideration of broader anthropogenic impacts, would allow better determination of appropriate management responses.

A limitation in understanding the impact of fisheries on seabird populations is the lack of data on cryptic mortality, which is used in the estimation of annual potential fatalities. For some species, most of the estimated annual potential fatalities are cryptic mortalities. For example, for large seabirds that are primarily caught in trawl fisheries, annual potential fatalities are over eight times as high as the number of observable captures. Although the calculation of the multipliers for cryptic mortalities was improved from Richard et al. (2011) by considering uncertainty, there are no studies of cryptic mortality in New Zealand fisheries that could be used for estimating these multipliers. Estimation of cryptic mortality was primarily based on two studies (Watkins et al. 2008, Brothers et al. 2010) that were conducted in fisheries in South Africa and Australia, respectively. The study of cryptic mortality in trawl fisheries was based on results from a single trip (Watkins et al. 2008), and so is very limited. Moreover, estimation of cryptic mortality only considered birds that were killed but not brought on-board the vessel. It did not include possible problems such as seabird bycatch not being reported when the observer is off duty, or seabird carcasses not being seen by the observer because of the volume of catch. Although collecting data on cryptic mortality is inherently difficult, New Zealand specific information on the relation between observed captures and total fatalities will be required to improve the reliability of the risk assessment. Without a better characterisation, it is possible that the risk assessment will either fail to identify seabird species that are at risk, or will classify species as being at risk when in fact they are not.

Estimation of seabird captures relies on observer data. In many fisheries, particularly small-vessel inshore fisheries, observer coverage is low (less than 5%). Estimation of total captures assumes that there has been sufficient observer coverage to characterise the interactions. In set-net fisheries, observer coverage is not yet sufficient. As part of a study of set-net captures of seabirds in Otago Harbour, Lalas (1991) reported an event where 20 spotted shags were caught in a set net (although 15 of the birds were released alive). Multiple captures of shearwaters have been reported from Kaikoura, with a set net being found with 50 dead Hutton's shearwater (West & Imber 1985), and a net being reported catching 9 Hutton's and 29 fluttering shearwater (Tarburton 1981). Similar multiple capture events have not yet been reported by observers on set-net vessels (although there have been two reports of two birds being caught in a set). It is likely that if more set-net fishing was observed, then large multiple captures would be recorded. Similarly, small-vessel longline and trawl fisheries have not been well observed, and it is possible that the observations are not yet sufficient to characterise seabird interactions. Increasing observer coverage in these fisheries would allow seabird captures to be more accurately estimated, and may reveal qualitatively different interactions.

The next step is to take the results from this risk assessment and interpret them in relation to management goals. In particular, the PBR recovery factor appropriate to each species has not been specified. Despite this limitation, the current assessment highlighted seven species that appear to be at risk, regardless of the value chosen for the recovery factor. There were a further 17 seabird species that may be at risk, depending on the values chosen for the recovery factor. For the remaining 46 seabird species, there appears to be little risk of population declines as a result of commercial fishing within the New Zealand region, subject to the limitations on our knowledge highlighted above. For the species at risk, an appropriate management response needs to be determined.

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APPENDIX A: SUMMARY TABLES

Table A-1: Summary of demographic parameters (mean and 95% confidence interval) used for the calculation of the Potential Biological Removal, including adult survival (S), age at first reproduction (A), the proportion of adults breeding (P_B), and the number of annual breeding pairs (N_{BP}) for each seabird species. The species names are coloured according to their respective risk categories: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	S		A		P_B		N_{BP}	
	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	11.00	10.10–12.00	0.60	0.50–0.69	5 240	4 840–7 020
Antipodean albatross	0.96	0.94–0.97	11.50	10.10–12.90	0.60	0.50–0.69	5 650	4 880–7 070
Southern royal albatross	0.95	0.93–0.96	9.55	8.55–10.50	0.60	0.50–0.69	7 070	6 120–8 870
Northern royal albatross	0.94	0.91–0.97	9.54	8.55–10.50	0.61	0.51–0.70	4 320	2 770–8 150
Campbell black-browed albatross	0.94	0.93–0.96	9.54	6.18–12.80	0.89	0.75–0.96	15 500	9 760–28 900
New Zealand white-capped albatross	0.95	0.91–0.99	11.90	9.16–14.80	0.75	0.64–0.83	57 300	36 800–111 000
Salvin's albatross	0.96	0.94–0.98	12.00	9.13–14.80	0.89	0.75–0.96	26 000	19 400–40 800
Chatham Island albatross	0.96	0.94–0.98	12.00	9.15–14.90	0.89	0.75–0.96	4 700	4 080–5 900
Grey-headed albatross	0.95	0.93–0.97	10.00	7.16–12.90	0.75	0.64–0.83	4 860	3 090–9 260
Southern Buller's albatross	0.95	0.93–0.98	12.00	9.15–14.80	0.89	0.75–0.96	12 200	10 500–15 300
Northern Buller's albatross	0.95	0.93–0.98	12.00	9.14–14.90	0.89	0.75–0.96	14 700	12 700–18 400
Light-mantled sooty albatross	0.97	0.96–0.98	12.00	9.17–14.80	0.60	0.50–0.69	6 790	6 770–6 880
Northern giant petrel	0.89	0.81–0.96	8.01	6.10–9.89	0.89	0.75–0.96	2 090	1 550–3 260
Grey petrel	0.94	0.90–0.97	7.00	5.09–8.90	0.89	0.75–0.96	37 900	32 100–65 700
Black petrel	0.90	0.86–0.94	6.60	6.23–6.97	0.80	0.68–0.88	951	829–1 190
Westland petrel	0.91	0.89–0.93	6.49	4.13–8.88	0.89	0.76–0.96	3 250	2 400–5 050
White-chinned petrel	0.94	0.90–0.97	6.49	4.11–8.88	0.89	0.75–0.96	125 000	79 300–239 000
Flesh-footed shearwater	0.92	0.84–0.96	6.48	4.13–8.87	0.89	0.76–0.96	7 280	6 700–9 890
Wedge-tailed shearwater	0.92	0.89–0.96	3.98	3.05–4.95	0.89	0.75–0.96	53 800	52 500–59 000
Buller's shearwater	0.92	0.84–0.96	6.50	4.14–8.85	0.89	0.75–0.96	148 000	94 800–284 000
Sooty shearwater	0.92	0.86–0.98	5.99	5.04–6.94	0.89	0.76–0.96	3 660 000	2 310 000–6 820 000
Fluttering shearwater	0.92	0.89–0.96	5.00	4.05–5.95	0.89	0.75–0.96	36 000	20 300–152 000
Hutton's shearwater	0.92	0.89–0.96	4.99	4.05–5.96	0.89	0.75–0.96	76 300	57 900–118 000
Little shearwater	0.92	0.89–0.96	5.01	4.05–5.96	0.89	0.76–0.96	118 000	101 000–202 000
Cape petrel	0.85	0.78–0.94	5.50	3.15–7.85	0.89	0.76–0.96	6 260	4 010–11 800
Fairy prion	0.84	0.77–0.89	4.50	4.02–4.97	0.89	0.76–0.96	966 000	707 000–2 490 000
Antarctic prion	0.84	0.77–0.89	5.50	5.03–5.97	0.89	0.75–0.96	181 000	101 000–754 000
Broad-billed prion	0.84	0.77–0.89	4.51	4.03–4.97	0.89	0.75–0.96	738 000	470 000–1 400 000
Pycroft's petrel	0.93	0.85–0.98	6.49	6.02–6.97	0.89	0.75–0.96	2 160	2 000–2 830
Cook's petrel	0.93	0.84–0.98	6.50	6.03–6.97	0.89	0.75–0.96	51 700	50 100–58 600
Chatham petrel	0.93	0.84–0.98	6.50	6.03–6.98	0.89	0.75–0.96	203	151–315
Mottled petrel	0.93	0.85–0.98	6.50	6.02–6.98	0.89	0.76–0.96	316 000	301 000–386 000
White-naped petrel	0.93	0.84–0.98	6.50	6.03–6.97	0.89	0.76–0.97	37 100	23 800–71 000
Kermadec petrel	0.93	0.85–0.98	6.50	6.02–6.98	0.89	0.76–0.96	5 320	5 010–6 680
Grey-faced petrel	0.93	0.85–0.98	6.51	6.03–6.97	0.89	0.75–0.96	216 000	200 000–287 000
Chatham Island taiko	0.93	0.85–0.98	6.50	6.02–6.98	0.89	0.76–0.96	15	13–19
White-headed petrel	0.93	0.85–0.98	5.53	4.07–6.93	0.60	0.50–0.69	148 000	94 800–277 000
Soft-plumaged petrel	0.93	0.84–0.98	6.51	6.03–6.97	0.89	0.75–0.96	1 830	1 020–7 640
Common diving petrel	0.81	0.75–0.87	2.49	2.02–2.97	0.89	0.74–0.96	479 000	304 000–1 630 000
South Georgian diving petrel	0.81	0.75–0.87	2.51	2.02–2.98	0.89	0.74–0.96	47	30–91
New Zealand white-faced storm petrel	0.90	0.83–0.94	4.00	3.05–4.95	0.89	0.76–0.96	977 000	706 000–2 520 000
White-bellied storm petrel	0.90	0.83–0.94	4.50	4.02–4.97	0.89	0.75–0.96	743	473–1 420
Black-bellied storm petrel	0.90	0.82–0.94	4.50	4.02–4.97	0.89	0.75–0.96	57 500	50 200–91 100
Kermadec storm petrel	0.90	0.82–0.94	4.00	3.04–4.95	0.89	0.75–0.96	31	20–98
New Zealand storm petrel	0.90	0.82–0.95	4.50	4.02–4.98	0.89	0.75–0.96	74	20–576
Yellow-eyed penguin	0.87	0.80–0.92	2.51	2.03–2.98	0.60	0.49–0.69	1 820	1 700–2 320
Northern little penguin	0.83	0.79–0.86	2.49	2.02–2.97	0.89	0.76–0.96	5 750	5 020–9 170
White-flippered little penguin	0.83	0.79–0.87	2.50	2.03–2.98	0.89	0.75–0.96	1 780	1 320–2 740
Southern little penguin	0.83	0.79–0.87	2.49	2.02–2.98	0.89	0.75–0.96	5 740	5 020–9 170
Chatham Island little penguin	0.83	0.79–0.86	2.51	2.03–2.98	0.89	0.76–0.96	5 740	5 020–9 170
Western rockhopper penguin	0.84	0.82–0.86	4.50	3.07–5.93	0.89	0.76–0.96	42 100	39 100–55 600
Fiordland crested penguin	0.84	0.82–0.86	4.50	3.07–5.92	0.89	0.75–0.96	2 220	1 400–4 200
Snares crested penguin	0.84	0.82–0.86	5.50	5.03–5.97	0.89	0.75–0.96	22 400	14 200–43 600
Erect-crested penguin	0.84	0.82–0.86	5.50	5.03–5.98	0.89	0.75–0.96	78 400	77 000–83 900
Australasian gannet	0.93	0.85–0.98	4.97	3.09–6.90	0.89	0.75–0.96	33 900	21 800–65 100
Masked booby	0.85	0.78–0.90	2.99	2.05–3.95	0.89	0.75–0.96	194	145–299
Pied shag	0.88	0.86–0.90	2.67	2.03–3.30	0.89	0.75–0.96	626	460–1 570
Little black shag	0.88	0.86–0.90	2.00	1.04–2.95	0.89	0.75–0.96	457	401–730
New Zealand king shag	0.88	0.86–0.90	4.01	3.06–4.95	0.89	0.76–0.96	106	102–123
Stewart Island shag	0.88	0.86–0.90	4.00	3.05–4.94	0.89	0.75–0.96	1 830	1 800–1 970
Chatham Island shag	0.88	0.86–0.90	4.00	3.05–4.95	0.89	0.75–0.96	320	277–398
Bounty Island shag	0.88	0.86–0.90	3.99	3.05–4.94	0.89	0.75–0.96	97	72–151
Auckland Island shag	0.88	0.86–0.90	4.01	3.06–4.95	0.89	0.75–0.97	1 320	964–3 410
Campbell Island shag	0.88	0.86–0.90	4.00	3.05–4.96	0.89	0.75–0.96	1 490	929–2 860
Spotted shag	0.88	0.86–0.90	2.00	1.05–2.95	0.89	0.76–0.96	12 600	10 100–26 400
Pitt Island shag	0.88	0.86–0.90	4.01	3.05–4.95	0.89	0.75–0.96	495	314–930
Subantarctic skua	0.94	0.91–0.97	8.03	7.64–8.42	0.89	0.76–0.96	454	450–468
Southern black-backed gull	0.81	0.74–0.86	4.01	3.04–4.94	0.89	0.76–0.96	974 000	706 000–2 560 000
Caspian tern	0.88	0.82–0.93	3.01	2.06–3.95	0.89	0.75–0.96	809	600–1 260
White tern	0.81	0.78–0.83	4.00	3.05–4.95	0.89	0.75–0.96	66	60–94

