Assessment of the risk to seabird populations from New Zealand commercial fisheries

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EXECUTIVE SUMMARY

We examined the risk of incidental mortality from commercial fishing for 64 seabird species in New Zealand trawl and longline fisheries. For each species, the risk was assessed by comparing the total number of birds potentially killed while fishing against the Potential Biological Removal (PBR) index. This index represents the amount of human-induced mortality a species can sustain without compromising its persistence. The PBR was calculated from the best available information on the species' demography.

Because estimates of seabirds' demographic parameters and of fisheries related mortality are imprecise, the uncertainty around the demographic and mortality estimates was explicitly considered. This allowed uncertainty in the resulting risk to be calculated, and also allowed the identification of parameters where improved precision would reduce overly large uncertainties. However, not all sources of uncertainty could be included, and the results are best used as a guide in the setting of research and management priorities. In general, both seabird demographic information and the distribution of seabirds within New Zealand waters were poorly known.

Amongst the 64 studied species, the black petrel (*Procellaria parkinsoni*) clearly stood out as the species the most at risk from commercial fishing activities within the New Zealand Exclusive Economic Zone. With an average number of potential annual fishing-related fatalities estimated to be almost 10 times higher than the PBR, our study suggests that this species should become the primary subject of more detailed research and management.

Seven other species had a number of annual potential fatalities significantly exceeding the PBR, as the 95% confidence interval of their risk ratio was strictly above one: the grey-headed albatross, the Chatham albatross, the Westland petrel, the light-mantled albatross, the Salvin's albatross, the flesh-footed shearwater, and the Stewart Island shag. For a further 12 species, the confidence interval of the risk ratio included one.

Small inshore fisheries, especially trawl fisheries targeting flatfish, and small bottom and surface fisheries, appeared to be associated with the greatest level of risk to species. This was due to a combination of low observer coverage, high effort, and overlap with the distributions of many seabird species in these fisheries. In fisheries where there were few observations, the number of potential fatalities was estimated in a precautionary way, with the estimates being biased toward the high end of the range of values that were consistent with the observer data. In these poorly observed fisheries, the risk is primarily associated with the lack of information. Of the species that had a risk ratio greater than one, the risk for four of them (grey-headed albatross, Westland petrel, Chatham albatross, and light-mantled albatross) was associated with a lack of observer coverage in inshore fisheries that overlap with the distribution of these birds. Increasing the number of observations in inshore trawl and small vessel longline fisheries, especially in FMAs 1, 2, 3, and 7, would increase the precision of the estimated

fatalities. The risk was estimated independently for each fishery, and there was no assumption that the vulnerability of seabirds to capture was related between different fisheries. This has the consequence that birds (such as light-mantled sooty albatross) may be caught infrequently in well observed fisheries, but still have high risk associated with poorly observed fisheries.

Many limitations were identified in the risk assessment. These may result in biased estimates (either too high or too low) of the risk of fishing to some seabirds. Moreover, some fisheries were not included in our analysis, and other sources of human-induced mortality were ignored. The conclusions of our results should therefore be interpreted with caution, as some species might be at risk, even if their risk ratio was estimated to be lower than one. Conversely, the fisheries-related fatalities may be overestimated in poorly observed fisheries. The risk assessment method assumed a high number of captures in the absence of observations to the contrary, so the estimated potential fatalities in poorly-observed fisheries may be higher than the actual fatalities.

Note that sections C and D mentioned in this report are part of the adjoining document providing supplementary materials (Richard et al. 2011).

1. INTRODUCTION

Because of its location, extensive coastline, and numerous islands, New Zealand is a global center of seabird diversity (Karpouzi et al. 2007). There are over 80 seabird species breeding in New Zealand, with many of them endemic (e.g., Taylor 2000a, 2000b). Seabirds are caught in a range of fisheries (e.g., Abraham et al. 2010b), and the management of fisheries to ensure the long-term viability of seabird populations requires an understanding of the risks to their sustainability. Several studies have already estimated the number of seabirds caught annually within the New Zealand Exclusive Economic Zone (NZEEZ) in a range of fisheries (e.g., Baird & Smith 2008, Waugh et al. 2008c, Abraham et al. 2010b). In order to evaluate whether the viability of seabird populations is jeopardised by incidental mortality from commercial fishing, the number of annual fatalities needs to be compared with the capacity of the populations to replace those losses. For example, the capture of hundreds of sooty shearwaters annually might not have a large impact on the population viability, given a population estimated to be 5 million breeding pairs in New Zealand, but the capture of hundreds of king shags would have very different consequences, as they only have a total population of approximately 300 breeding pairs. Unfortunately, sufficient data to build detailed population models are only available for very few species (e.g., Fletcher et al. 2008, Francis & Bell 2010, Francis et al. 2008). For this reason, broad seabird risk assessments need to rely on expert knowledge (level-1) or to be semi-quantitative (level-2) (Hobday et al. 2007). Two level-1 seabird risk assessments (SRA) have been carried out (Baird & Gilbert 2010, Rowe 2009), but being based on expert knowledge, the assessed risks were relative and could not be directly used for determining sustainability.

A workshop was held in February 2009, to develop a method for carrying out level-2 SRA that could be consistently applied to a wide range of New Zealand's seabirds. The workshop was convened by the Ministry of Fisheries, and had participation from a range of stakeholders, including government, the fishing industry, and environmental non-governmental organisations. The resulting method, developed from previous productivity-sensitivity analyses (Kirby & Hobday 2007, Kirby et al. 2009), was summarised by Sharp et al. (2011). As a measure of sustainability, the level-2 SRA compares estimated seabird mortality to the Potential Biological Removal (PBR; Wade 1998) index. The PBR was developed initially in a marine mammal setting, in order to meet the need for some measure of population productivity when sufficient data are lacking. The PBR indicates the human-induced fatalities a species can sustain, and is based solely on population size, maximum growth rate, and a subjective 'recovery factor', f, indicative of the degree of conservatism desired by managers, usually reflecting species threat status. This index was thoroughly tested and performed well when compared to alternative indices in a wide range of conditions, including biases in source data, uncertainty in estimates, gradual change in carrying capacity, range in life history strategies, and in situations of already depleted populations (Wade 1998, Milner-Gulland & Akcakaya 2001). Given the robustness of the PBR, the same approach may be reasonably applied to seabirds, as most seabird species are also long-lived, with low reproductive rates and delayed maturity.

The level-2 SRA methodology outlined by Sharp et al. (2011) was partially implemented by Waugh et al. (2009). A key difference was that Waugh et al. (2009) did not consider uncertainty in their risk estimates. The purpose of this study was to improve the risk assessment carried out by Waugh et al. (2009), by including more species, using alternative methodologies to estimate key parameters, including catchability at species level (although some group-level catchability coefficients are used for species whose distribution overlaps with poorly observed fisheries), through more detailed estimation of seabird bycatch, by refining information on species distributions, and by incorporating uncertainty in the estimation of potential fatalities and species-level demographic parameters, as advised by Sharp et al. (2011). A risk index was defined for each species by calculating the ratio of the number of annual fatalities to the PBR. There remain a number of simplifications from the method outlined by Sharp et al. (2011), in particular we do not consider other sources of seabird mortality other than direct mortality in New Zealand trawl and longline fisheries. This ignores extra-territorial fisheries fatalities, fatalities in other New Zealand fisheries, and a range of other potential human-induced fatalities. We used a simplified estimation of seabird fatalities that would not be recorded by observers on fishing vessels (referred to as cryptic mortalities), as the data were not available to support the full method detailed by Sharp et al. (2011). The multipliers used for estimating total fatalities as a function of observable captures were provided by Ben Sharp (Ministry of Fisheries).

The estimation of potential annual fishing-related fatalities was carried out by determining the relationship between seabird density (derived from distribution maps), and the seabird captures recorded by fisheries observers. This relation was then extrapolated to all the fishing effort data to obtain an estimate of the annual potential captures. In fisheries with low observer coverage, the number of potential captures was only poorly constrained (i.e., a few records of birds not being caught in a fishery are not enough to rule out the possibility of birds being caught during the unobserved fishing), and so in this case the resulting risk index was high. This is a reflection of the lack of information in those fisheries. From the estimated captures, total fishing-related fatalities were calculated by including cryptic mortalities (such as birds struck by trawl warps but not brought on board the vessel) that would not have been recorded by observers.

As is often the case in risk assessments, some of the input data on which the present analysis depends was of poor quality. For instance, the estimation of the potential seabird fatalities during fishing sometimes relies on very few observations in poorly observed fisheries; the knowledge on the spatial distribution of most seabirds is very limited; seasonal variations in seabird distributions are typically poorly known and were not included; and estimates of life history parameters are often uncertain. Uncertainty is present at every step of the analysis. Although we took care to evaluate and consider uncertainties, not all sources of uncertainty could be accounted for. For this reason and also because of the possibility of biases in the calculations, the results of this study should be interpreted with caution.

2. METHODS

2.1 Defining risk

The risk index is defined as the ratio of the estimated annual potential fatalities of seabird species in 16 New Zealand fishery groups, to an index of potential population growth. If the risk index is much larger than one, then captures in the assessed fisheries are considered to exceed the capacity of the population to replace itself. If the risk index is much less than one, then the captures in the assessed fisheries are assumed to not impact the population.

To calculate potential population growth, the Potential Biological Removal (PBR; Wade 1998) calculation is followed. This is a conservative measure of the human-induced mortality a species can sustain.

The risk ratio (RR) is then expressed as

$$\mathrm{RR} = \mathrm{F}/\mathrm{PBR}, \tag{1}$$

where F is the estimated number of annual potential fatalities in the 16 assessed fisheries groups within the NZEEZ.

2.2 Potential Biological Removal (PBR)

The Potential Biological Removal (PBR) index (Wade 1998) was developed under the United States Marine Mammal Protection Act (MMPA) in order to assess the maximum level of human-induced mortality that a marine mammal population can sustain to stay above half its carrying capacity. This threshold corresponds to the maximum net productivity level, assuming logistic growth, below which a population is considered depleted by the U.S. National Marine Fisheries Service. The development of the PBR was a response to the requirements of the U.S. National Marine Fisheries Service that uncertainty should be explicitly considered, that management should be based on parameters that could be estimated, and that incentives should be provided to gather better data (Taylor et al. 2000). Populations suffering a human-induced mortality equal to PBR should have the following properties (Taylor et al. 2000):

- Populations recovering from depletion (below 30% of carrying capacity) have a 95% probability of being above the maximum net productivity level (MNPL, i.e. the population level at which the productivity curve is maximum) in 100 years,
- Healthy populations (above MNPL) will have a 95% probability of remaining above MNPL after 20 years, and
- Populations at high risk (5% of carrying capacity) will have a 95% probability of not delaying the time to reach MNPL by over 10%, relative to a zero human-caused kill scenario.

The PBR is calculated from the formula:

$$\text{PBR} = \frac{1}{2} r_{\text{max}} N_{\text{min}} f \tag{2}$$

where N_{min} is a conservative estimate of the total population size, f is a recovery factor between 0.1 and 1, and r_{max} the maximum population growth rate ($\frac{1}{2} r_{\text{max}}$ represents the population growth rate at the maximum net productivity level under the logistic growth model).