Table A-2: Summary of the input parameters to the calculation of the Potential Biological Removal (PBR) for seabird species breeding in New Zealand, including estimated total population size N^G, estimated maximum growth rate r_{max}^{NL} (mean and 95% confidence interval rounded to two significant digits), and the PBR calibration factor ρ. The species names were coloured according to their respective risk categories: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	Population size, N^G		Growth rate, r_{max}^{NL}		ρ
	Mean	95% c.i.	Mean	95% c.i.	
Gibson's albatross	30 500	20 200–44 200	0.04	0.03–0.06	0.37
Antipodean albatross	34 100	25 200–46 400	0.05	0.04–0.05	0.37
Southern royal albatross	42 100	31 000–56 900	0.06	0.05–0.06	0.37
Northern royal albatross	35 400	16 900–65 200	0.06	0.05–0.07	0.37
Campbell black-browed albatross	81 300	40 400–150 000	0.06	0.04–0.08	0.43
New Zealand white-capped albatross	396 000	162 000–873 000	0.05	0.02–0.07	0.43
Salvin's albatross	109 000	66 800–177 000	0.04	0.03–0.05	0.43
Chatham Island albatross	17 700	12 700–25 800	0.04	0.03–0.06	0.43
Grey-headed albatross	29 000	14 400–52 300	0.05	0.04–0.07	0.43
Southern Buller's albatross	52 200	34 700–79 500	0.05	0.03–0.06	0.43
Northern Buller's albatross	62 800	41 400–96 300	0.05	0.03–0.06	0.43
Light-mantled sooty albatross	32 200	25 700–41 000	0.04	0.03–0.05	0.37
Northern giant petrel	15 100	6 310–32 900	0.08	0.05–0.11	0.34
Grey petrel	171 000	96 100–285 000	0.08	0.05–0.10	0.33
Black petrel	4 860	3 490–6 920	0.09	0.08–0.11	0.33
Westland petrel	15 800	9 100–25 900	0.09	0.07–0.13	0.33
White-chinned petrel	586 000	284 000–1 090 000	0.08	0.05–0.12	0.33
Flesh-footed shearwater	32 000	19 500–58 000	0.09	0.06–0.14	0.41
Wedge-tailed shearwater	162 000	133 000–203 000	0.12	0.09–0.17	0.41
Buller's shearwater	801 000	359 000–1 690 000	0.09	0.06–0.14	0.41
Sooty shearwater	18 400 000	8 440 000–35 500 000	0.09	0.06–0.12	0.41
Fluttering shearwater	245 000	63 500–600 000	0.10	0.08–0.13	0.41
Hutton's shearwater	299 000	187 000–463 000	0.10	0.08–0.13	0.41
Little shearwater	474 000	288 000–739 000	0.10	0.08–0.13	0.32
Cape petrel	43 100	16 500–101 000	0.13	0.08–0.21	0.32
Fairy prion	6 720 000	2 810 000–13 200 000	0.15	0.13–0.17	0.32
Antarctic prion	1 990 000	485 000–5 280 000	0.13	0.11–0.15	0.32
Broad-billed prion	4 460 000	2 230 000–8 030 000	0.15	0.13–0.17	0.32
Pycroft's petrel	8 390	5 470–14 400	0.08	0.05–0.11	0.32
Cook's petrel	188 000	132 000–320 000	0.08	0.05–0.11	0.32
Chatham petrel	871	492–1 610	0.08	0.05–0.11	0.32
Mottled petrel	1 180 000	811 000–2 000 000	0.08	0.05–0.11	0.32
White-naped petrel	179 000	83 800–367 000	0.08	0.05–0.11	0.41
Kermadec petrel	20 100	13 500–34 300	0.08	0.05–0.11	0.41
Grey-faced petrel	838 000	547 000–1 420 000	0.08	0.05–0.11	0.41
Chatham Island taiko	58	39–98	0.08	0.05–0.11	0.41
White-headed petrel	978 000	467 000–1 910 000	0.09	0.06–0.14	0.41
Soft-plumaged petrel	13 200	3 170–35 500	0.08	0.05–0.11	0.32
Common diving petrel	2 920 000	938 000–6 710 000	0.27	0.21–0.34	0.17
South Georgian diving petrel	208	107–364	0.26	0.21–0.34	0.17
New Zealand white-faced storm petrel	5 030 000	2 120 000–9 730 000	0.14	0.10–0.19	0.30
White-bellied storm petrel	3 500	1 760–6 290	0.13	0.10–0.16	0.30
Black-bellied storm petrel	241 000	150 000–378 000	0.13	0.10–0.16	0.30
Kermadec storm petrel	176	62–386	0.14	0.10–0.19	0.30
New Zealand storm petrel	849	72–3 150	0.13	0.10–0.16	0.30
Yellow-eyed penguin	8 580	6 480–11 400	0.23	0.17–0.30	0.55
Northern little penguin	21 600	14 400–31 200	0.25	0.21–0.31	0.49
White-flippered little penguin	6 740	4 300–10 200	0.25	0.21–0.31	0.49
Southern little penguin	21 600	14 300–31 600	0.25	0.21–0.31	0.49
Chatham Island little penguin	21 600	14 200–31 500	0.25	0.21–0.31	0.49
Western rockhopper penguin	203 000	134 000–298 000	0.15	0.12–0.21	0.49
Fiordland crested penguin	13 200	6 330–24 900	0.15	0.12–0.20	0.49
Snares crested penguin	157 000	81 600–279 000	0.13	0.12–0.14	0.49
Erect-crested penguin	404 000	333 000–503 000	0.13	0.12–0.14	0.49
Australasian gannet	147 000	70 400–284 000	0.10	0.06–0.16	0.57
Masked booby	778	478–1 210	0.21	0.15–0.30	0.57
Pied shag	2 910	1 280–5 390	0.21	0.17–0.26	0.57
Little black shag	1 490	968–2 180	0.29	0.19–0.51	0.57
New Zealand king shag	381	305–486	0.15	0.12–0.19	0.57
Stewart Island shag	6 360	5 240–7 970	0.15	0.12–0.19	0.57
Chatham Island shag	1 210	902–1 600	0.15	0.12–0.19	0.57
Bounty Island shag	408	258–624	0.15	0.12–0.19	0.57
Auckland Island shag	7 230	3 140–13 800	0.15	0.12–0.19	0.57
Campbell Island shag	7 030	3 630–12 400	0.15	0.12–0.19	0.57
Spotted shag	46 800	24 900–78 900	0.29	0.19–0.50	0.57
Pitt Island shag	2 370	1 200–4 140	0.15	0.12–0.19	0.57
Subantarctic skua	1 620	1 250–2 100	0.07	0.05–0.08	0.57
Southern black-backed gull	6 900 000	2 740 000–14 000 000	0.18	0.14–0.23	0.61
Caspian tern	3 030	1 850–4 760	0.19	0.13–0.28	0.61
White tern	343	225–508	0.18	0.14–0.22	0.61

Table A-3: Number of observed seabird captures (C) and the proportion of overlap observed (P) with trawl, bottom-longline (BLL), surface-longline (SLL), and set-net fisheries between 2006–07 and 2010–11. The species names were coloured according to their respective risk categories: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	Trawl		BLL		SLL		Set net	
Species	C	P (%)	C	P (%)	C	P (%)	C	P (%)
Gibson's albatross	1	11.9	0	3.3	21	14.6	0	2.3
Antipodean albatross	0	11.1	0	4.0	26	9.6	0	2.4
Southern royal albatross	4	12.9	1	3.7	0	13.5	0	1.9
Northern royal albatross	0	8.6	0	3.8	1	11.1	0	2.8
Campbell black-browed albatross	4	13.8	3	5.4	12	13.4	0	3.5
NZ white-capped albatross	284	14.9	0	3.5	69	12.9	0	2.5
Salvin's albatross	119	11.0	25	4.1	6	13.4	0	1.9
Chatham Island albatross	7	16.2	13	4.5	0	6.2	0	2.1
Grey-headed albatross	0	11.6	0	3.3	0	14.0	0	2.0
Southern Buller's albatross	70	10.0	6	4.9	197	45.4	0	5.1
Northern Buller's albatross	0	10.4	0	2.6	0	7.1	0	1.4
Light-mantled sooty albatross	0	12.1	0	3.3	0	14.3	0	2.1
Northern giant petrel	4	15.0	0	3.9	0	13.5	0	1.6
Grey petrel	22	12.6	8	4.5	28	12.4	0	2.0
Black petrel	2	4.2	58	2.1	10	5.7	0	0.1
Westland petrel	6	6.7	0	1.8	4	7.9	3	2.2
White-chinned petrel	395	13.6	48	3.8	23	14.6	1	3.2
Flesh-footed shearwater	30	3.6	26	2.1	6	5.5	0	0.2
Wedge-tailed shearwater	0	81.5	0	0.0	0	10.5	0	0.0
Buller's shearwater	0	6.5	0	2.1	0	10.6	0	1.8
Sooty shearwater	468	10.3	14	3.1	2	14.7	7	6.3
Fluttering shearwater	0	1.9	1	0.4	0	12.7	0	0.0
Hutton's shearwater	0	7.2	0	2.5	0	4.6	0	8.7
Little shearwater	0	9.5	0	1.9	0	12.6	0	1.1
Cape petrel	22	13.1	7	5.3	2	13.1	9	4.6
Fairy prion	3	5.3	0	0.7	0	14.1	0	3.2
Antarctic prion	1	18.8	0	3.4	0	14.1	0	1.5
Broad-billed prion	0	12.4	0	2.5	0	13.0	0	2.1
Pycroft's petrel	0	3.9	0	1.6	0	6.1	0	0.0
Cook's petrel	0	2.4	0	2.2	0	5.5	0	0.4
Chatham petrel	0	15.0	0	1.2	0	0.0	0	0.0
Mottled petrel	0	6.4	0	8.6	0	22.7	0	8.7
White-naped petrel	0	100.0	0	0.0	0	16.0	0	0.0
Kermadec petrel	0	6.9	0	2.3	0	12.1	0	0.9
Grey-faced petrel	0	5.6	6	1.4	3	10.5	0	0.4
Chatham Island taiko	0	20.2	0	1.3	0	0.0	0	0.0
White-headed petrel	0	15.3	0	4.0	0	14.5	0	1.8
Soft-plumaged petrel	0	8.9	0	3.2	0	16.0	0	1.6
Common diving petrel	4	7.0	0	6.4	0	12.7	0	8.0
South Georgian diving petrel	0	7.4	0	12.1	0	51.0	0	12.0
NZ white-faced storm petrel	0	15.8	0	1.3	0	6.4	0	1.2
White-bellied storm petrel	0	37.4	0	1.5	0	12.0	0	0.0
Black-bellied storm petrel	1	9.8	0	2.8	0	12.4	0	1.8
Kermadec storm petrel	1	7.4	0	2.5	0	14.8	0	1.5
NZ storm petrel	0	10.1	0	2.9	0	12.9	0	1.8
Yellow-eyed penguin	0	6.9	0	5.9	0	0.0	7	4.9
Northern little penguin	0	3.2	0	1.5	0	5.7	0	1.1
White-flippered little penguin	0	4.8	0	3.4	0	0.0	0	3.3
Southern little penguin	0	8.2	0	2.2	0	12.6	0	6.1
Chatham Island little penguin	0	16.4	0	1.8	0	0.0	0	0.0
Western rockhopper penguin	0	20.1	0	10.6	0	34.7	0	3.4
Fiordland crested penguin	0	4.7	0	1.0	0	22.1	1	4.3
Snares crested penguin	0	15.3	0	7.4	0	48.2	0	5.8
Erect-crested penguin	0	24.8	0	20.2	0	0.0	0	0.0
Australasian gannet	0	3.2	0	1.2	0	11.3	0	0.4
Masked booby	0	10.1	0	2.9	0	12.9	0	1.8
Pied shag	0	1.4	0	1.7	0	1.7	1	1.4
Little black shag	0	1.5	0	1.6	0	0.1	0	0.4
NZ king shag	0	0.7	0	0.1	0	0.0	0	1.7
Stewart Island shag	0	8.4	0	0.1	0	0.0	2	6.6
Chatham Island shag	0	2.5	0	2.1	0	0.0	0	0.0
Bounty Island shag	0	100.0	0	24.7	0	0.0	0	0.0
Auckland Island shag	0	26.8	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	32	4.0	0	1.7	0	0.0	3	2.0
Pitt Island shag	0	1.3	0	1.8	0	0.0	0	0.0
Subantarctic skua	0	9.7	0	0.9	0	12.9	0	3.4
Southern black-backed gull	1	3.3	1	1.7	0	2.2	0	1.5
Caspian tern	0	3.3	0	1.7	0	3.6	0	1.6
White tern	0	8.0	0	2.1	0	10.1	0	1.1

Table A-4: Estimated number of annual potential fatalities (APF) in trawl fisheries, with colour shading indicating the mean ratio of the APF to the Potential Biological Removal with a recovery factor f set to 1 (PBR_1) (light yellow: mean APF between 1 and 10% of the mean PBR_1; light orange: mean APF between 10% and 30% of the mean PBR_1; dark orange: mean APF between 30% and 100% of the mean PBR_1; red: mean APF exceeding the mean PBR_1).