The recovery factor f can be considered as a safety factor, to account for unknown biases. There is no objective way to determine f, but its value should reflect the potential consequences of setting the PBR value too high. Wade (1998) showed that a maximum value of 0.5 for f should be sufficient for sustainable management of most healthy populations of marine mammals. Following Waugh et al. (2009) and Sharp et al. (2011), we set f according to the IUCN threat status for each species, with 0.1 for Critical, 0.2 for Endangered, 0.3 for Vulnerable, 0.4 for Near Threatened, and 0.5 for other species (Niel & Lebreton 2005, Dillingham & Fletcher 2008). The New Zealand Threat Classification System (Hitchmough et al. 2007) could have been used, but its larger number of threat categories and associated qualifiers would have made the assignment of f values more complicated.

In order to take into account the uncertainty in all parameters explicitly, we modified the formulation of the PBR. Instead of calculating it from point estimates, it was calculated from samples of distributions of the parameters. This allowed for uncertainty in the risk ratio to be derived.

In the marine mammal context in which the PBR was initially developed, the maximum population growth rate in the PBR formula is assigned a value of 0.12 for pinnipeds and 0.04 for cetaceans (Wade 1998), if other estimates are not available. Direct estimates of these quantities have generally not been made for seabirds, and the generic values used for marine mammals are inappropriate. Similarly, estimates of the total population size, required for calculating N_{min}, are generally not available for seabirds. Often counts are made of the number of breeding pairs, and the total population must be estimated.

2.2.1 Maximum population growth rate (r_{max})

One challenge in applying the PBR approach to seabirds is that there are few estimates for r_{max} as it represents the rate of increase under optimal conditions, i.e. with no food or space limitation, and so is difficult to measure empirically. However, Niel & Lebreton (2005) suggested that it can be estimated for bird species, assuming constant adult survival and fecundity after the age at first reproduction, by using the formulae:

$$r_{max} = \lambda_{max} - 1, \tag{3}$$

$$\lambda_{max} = \exp\left[\left(\alpha + \frac{S}{\lambda_{max} - S}\right)^{-1}\right], \tag{4}$$

where α is the age at first reproduction, S the adult annual survival, and λ_{max} the maximum annual population growth rate, i.e. without limiting factors.

This approach, also followed by Waugh et al. (2009), assumes that the life history parameters of a species reflect the evolutionary trade-offs between productivity, survival, and age at maturity. Small organisms generally show early maturity, low survival, and high productivity, whereas larger ones are characterised by delayed maturity, high survival, and low productivity. Equation 4 was derived from the theory that the maximum growth rate per generation is constant among species, which was supported by the study by Niel & Lebreton (2005) on 13 bird species over a large range of body weights and from 10 families, in conditions close to optimal (e.g. following reintroduction under complete protection, or during invasion processes).

2.2.2 Population size (N_{min})

For seabirds, most population estimates are derived from population surveys where only the adults breeding in a given year are counted. However, the proportion of the total population they represent is generally unknown, as immature individuals typically cannot be counted, being pelagic for several years before returning to colonies as pre-adults. Also, not every adult breeds every year, because of lack of food, a need to recover from previous reproduction, or because of hormonal inhibition (as is often the case in biennial species).

Following Gilbert (2009), We calculated the ratio of the total number of individuals greater than one year old (i.e. the individuals susceptible to captures in fisheries), to the number of adults using the relationship

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

where N_i is the number of individuals of age i, and α is the age at first reproduction.

By assuming a constant survival rate, S, for all birds over one year old, and that the population is at equilibrium, the number of individuals of age i is:

$$N_i = N_0 S_0 S^{i-1}, \tag{6}$$

where N_0 is the number of individuals of age 0 (chicks), and S_0 the survival to age 1. Each $\sum_i N_i$ in Equation 5 being a geometric sum, the ratio becomes:

$$R = S^{1-\alpha} \tag{7}$$

Because N_0 and S_0 appear multiplicatively in both the numerator and denominator of the fraction in Equation 5 (from Equation 6), this ratio is independent of clutch size and chick survival.

During initial development of the PBR, it was tested using a conservative value of the total population size (Wade 1998), often based on the 20th percentile of a log-normal distribution. To ensure that the population size was conservative, the distribution of the number of breeding pairs (N_{BP}), was replaced with the lower quartile of the distribution ($N_{BP_{min}}$). The distribution of a conservative estimate of the total number of individuals aged over one year old was then found using:

$$N_{min} = \frac{2N_{BP_{min}}}{P}R \tag{8}$$

where P is the proportion of adults breeding in any given year, and R is the ratio of the total number of birds over one year old to the number of adults, calculated using Equation 7. A similar formula, but with $N_{BP_{min}}$ replaced by N_{BP} was used to calculate the distribution of the total population, N_{tot}. This was used in calculating the number of potential seabird fatalities.

Using Equations 2 to 8, the PBR calculation depends on four parameters: the number of pairs breeding annually (N_{BP}), the proportion of adults breeding in any given year (P), the adult annual survival rate (S), and the age at first reproduction (α).

2.2.3 Data collation

For each species, we first extensively searched 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. The main sources of information were the primary literature; published books on seabirds; gray literature; and trusted resources on 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).

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, for estimates of survival rates, the quality when using capture-mark-recapture modelling on a sample size of over 100 individuals was considered high, whereas the quality was qualified as poor when the sample size was less than 50 individuals, with the survival estimate considered to be simply the ratio of banded birds returning alive to the breeding site to the total number of banded birds. When details on the methodology were not provided, e.g. when estimates were reported by a source not being the original publication of the study, we used the quality assessment of the citing source when possible, which was mostly the case for estimates from ACAP.

Where specified, the uncertainty in the estimates was recorded, either as standard errors, standard deviations, confidence intervals, or ranges. Sometimes only a minimum or a maximum of a parameter was given.

We were not able to find the necessary estimates for all species. An estimate of the number of breeding pairs was found for all species, except the New Zealand storm-petrel (*Oceanites maorianus*). This species was only recently rediscovered off the Coromandel peninsula and its distribution is unknown. The estimate was chosen as being between 20 and 2000 pairs. For survival and age at first reproduction, values from similar species were used when no estimates were available. Estimates of the proportion of adults breeding in any given year were unknown for most species, and were in this case fixed to 0.9 for species breeding annually, 0.6 for biennial species, and 0.75 for partially biennial species.

The extensive list of estimates was groomed to remove improbable values and to keep the best quality and most recent estimates when several of them were available. All the estimates we found in the literature for the 64 studied species are presented in Appendix D, with their associated uncertainty (if any) and reference to their origin. For each parameter, these tables show whether proxy species were used. The values indicated with an asterisk were the ones used in the calculation of the PBR.

2.2.4 Uncertainties

Every estimate is known with some level of uncertainty, which is often large. Most data are collected from colonies that are remote and difficult to access, and 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 often missing. In order to take into account uncertainty explicitly in our analysis, every estimate was assigned a standard deviation (s.d.) or a range when necessary, to match the uncertainties typically found in the literature.

When no uncertainty was reported, survival estimates were given a standard deviation of 0.01 for good quality estimates, 0.02 for medium ones, and 0.03 for poor ones. 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:

$$\text{s.d.}(\bar{S}) = \frac{\text{s.d.}(\text{logit}(\bar{S}))}{\bar{S}(1-\bar{S})} \tag{9}$$

Ages at first reproduction and the number of breeding pairs were reported either as a minimum only, a maximum only, a minimum and a mean, a mean and a maximum, or only a mean. For the age at first reproduction, when only a minimum was reported, the maximum was derived by multiplying the minimum by $5/3$. When only a maximum was reported, the minimum was derived by multiplying the maximum by $1/3$. 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 $5/6$ to get the minimum, and by $7/6$ to get the maximum.

For the number of breeding pairs, when only the minimum was reported, it was multiplied by 3 to get the maximum, and it was also reduced to 70% of its value to consider the possibility of a population decline since the time of the figure. When only the maximum was reported, it was divided by 5 to get the minimum and it was multiplied by 1.2 to allow for a population increase. The calculation of the maximum or minimum when only the mean and the minimum or the maximum respectively were reported was identical to the age at first reproduction. When only a mean 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 and 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 chosen.

Whereas only one estimate of the number of breeding pairs was chosen during the grooming process, estimates of similar quality and similar age for 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 c.i. = mean $\pm$ $1.96\,$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.

2.3 Fisheries data

Data extraction and grooming followed the methods described by Abraham et al. (2010b), with data updated to include the 2008–09 fishing year. Ministry of Fishery observers on commercial fishing vessels 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 of Fisheries. Currently, data are housed in the Centralised Observer Database (COD). Information on the observed captures and on the observed fishing events were extracted for the period of the study. Data from the recent inshore observer programme, that operated in the summer of 2008–09, were also included. 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. They were excluded as they are rarely observed and they generally consist of birds released alive (e.g. 23 non-fishing related captures were observed in 2008–09, and all but one were released alive).

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, or trawl fishing were obtained, covering the period from the 2003–04 to the 2008–09 fishing year. Commercial setnet and purse seine fishing effort was excluded because they were poorly observed and quite heterogeneous. 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, and the number of line sets for bottom and surface longline fisheries.

Fishing effort was assigned to fishery groups using the rules given in Table 1, identical to Waugh et al. (2009). The assignment was made on the basis of the fisher reported target species of each fishing event, the size of the vessel, and (for trawl fishing targeting middle depth species) whether the vessel either had a meal plant on board, or was a processor or a fresher, following Sharp et al. (2011). The target species groups follow those defined in reporting of protected species captures (e.g., Abraham et al. 2010b), with the exception that trawl fishing targeting hoki, hake, and ling is included with trawl fishing targeting other middle depths species. For each of the fishery groups, maps of the distribution of fishing effort and observations are given in Appendix B.

2.3.1 Species distribution

The number of birds present at the location of each fishing event was derived from the best available information on the distribution of the studied species and on the total population size breeding within the New Zealand Exclusive Economic Zone (NZEEZ). We generated the distribution map for each studied species, except for the recently rediscovered New Zealand storm-petrel (*Oceanites maorianus*), and the masked booby (*Sula dactylatra*), for which we did not have distribution information. The 0.1° resolution distribution maps encompassed the whole NZEEZ, with latitude and longitude extending respectively from 57°S to 23°S and from 160°E to 170°W.

Table 1: Assignment of fishing effort to fishery groups (fisheries: SBW - southern blue whiting; SQU - squid; SCI - scampi; SNA - snapper).

Method	Name	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.

The distribution maps were derived from existing maps published by NABIS and BirdLife. Three kinds of distribution maps were available:

- NABIS annual distribution maps. These maps contained three layers of seabird density: the Hot Spot layer, the 90% of the population presence layer, and the 100% of population presence. The maps were created from various sources of information (observation at sea, observer data, telemetry, main colony positions). These maps were converted into density maps by assigning a bird density to each layer. Following the choices used previously (Waugh et al. 2009), the hot spot layer was assigned a value of 0.5, the 90% presence layer a value of 0.4, and the 100%-presence layer a value of 0.1. The resulting maps were then normalised, so that the density summed to one across the region of the maps. The NABIS maps are intended to be annual average distributions. They do not provide information on seasonal changes in distribution, such as would occur during annual migrations, or at different stages of the breeding cycle.

- Birdlife single-layer range maps. These maps represent the range of the species at a global scale. The density of birds is equal to one in the species range and equal to zero outside. Depending on the species, the maps were established from observations at sea, observer data and/or telemetry (GLS, GPS, Argos, and radio tracking). These maps were clipped to the latitude and longitude range used for the distributions, and normalised.

- BirdLife telemetry global distribution maps. These distribution maps were derived from GPS and Argos satellite tracking data for large Procellariiform species. The maps were composed of remote-tracking data layers, with 50, 75, 90, 95% utility distributions (see BirdLife 2004 for methods to determining kernel distributions of birds), for non-breeding and breeding range. Both maps have been clipped and normalised. These maps are only available for the northern royal albatross (*Diomedea sanfordi*), the Gibson's albatross (*Diomedea antipodensis gibsoni*), the Campbell albatross (*Thalassarche impavida*), the Chatham albatross (*Thalassarche eremita*), the grey-headed albatross (*Thalassarche chrysostoma*), the southern Buller's albatross (*Thalassarche bulleri bulleri*), and the northern Buller's albatross (*Thalassarche bulleri platei*).

As the Birdlife single layer map and the NABIS maps tend to misrepresent the presence of birds at high density spots around the breeding colonies, two different distribution maps were created to assess the sensitivity of the results to the distribution maps. The first one (strategy 1) was created as a composite map from the different available sources, the second map (strategy 2) was created from the outer boundary of the strategy 1 map, but with known colonies added (information on seabird colonies was provided by Susan Waugh, Birdlife). For the strategy 2 map, two layers were combined: one for the breeding birds and one for the non-breeding ones. The layer of breeding birds only included the breeding birds present during the breeding season, which were distributed in discs centred around the colonies. The radius of these discs (rad_{max}) was found in the literature (Appendix D), but anecdotal sightings were used to provide a minimum radius. We set the maximum radius to 200 km when the radius found in the literature was less than 100 km, and we doubled it otherwise. The density of birds within these discs was assumed to decrease exponentially with the distance to colonies (rad), following Equation 10:

$$d_B(\text{rad}) = \begin{cases} e^{\ln(0.01)\frac{\text{rad}}{\text{rad}_{\text{max}}}} & \text{if rad} \leq \text{rad}_{\text{max}} \\ 0 & \text{if rad} > \text{rad}_{\text{max}} \end{cases} \tag{10}$$

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

For coastal species breeding around New Zealand (i.e. the eight species of shags, the Caspian tern, and the black-backed gull), both breeding and non-breeding birds were distributed along the coast where they are regularly observed. Equation 10 was also used to calculate the density of these birds, but with the radius taken as the closest distance to shore and with a maximum distance of 100 km.

The layer of non-breeding birds included both breeding birds outside the breeding season, and the rest of the New Zealand population. These birds were distributed uniformly across the outer limit of the range range defined in the strategy 1 distribution map. Both layers were then combined as:

$$d_{x,y} = d_{NBx,y}\left(N_{NB} + N_B\left(1 - \frac{t_{BS}}{12}\right)\right) + d_{Bx,y}N_B\frac{t_{BS}}{12} \tag{11}$$

where $d_{x,y}$ is the density of birds at a location (x,y), $d_{NBx,y}$ and $d_{Bx,y}$ the density of birds respectively in the layer of non-breeding and breeding birds at the same location, N_{NB} and N_B the total number of non-breeding and breeding birds respectively, and t_{BS} the length of the breeding season (table 2).

The total number of non-breeding birds in Equation 11 was deduced from the number of breeding pairs and from the total population size, which was estimated by multiplying the number of pairs breeding in New Zealand by a factor of 3 for annual breeding albatrosses and petrels, 3.5 for biennial species, and 4 for species whose pairs produce more than one offspring each year. This method of calculating population sizes was used by Waugh et al. (2009). The population calculations used for constructing the maps were carried out independently from the population calculations used elsewhere in the SRA.

Both distribution maps (strategies 1 & 2) were then normalised so that densities summed to 1 across the whole New Zealand region. For each of the bird species included in the assessment, the two distribution maps used are given in Appendix C.

Table 2: Information on colonies, foraging distance, and breeding period for each seabird species, used for the creation of the species' distribution. The species order follows the phylogenetic classification adopted by the Ornithological Society of New Zealand (Gill 2010).

	Colonies map	NABIS map	Foraging dist. (km)	Breeding period	
				Start	End
Southern rockhopper penguin	yes	no	200	October	May
Fiordland crested penguin	yes	no	200	June	November
Snares crested penguin	yes	no	200	September	January
Erect-crested penguin	yes	no	200	September	March
Yellow-eyed penguin	yes	no	60	August	March
Antipodean albatross	yes	yes	1500	January	January
Gibson's albatross	yes	yes	1500	December	December
Southern royal albatross	yes	yes	1000	October	October
Northern royal albatross	yes	yes	1250	January	January
Light-mantled albatross	yes	yes	1516	September	May
Grey-headed albatross	yes	yes	800	September	May
Black-browed albatross	yes	no	1350	September	May
Campbell albatross	yes	yes	640	August	May
Northern Buller's albatross	yes	yes	413	December	September
Southern Buller's albatross	yes	yes	413	March	December
White-capped albatross	yes	yes	413	November	November
Chatham albatross	yes	yes	750	July	April
Salvin's albatross	yes	yes	1500	August	April
Northern giant petrel	yes	no	550	August	May
Cape petrel	yes	no	360	October	January
Great-winged petrel	yes	yes	600	June	January
White-headed petrel	yes	no	600	November	April
Magenta petrel	yes	no	195	December	May
Kermadec petrel	yes	yes	400	October	June
Soft-plumaged petrel	yes	no	600	November	April
Mottled petrel	yes	no	250	October	June
White-necked petrel	yes	no	400	August	February
Chatham petrel	yes	no	120	November	April
Cook's petrel	yes	no	250	October	April
Pycroft's petrel	yes	no	195	October	March
Broad-billed prion	yes	no	161	July	November
Antarctic prion	yes	no	300	November	March
Fairy prion	yes	no	161	September	March
White-chinned petrel	yes	yes	1868	October	May
Westland petrel	yes	yes	150	February	December
Black petrel	yes	yes	425	October	June
Grey petrel	yes	yes	600	February	December
Wedge-tailed shearwater	yes	no	80	June	December
Buller's shearwater	yes	yes	60	September	May
Flesh-footed shearwater	yes	yes	300	September	May
Sooty shearwater	yes	yes	100	September	May
Hutton's shearwater	yes	yes	70	October	March
Little shearwater	yes	no	210	June	December
New Zealand white-faced storm petrel	yes	yes	100	October	March
Kermadec white-faced storm petrel	yes	yes	100	October	March
New Zealand storm petrel	no	no	-	-	-
Black-bellied storm petrel	yes	no	-	-	-
White-bellied storm petrel	yes	no	-	-	-
Common diving petrel	yes	no	200	September	February
South Georgia diving petrel	yes	yes	-	November	March
Australasian gannet	yes	no	150	August	February
Masked booby	no	no	230	-	-
New Zealand king shag	yes	yes	16	-	-
Stewart Island shag	yes	yes	16	-	-
Chatham Island shag	yes	no	16	-	-
Bounty Island shag	yes	yes	16	-	-
Auckland Island shag	no	yes	16	-	-
Campbell Island shag	yes	yes	16	-	-
Spotted shag	yes	no	16	-	-
Pitt Island shag	yes	yes	16	-	-
Brown skua	yes	no	-	-	-
Black-backed gull	yes	no	-	-	-
Common white tern	no	yes	-	-	-
Caspian tern	no	yes	-	-	-

2.3.2 Potential observable captures

The annual average number of potential observable bird captures by each fishery was estimated using Bayesian models. The number of birds potentially captured by one fishing event was assumed to follow a Poisson distribution, with the mean being the product of the density of birds at the location of the event, and a vulnerability coefficient. The vulnerability to capture was assumed to be constant over time and within each species, but variable between species and fishery groups. Because for some species there was an extremely small number of observed fishing events, these species were grouped together to allow the estimation of their vulnerability. These groups are shown in Table 3. They differed from Waugh et al. (2009) who estimated the vulnerability of seven species groups only (large albatrosses, small albatrosses, small shearwaters, large shearwaters, *Procellaria* petrels, large *Pterodroma* petrels, and other petrels). As we included data from more years, we were able to split these seven groups further to estimate the vulnerability of individual species, and also to include more species in the analysis. The density of birds at the location of a fishing event was the product of the normalised density of birds at that location, obtained from the distribution map (strategy 1 or 2; see Section 2.3.1), and the total New Zealand population size, obtained from the mean of the sample calculated for the PBR estimate (N_{tot}; see Section 2.2.2). When combining distributions of the species within a group, the population size was not adjusted for birds that seasonally range outside the EEZ. The sum of population sizes of the species within a group was used when the vulnerability was calculated for a group of species.

The model was defined as follows:

$$\begin{aligned} C_{fgs} &\sim \text{Poisson}(\mu_{fgs}) \\ \mu_{fgs} &= v_{gs} d_{fs} N_s E_f, \end{aligned} \tag{12}$$

where C_{fgs} is the number of observable bird captures during the fishing event f of the fishing group g and for the species s, μ_{fgs} the mean of the Poisson distribution, v_{gs} the vulnerability of the species s for the fishing group g, d_{fs} the density of birds of species s at the fishing event f, N_s the total population size of species s, and E_f the fishing effort during the event f.

We fitted this model to the observed fishing events between the fishing years 2003–04 and 2008–09, for each fishery and for each species (or species group). The models were coded in the BUGS language (Spiegelhalter et al. 2003), a domain specific language for describing Bayesian models, and were fitted with the software package JAGS (Plummer 2005), using MCMC methods.

A uniform prior was used for the distribution for the vulnerability. The bounds of the prior were chosen to be 0 and 0.1, after running preliminary models on well-observed species-fishery groups indicating that the vulnerability was unlikely to be larger than 0.1. Increasing this threshold led to unreasonable results, with some very large numbers of potential captures for cases with very few observations. Two chains were run, each for 30 000 iterations after a burn-in of 10 000 iterations. For each model, a sample of 5000 values of vulnerability was taken from the Monte-Carlo Markov chains. The convergence of both chains was verified in each case using the test of Heidelberger & Welch (1983), implemented in the CODA package for the R statistical analysis system (Plummer et al. 2006).

The choice of prior was particularly important for species and fishery groups where there had been no or very few observations in the area where the species distribution and the fishery overlapped. There is a rule of thumb that the upper 95% confidence interval for the mean of a Poisson distribution is $n/3$, where n is the number of observations, if there were zeros recorded during all observations. This rule is known as the 'rule of three' (Jovanovic & Levy 1997). As the number of observed zeros increases, the upper confidence limit decreases towards zero. In a Bayesian analysis, a uniform prior for the Poisson mean recovers the rule of three (Jovanovic & Levy 1997, Winkler et al. 2002), and this is the prior that was used in this analysis. An alternate prior for a Poisson mean could be a log-normal distribution, the use a log-scale would reflect the positive nature of the Poisson rate. If a diffuse log-normal prior is used then

Table 3: Groups of species used to calculate the vulnerability of species to capture. The vulnerability was constrained to be the same among the species within each group. Species codes are either those used by the FAO (e.g., Garibaldi 2002), or by the Ministry of Fisheries.