	Small inshore trawl		Large processor trawl		Large meal trawl		Large fresher trawl		SBW trawl	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	2	0–8	1	0–3	1	0–4	0	0–1	0	0–1
Antipodean albatross	2	0–8	0	0–3	1	0–4	0	0–1	1	0–2
Southern royal albatross	2	0–9	1	0–3	1	0–5	0	0–1	2	0–5
Northern royal albatross	**4**	0–21	1	0–7	2	0–11	0	0–1	0	0–1
Campbell black-browed albatross	4	0–17	2	0–10	**11**	2–35	0	0–1	4	0–17
NZ white-capped albatross	**1 080**	549–2 000	**249**	135–411	**114**	54–196	10	0–43	3	0–14
Salvin's albatross	**1 120**	628–1 710	**341**	224–489	**168**	95–269	3	0–18	**12**	2–34
Chatham Island albatross	**2**	0–13	**3**	0–15	**4**	0–13	0	0–2	0	0–1
Grey-headed albatross	0	0–2	0	0–2	0	0–2	0	0–0	0	0–1
Southern Buller's albatross	**26**	4–73	**92**	51–157	**192**	114–286	1	0–6	0	0–1
Northern Buller's albatross	**13**	2–36	**30**	16–52	**34**	18–53	1	0–9	0	0–0
Light-mantled sooty albatross	0	0–2	0	0–1	0	0–3	0	0–0	0	0–0
Northern giant petrel	**4**	0–16	2	0–10	**13**	2–40	0	0–3	1	0–4
Grey petrel	4	0–18	1	0–5	3	0–9	0	0–1	**38**	16–84
Black petrel	**21**	0–109	0	0–1	0	0–1	0	0–1	0	0–0
Westland petrel	**6**	0–42	**4**	0–17	**9**	2–25	0	0–1	0	0–0
White-chinned petrel	7	0–40	**167**	80–324	**80**	35–155	0	0–4	0	0–2
Flesh-footed shearwater	**71**	7–233	3	0–16	1	0–6	0	0–2	0	0–0
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	0	0–2	0	0–1	0	0–1	0	0–0	0	0–0
Sooty shearwater	216	85–491	276	144–488	166	86–306	2	0–25	1	0–7
Fluttering shearwater	1	0–6	0	0–0	0	0–0	0	0–0	0	0–0
Hutton's shearwater	0	0–3	0	0–2	0	0–1	0	0–0	0	0–0
Little shearwater	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0
Cape petrel	**44**	14–98	7	1–18	**21**	8–45	0	0–2	0	0–3
Fairy prion	3	0–16	0	0–1	1	0–3	0	0–0	0	0–0
Antarctic prion	0	0–2	0	0–1	1	0–2	0	0–0	0	0–1
Broad-billed prion	1	0–3	0	0–2	1	0–3	0	0–0	0	0–1
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Cook's petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0
Chatham petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–3	0	0–1	0	0–1	0	0–0	0	0–0
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	0	0–3	0	0–0	0	0–1	0	0–0	0	0–0
Chatham Island taiko	0	0–0	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	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	14	1–48	2	0–9	2	0–6	1	0–5	0	0–1
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	3	0–16	1	0–4	3	0–14	2	0–12	0	0–0
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–3	0	0–1	1	0–3	0	0–0	1	0–7
Kermadec storm petrel	0	0–0	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	0	0–0
Yellow-eyed penguin	0	0–1	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	0	0–0
White-flippered little penguin	0	0–0	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	0	0–0
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Western rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Fiordland crested penguin	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
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	1	0–7	0	0–1	0	0–1	0	0–0	0	0–0
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Little black shag	0	0–0	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	0	0–0
Stewart Island shag	0	0–1	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	0	0–0
Bounty Island shag	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
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Spotted shag	2	0–8	0	0–2	1	0–3	0	0–1	0	0–0
Pitt 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
Southern black-backed gull	5	0–22	0	0–3	0	0–2	0	0–1	0	0–0
Caspian tern	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
Total	2 650	1 850–3 650	1 190	929–1 510	831	641–1 050	22	5–66	66	36–113

Table A-5: Estimated number of annual potential fatalities (APF) in trawl fisheries, with colour shading indicating the mean ratio of the APF to the Potential Biological Removal with a recovery factor f set to 1 (PBR_1) (light yellow: mean APF between 1 and 10% of the mean PBR_1; light orange: mean APF between 10% and 30% of the mean PBR_1; dark orange: mean APF between 30% and 100% of the mean PBR_1; red: mean APF exceeding the mean PBR_1).

	Scampi trawl		Mackerel trawl		Squid trawl		Deepwater trawl		Flatfish trawl	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	1	0–7	0	0–0	**5**	1–13	1	0–3	1	0–16
Antipodean albatross	1	0–4	0	0–1	1	0–4	1	0–3	1	0–14
Southern royal albatross	1	0–8	0	0–1	**6**	1–14	1	0–3	2	0–17
Northern royal albatross	2	0–12	0	0–2	**4**	1–13	1	0–3	**4**	0–47
Campbell black-browed albatross	**16**	1–57	0	0–3	2	0–12	1	0–5	5	0–50
NZ white-capped albatross	**175**	57–369	6	0–18	**924**	549–1 420	28	10–59	**62**	1–311
Salvin's albatross	**385**	225–587	3	0–10	**34**	12–67	**48**	25–79	**126**	17–392
Chatham Island albatross	**5**	0–25	0	0–1	1	0–3	**29**	12–58	**2**	0–21
Grey-headed albatross	1	0–6	0	0–1	0	0–4	0	0–1	0	0–2
Southern Buller's albatross	**8**	1–22	5	1–21	**150**	94–212	2	0–6	**47**	3–160
Northern Buller's albatross	**16**	3–45	0	0–1	1	0–3	5	1–18	2	0–8
Light-mantled sooty albatross	1	0–5	0	0–0	0	0–3	0	0–1	0	0–2
Northern giant petrel	**13**	1–51	0	0–2	2	0–9	**5**	0–18	**6**	0–41
Grey petrel	2	0–8	0	0–4	3	0–8	2	0–7	4	0–29
Black petrel	**4**	0–20	0	0–3	0	0–0	0	0–2	**1**	0–7
Westland petrel	1	0–8	1	0–7	1	0–4	1	0–3	**8**	0–62
White-chinned petrel	**481**	234–864	15	4–33	**525**	291–966	1	0–5	8	0–37
Flesh-footed shearwater	**140**	57–314	1	0–4	1	0–3	1	0–5	2	0–16
Wedge-tailed shearwater	0	0–0	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	0	0–2
Sooty shearwater	220	101–434	3	0–11	679	345–1 270	13	3–29	58	3–276
Fluttering shearwater	1	0–4	0	0–0	0	0–0	0	0–0	0	0–0
Hutton's shearwater	0	0–1	0	0–0	0	0–0	0	0–1	0	0–1
Little shearwater	0	0–1	0	0–0	0	0–1	0	0–0	0	0–0
Cape petrel	**14**	3–37	0	0–1	6	1–18	7	2–16	**9**	0–47
Fairy prion	0	0–2	3	0–12	0	0–1	0	0–1	3	0–21
Antarctic prion	1	0–5	0	0–1	1	0–4	0	0–0	0	0–2
Broad-billed prion	1	0–3	0	0–1	0	0–1	0	0–1	1	0–3
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Cook's petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Chatham 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	0–1	0	0–0	0	0–2
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Grey-faced petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0
Chatham Island taiko	0	0–0	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	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	1	0–6	1	0–4	1	0–2	2	0–5	5	0–28
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	2	0–8	0	0–1	0	0–1	4	0–11	1	0–8
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–1	0	0–1	0	0–2	0	0–0	1	0–5
Kermadec storm petrel	0	0–0	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	0	0–0
Yellow-eyed penguin	0	0–1	0	0–0	0	0–0	0	0–0	0	0–2
Northern little penguin	0	0–1	0	0–0	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	0	0–0
Southern little penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–1
Chatham Island little penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Western rockhopper penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Fiordland crested penguin	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
Erect-crested penguin	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	0	0–2	0	0–0	0	0–0	0	0–0	0	0–2
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–1
Little black shag	0	0–0	0	0–0	0	0–0	0	0–0	**6**	4–10
NZ king shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Stewart Island shag	0	0–0	0	0–0	0	0–0	0	0–0	1	0–11
Chatham 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
Auckland Island shag	0	0–1	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	0	0–0
Spotted shag	0	0–2	0	0–1	0	0–0	0	0–0	**677**	442–989
Pitt 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
Southern black-backed gull	1	0–6	0	0–0	0	0–2	0	0–1	28	1–117
Caspian tern	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
Total	1 490	1 090–2 070	43	24–69	2 350	1 720–3 180	154	108–209	1 070	713–1 580

Table A-6: Estimated number of annual potential fatalities (APF) in bottom-longline (BLL) fisheries, with colour shading indicating the mean ratio of the APF to the Potential Biological Removal with a recovery factor f set to 1 (PBR_1) (light yellow: mean APF between 1 and 10% of the mean PBR_1; light orange: mean APF between 10% and 30% of the mean PBR_1; dark orange: mean APF between 30% and 100% of the mean PBR_1; red: mean APF exceeding the mean PBR_1).