Group	Species common name	Species scientific name	Species code
Penguins	Erect-crested penguin	*Eudyptes sclateri*	EVE
	Fiordland crested penguin	*Eudyptes pachyrhynchus*	EVF
	Snares crested penguin	*Eudyptes robustus*	EVS
	Southern rockhopper penguin	*Eudyptes chrysocome*	EVC
	Yellow-eyed penguin	*Megadyptes antipodes*	XYP
Great albatrosses	Antipodean albatross	*Diomedea antipodensis antipodensis*	ANA
	Gibson’s albatross	*Diomedea antipodensis gibsoni*	GBA
	Northern royal albatross	*Diomedea sanfordi*	DIS
	Southern royal albatross	*Diomedea epomophora*	DIP
Light-mantled sooty albatross	Light-mantled albatross	*Phoebetria palpebrata*	PHE
Grey-headed albatross	Grey-headed albatross	*Thalassarche chrysostoma*	DIC
Black-browed albatrosses	Black-browed albatross	*Thalassarche melanophrys*	DIM
	Campbell albatross	*Thalassarche impavida*	TQW
Buller’s albatrosses	Northern Buller’s albatross	*Thalassarche bulleri platei*	DNB
	Southern Buller’s albatross	*Thalassarche bulleri bulleri*	DIB
White-capped albatross	White-capped albatross	*Thalassarche steadi*	XWM
Chatham albatross	Chatham albatross	*Thalassarche eremita*	DER
Salvin’s albatross	Salvin’s albatross	*Thalassarche salvini*	DLS
Northern giant petrel	Northern giant petrel	*Macronectes halli*	MAH
Cape petrel	Cape petrel	*Daption capense*	DAC
Pterodroma petrels	Chatham petrel	*Pterodroma axillaris*	PTA
	Cook’s petrel	*Pterodroma cookii*	PTC
	Great-winged petrel	*Pterodroma macroptera*	PDM
	Kermadec petrel	*Pterodroma neglecta*	PVB
	Magenta petrel	*Pterodroma magentae*	PTM
	Mottled petrel	*Pterodroma inexpectata*	XMP
	Pycroft’s petrel	*Pterodroma pycrofti*	PTP
	Soft-plumaged petrel	*Pterodroma mollis*	PTS
	White-headed petrel	*Pterodroma lessonii*	XWH
	White-necked petrel	*Pterodroma cervicalis*	WNP
Prions	Antarctic prion	*Pachyptila desolata*	PWD
	Broad-billed prion	*Pachyptila vittata*	XPV
	Fairy prion	*Pachyptila turtur*	XFP
White-chinned petrel	White-chinned petrel	*Procellaria aequinoctialis*	PRO
Westland petrel	Westland petrel	*Procellaria westlandica*	PCW
Black petrel	Black petrel	*Procellaria parkinsoni*	PRK
Grey petrel	Grey petrel	*Procellaria cinerea*	PCI
Wedge-tailed shearwater	Wedge-tailed shearwater	*Puffinus pacificus*	PUP
Shearwaters	Buller’s shearwater	*Puffinus bulleri*	PBU
	Hutton’s shearwater	*Puffinus huttoni*	PHU
	Little shearwater	*Puffinus assimilis*	PUA
Flesh-footed shearwater	Flesh-footed shearwater	*Puffinus carneipes*	PFC
Sooty shearwater	Sooty shearwater	*Puffinus griseus*	PFG
Storm petrels	Black-bellied storm petrel	*Fregetta tropica*	FGQ
	Kermadec white-faced storm petrel	*Pelagodroma marina albiclunis*	KSP
	New Zealand storm petrel	*Oceanites maorianus*	NZS
	New Zealand white-faced storm petrel	*Pelagodroma marina*	WSP
	White-bellied storm petrel	*Fregetta grallaria*	FGR
Diving petrels	Common diving petrel	*Pelecanoides urinatrix*	GDU
	South Georgia diving petrel	*Pelecanoides georgicus*	GDP
Boobies and gannets	Australasian gannet	*Morus serrator*	MOS
	Masked booby	*Sula dactylatra*	MBO
Shags	Auckland Island shag	*Phalacrocorax colensoi*	ASG
	Bounty Island shag	*Phalacrocorax ranfurlyi*	BSG
	Campbell Island shag	*Phalacrocorax campbelli*	CSG
	Chatham Island shag	*Phalacrocorax onslowi*	CHS
	New Zealand king shag	*Phalacrocorax carunculatus*	KSG
	Pitt Island shag	*Phalacrocorax featherstoni*	PSG
	Spotted shag	*Phalacrocorax punctatus*	NSG
	Stewart Island shag	*Phalacrocorax chalconotus*	SSG
Gulls, terns & skua	Black-backed gull	*Larus dominicanus*	XBG
	Brown skua	*Catharacta lonnbergi*	CAQ
	Caspian tern	*Sterna caspia*	CAT
	Common white tern	*Gygis alba*	GAL

lower estimates of the Poisson mean will be obtained, as the diffuse log-normal distribution is peaked towards zero. The log-normal prior was used by Waugh et al. (2009), however the use of a uniform prior is consistent with the intent of a risk assessment, as it will be relatively conservative, tending to provide a higher estimate of the number of captures, but consistent with the observations.

From the 629 300 fishing records between 2003–04 and 2008–09, 122 079 had missing latitude-longitude information, primarily due to the use of CELR forms in the earlier years. Assuming that the spatial distribution of fishing effort within the same fishery was similar between years, these locations were imputed from records, if possible, of the same vessels in the same area that used the same fishing method and targeted the same species (60% of imputations), otherwise from other vessels in the same area that used the same fishing method and targeted the same species (39%), or else from other vessels in the same area and using the same method but that targeted other species (1%). Only 30 records were finally discarded due to having a missing location.

The number of potential observable bird captures for each fishery type and each species (or species group) was calculated by applying the model to the effort data, with the estimated value of the vulnerability. The potential captures occurring during each fishing event were summed and divided by the number of years, to obtain the annual average number of potential captures of each species in each fishery. From each model, a sample of 5000 estimates of the mean annual potential captures was obtained.

The estimation of potential observable captures was repeated twice, once for each species distribution (strategy 1 and strategy 2). The results were then merged by sub-sampling the two posterior distribution of potential observable captures (2500 samples from each distribution). The final distribution of potential observable captures includes a mix of the distributions derived using each map.

2.4 Estimating potential fatalities

Bird captures recorded during an observed fishing event are likely to be an underestimate of total fatalities. A number of birds can be killed by warp strikes (Abraham & Thompson 2010b) or hooked in longline fisheries during sets without being brought back on board (Brothers et al. 2010). The estimated potential captures were converted to potential fatalities by including mortalities that would not have been reported by observers. It was also assumed that all the estimated captures were mortalities. This is equivalent to the assumption that none of the birds released alive by observers survive. There is currently no information on seabird survival rates following capture.

A 15-year study counted the number of seabirds that were caught when lines were set in surface longline fisheries, and found that only half of the bodies were retrieved during line hauling (Brothers et al. 2010). No equivalent information is available for bottom longline fisheries. Without further information, it was assumed that the potential fatalities in all longline fisheries were twice number of potential captures.

In trawl fisheries, cryptic fatalities may occur through interactions with either the trawl warps or the net. Birds may be killed by being struck by the warps while the birds are flying, or while they are on the surface water. In the South African hake (*Merluccius* spp.) trawl fishery, observations were made of interactions between seabirds and trawl warps, with an assessment made of the fate of each bird following the interaction. Birds that were killed and retrieved on board the vessel were also recorded. During the observation there were 728 birds recorded as having heavy collisions with the warps, and of these 30 were recorded as being killed. Of the birds that were killed by the warp interactions, only 2 albatrosses were brought on board. From these figures, as well as from data on warp strike rates collected in New Zealand (Abraham & Thompson 2010b), and records of the number of birds caught in the nets and caught in the warps, Ben Sharp (Ministry of Fisheries) calculated multipliers giving the ratio between

Table 4: Multiplier used for calculating the total fatalities from the observable captures. The multiplier was calculated by Ben Sharp (Ministry of Fisheries), using the methods given in Appendix B.

Birds	Description	Longline	Trawl
Large	Albatrosses and giant petrels	2	6.19
Small flying	Larger petrels and shearwaters	2	4.10
Small hovering	Small petrels, prions, storm-petrels, diving petrels, and shearwaters	2	3.49
Small diving	Shags, gannets, penguins, boobies	2	1.3

the number of observable captures (birds retrieved on board) and the number of fatalities (see Appendix B). It was assumed that, for net captures, the ratio of total fatalities to observable captures was 1.3. In trawl fisheries, the multipliers ranged from 1.3, for diving birds, to 6.19 for albatrosses and giant petrels (Table 4).

2.5 Risk ratio

The average total number of birds potentially killed annually in the 16 assessed fishery groups was calculated for each species by summing all potential fatalities (samples of 5000 values) across all trawl and longline fishery groups. The risk ratio for each species was then calculated by dividing this sample by the sample of PBR values (see Section 2.2). Risk ratios greater or equal to one indicate that annual potential fatalities for the concerned species exceed the PBR. The probability of the number of potential fatalities to exceed the PBR was estimated by the proportion of the risk ratio values that were greater or equal to one. A summary of the calculation of the risk ratio, as described in the previous sections, is given in Figure 1.

2.6 Sensitivity

The sensitivity of the risk ratio uncertainty to each input parameter was assessed by calculating the decrease in the uncertainty of the risk ratio gained by eliminating the uncertainty around each parameter. This was achieved by recalculating the risk ratio of each species after fixing each input parameter, in turn, to its mean value. The sensitivity was then estimated as the resulting percentage reduction in the 95% confidence interval of the risk ratio. Using this method, we estimated the sensitivity to the uncertainty in annual potential fatalities (reflecting the uncertainty in vulnerability estimates) and to the uncertainty in the four input parameters used for the PBR calculation: the survival rate, the age at first reproduction, the number of pairs breeding annually, and the proportion of adults breeding in any given year (see Section 2.2). Additionally, we calculated the sensitivity to the distribution map (with or without colonies) by assessing the reduction in the 95% confidence interval of the risk ratio obtained by using either distribution maps and averaging the two results.

The overlap changes between fisheries and species, resulting in various numbers of observations being used to estimate the number of annual fatalities. For some species, the number of observations used to estimate the number of annual fatalities was very small, and the final estimates in these cases are likely to be sensitive to the choice of prior that we used. Indeed, when there were very few observations to estimate a species' vulnerability, the estimation of potential captures allowed for the possibility that species' vulnerability could be large. In these cases, our estimates of annual fatalities were precautionary, representing potential levels of fisheries-related mortality rather than actual.

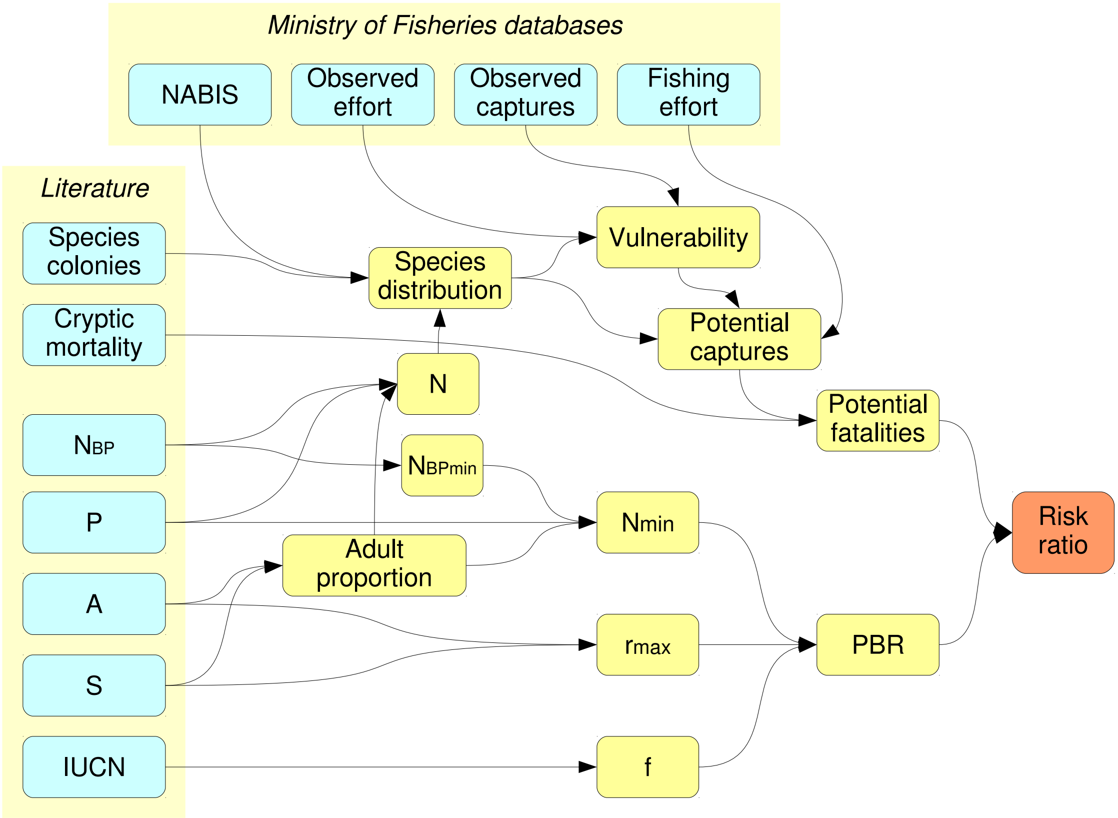

Figure 1: Diagram of the modelling approach to calculate the risk index for each species. $N_{\mathbf{BP}}$**: number of annual breeding pairs;** N**: total number of birds over one year old;** $N_{\mathbf{BP}_{\mathrm{min}}}$**: lower 25% of the distribution of** $N_{\mathbf{BP}}$**;** N_{min}**: lower 25% of the distribution of the total number of birds over one year old;** r_{max}**: maximum population growth rate;** f**: recovery factor;** PBR**: Potential Biological Removal;** P**: proportion of adults breeding in any given year;** A**: age at first reproduction;** S**: annual adult survival rate.**

The dependence of the risk ratio on the choice of prior was assessed for each species by recalculating the risk ratio with a different prior that assumed that the vulnerability was likely to be small in absence of observations. This prior was a vague log-normal distribution, with the logarithm of the product between the vulnerability and the relative population size being distributed normally, with a mean 0, and a standard deviation of 100. When there were many observations, there was a small difference in the risk ratios estimated using the two different priors, whereas when there were few observations the risk ratio would be smaller when the log-normal prior was used.

2.7 Change in fatalities over time

To examine whether annual potential fatalities changed over time, the same analysis was redone for two time periods of three fishing years separately, from 2003 to 2006 and from 2006 to 2009. Very few data exist on some fishery groups in the earlier period, especially for inshore fisheries and small vessels. For the comparison between the two time periods, we only focused on offshore trawl fisheries and large bottom and surface longline fisheries. For each species, the change in the average number of fatalities between the two periods was assessed by the ratio of the number of fatalities for 2006 to 2009 over that for 2003 to 2006, with values above 1 indicating an increase over time.

2.8 Comparison of capture estimates with other methods

In order to check the plausibility of the calculation of potential observable captures, our estimates were compared with those obtained when using the ratio method (Abraham et al. 2010b) and from statistical modelling (Abraham & Thompson 2011, 2010a). In the ratio method, a capture rate was calculated for each combination of seabird species, fishery, year, and fishing area, based on the ratio of the number of observed captures to the number of observed fishing events. This was then multiplied by the fishing effort to get the total number of captures. The statistical modelling in Abraham & Thompson (2011, 2010a) follows the same approach, but using statistical models that include vessel covariates, which allow a better estimation of the number of bird captures when the observed fishing events are not representative of the overall fishing effort. In order to be able to compare the capture estimates, estimates were made of the total number of annual captures of white-chinned petrels, white-capped albatrosses, sooty shearwaters, and of all birds, along with the proportion of fishing effort used in the estimation, for trawl, bottom longline, and surface longline fisheries. We compared the potential observable captures (i.e. without cryptic mortality included), with the number of annual captures calculated by the ratio method and the statistical modelling over the same period, i.e. from 2003–04 to 2008–09.

3. RESULTS

3.1 Potential Biological Removal (PBR)

For the 64 studied species, we collected a total of 371 estimates of the four parameters necessary for the calculation of the PBR. Of these, 119 were of adult survival (S), 97 of age at first reproduction (A), 150 of the number of annual breeding pairs (N), and 5 of the proportion of adults breeding in any given year (P). After grooming, 206 estimates were selected for the calculation of PBR, 70 for S, 68 for A, 64 for N, and 4 for P. Of these estimates, 65 were from proxy species (39 for S and 26 for A). The final estimates are presented in Table A-1 in Appendix A, and in Appendix D.

The maximum growth rate λ_{max} was calculated from the age at first reproduction and the annual adult survival, and provided the estimates of maximum population growth rate $r_{\max}$ (Figure 2). Median values of $r_{\max}$ ranged from 0.04 for the light-mantled albatross to 0.26 for the common diving petrel, following the expected gradient from large long-lived species to small short-lived ones.

The total population size of individuals over one year old within the New Zealand Exclusive Economic Zone was calculated from the number of annual breeding pairs, the ratio of the total population to the number of adults (Figure 2), and the proportion of adults breeding in any given year. The conservative estimate ($N_{\min}$), taken as the lower quartile, varied from 54 for the common white tern to over 12 million for the sooty shearwater.

The median PBR, estimated from the maximum population growth rate $r_{\max}$ and the conservative estimate of the total population size of individuals over one year old, ranged from 1 for the Kermadec white-faced storm petrel to 187 000 for the black-backed gull.

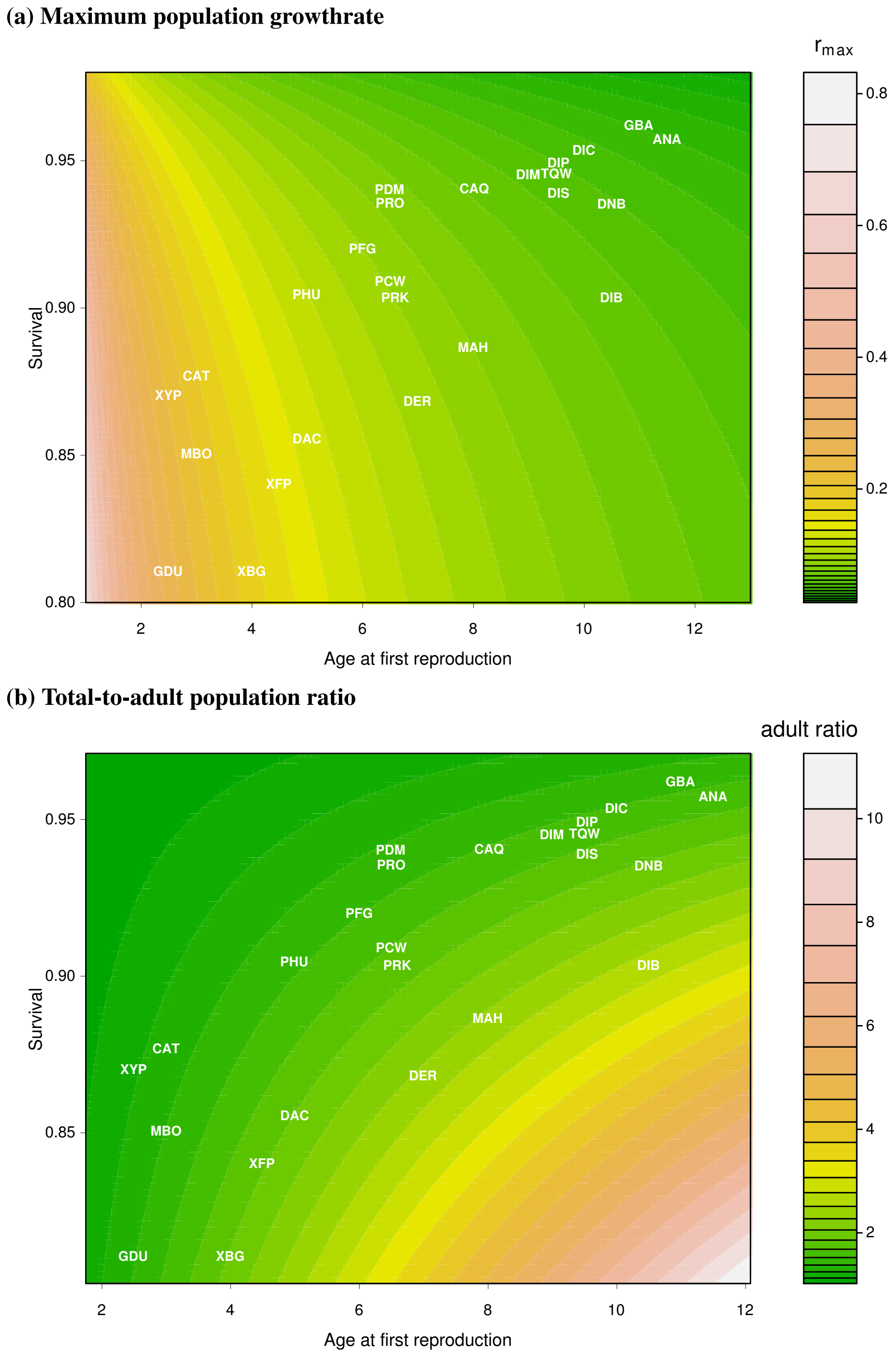

Figure 2: (a) Maximum population growth rate ($r_{\max}$). (b) Ratio of the total population to the number of adults. Both parameters were calculated from the age at first reproduction and the survival rate. Only the species whose estimates were not from proxy species are presented (Species codes: ANA - Antipodean albatross, CAT - Caspian tern, CAQ - Brown skua, DAC - Cape petrel, DER - Chatham albatross, DIB - Southern Buller's albatross, DIC - Grey-headed albatross, DIM - Black-browed albatross, DIP - Southern royal albatross, DIS - Northern Royal albatross, DNB - Northern Buller's albatross, GBA - Gibson's albatross, GDU - Common diving petrel, MAH - Northern giant petrel, MBO - Masked booby, PCW - Westland petrel, PDM - Great-winged petrel, PFG - Sooty shearwater, PHU - Hutton's shearwater, PRK - Black petrel, PRO - White-chinned petrel, TQW - Campbell albatross, XBG - Black-backed gull, XFP - Fairy prion, XYP - Yellow-eyed penguin).