	Bluenose BLL		Small BLL		Snapper BLL		Large BLL	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	**4**	0–18	1	0–6	1	0–3	0	0–2
Antipodean albatross	**5**	0–19	1	0–7	0	0–1	1	0–3
Southern royal albatross	4	0–17	1	0–6	0	0–3	1	0–2
Northern royal albatross	**10**	0–40	3	0–18	0	0–2	1	0–6
Campbell black-browed albatross	**55**	12–127	**37**	5–121	2	0–8	1	0–4
NZ white-capped albatross	1	0–4	1	0–14	0	0–3	0	0–2
Salvin's albatross	**10**	0–38	**404**	266–589	4	0–22	8	3–16
Chatham Island albatross	**9**	0–38	**143**	86–234	1	0–8	**4**	0–14
Grey-headed albatross	1	0–5	2	0–11	0	0–2	0	0–1
Southern Buller's albatross	**20**	6–48	**6**	0–23	0	0–0	**6**	2–13
Northern Buller's albatross	**57**	12–160	**7**	0–27	3	0–17	3	1–7
Light-mantled sooty albatross	0	0–3	1	0–11	0	0–2	0	0–1
Northern giant petrel	0	0–6	1	0–6	0	0–1	0	0–1
Grey petrel	11	0–44	**66**	21–160	4	0–22	10	3–20
Black petrel	**541**	300–877	**360**	181–562	**436**	281–743	**1**	0–4
Westland petrel	1	0–11	**4**	0–38	0	0–2	0	0–2
White-chinned petrel	60	4–202	**105**	24–293	2	0–11	**111**	76–157
Flesh-footed shearwater	**15**	0–74	**74**	15–149	**430**	241–645	1	0–5
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	3	0–25	5	0–18	1	0–5	0	0–2
Sooty shearwater	10	0–53	35	4–123	5	0–28	44	24–75
Fluttering shearwater	4	0–32	10	1–34	2	0–10	0	0–1
Hutton's shearwater	2	0–15	7	0–27	0	0–2	0	0–1
Little shearwater	1	0–5	2	0–5	0	0–3	0	0–1
Cape petrel	8	0–36	**78**	30–167	3	0–13	7	2–14
Fairy prion	1	0–5	6	0–36	0	0–2	0	0–1
Antarctic prion	0	0–2	0	0–2	0	0–1	0	0–1
Broad-billed prion	2	0–13	2	0–13	0	0–3	0	0–1
Pycroft's petrel	0	0–0	0	0–1	0	0–0	0	0–0
Cook's petrel	1	0–6	11	3–26	2	0–11	0	0–0
Chatham petrel	0	0–0	0	0–1	0	0–0	0	0–0
Mottled petrel	1	0–8	38	12–92	0	0–1	1	0–4
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–1	0	0–0	0	0–0
Grey-faced petrel	6	0–28	85	33–185	2	0–10	0	0–1
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	1	0–4	19	8–36	0	0–1	0	0–0
Soft-plumaged petrel	0	0–0	1	0–2	0	0–0	0	0–0
Common diving petrel	2	0–11	2	0–11	1	0–5	1	0–3
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	4	0–33	9	0–59	0	0–2	1	0–6
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	0	0–1	0	0–0	0	0–0
Kermadec 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	0–1	2	0–15	0	0–0	0	0–1
Northern little penguin	1	0–4	1	0–8	0	0–2	0	0–0
White-flippered little penguin	0	0–0	0	0–2	0	0–0	0	0–0
Southern little penguin	0	0–1	1	0–6	0	0–0	0	0–0
Chatham Island little penguin	1	0–5	2	0–11	0	0–0	0	0–0
Western rockhopper penguin	0	0–3	1	0–5	0	0–0	0	0–1
Fiordland crested penguin	0	0–2	3	0–13	0	0–0	0	0–0
Snares crested penguin	1	0–5	2	0–12	0	0–0	0	0–1
Erect-crested penguin	0	0–0	0	0–1	0	0–0	1	0–4
Australasian gannet	5	0–36	2	0–13	2	0–12	0	0–2
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–1	0	0–4	0	0–5	0	0–0
Little black shag	0	0–0	0	0–1	0	0–1	0	0–0
NZ king shag	0	0–0	0	0–3	0	0–0	0	0–0
Stewart Island shag	0	0–0	0	0–2	0	0–0	0	0–0
Chatham Island shag	0	0–0	0	0–4	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	2	0–12	5	0–48	2	0–23	0	0–1
Pitt Island shag	0	0–0	1	0–6	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	6	0–63	16	0–84	20	1–81	0	0–3
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
Total	866	587–1 230	1 570	1 240–1 950	924	660–1 240	205	159–261

Table A-7: Estimated number of annual potential fatalities (APF) in surface-longline (SLL) fisheries, with colour shading indicating the mean ratio of the APF to the Potential Biological Removal with a recovery factor f set to 1 (PBR_1) (light yellow: mean APF between 1 and 10% of the mean PBR_1; light orange: mean APF between 10% and 30% of the mean PBR_1; dark orange: mean APF between 30% and 100% of the mean PBR_1; red: mean APF exceeding the mean PBR_1).

	Large SLL		Small SLL	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	2	0–4	**100**	69–141
Antipodean albatross	1	0–2	**73**	51–102
Southern royal albatross	1	0–3	**94**	63–133
Northern royal albatross	1	0–2	**71**	48–100
Campbell black-browed albatross	2	0–4	**49**	28–79
NZ white-capped albatross	24	15–34	**154**	100–217
Salvin's albatross	2	0–4	**21**	9–37
Chatham Island albatross	0	0–0	**2**	0–11
Grey-headed albatross	0	0–0	1	0–2
Southern Buller's albatross	**77**	59–97	**29**	22–38
Northern Buller's albatross	4	1–8	**238**	166–339
Light-mantled sooty albatross	0	0–0	1	0–3
Northern giant petrel	0	0–0	1	0–5
Grey petrel	8	3–13	**84**	49–133
Black petrel	0	0–0	**74**	40–118
Westland petrel	1	0–2	**21**	5–56
White-chinned petrel	7	2–12	**84**	34–189
Flesh-footed shearwater	0	0–1	**41**	13–81
Wedge-tailed shearwater	0	0–0	0	0–0
Buller's shearwater	0	0–0	1	0–4
Sooty shearwater	1	0–2	9	1–26
Fluttering shearwater	0	0–0	0	0–1
Hutton's shearwater	0	0–0	0	0–1
Little shearwater	0	0–0	0	0–2
Cape petrel	0	0–1	**9**	1–28
Fairy prion	0	0–0	0	0–2
Antarctic prion	0	0–0	0	0–1
Broad-billed prion	0	0–0	1	0–3
Pycroft's petrel	0	0–0	0	0–0
Cook's petrel	0	0–0	2	0–5
Chatham petrel	0	0–0	0	0–0
Mottled petrel	0	0–1	1	0–4
White-naped petrel	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–0
Grey-faced petrel	0	0–1	12	4–27
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	0	0–0	2	0–5
Soft-plumaged petrel	0	0–0	0	0–1
Common diving petrel	0	0–1	1	0–6
South Georgian diving petrel	0	0–0	0	0–0
NZ white-faced storm petrel	0	0–0	1	0–7
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	1	0–4
Kermadec 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	2	0–9
White-flippered little penguin	0	0–0	0	0–0
Southern little penguin	0	0–0	0	0–1
Chatham Island little penguin	0	0–0	0	0–0
Western rockhopper penguin	0	0–0	0	0–1
Fiordland crested penguin	0	0–0	0	0–1
Snares crested penguin	0	0–1	0	0–2
Erect-crested penguin	0	0–0	0	0–0
Australasian gannet	0	0–0	1	0–5
Masked booby	0	0–0	0	0–0
Pied shag	0	0–0	1	0–12
Little black shag	0	0–0	1	0–5
NZ king shag	0	0–0	0	0–0
Stewart Island 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	17	0–175
Pitt Island shag	0	0–0	0	0–0
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	0	0–0	6	0–42
Caspian tern	0	0–0	0	0–0
White tern	0	0–0	0	0–0
Total	130	107–153	1 200	1 040–1 440

Table A-8: Estimated number of annual potential fatalities (APF) in trawl, surface-longline (SLL), bottom-longline (BLL), and set-net (SN) fisheries, with colour shading indicating the mean ratio of the APF to the Potential Biological Removal with a recovery factor f set to 1 (PBR_1) (light yellow: mean APF between 1 and 10% of the mean PBR_1; light orange: mean APF between 10% and 30% of the mean PBR_1; dark orange: mean APF between 30% and 100% of the mean PBR_1; red: mean APF exceeding the mean PBR_1)

	Trawl		BLL		SLL		SN		Total	
	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	**11**	4–27	**6**	1–20	**103**	71–143	1	0–5	**121**	86–164
Antipodean albatross	**8**	2–22	**7**	1–22	**73**	51–102	1	0–4	**89**	63–121
Southern royal albatross	**14**	5–33	**6**	1–20	**94**	64–134	1	0–5	**116**	82–160
Northern royal albatross	**19**	6–65	**15**	1–47	**71**	48–101	2	0–9	**108**	72–160
Campbell black-browed albatross	**46**	18–100	**94**	31–219	**51**	29–81	0	0–2	**192**	111–324
NZ white-capped albatross	**2 650**	1 900–3 590	3	0–19	**178**	122–240	3	0–10	**2 830**	2 080–3 790
Salvin's albatross	**2 240**	1 660–2 950	**427**	287–614	**22**	10–38	1	0–3	**2 690**	2 100–3 420
Chatham Island albatross	**45**	21–89	**158**	95–261	**2**	0–11	0	0–0	**205**	136–316
Grey-headed albatross	3	0–10	3	0–15	1	0–2	0	0–1	**6**	1–20
Southern Buller's albatross	**523**	386–693	**32**	14–63	**106**	87–127	1	0–5	**663**	520–839
Northern Buller's albatross	**104**	68–150	**70**	22–174	**242**	170–343	1	0–3	**418**	312–560
Light-mantled sooty albatross	**2**	0–9	2	0–11	1	0–3	2	0–5	**7**	2–20
Northern giant petrel	**45**	17–101	1	0–8	1	0–5	0	0–0	**47**	18–103
Grey petrel	**57**	30–105	**90**	38–187	**92**	56–142	8	3–15	**247**	169–364
Black petrel	**27**	3–114	**1 340**	980–1 780	**74**	40–118	**2**	0–4	**1 440**	1 070–1 900
Westland petrel	**31**	10–88	**5**	0–39	**22**	5–56	**6**	2–12	**63**	28–129
White-chinned petrel	**1 280**	873–1 920	**277**	151–518	**90**	40–196	22	7–41	**1 670**	1 210–2 330
Flesh-footed shearwater	**219**	101–434	**519**	313–742	**41**	13–81	0	0–0	**780**	523–1 090
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller's shearwater	1	0–3	8	1–30	1	0–4	0	0–1	10	2–32
Sooty shearwater	1 640	1 150–2 350	93	42–189	10	1–26	20	10–33	1 760	1 260–2 480
Fluttering shearwater	2	0–8	15	2–50	0	0–1	2	1–4	19	5–54
Hutton's shearwater	1	0–4	9	0–30	0	0–1	4	2–8	15	4–36
Little shearwater	0	0–2	3	0–9	0	0–2	0	0–1	4	1–10
Cape petrel	**109**	63–174	**96**	43–186	**9**	2–28	**40**	22–62	**254**	175–361
Fairy prion	11	3–31	7	0–37	0	0–2	4	0–14	22	7–56
Antarctic prion	3	1–8	1	0–4	0	0–1	1	0–2	5	2–10
Broad-billed prion	4	1–8	5	0–20	1	0–3	1	0–3	11	4–26
Pycroft's petrel	0	0–0	1	0–2	0	0–0	0	0–0	1	0–2
Cook's petrel	0	0–1	14	4–32	2	0–5	1	0–2	17	6–35
Chatham petrel	0	0–0	**0**	0–1	0	0–0	0	0–0	**0**	0–1
Mottled petrel	1	0–4	40	14–94	2	0–4	2	0–9	45	17–98
White-naped petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–1	0	0–0	0	0–0	0	0–1
Grey-faced petrel	1	0–3	93	38–191	12	4–27	2	0–7	108	51–207
Chatham Island taiko	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
White-headed petrel	0	0–1	20	9–37	2	0–5	0	0–1	23	11–41
Soft-plumaged petrel	0	0–0	1	0–2	0	0–1	0	0–0	1	0–3
Common diving petrel	28	10–66	5	0–18	1	0–6	2	0–7	36	15–77
South Georgian diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ white-faced storm petrel	15	4–34	15	0–70	1	0–7	15	0–49	45	12–111
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	4	1–11	0	0–1	1	0–4	3	0–10	8	2–17
Kermadec storm petrel	**0**	0–0	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	0	0–0
Yellow-eyed penguin	1	0–3	3	0–15	0	0–0	**32**	17–49	**35**	19–56
Northern little penguin	0	0–1	2	0–11	2	0–9	5	0–13	9	2–23
White-flippered little penguin	0	0–1	0	0–2	0	0–0	1	0–3	2	0–4
Southern little penguin	0	0–2	1	0–6	0	0–1	2	0–6	3	1–9
Chatham Island little penguin	0	0–1	3	0–14	0	0–0	0	0–0	3	0–14
Western rockhopper penguin	0	0–1	1	0–6	0	0–1	1	0–4	3	1–8
Fiordland crested penguin	0	0–1	3	0–13	0	0–1	3	1–6	**6**	1–17
Snares crested penguin	0	0–1	3	0–14	0	0–2	4	1–10	8	2–19
Erect-crested penguin	0	0–1	2	0–5	0	0–0	0	0–0	2	0–5
Australasian gannet	2	0–8	9	0–84	1	0–5	**50**	2–175	**62**	7–222
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Pied shag	0	0–1	1	0–6	1	0–12	**8**	2–19	**10**	3–24
Little black shag	**7**	4–10	0	0–1	1	0–5	1	0–2	**8**	5–14
NZ king shag	0	0–0	**0**	0–3	0	0–0	**0**	0–1	**1**	0–4
Stewart Island shag	1	0–11	0	0–2	0	0–0	**11**	3–26	**13**	3–29
Chatham Island shag	0	0–0	0	0–4	0	0–0	0	0–0	0	0–4
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	**681**	444–991	9	0–67	17	0–175	**38**	7–75	**745**	485–1 100
Pitt Island shag	0	0–0	1	0–6	0	0–0	0	0–0	1	0–6
Subantarctic skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Southern black-backed gull	34	4–125	42	3–142	6	0–42	12	0–45	94	25–231
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	9 870	8 560–11 300	3 560	3 040–4 150	1 340	1 170–1 570	317	228–460	15 100	13 600–16 600

Table A-9: Vulnerability to capture of each seabird species grouping in trawl, bottom-longline (BLL), and surface-longline (SLL) fisheries. Vulnerabilities were estimated relative to that of white-chinned petrel (set to 1 as the base case). Note that this species does not overlap with bottom longline fisheries, and this led to a large apparent vulnerability of black petrels in these fisheries.