3.2 Annual potential fatalities

The total fishing effort of each fishery group in the period 2003–04 to 2008–09 is presented in Table 5, along with the number of observations and observed bird captures. Maps showing the spatial distribution of the fishing effort, observations, and observed bird captures for each fishery and each year can be found in Appendix C.

The vulnerability to capture of each species (or species group) in each fishery group, estimated from the observed fishing effort, the observed bird captures, and the overlap between the species distribution and fishing effort, is presented in Tables A-2 to A-5 of Appendix A. The number of observable captures depends on both vulnerability and fishing effort, and a high vulnerability does not necessarily indicate a large number of captures. For species groups and fisheries with little overlap, the estimation of vulnerability was poorly constrained and the values reflect a lack of information. For example, the maximum vulnerability in trawl fisheries was estimated at 49.78 (95% c.i. 2.27–97.79) km^2 per 1000 fishing events for the Westland petrel *Procellaria westlandica* in the SBW trawl fishery. This high vulnerability occurred despite there being no observed captures of Westland petrel in this fishery, and it simply reflects a lack of information. Although the vulnerability was high, there were no estimated captures of Westland petrel in the SBW trawl fishery. Amongst bottom longline (BLL) fisheries, the Black petrel *Procellaria parkinsoni* was the most vulnerable species at 57.83 (95% c.i. 18.23–98.33) km^2 per 1000 fishing events in the bluenose BLL fishery. Amongst surface longline (SLL) fisheries, the group of black-browed albatrosses was the most vulnerable at 58.18 (95% c.i. 23.54–104.03) km^2 per 1000 fishing events in the small SLL fishery.

The number of annual potential fatalities (including cryptic mortality) was estimated for each seabird species (Figure 3, Table A-11) and fishery group (Tables Appendix A-6 to Appendix A-9). The white-capped albatross *Thalassarche steadi* was the species with the highest number of potential fatalities across all assessed fishery groups, with 5123 (95% c.i. 4571–5718) estimated potential fatalities annually. Amongst trawl fisheries, the white-capped albatross *Thalassarche steadi* was also the species with the highest number of potential fatalities, with a median of 2201 (95% c.i. 1849–2563) estimated potential fatalities each year in the SQU trawl fishery. The flesh-footed shearwater *Puffinus carneipes* was estimated to be the most frequently killed in bottom longline fisheries, with 513 (95% c.i. 328–737) estimated potential fatalities each year in the SNA BLL fisheries group. The grey petrel *Procellaria cinerea* was found to be the most frequently killed species in surface longline fisheries, with 221 (95% c.i. 166–286) estimated potential fatalities annually in the small SLL fisheries group.

Table 5: Summary of fishing effort, observations, observer coverage (the percentage of fishing effort that was observed), and observed captures for each fishery group. The capture rate is the number of bird captures per 100 fishing events. The fishing effort was defined as the number of tows for trawl fisheries and the number of line sets for longline fisheries, and therefore cannot be compared among fishery groups.

Fishery group	Effort			Observations			Observer coverage (%)			Observed captures			Observed capture rate		
	2003–06	2006–09	All years	2003–06	2006–09	All years	2003–06	2006–09	All years	2003–06	2006–09	All years	2003–06	2006–09	All years
Small inshore trawl	143 003	122 552	265 555	259	2 127	2 386	0.18	1.74	0.90	4	57	61	1.54	2.68	2.56
SBW trawl	2 349	2 726	5 075	793	854	1 647	33.76	31.33	32.45	4	6	10	0.50	0.70	0.61
SCI trawl	13 835	14 493	28 328	886	1 309	2 195	6.40	9.03	7.75	30	56	86	3.39	4.28	3.92
Mackerel trawl	8 059	7 952	16 011	1 419	2 433	3 852	17.61	30.60	24.06	8	8	16	0.56	0.33	0.42
SQU trawl	27 939	14 421	42 360	5 383	4 042	9 425	19.27	28.03	22.25	786	551	1 337	14.60	13.63	14.19
Flatfish trawl	75 632	62 039	137 671	0	569	569	0.00	0.92	0.41	0	35	35		6.15	6.15
Large processer trawl	14 056	16 847	30 903	977	1 845	2 822	6.95	10.95	9.13	21	83	104	2.15	4.50	3.69
Large meal trawl	35 505	22 761	58 266	6 445	5 515	11 960	18.15	24.23	20.53	216	108	324	3.35	1.96	2.71
Large fresher trawl	15 790	8 992	24 782	469	503	972	2.97	5.59	3.92	1	1	2	0.21	0.20	0.21
Deepwater trawl	25 882	21 207	47 089	4 171	7 503	11 674	16.12	35.38	24.79	27	13	40	0.65	0.17	0.34
Bluenose BLL	10 123	13 896	24 019	8	191	199	0.08	1.37	0.83	0	14	14	0.00	7.33	7.04
SNA BLL	23 044	19 056	42 100	397	209	606	1.72	1.10	1.44	34	21	55	8.56	10.05	9.08
Small BLL	17 455	18 197	35 652	90	526	616	0.52	2.89	1.73	1	60	61	1.11	11.41	9.90
Large BLL	8 347	6 377	14 724	1 507	1 006	2 513	18.05	15.78	17.07	90	37	127	5.97	3.68	5.05
Small SLL	14 384	8 799	23 183	317	479	796	2.20	5.44	3.43	37	116	153	11.67	24.22	19.22
Large SLL	1 398	1 439	2 837	829	562	1 391	59.30	39.05	49.03	112	163	275	13.51	29.00	19.77
All fisheries	436 801	361 754	798 555	23 950	29 673	53 623	5.48	8.20	6.72	1 371	1 329	2 700	5.72	4.48	5.04

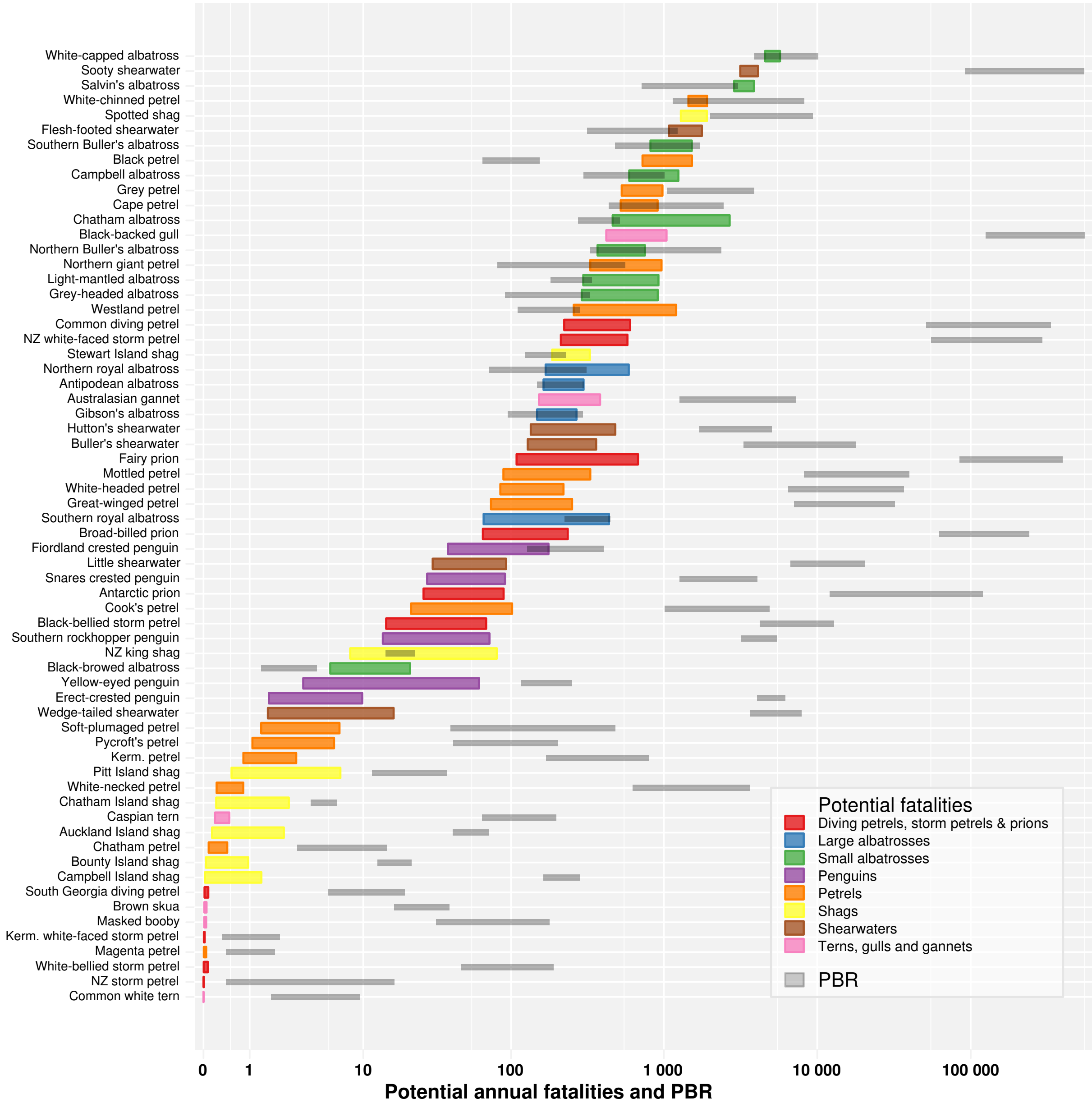

Figure 3: Mean annual number of potential seabird fatalities in the assessed fishery groups (colour bars) and the PBR (grey bars), for each of the 64 studied species. The bars indicate the 95% confidence intervals of the distributions. The species are sorted in decreasing order of the lower confidence level of the number of fatalities.

3.3 Risk ratios

The risk ratio, defined as the ratio of the number of annual potential fatalities to the PBR, is shown in Figure 4 for each species and in Table A-11 (Appendix A). Eight species had a number of annual potential fatalities significantly exceeding the PBR, as the 95% confidence interval of their risk ratio was strictly above one: the black petrel, the grey-headed albatross, the Westland petrel, the Chatham albatross, the flesh-footed shearwater, the Salvin's albatross, the light-mantled albatross, and the Stewart Island shag. For a further 12 species, the confidence interval of the risk ratio included one. These species were, in descending order of the lower confidence limit of the risk: the northern giant petrel, the Campbell albatross, the northern royal albatross, the Antipodean albatross, Gibson's albatross, the southern Buller's albatross, the white-capped albatross, the New Zealand king shag, the Cape petrel, the northern Buller's albatross, the white-chinned petrel, and the southern royal albatross. The risk ratio for black-browed albatross was significantly higher than 1. It is believed, however, that the potential fatalities would largely be of birds that breed outside of the New Zealand region, as there is only a small population breeding in New Zealand. The black-browed albatross has been excluded from this list. The risk ratio was significantly less than one for the other 43 studied species.