	Trawl		BLL		SLL	
Species groups	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
Great albatrosses (spp)	0.36	0.03–1.51	5.40	0.07–37.50	23.50	2.49–108.00
White-capped albatross	4.41	0.69–15.90	0.27	0.00–1.95	17.00	1.42–74.70
Salvin's albatross	12.70	1.93–46.00	20.70	0.49–128.00	2.41	0.20–11.10
Campbell black-browed albatross	0.44	0.03–1.94	32.70	0.44–182.00	16.30	1.62–74.00
Chatham albatross	1.13	0.06–5.42	24.60	0.52–156.00	0.55	0.00–4.32
Grey-headed albatross	0.09	0.00–0.66	2.49	0.00–15.00	0.39	0.00–2.38
Buller's albatrosses (spp)	2.33	0.32–8.62	6.31	0.16–40.60	45.80	5.31–215.00
Light-mantled sooty albatross	0.07	0.00–0.49	1.38	0.00–9.73	0.24	0.00–1.77
Giant petrel	5.13	0.41–22.90	3.04	0.00–16.60	1.03	0.00–7.78
Grey petrel	1.00	0.11–3.84	16.80	0.39–114.00	14.10	1.55–69.10
Black petrel	8.96	0.29–45.20	1 870.00	67.20–11 500.00	42.20	2.36–210.00
Westland petrel	1.59	0.13–7.40	1.10	0.00–9.62	7.11	0.49–34.40
White-chinned petrel	1.00	1.00–1.00	1.00	1.00–1.00	1.00	1.00–1.00
Flesh-footed shearwater	5.87	0.59–24.20	58.80	1.32–357.00	7.71	0.49–38.00
Shearwaters (spp)	0.00	0.00–0.02	0.22	0.00–1.55	0.01	0.00–0.09
Sooty shearwater	0.16	0.03–0.60	0.15	0.00–1.01	0.02	0.00–0.13
Cape petrel	12.80	1.71–50.20	77.70	1.46–449.00	4.58	0.18–23.90
Prions (spp)	0.00	0.00–0.02	0.03	0.00–0.18	0.00	0.00–0.02
Pterodroma petrels (spp)	0.00	0.00–0.01	0.28	0.00–1.78	0.05	0.00–0.30
Diving petrels (spp)	0.03	0.00–0.12	0.02	0.00–0.14	0.01	0.00–0.07
Storm petrels (spp)	0.10	0.01–0.42	0.05	0.00–0.34	0.06	0.00–0.37
Crested penguins (spp)	0.01	0.00–0.04	0.91	0.00–6.35	0.12	0.00–0.78
Yellow-eyed penguin	0.10	0.00–0.71	1.72	0.00–14.30	72.40	0.00–827.00
Blue penguins (spp)	0.02	0.00–0.11	0.21	0.00–1.51	0.11	0.00–0.82
Boobies and gannets (spp)	0.02	0.00–0.14	0.23	0.00–1.94	0.06	0.00–0.36
Group foraging shags (spp)	0.80	0.04–3.83	0.29	0.00–2.23	43.70	0.00–478.00
Solitary shags (spp)	0.11	0.00–0.92	1.51	0.00–12.90	25.20	0.00–226.00
Gulls, terns and skua (spp)	0.00	0.00–0.03	0.05	0.00–0.35	0.12	0.00–0.88

Table A-10: Vulnerability to capture of each seabird species group in set-net fisheries. Vulnerabilities were estimated relative to that of white-chinned petrel (set to 1 as the base case).

Species groups	Mean	95% c.i.
Great albatrosses (spp)	0.95	0.02–3.49
Shearwaters (spp)	0.01	0.00–0.01
Cape petrel	51.30	24.60–87.30
Prions (spp)	0.01	0.00–0.03
Pterodroma petrels (spp)	0.01	0.00–0.05
Diving petrels (spp)	0.01	0.00–0.04
Storm petrels (spp)	0.39	0.01–1.47
Crested penguins (spp)	1.15	0.15–3.34
Yellow-eyed penguin	7.79	3.35–14.10
Blue penguins (spp)	0.17	0.00–0.62
Boobies and gannets (spp)	0.85	0.02–3.06
Group foraging shags (spp)	0.15	0.04–0.34
Solitary shags (spp)	1.30	0.36–2.86
Gulls, terns and skua (spp)	0.00	0.00–0.01
Small albatrosses and giant petrel	0.14	0.00–0.51
Procellaria petrels (spp)	1.48	0.49–3.04

Table A-11: Vulnerability to capture of seabirds in each fishery group, for trawl and longline methods (bottom longline, BLL; surface longline, SLL). Vulnerabilities for each fishing method were estimated independently and relative to the vulnerability in deepwater trawling, large-vessel bottom longlining, and small-vessel bottom longlining, respectively (set to 1 as the base case).

Method	Fishery group	Mean	95% c.i.
Trawl	Small inshore trawl	0.73	0.15–2.16
	Large processor trawl	3.36	0.72–9.66
	Large meal trawl	4.01	0.94–11.20
	Large fresher trawl	0.20	0.00–0.96
	SBW trawl	4.22	0.63–14.10
	Scampi trawl	6.49	1.46–18.80
	Mackerel trawl	1.06	0.18–3.51
	Squid trawl	3.83	0.79–11.70
	Deepwater trawl	1.00	1.00–1.00
	Flatfish trawl	0.78	0.10–2.75
Bottom longline	Bluenose BLL	2.14	0.21–8.20
	Small BLL	5.01	0.68–18.70
	Snapper BLL	0.28	0.01–1.22
	Large BLL	1.00	1.00–1.00
Surface longline	Small SLL	2.07	0.77–4.91
	Large SLL	1.00	1.00–1.00

Table A-12: Comparison of the Potential Biological removal (PBR) between Richard et al. (2011) and this study for the same studied species. Also included are PBR values reported in Dillingham & Fletcher (2011) for a subset of species. All PBR values were calculated with $f = 1$ and were back-calculated when necessary. (Values are rounded to two significant digits.). The values of f that were used to assess the risk in Richard et al. (2011) are also shown ($f = 1$ in the present study). The species names were coloured according to their respective risk categories in the present study: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	Richard et al. (2011)			This study		D. & F. (2011)
	Mean	95% c.i.	f	Mean	95% c.i.	
Gibson's albatross	603	316–985	0.3	260	132–425	500
Antipodean albatross	703	493–998	0.3	295	203–419	700
Southern royal albatross	1 050	749–1 490	0.3	441	302–630	1 200
Northern royal albatross	744	357–1 560	0.2	396	164–782	800
Campbell black-browed albatross	1 680	993–3 360	0.3	1 020	514–1 830	2 100
NZ white-capped albatross	16 700	9 700–25 300	0.4	4 040	908–9 840	9 670
Salvin's albatross	5 230	2 380–10 100	0.3	975	521–1 740	3 200
Chatham Island albatross	1 240	918–1 720	0.3	159	94–264	500
Grey-headed albatross	547	304–1 090	0.3	333	157–613	
Southern Buller's albatross	2 450	1 200–4 290	0.4	513	270–831	1 400
Northern Buller's albatross	2 170	824–5 930	0.4	617	325–1000	1 900
Light-mantled sooty albatross	630	455–844	0.4	237	167–319	1 030
Northern giant petrel	501	163–1 120	0.5	217	66–486	260
Grey petrel	5 000	2 630–9 680	0.4	2 170	1 010–3 900	5 670
Black petrel	331	216–512	0.3	74	47–117	200
Westland petrel	572	368–941	0.3	241	142–384	400
White-chinned petrel	8 580	3 820–27 400	0.3	7 920	3 280–15 800	23 000
Flesh-footed shearwater	1 240	631–2 450	0.5	590	288–1 200	1 200
Wedge-tailed shearwater	11 200	7 300–15 800	0.5	4 120	2 720–5 760	
Buller's shearwater	25 400	11 000–59 300	0.3	14 800	5 530–33 800	84 000
Sooty shearwater	606 000	230 000–1 370 000	0.4	348 000	115 000–751 000	533 000
Hutton's shearwater	14 800	8 560–25 300	0.2	6 370	3 490–10 600	13 000
Little shearwater	22 800	13 400–40 800	0.5	7 800	4 090–13 200	
Cape petrel	2 190	876–4 900	0.5	840	283–1 890	
Fairy prion	308 000	170 000–796 000	0.5	159 000	62 800–330 000	
Antarctic prion	58 700	24 100–239 000	0.5	40 100	9 230–110 000	
Broad-billed prion	235 000	125 000–482 000	0.5	106 000	48 700–201 000	
Pycroft's petrel	300	138–679	0.3	109	48–241	
Cook's petrel	7 300	3 380–16 300	0.3	2 430	1 140–5 500	
Chatham petrel	33	15–73	0.2	11	5–26	
Mottled petrel	44 300	20 500–99 400	0.4	15 300	7 040–33 500	
White-naped petrel	5 080	2 080–12 100	0.3	2 990	1 060–7 410	
Kermadec petrel	740	340–1 590	0.5	336	153–752	
Grey-faced petrel	29 700	14 100–64 000	0.5	14 000	6 290–31 200	30 000
Chatham Island taiko	9	4–19	0.1	1	0–2	0
White-headed petrel	31 700	12 900–73 500	0.5	18 500	6 760–44 000	
Soft-plumaged petrel	250	79–964	0.5	171	32–553	
Common diving petrel	198 000	102 000–664 000	0.5	64 600	19 400–152 000	
South Georgian diving petrel	20	11–39	0.5	5	2–8	
NZ white-faced storm petrel	218 000	111 000–586 000	0.5	105 000	38 800–226 000	
White-bellied storm petrel	187	94–381	0.5	66	29–131	
Black-bellied storm petrel	14 500	8 450–25 700	0.5	4 550	2 410–8 220	
Kermadec storm petrel	7	3–22	0.1	4	1–9	
NZ storm petrel	20	4–166	0.1	16	1–64	
Yellow-eyed penguin	861	581–1 260	0.2	537	352–805	
Western rockhopper penguin	13 300	10 700–18 200	0.3	7 510	5 580–9 990	
Fiordland crested penguin	701	426–1 350	0.3	488	255–866	
Snares crested penguin	6 930	4 230–13 600	0.3	4 910	2 520–8 800	
Erect-crested penguin	24 600	20 200–30 900	0.2	12 600	10 200–15 600	
Australasian gannet	6 230	2 530–14 400	0.5	4 190	1 500–9 770	
Masked booby	119	64–359	0.5	46	26–76	
NZ king shag	60	48–76	0.3	16	13–20	
Stewart Island shag	534	414–761	0.3	269	218–334	
Chatham Island shag	50	40–64	0.1	51	38–68	
Bounty Island shag	54	42–72	0.3	17	11–26	
Auckland Island shag	176	137–237	0.3	305	132–581	
Campbell Island shag	703	543–943	0.3	298	153–534	
Spotted shag	7 330	4 010–18 700	0.5	3 780	1 730–7 570	
Pitt Island shag	97	58–189	0.2	100	51–178	
Subantarctic skua	54	33–78	0.5	31	19–45	
Southern black-backed gull	437 000	251 000–1 110 000	0.5	371 000	148 000–751 000	
Caspian tern	231	128–395	0.5	176	92–299	
White tern	6	4–19	0.5	19	13–26	

Table A-13: Comparison of the total number of annual potential fatalities in trawl and longline fisheries between Richard et al. (2011) and this study for the same studied species. Values are rounded to two significant digits. The species names were coloured according to their respective risk categories in the present study: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	Richard et al. (2011)		This study	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	205	148–269	121	86–164
Antipodean albatross	227	163–299	89	63–121
Southern royal albatross	227	66–438	116	82–160
Northern royal albatross	286	169–590	108	72–160
Campbell black-browed albatross	855	594–1 240	192	111–324
NZ white-capped albatross	5 120	4 570–5 720	2 830	2 080–3 790
Salvin's albatross	3 330	2 870–3 860	2 690	2 100–3 420
Chatham Island albatross	980	463–2 680	205	136–316
Grey-headed albatross	525	291–912	6	1–20
Southern Buller's albatross	1 100	817–1 520	663	520–839
Northern Buller's albatross	531	369–752	418	312–560
Light-mantled sooty albatross	534	298–922	7	2–20
Northern giant petrel	567	331–965	47	18–103
Grey petrel	709	531–979	247	169–364
Black petrel	1 060	725–1 520	1 440	1 080–1 900
Westland petrel	539	258–1 200	63	28–129
White-chinned petrel	1 640	1 450–1 920	1 670	1 210–2 330
Flesh-footed shearwater	1 380	1 080–1 770	780	523–1 090
Wedge-tailed shearwater	7	2–16	0	0–0
Buller's shearwater	217	129–361	10	2–32
Sooty shearwater	3 540	3 150–4 110	1 760	1 260–2 480
Hutton's shearwater	266	135–482	15	4–36
Little shearwater	54	30–93	4	1–10
Cape petrel	684	523–910	254	175–361
Fairy prion	253	109–678	22	7–56
Antarctic prion	49	26–89	5	2–10
Broad-billed prion	128	65–236	11	4–26
Pycroft's petrel	3	1–6	1	0–2
Cook's petrel	49	22–102	17	6–35
Chatham petrel	0	0–0	0	0–1
Mottled petrel	164	89–331	45	17–98
White-naped petrel	0	0–1	0	0–0
Kermadec petrel	2	1–3	0	0–1
Grey-faced petrel	139	74–251	108	51–207
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	132	85–221	23	11–41
Soft-plumaged petrel	3	1–7	1	0–3
Common diving petrel	371	223–602	36	15–77
South Georgian diving petrel	0	0–0	0	0–0
NZ white-faced storm petrel	353	212–579	45	12–111
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	35	15–69	8	2–17
Kermadec storm petrel	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0
Yellow-eyed penguin	20	3–61	35	19–56
Western rockhopper penguin	35	14–72	3	1–8
Fiordland crested penguin	87	38–176	6	1–17
Snares crested penguin	52	28–91	8	2–19
Erect-crested penguin	4	2–10	2	0–5
Australasian gannet	249	153–383	62	7–222
Masked booby	0	0–0	0	0–0
NZ king shag	37	8–81	1	0–4
Stewart Island shag	251	186–328	13	3–29
Chatham Island shag	1	0–3	0	0–4
Bounty Island shag	0	0–1	0	0–0
Auckland Island shag	1	0–2	0	0–1
Campbell Island shag	0	0–1	0	0–0
Spotted shag	1 580	1 290–1 910	745	485–1 100
Pitt Island shag	3	1–7	1	0–6
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	685	421–1 040	94	25–231
Caspian tern	0	0–0	0	0–1
White tern	0	0–0	0	0–0

Table A-14: Comparison of the risk ratios between Richard et al. (2011) and this study for the same studied species. Risk ratios of Richard et al. (2011) were back-calculated with the recovery factor set to 1. The mean values are presented as median values were not available from Richard et al. (2011). A "+" or "-" sign in the "Change" column indicates whether the new risk ratio is higher (respectively lower). A direction of change is only indicated if both mean values are outside the other assessment's confidence intervals. The species names were coloured according to their respective risk categories in the present study: Red: risk ratio with a median over 1 or upper 95% confidence 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.

	Richard et al. (2011)		This study		Change
	Mean	95% c.i.	Mean	95% c.i.	
Gibson's albatross	0.37	0.19–0.69	0.52	0.25–1.00	
Antipodean albatross	0.33	0.20–0.51	0.31	0.18–0.49	
Southern royal albatross	0.22	0.06–0.47	0.27	0.16–0.43	
Northern royal albatross	0.44	0.15–1.08	0.32	0.12–0.70	
Campbell black-browed albatross	0.55	0.23–0.96	0.21	0.08–0.44	-
NZ white-capped albatross	0.33	0.20–0.53	1.03	0.28–3.13	
Salvin's albatross	0.75	0.32–1.42	3.03	1.47–5.41	+
Chatham Island albatross	0.81	0.34–2.28	1.39	0.68–2.59	
Grey-headed albatross	1.05	0.40–2.15	0.02	0.00–0.07	-
Southern Buller's albatross	0.51	0.23–1.00	1.42	0.75–2.58	+
Northern Buller's albatross	0.32	0.08–0.70	0.74	0.38–1.36	+
Light-mantled sooty albatross	0.87	0.43–1.61	0.03	0.01–0.09	-
Northern giant petrel	1.50	0.41–3.93	0.29	0.06–0.85	-
Grey petrel	0.16	0.07–0.29	0.13	0.06–0.27	
Black petrel	3.34	1.78–5.57	20.50	11.40–32.80	+
Westland petrel	0.99	0.38–2.35	0.28	0.10–0.66	-
White-chinned petrel	0.24	0.06–0.43	0.25	0.10–0.53	
Flesh-footed shearwater	1.25	0.54–2.27	1.50	0.59–2.94	
Wedge-tailed shearwater	0.00	0.00–0.00	0.00	0.00–0.00	
Buller's shearwater	0.01	0.00–0.02	0.00	0.00–0.00	
Sooty shearwater	0.01	0.00–0.02	0.01	0.00–0.02	
Hutton's shearwater	0.02	0.01–0.04	0.00	0.00–0.01	-
Little shearwater	0.00	0.00–0.01	0.00	0.00–0.00	
Cape petrel	0.38	0.14–0.81	0.39	0.12–0.93	
Fairy prion	0.00	0.00–0.00	0.00	0.00–0.00	
Antarctic prion	0.00	0.00–0.00	0.00	0.00–0.00	
Broad-billed prion	0.00	0.00–0.00	0.00	0.00–0.00	
Pycroft's petrel	0.01	0.00–0.03	0.01	0.00–0.03	
Cook's petrel	0.01	0.00–0.02	0.01	0.00–0.02	
Chatham petrel	0.01	0.00–0.02	0.02	0.00–0.10	
Mottled petrel	0.00	0.00–0.01	0.00	0.00–0.01	
White-naped petrel	0.00	0.00–0.00	0.00	0.00–0.00	
Kermadec petrel	0.00	0.00–0.01	0.00	0.00–0.00	
Grey-faced petrel	0.01	0.00–0.01	0.01	0.00–0.02	
Chatham Island taiko	0.00	0.00–0.01	0.01	0.00–0.00	
White-headed petrel	0.01	0.00–0.01	0.00	0.00–0.00	
Soft-plumaged petrel	0.02	0.00–0.06	0.01	0.00–0.05	
Common diving petrel	0.00	0.00–0.00	0.00	0.00–0.00	
South Georgian diving petrel	0.00	0.00–0.01	0.00	0.00–0.00	
NZ white-faced storm petrel	0.00	0.00–0.00	0.00	0.00–0.00	
White-bellied storm petrel	0.00	0.00–0.00	0.00	0.00–0.00	
Black-bellied storm petrel	0.00	0.00–0.01	0.00	0.00–0.01	
Kermadec storm petrel	0.00	0.00–0.00	0.08	0.02–0.18	+
NZ storm petrel	0.00	0.00–0.00	0.01	0.00–0.12	
Yellow-eyed penguin	0.02	0.00–0.08	0.07	0.03–0.12	
Western rockhopper penguin	0.00	0.00–0.01	0.00	0.00–0.00	
Fiordland crested penguin	0.13	0.04–0.29	0.01	0.00–0.04	-
Snares crested penguin	0.01	0.00–0.02	0.00	0.00–0.01	
Erect-crested penguin	0.00	0.00–0.00	0.00	0.00–0.00	
Australasian gannet	0.05	0.01–0.11	0.02	0.00–0.07	
Masked booby	0.00	0.00–0.00	0.00	0.00–0.01	
NZ king shag	0.62	0.13–1.43	0.06	0.00–0.24	-
Stewart Island shag	0.48	0.30–0.69	0.05	0.01–0.11	-
Chatham Island shag	0.02	0.00–0.05	0.01	0.00–0.08	
Bounty Island shag	0.01	0.00–0.02	0.00	0.00–0.02	
Auckland Island shag	0.01	0.00–0.01	0.00	0.00–0.00	
Campbell Island shag	0.00	0.00–0.00	0.00	0.00–0.00	
Spotted shag	0.25	0.08–0.41	0.23	0.09–0.48	
Pitt Island shag	0.03	0.01–0.08	0.01	0.00–0.06	
Subantarctic skua	0.00	0.00–0.00	0.00	0.00–0.01	
Southern black-backed gull	0.00	0.00–0.00	0.00	0.00–0.00	
Caspian tern	0.00	0.00–0.00	0.00	0.00–0.00	
White tern	0.00	0.00–0.00	0.00	0.00–0.00	

Table A-15: Estimated number of annual observable captures of seabirds (not including cryptic mortality), and estimated number of annual potential fatalities (including cryptic mortality) in trawl, bottom-longline, surface-longline, and set-net fisheries in New Zealand's Exclusive Economic Zone. The species names were coloured according to their respective risk categories: Red: risk ratio with a median over 1 or upper 95% confidence 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.

Species	No cryptic mortality		With cryptic mortality	
	Mean	95% c.i.	Mean	95% c.i.
Gibson's albatross	55	41–73	121	86–164
Antipodean albatross	42	31–55	89	63–121
Southern royal albatross	50	36–67	116	82–160
Northern royal albatross	45	30–65	108	72–160
Campbell black-browed albatross	77	43–135	192	111–324
NZ white-capped albatross	394	338–454	2 830	2 080–3 790
Salvin's albatross	476	396–577	2 690	2 100–3 420
Chatham Island albatross	82	54–124	205	136–316
Grey-headed albatross	2	0–7	6	1–20
Southern Buller's albatross	136	119–159	663	520–839
Northern Buller's albatross	157	114–215	418	312–560
Light-mantled sooty albatross	3	0–10	7	2–20
Northern giant petrel	6	2–13	47	18–103
Grey petrel	112	79–161	247	169–364
Black petrel	693	522–884	1 440	1 070–1 900
Westland petrel	28	14–51	63	28–129
White-chinned petrel	567	485–686	1 670	1 210–2 330
Flesh-footed shearwater	333	234–434	780	523–1 090
Wedge-tailed shearwater	0	0–0	0	0–0
Buller's shearwater	5	1–16	10	2–32
Sooty shearwater	539	477–613	1 760	1 260–2 480
Fluttering shearwater	10	3–27	19	5–54
Hutton's shearwater	9	3–19	15	4–36
Little shearwater	2	0–5	4	1–10
Cape petrel	125	88–172	254	175–361
Fairy prion	11	3–28	22	7–56
Antarctic prion	2	1–4	5	2–10
Broad-billed prion	5	1–13	11	4–26
Pycroft's petrel	0	0–1	1	0–2
Cook's petrel	8	3–17	17	6–35
Chatham petrel	0	0–0	0	0–1
Mottled petrel	23	8–47	45	17–98
White-naped petrel	0	0–0	0	0–0
Kermadec petrel	0	0–0	0	0–1
Grey-faced petrel	53	26–98	108	51–207
Chatham Island taiko	0	0–0	0	0–0
White-headed petrel	11	5–20	23	11–41
Soft-plumaged petrel	1	0–1	1	0–3
Common diving petrel	14	6–26	36	15–77
South Georgian diving petrel	0	0–0	0	0–0
NZ white-faced storm petrel	26	5–62	45	12–111
White-bellied storm petrel	0	0–0	0	0–0
Black-bellied storm petrel	4	1–12	8	2–17
Kermadec storm petrel	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0
Yellow-eyed penguin	34	18–52	35	19–56
Northern little penguin	7	1–16	9	2–23
White-flippered little penguin	1	0–4	2	0–4
Southern little penguin	3	0–7	3	1–9
Chatham Island little penguin	1	0–7	3	0–14
Western rockhopper penguin	2	1–5	3	1–8
Fiordland crested penguin	4	1–10	6	1–17
Snares crested penguin	6	2–13	8	2–19
Erect-crested penguin	1	0–2	2	0–5
Australasian gannet	56	5–181	62	7–222
Masked booby	0	0–0	0	0–0
Pied shag	9	3–20	10	3–24
Little black shag	6	4–9	8	5–14
NZ king shag	1	0–2	1	0–4
Stewart Island shag	12	3–28	13	3–29
Chatham Island shag	0	0–2	0	0–4
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	558	361–766	745	485–1 100
Pitt Island shag	0	0–3	1	0–6
Subantarctic skua	0	0–0	0	0–0
Southern black-backed gull	46	12–105	94	25–231
Caspian tern	0	0–0	0	0–1
White tern	0	0–0	0	0–0

Table A-16: Total observed captures and annual potential fatalities, relative to the breeding season of each seabird species. Species with unspecified breeding periods breed all year long (e.g., albatrosses), their distribution does not change between seasons (e.g., coastal species), or their distribution is unknown (e.g., New Zealand storm petrel); only one distribution map was used for these species. The species names were coloured according to their respective risk categories: Red: risk ratio with a median over 1 or upper 95% confidence 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.