3.4 Sensitivity to prior

The comparison of the estimated number of annual potential fatalities and of the risk ratios, calculated using two different priors for the vulnerability estimation, is presented in Figure 5 and Table A-15. The estimates of the number of annual potential fatalities and therefore of risk ratios, were smaller when using a log-normal prior for the vulnerability estimation, compared to those obtained from using a vague uniform prior (the prior used elsewhere in the analysis). This decrease was due to the log-normal prior resulting in fewer estimated captures in poorly observed fisheries.

When a log-normal prior was used, the risk was reduced to below one for the grey-headed albatross, the Westland petrel, the Chatham albatross, the light-mantled albatross, the northern giant petrel, the Cape petrel, and the southern royal albatross. For these species, the identified risk can be interpreted as being due to a lack of information in poorly observed fisheries that overlap with their distributions. Because of this sensitivity to the prior, the values for the potential estimated captures should be treated as indicative.

There were four species (black petrel, Salvin's albatross, flesh-footed shearwater, and Stewart Island shag) that had a risk-ratio confidence interval entirely above one, and that remained at risk even with the log-normal prior. The other birds that were found to be at risk (Campbell albatross, northern royal albatross, Antipodean albatross, Gibson's albatross, southern Buller's albatross, white-capped albatross, New Zealand king shag, northern Buller's albatross, and white-chinned petrel), also remained at risk when fewer captures were assumed in poorly observed fisheries.

3.5 Sensitivity to parameters

The sensitivity of the risk ratio to the uncertainty in the four initial parameters used for the PBR calculation (the adult survival, the age at first reproduction, the number of annual breeding pairs, and the proportion of adults breeding in any given year), to the number of annual potential fatalities, and to the distribution map, is presented for each species in Tables A-13 and A-14 of Appendix A. The sensitivity was calculated as the percentage reduction in the 95% confidence interval of the risk ratio when each parameter was fixed to its mean, except for the sensitivity to the distribution map that was defined as the mean change from using either map (with or without colonies).

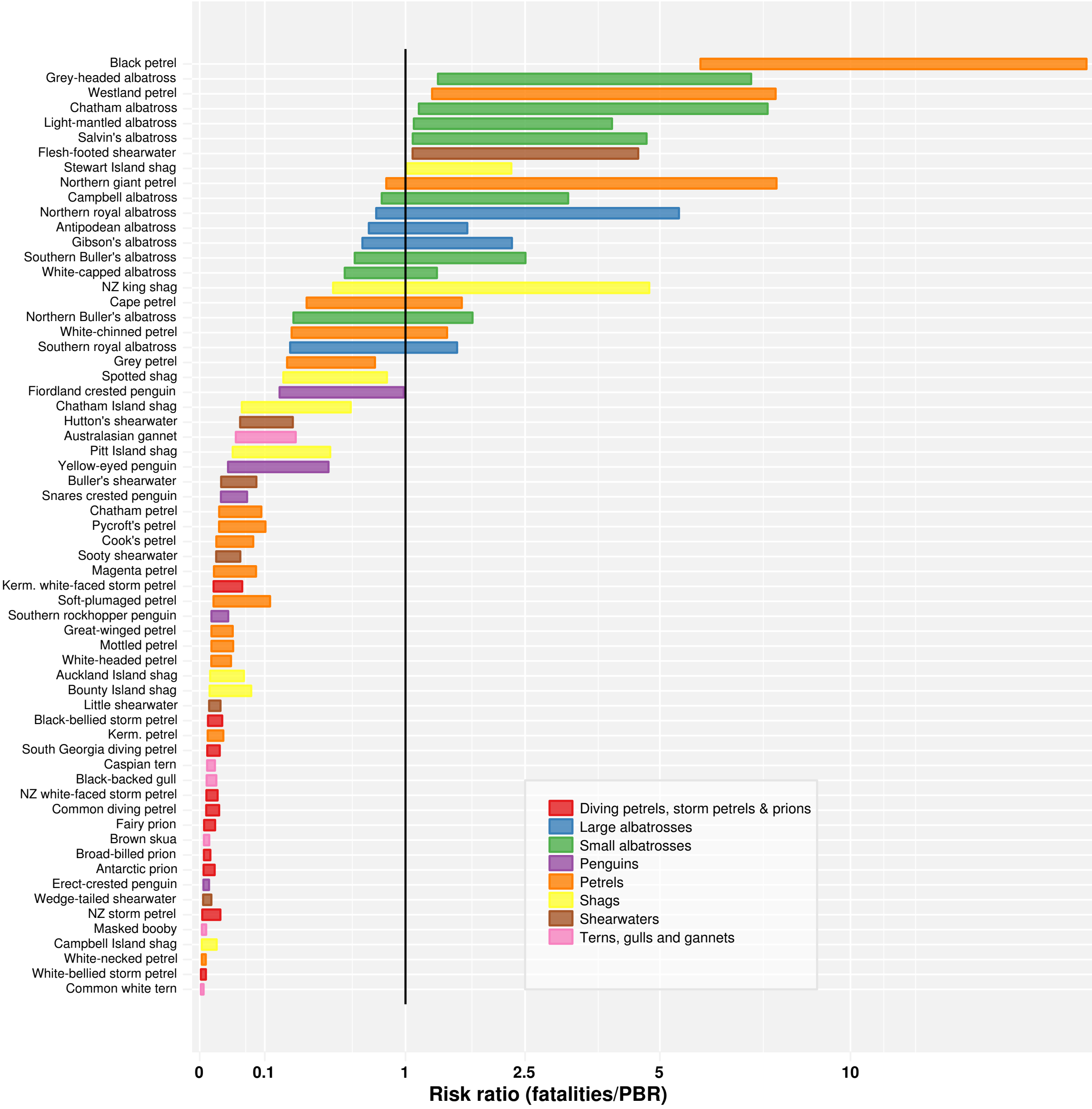

Figure 4: Risk ratio (total annual potential fatalities / PBR) for each of the studied species (without the black-browed albatross, see Discussion). The risk ratio is displayed on a logarithmic scale. The threshold where the number of potential bird fatalities equals the PBR is presented by the vertical black line. The bars indicate the 95% confidence intervals of the distributions. The species are sorted in decreasing order of the lower confidence level of the risk ratio.

Uncertainty in the risk was mainly driven by the uncertainty in four parameters: the number of annual breeding pairs (N), the number of annual potential fatalities (F, reflecting the uncertainty in the vulnerability), the adult annual survival rate (S), and the spatial distribution. The risk estimate for some species groups was dominated by only one parameter, such as the number of annual potential fatalities in most shags, the adult annual survival in the Northern and Southern Buller's albatrosses, or the number of annual breeding pairs in prions. The risk was in general not sensitive to the age at first reproduction (A) or to the proportion of adults breeding in a given year (P), except for two species, although the risk ratio of spotted shags showed some sensitivity to A. The sensitivity of the risk ratio to the distribution map was the highest for the New Zealand king shag, the magenta petrel (or taiko), the black-browed albatross,

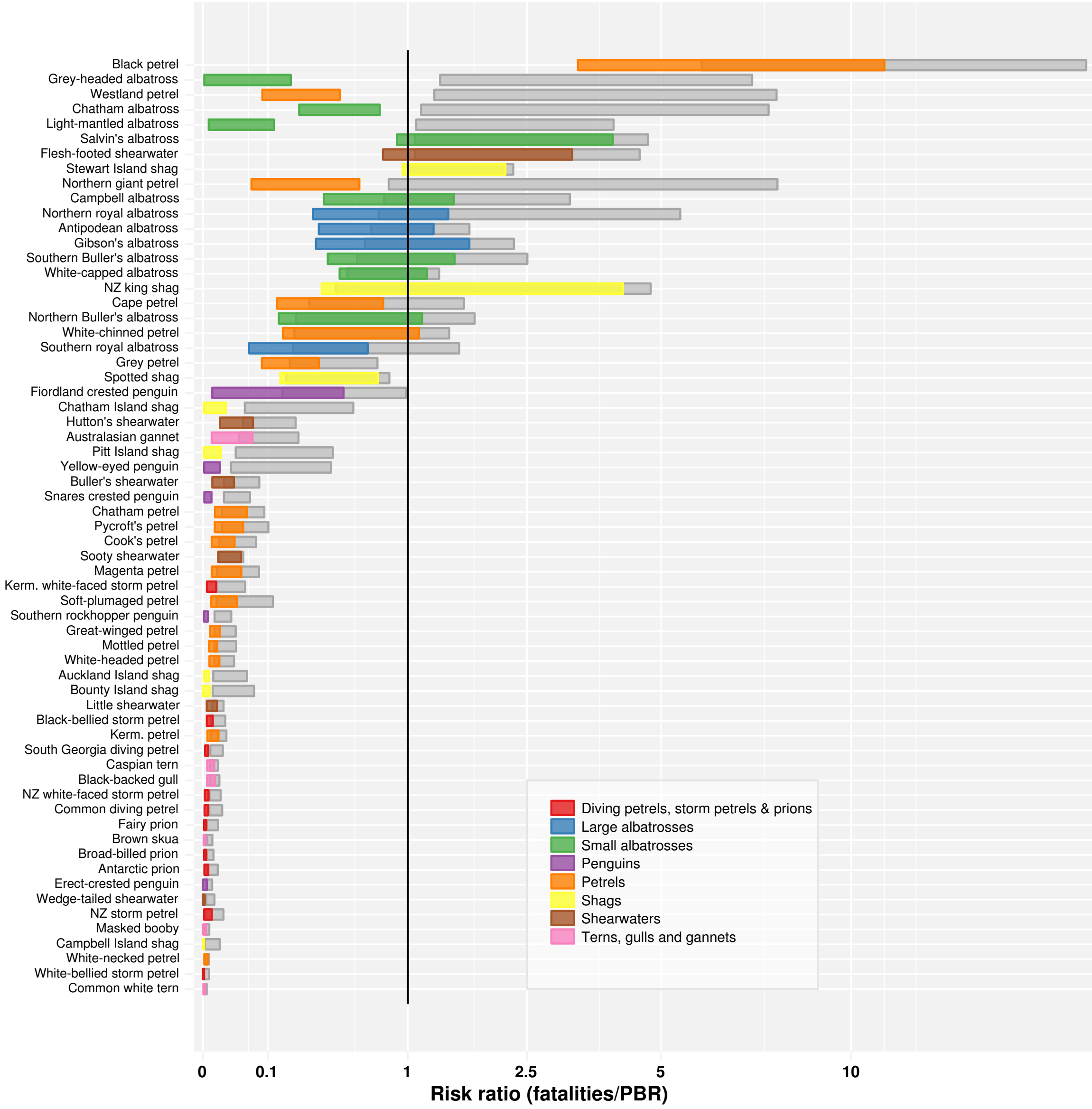

Figure 5: Risk ratios calculated using a log-normal prior (colour bars) instead of the vague uniform prior used elsewhere in the study (grey bars). Large differences between the two estimated risk ratios for some species highlight the lack of observer data, which prevents an accurate estimation of the number of observable captures for these species.

and the black-bellied storm petrel, but was low for the majority of species.