			During breeding season			Outside breeding season		
		Leaves	Observed	Estimated fatalities		Observed	Estimated fatalities	
Species	Breeding period	NZEEZ	captures	Mean	95% c.i.	captures	Mean	95% c.i.
Gibson's albatross	–	No	22	121	86–164	0	0	0–0
Antipodean albatross	–	No	26	89	63–121	0	0	0–0
Southern royal albatross	–	No	5	116	82–160	0	0	0–0
Northern royal albatross	–	No	1	108	72–160	0	0	0–0
Campbell black-browed albatross	Aug–May (10)	No	12	151	76–281	7	41	21–73
New Zealand white-capped albatross	–	No	353	2 830	2 080–3 790	0	0	0–0
Salvin's albatross	Aug–Apr (9)	No	147	2 060	1 510–2 750	3	627	453–855
Chatham Island albatross	Jul–Apr (10)	No	20	177	109–285	0	28	16–45
Grey-headed albatross	Sep–May (9)	No	0	4	0–18	0	1	0–6
Southern Buller's albatross	Mar–Dec (10)	No	265	521	386–690	8	142	98–196
Northern Buller's albatross	Dec–Sep (10)	No	0	374	269–515	0	44	30–64
Light-mantled sooty albatross	Sep–May (9)	No	0	5	1–17	0	2	0–6
Northern giant petrel	Aug–May (10)	No	4	39	12–92	0	8	2–20
Grey petrel	Feb–Dec (11)	No	58	223	147–340	0	24	13–40
Black petrel	Oct–Jun (9)	Yes	70	1 440	1 070–1 900	0	0	0–0
Westland petrel	Feb–Dec (11)	Yes	13	63	28–129	0	0	0–0
White-chinned petrel	Oct–May (8)	Yes	465	1 670	1 210–2 330	2	0	0–0
Flesh-footed shearwater	Sep–May (9)	Yes	62	780	523–1 090	0	0	0–0
Wedge-tailed shearwater	Jun–Dec (7)	Yes	0	0	0–0	0	0	0–0
Buller's shearwater	Sep–May (9)	Yes	0	10	2–32	0	0	0–0
Sooty shearwater	Sep–May (9)	Yes	489	1 760	1 260–2 480	2	0	0–0
Fluttering shearwater	Aug–Feb (7)	No	0	18	4–53	1	1	0–3
Hutton's shearwater	Oct–Mar (6)	Yes	0	15	4–36	0	0	0–0
Little shearwater	Jun–Dec (7)	No	0	2	0–7	0	2	0–6
Cape petrel	Oct–Jan (4)	No	3	105	64–160	37	150	84–248
Fairy prion	Sep–Mar (7)	No	3	20	5–54	0	2	1–6
Antarctic prion	Nov–Mar (5)	No	1	3	1–7	0	2	1–6
Broad-billed prion	Jul–Nov (5)	No	0	5	1–19	0	5	2–13
Pycroft's petrel	Oct–Mar (6)	Yes	0	1	0–2	0	0	0–0
Cook's petrel	Oct–Apr (7)	Yes	0	17	6–35	0	0	0–0
Chatham petrel	Nov–Apr (6)	Yes	0	0	0–1	0	0	0–0
Mottled petrel	Oct–Jun (9)	Yes	0	45	17–98	0	0	0–0
White-naped petrel	Aug–Feb (7)	Yes	0	0	0–0	0	0	0–0
Kermadec petrel	Oct–Jun (9)	No	0	0	0–0	0	0	0–0
Grey-faced petrel	Jun–Jan (8)	No	3	92	36–190	6	16	7–33
Chatham Island taiko	Dec–May (6)	Yes	0	0	0–0	0	0	0–0
White-headed petrel	Nov–Apr (6)	No	0	9	3–19	0	14	5–30
Soft-plumaged petrel	Nov–Apr (6)	No	0	0	0–1	0	1	0–2
Common diving petrel	Sep–Feb (6)	No	1	27	8–65	3	9	3–20
South Georgian diving petrel	Nov–Mar (5)	No	0	0	0–0	0	0	0–0
New Zealand white-faced storm petrel	Oct–Mar (6)	Yes	0	45	12–111	0	0	0–0
White-bellied storm petrel	–	No	0	0	0–0	0	0	0–0
Black-bellied storm petrel	–	No	1	8	2–17	0	0	0–0
Kermadec storm petrel	Oct–Mar (6)	No	1	0	0–0	0	0	0–0
New Zealand storm petrel	–	No	0	0	0–0	0	0	0–0
Yellow-eyed penguin	Aug–Mar (8)	No	7	22	9–39	0	13	5–24
Northern little penguin	Aug–Feb (7)	No	0	6	1–16	0	3	0–11
White-flippered little penguin	Aug–Feb (7)	No	0	1	0–3	0	1	0–3
Southern little penguin	Aug–Feb (7)	No	0	2	0–7	0	1	0–4
Chatham Island little penguin	Aug–Feb (7)	No	0	1	0–8	0	1	0–10
Western rockhopper penguin	Oct–May (8)	No	0	2	0–6	0	1	0–4
Fiordland crested penguin	Jun–Nov (6)	No	0	3	0–14	1	2	0–7
Snares crested penguin	Sep–Jan (5)	No	0	3	0–8	0	5	1–15
Erect-crested penguin	Sep–Mar (7)	No	0	1	0–5	0	0	0–1
Australasian gannet	Aug–Feb (7)	No	0	57	3–218	0	6	0–20
Masked booby	–	No	0	0	0–0	0	0	0–0
Pied shag	–	No	1	10	3–24	0	0	0–0
Little black shag	Oct–Dec (3)	No	0	2	1–4	0	6	3–11
New Zealand king shag	–	No	0	1	0–4	0	0	0–0
Stewart Island shag	–	No	2	13	3–29	0	0	0–0
Chatham Island shag	–	No	0	0	0–4	0	0	0–0
Bounty Island shag	–	No	0	0	0–0	0	0	0–0
Auckland Island shag	–	No	0	0	0–1	0	0	0–0
Campbell Island shag	–	No	0	0	0–0	0	0	0–0
Spotted shag	–	No	35	745	485–1 100	0	0	0–0
Pitt Island shag	–	No	0	1	0–6	0	0	0–0
Subantarctic skua	–	No	0	0	0–0	0	0	0–0
Southern black-backed gull	–	No	2	94	25–231	0	0	0–0
Caspian tern	Oct–Dec (3)	No	0	0	0–0	0	0	0–0
White tern	–	No	0	0	0–0	0	0	0–0

Table A-17: Sensitivity of the uncertainty in the risk ratio to uncertainty in the underlying parameters. For each seabird type, the following parameters are considered: annual potential fatalities in trawl, bottom longline, surface longline and set-net fisheries (TWL, BLL, SLL, SN, respectively); the cryptic multipliers (CM); age at first reproduction (A); adult survival (S_A); the number of annual breeding pairs (N_{BP}); and the proportion of adults breeding (P_{B}). The sensitivity is defined as the percentage of reduction in the 95% confidence interval of the risk ratio that occurs when the parameter is set to its arithmetic mean. For each species the highest value is indicated in bold. The species with no sensitivity shown have a risk ratio that is too small for the sensitivity to be defined.

	Fishing methods					Demographic parameters			
	TWL	BLL	SLL	SN	CM	A	S_A	N_{BP}	P_{B}
Gibson's albatross	3	1	12	1	2	1	**45**	9	2
Antipodean albatross	2	4	**18**	0	4	1	16	9	5
Southern royal albatross	3	2	**20**	1	5	1	14	9	5
Northern royal albatross	1	2	3	0	0	0	22	**32**	0
Campbell black-browed albatross	3	17	1	0	0	0	2	**34**	0
New Zealand white-capped albatross	1	0	0	0	2	0	**61**	19	0
Salvin's albatross	7	0	0	0	4	1	**27**	24	1
Chatham Island albatross	3	24	1	0	7	3	**27**	6	0
Grey-headed albatross	11	**39**	0	0	6	0	2	17	0
Southern Buller's albatross	9	1	1	0	1	1	**51**	7	2
Northern Buller's albatross	1	4	6	0	0	0	**47**	5	1
Light-mantled sooty albatross	26	**34**	5	8	0	1	8	0	3
Northern giant petrel	23	0	0	0	2	0	**36**	8	0
Grey petrel	3	10	5	0	0	2	**30**	26	2
Black petrel	1	14	0	0	4	1	**30**	8	2
Westland petrel	**27**	6	11	1	3	0	8	15	1
White-chinned petrel	7	0	0	0	0	0	21	**35**	0
Flesh-footed shearwater	6	7	0	0	1	1	**42**	7	2
Wedge-tailed shearwater	0	15	**97**	0	4	0	0	0	0
Buller's shearwater	0	**48**	2	0	1	0	9	18	0
Sooty shearwater	8	1	0	0	0	0	**42**	29	1
Fluttering shearwater	2	39	0	1	4	1	7	**54**	1
Hutton's shearwater	2	**48**	0	2	0	1	8	8	0
Little shearwater	2	**44**	2	0	0	1	7	9	0
Cape petrel	0	4	1	0	0	0	**38**	29	0
Fairy prion	11	22	0	2	0	0	7	**34**	0
Antarctic prion	13	6	1	3	0	0	8	**60**	0
Broad-billed prion	3	**35**	1	1	0	1	4	20	0
Pycroft's petrel	0	**42**	5	1	3	0	16	5	0
Cook's petrel	0	**37**	0	0	0	1	27	0	0
Chatham petrel	0	**62**	0	0	0	1	14	7	0
Mottled petrel	0	**34**	1	0	0	0	24	1	0
White-naped petrel	0	1	**67**	0	1	0	15	15	0
Kermadec petrel	0	**44**	6	1	0	0	15	2	1
Grey-faced petrel	0	28	0	1	0	0	**32**	6	1
Chatham Island taiko	.	.	.	.	.	.	.	.	.
White-headed petrel	1	17	1	0	0	0	22	**22**	1
Soft-plumaged petrel	1	22	1	0	0	0	19	**55**	0
Common diving petrel	24	1	1	0	0	0	3	**52**	0
South Georgian diving petrel	.	.	.	.	.	.	.	.	.
New Zealand white-faced storm petrel	5	19	2	7	1	0	7	**31**	0
White-bellied storm petrel	.	.	.	.	.	.	.	.	.
Black-bellied storm petrel	**19**	0	2	18	0	0	11	12	0
Kermadec storm petrel	0	0	0	0	0	0	16	**64**	0
New Zealand storm petrel	27	0	0	18	0	0	1	**79**	0
Yellow-eyed penguin	0	5	0	**31**	2	1	14	5	2
Northern little penguin	0	15	12	**18**	4	0	0	9	1
White-flippered little penguin	3	14	0	**39**	0	0	3	11	0
Southern little penguin	3	**24**	1	22	2	0	0	10	0
Chatham Island little penguin	0	**82**	0	0	0	0	0	0	0
Western rockhopper penguin	0	**41**	1	14	0	0	2	3	0
Fiordland crested penguin	0	**46**	0	5	0	0	1	15	0
Snares crested penguin	0	**30**	1	9	0	0	0	17	0
Erect-crested penguin	3	**77**	0	0	0	0	0	0	0
Australasian gannet	1	11	0	**41**	7	0	10	9	0
Masked booby	0	7	4	**33**	6	0	6	12	0
Pied shag	0	2	9	22	0	0	0	**33**	0
Little black shag	13	0	9	3	3	8	3	**19**	1
New Zealand king shag	1	**56**	0	9	0	0	0	0	0
Stewart Island shag	13	0	0	**50**	0	1	1	1	0
Chatham Island shag	1	**93**	0	0	0	0	0	2	0
Bounty Island shag	0	**93**	0	0	0	0	0	0	0
Auckland Island shag	**84**	0	0	0	8	0	0	18	0
Campbell Island shag	.	.	.	.	.	.	.	.	.
Spotted shag	13	0	2	1	8	11	2	**38**	1
Pitt Island shag	0	**86**	0	0	0	1	0	6	0
Subantarctic skua	9	12	**27**	1	2	0	7	0	0
Southern black-backed gull	15	16	0	1	0	0	1	**33**	0
Caspian tern	16	**20**	10	4	0	0	6	5	0
White tern	.	.	.	.	.	.	.	.	.

APPENDIX B: ESTIMATION OF CRYPTIC FATALITIES

B.1 Introduction

Not all seabirds that are killed by fishing activity are recorded by observers, even when observers are on the vessels. Birds may be killed, but not brought on board the fishing vessel. These cryptic fatalities must be included in an assessment of the risk to seabirds from fishing. The total number of potential fatalities, F, is calculated as the sum of observable captures, C, and unobservable or cryptic fatalities, U:

$$F = C + U \tag{B-1}$$

Some of the captures, C, involve birds that were released alive. As the fate of these birds following release is unknown, it was assumed in the risk assessment that all observed captures are fatalities.

The methods in this section follow the framework originally developed by Sharp et al. (2011), applied and presented in Richard et al. (2011) following review by the Ministry for Primary Industries Aquatic Environment Working Group. We derived multipliers for cryptic mortalities ("cryptic multipliers"), $M = F/C$, that allow the total fatalities to be expressed as the product of the cryptic multiplier and the observable captures. Cryptic multipliers were estimated separately for longline and trawl fisheries. For longline fisheries, a single cryptic multiplier was estimated for all species, whereas for trawl fisheries, different multipliers were estimated for four different species groups.

In the present risk assessment, the cryptic fatality estimates have been updated to include more recent available data, and uncertainties around the cryptic multipliers have been estimated.

B.2 Longline fisheries

A multi-year study conducted in Australia that compared the number of individual birds hooked during the set and haul processes with observed captures that were subsequently recorded, revealed that of 176 seabirds observed caught on hooks, only 85 carcasses were retrieved (Brothers et al. 2010). Using these values, we deduced the probability distribution of capturing a bird, given it was caught on the line, from the likelihood of the binomial distribution (Equation B-2):

$$\mathscr{L} = \frac{n!}{k!(n-k)!} p^k (1-p)^{n-k}, \tag{B-2}$$

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 B-2 led to a mean of M of 2.08, with a 95% confidence interval of 1.79 to 2.44.

This distribution was used for all seabird species 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.

B.3 Trawl fisheries

To estimate total fatalities in trawl fisheries, it is useful to first distinguish between three types of seabird-trawler interactions:

- 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 be then defined as:

$$F_{tot} = F_{net} + F_{surf} + F_{air} \quad \text{(B-3)}$$
$$= C_{net}M_{net} + C_{surf}M_{surf} + C_{air}M_{air} \quad \text{(B-4)}$$

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 B-1). Uncertainties were estimated by drawing 5000 samples from a probability distribution for the underlying data. When the data were given as a number of incidents in a number of trials, a binomial distribution was assumed (Equation B-2). 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 defined using the equations (Samaranayaka & Fletcher 2010):

$$\alpha = \mu\left(\frac{\mu(1-\mu)}{\sigma_S^2} - 1\right), \qquad \beta = \frac{(1-\mu)\alpha}{\mu}.$$

B.3.1 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 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

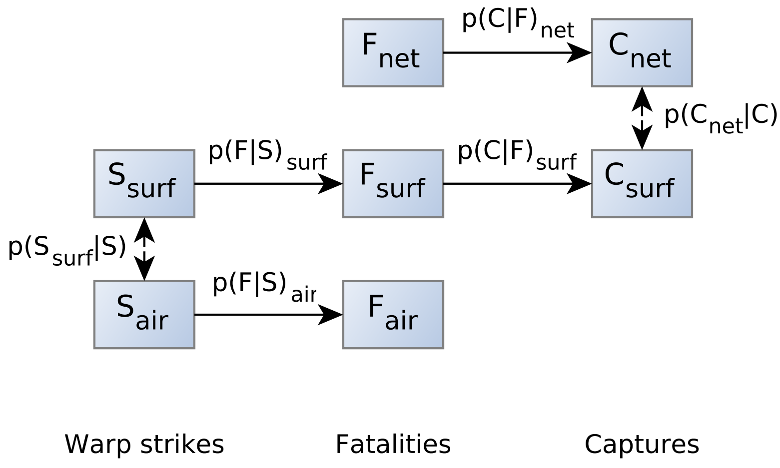

Figure B-1: Diagram of the parameters and processes involving seabird fatalities in trawl fisheries. Seabirds can be struck by warps either on the surface of the water, S_{surf}, or when flying, S_{air}. These warp strikes can lead to fatalities (F_{surf}, F_{air}). Fatalities of seabirds can also occur from their entanglement or capture in nets, F_{net}. Captures of seabirds recovered on board the fishing vessel are assumed to be only from interactions with the net, C_{net}, or from surface warp strikes, C_{surf}.

of $U_{net}/C_{net} = 0.3$ was used in 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

$$M_{net} = F_{net}/C_{net} = 1 + U_{net}/C_{net}. \quad \text{(B-5)}$$

B.3.2 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. Abraham (2010) provide 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 2004–2005 and 2008–2009.

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.

Due to behavioural and anatomical differences affecting warp-bird interactions, estimates of warp strike parameters were calculated independently for large versus small seabirds (see the grouping of seabird species in Table B-18). 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.

Table B-18: Classification of species into behavioural groups, used for estimating cryptic fatalities in trawl fisheries.

Species	Group
Gibson's albatross	Large
Antipodean albatross	Large
Southern royal albatross	Large
Northern royal albatross	Large
Campbell black-browed albatross	Large
New Zealand white-capped albatross	Large
Salvin's albatross	Large
Chatham Island albatross	Large
Grey-headed albatross	Large
Southern Buller's albatross	Large
Northern Buller's albatross	Large
Light-mantled sooty albatross	Large
Northern giant petrel	Large
Grey petrel	Small fast-flying
Black petrel	Small fast-flying
Westland petrel	Small fast-flying
White-chinned petrel	Small fast-flying
Flesh-footed shearwater	Small fast-flying
Wedge-tailed shearwater	Small fast-flying
Buller's shearwater	Small fast-flying
Sooty shearwater	Small fast-flying
Fluttering shearwater	Small fast-flying
Hutton's shearwater	Small fast-flying
Little shearwater	Small slow-flying
Cape petrel	Small slow-flying
Fairy prion	Small slow-flying
Antarctic prion	Small slow-flying
Broad-billed prion	Small slow-flying
Pycroft's petrel	Small slow-flying
Cook's petrel	Small slow-flying
Chatham petrel	Small slow-flying
Mottled petrel	Small slow-flying
White-naped petrel	Small slow-flying
Kermadec petrel	Small slow-flying
Grey-faced petrel	Small slow-flying
Chatham Island taiko	Small slow-flying
White-headed petrel	Small slow-flying
Soft-plumaged petrel	Small slow-flying
Common diving petrel	Small slow-flying
South Georgian diving petrel	Small slow-flying
New Zealand white-faced storm petrel	Small slow-flying
White-bellied storm petrel	Small slow-flying
Black-bellied storm petrel	Small slow-flying
Kermadec storm petrel	Small slow-flying
New Zealand storm petrel	Small slow-flying
Yellow-eyed penguin	Small diving
Northern little penguin	Small diving
White-flippered little penguin	Small diving
Southern little penguin	Small diving
Chatham Island little penguin	Small diving
Western rockhopper penguin	Small diving
Fiordland crested penguin	Small diving
Snares crested penguin	Small diving
Erect-crested penguin	Small diving
Australasian gannet	Small diving
Masked booby	Small diving
Pied shag	Small diving
Little black shag	Small diving
New Zealand king shag	Small diving
Stewart Island shag	Small diving
Chatham Island shag	Small diving
Bounty Island shag	Small diving
Auckland Island shag	Small diving
Campbell Island shag	Small diving
Spotted shag	Small diving
Pitt Island shag	Small diving
Subantarctic skua	Large
Southern black-backed gull	Small slow-flying
Caspian tern	Small slow-flying
White tern	Small slow-flying

B.3.3 Surface warp strikes

The total cryptic fatalities from surface warp strikes are:

$$F_{surf} = C_{surf} + U_{surf}. \quad \text{(B-6)}$$

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 ($U_{surf}^{fast} = U_{air}^{fast} = 0$).

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,

$$p(C|S) \quad = \quad p(C|F)p(F|S). \quad \text{(B-7)}$$

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}). 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}), and Watkins et al. (2008) reports that of a total 376 observed strikes, 139 were surface warp strikes for large birds, leading to the mean probability that a strike is on 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 93.83 (95% c.i.: 67.49 – 125.66). Watkins et al. (2008) also reports 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 following the observed surface warp strikes were then estimated to be 26.84 (95% c.i.: 24 – 30), and the probability of a surface warp strike being fatal was estimated as 0.2 (95% c.i.: 0.13 – 0.27). From the product of $p(F_{surf}|S_{surf})$ and S_{surf}/C_{warp}, the number of large-birds fatalities per surface warp capture, F_{surf}/C_{warp}, was estimated to be 18.54 (95% c.i.: 10.88 – 28.8).

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 111.35 (95% c.i.: 26.95 – 295.44).

B.3.4 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. However, 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 3.2 (95% c.i.: 1.86 – 5.05) for large birds, 72.79 (95% c.i.: 24.1 – 175.27) for small, fast-flying birds, and 36.5 (95% c.i.: 11.93 – 81.95) for small, slow-flying birds. These estimates are speculative.

B.4 Total fatality estimation 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,

$$F_{trawl} = F_{net} + F_{surf} + F_{air} \quad \text{(B-8)}$$
$$= M_{net}C_{net} + (M_{surf} + M_{air})C_{warp} \quad \text{(B-9)}$$
$$= M_{net}\,p(C_{net}|C_{trawl}) + (M_{surf} + M_{air})(1 - p(C_{net}|C_{trawl}))C_{trawl}, \quad \text{(B-10)}$$

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. In the fishing years between 2006–2007 and 2010–2011, the number of observed captures of large seabirds retrieved in nets was 294 out of the 459 captures in trawl fisheries. For small birds, this ratio was 935 out of 947. From these values, we estimated that the mean proportion of trawl captures retrieved in the net, $p(C_{net}|C_{trawl})$, was 0.64 (95% c.i.: 0.6 – 0.68) for large birds, and 0.99 (95% c.i.: 0.98 – 0.99) for small birds.

Values for the parameters involving seabird fatalities in trawl fisheries (illustrated in Figure B-1) are summarised in Table B-19. From these parameters, and from Equation B-10, the number of fatalities in trawl fisheries relative to the number of observable captures was estimated for each seabird group (Table B-20).

Table B-19: Transition probabilities (%; mean and 95% confidence interval) for the calculation of cryptic mortality of seabirds in trawl fisheries (illustrated in Figure B-1), for different types of birds. "All" includes large, small slow-flying, small fast-flying, and small diving seabirds. (Fatalities of small diving seabirds were assumed to only occur due to interactions with nets.)

Transition probability	Seabird type	Mean	95% c.i.
$p(C\|F)_{surf}$	Large	5.72	3.47–9.19
	Small fast-flying	1.30	0.34–3.71
	Small slow-flying	1.28	0.34–3.52
$p(F\|S)_{surf}$	Large	19.75	13.33–27.08
	Small fast-flying	5.98	2.42–10.86
	Small slow-flying	5.98	2.49–10.85
$p(F\|S)_{air}$	Large	2.00	1.28–2.88
	Small fast-flying	1.00	0.64–1.43
	Small slow-flying	0.50	0.32–0.71
$p(S_{surf}\|S)$	Large	36.99	32.19–41.90
	Small	20.26	17.19–23.49
$p(C_{net}\|C)$	Large	63.98	59.57–68.30
	Small	98.64	97.80–99.28
$p(C\|F)_{net}$	All	78.06	58.67–90.90

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
- Small diving birds are killed only in the net

Table B-20: Number of seabird fatalities (mean and 95% confidence interval) in trawl fisheries relative to the number of observed captures, for each species type.

Species type	Mean	95% c.i.
Large	8.66	5.67–12.78
Small fast-flying	3.78	1.91–7.87
Small slow-flying	3.29	1.74–6.62
Small diving	1.30	1.10–1.70

- The mortality rate for surface warp strikes in New Zealand trawl fisheries can be approximated by applying that observed in South African deepwater hake fisheries
- The same cryptic multiplier can be applied to all trawl fisheries