The four species that were found to be at high risk, and where the risk was not driven by a lack of information, were the black petrel, Salvin's albatross, flesh-footed shearwater, and Stewart Island shag. For these species, the uncertainty in the risk was mainly sensitive to annual potential fatalities, the adult survival rate, and the number of annual breeding pairs (Figure 6). For the Salvin's albatross and flesh-footed shearwater, the uncertainty was dominated by the uncertainty in the adult survival, for Stewart Island shag, the uncertainty was dominated by the uncertainty in potential fatalities, and for black petrel, both potential fatalities and adult survival contributed to the uncertainty.

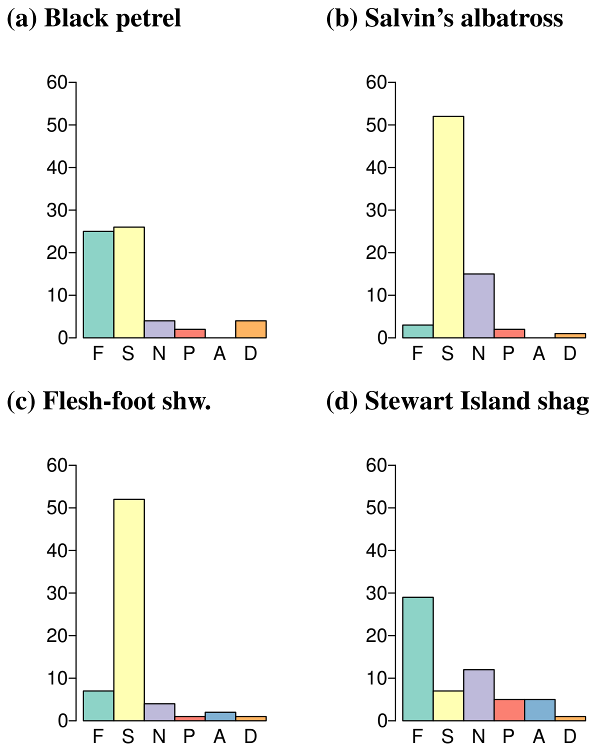

Figure 6: Sensitivity of the risk ratio to the uncertainty in the mean number of annual potential fatalities (*F*, reflecting the uncertainty in vulnerability), the adult annual survival rate (*S*), the number of annual breeding pairs (*N*), the proportion of adults breeding in a given year (*P*), the age at first reproduction (*A*), and to the distribution map (*D*), for the species most at risk (lower bound of the 95% c.i. above 1). This sensitivity is expressed as the percentage reduction in the 95% confidence interval of the risk ratio when each parameter is fixed to its mean.

3.6 Estimated potential fatalities by fishery type and FMA

The estimated number of annual potential bird fatalities greatly varied between fishery types (Tables A-6 to A-9) and FMAs (Table A-12). Some species, such as the sooty shearwater, had high numbers of potential fatalities in several different fisheries. In contrast, the risk for some species, such as Stewart Island shag, was mainly due to a single fisheries group (in this case, flatfish trawl fisheries). Overall, most estimated potential fatalities, and also most risk, occurred in the fishery groups associated with small inshore vessels: the trawl fishery targeting flatfish, small (less than 28 m length) inshore vessels not targeting deepwater species, small bottom longline vessels, and small (less than 45 m length) surface longline vessels. Following the distribution of the fishing effort from these fisheries, most potential fatalities, and associated risk, occurred in the FMAs 1, 2, 3, 5, and 7, (i.e., in the areas from the north to the east of the North Island, and off the west, east, and south coasts of the South Island). The uncertainty around the estimated number of potential fatalities was driven by the proportion of fishing effort that was observed in areas of high bird densities. For example, it was estimated that there were a large number of potential fatalities of white-capped albatrosses, Salvin's albatrosses, and sooty shearwaters by small inshore trawl vessels, and there was only moderate uncertainty around the estimates. In contrast, the uncertainty around the estimate of captures of Chatham albatross in inshore trawl fisheries was large, reflecting the fact that there has been no observer coverage in inshore fisheries around the Chatham Islands. Uncertainties in the number of potential fatalities were typically higher for the estimated number of potential fatalities by small inshore vessels, and lower for those from large offshore vessels.

3.7 Change in potential fatalities over time

The changes between the periods 2003–04 to 2005–06 and 2006–07 to 2008–09 in the number of potential fatalities for each species are presented in Table A-16 of the appendix. Potential fatalities in offshore trawl fisheries showed a decrease, which was significant (at $\alpha = 0.05$) for most species. This was primarily driven by a decrease in trawl effort between the two periods (see Table 5). Although the potential fatalities in large vessel bottom and surface longline fisheries increased for some species, the change in fatalities between the two periods across all large vessel fisheries was dominated by the decrease in large vessel offshore trawl fisheries. Overall, 46 of the 64 species showed a decrease in potential fatalities (with 80% probability or more) between the two time periods. There were no species that had a significant increase in potential fatalities between the periods.

3.8 Potential captures

Naturally, the number of species at risk was reduced when cryptic mortality was ignored in the risk calculation (Table A-17 of the appendix). Without cryptic mortality being included, there were four species with a mean risk ratio higher than one (the black petrel, New Zealand king shag, Westland petrel, and Stewart Island Shag), but there were no albatross species in this group. There were a further seven species that had an upper 95% of the confidence interval above one (flesh-footed shearwater, northern giant petrel, grey-headed albatross, Chatham albatross, northern royal albatross, Gibson's albatross, and Salvin's albatross).

3.9 Comparison of capture estimates

A comparison was made between the number of annual observable captures (i.e., not including cryptic mortality) estimated using the risk assessment method, statistical modelling (Abraham & Thompson 2011, 2010a), and the ratio method of Abraham et al. (2010b) (Figure 7). In all cases, the number of potential captures calculated in this study was higher than the ratio-estimated captures, and in most cases the potential captures were higher than the model-estimated captures. There are two reasons for this. Firstly, the ratio estimation of Abraham et al. (2010b) ignores many fishery-area strata. Similarly, poorly observed fisheries (such as inshore trawl, flatfish trawl, and small vessel ling longline) were not included in the statistical modelling. Secondly, the estimated potential captures were higher than ratio or model-estimated captures in poorly observed fisheries. The risk assessment allows for the possibility of captures in fisheries that have not been observed. For example, there were no observed captures of white-capped albatross in bottom longline fisheries, therefore there were no estimated captures in the ratio estimates. In contrast, the method followed by the risk estimation allows for the possibility that there may be captures of white-capped albatross in bottom longline fisheries despite the lack of observed captures.

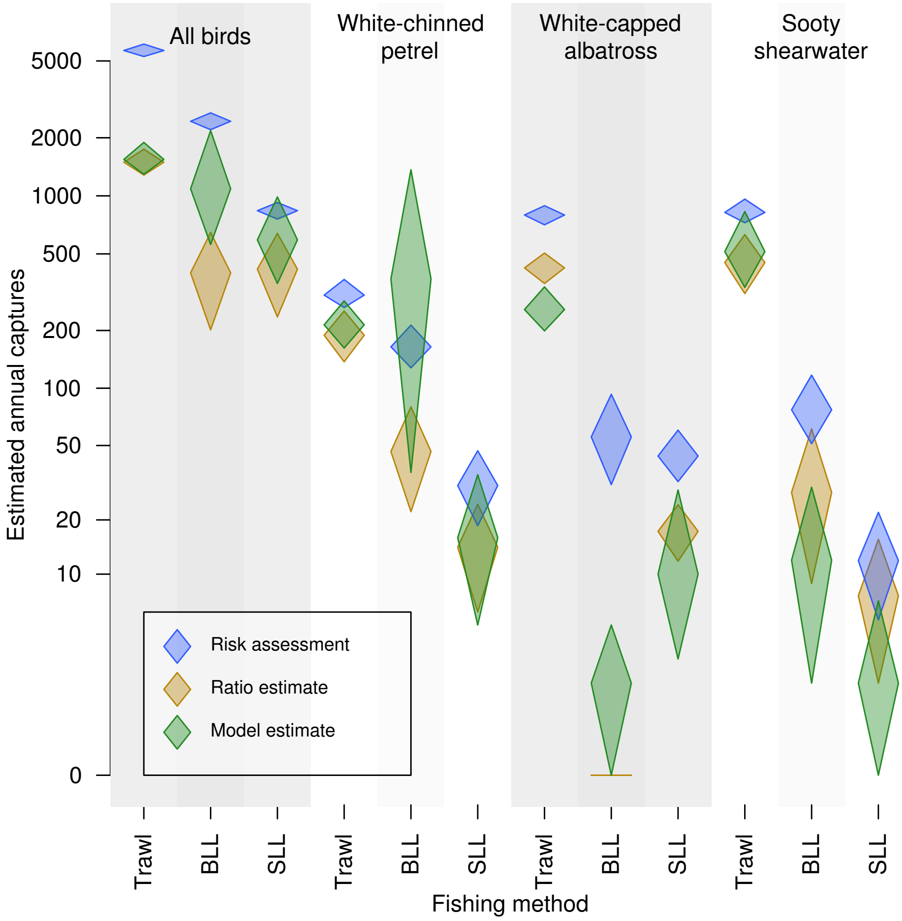

Figure 7: Comparison of the number of potential annual captures (without cryptic mortality) estimated using the risk assessment method, the ratio method, and statistical modelling, for the white-chinned petrel, the white-capped albatross, the sooty shearwater, and all birds, in trawl, bottom longline, and surface longline fisheries. The symbol represents the mean and the 95% confidence interval.

4. DISCUSSION

4.1 Species at risk

Annual potential fatalities significantly exceeded the PBR for eight species (the black petrel, the grey-headed albatross, the Westland petrel, the Chatham albatross, the flesh-footed shearwater, the Salvin's albatross, the light-mantled albatross, and the Stewart Island shag), suggesting that the viability of these species may be threatened by commercial fishing activities. The 95% confidence interval of the risk ratio of a further 12 species encompassed one, which indicates that the number of fatalities for these species might exceed the PBR. These species included the northern giant petrel, the northern royal albatross, the New Zealand king shag, the Campbell albatross, the southern Buller's albatross, the Gibson's albatross, the Antipodean albatross, the white-capped albatross, the white-chinned petrel, the northern Buller's albatross, the Cape petrel, and the southern royal albatross. The species with a mean risk ratio greater than one are each discussed in more detail in the following sections. Species that were not at risk when the log-normal prior was used are marked as information poor.

4.1.1 Black petrel

The black petrel (*Procellaria parkinsoni*) was the species most at risk from commercial fishing activities. The black petrel is endemic to New Zealand and is classified as Vulnerable by the IUCN (IUCN 2010). It breeds in only two colonies: approximately 2000 annual pairs on Great Barrier Island, and approximately 100 annual pairs on Little Barrier Island. Most observed captures were close to its breeding grounds, primarily in the bottom longline snapper fishery, but also in the bottom longline bluenose fishery, and in inshore trawl fisheries. From 27 observed captures, we estimated that between 725 and 1524 birds may have potentially been killed each year in the period 2003 to 2009. These fatalities exceeded the PBR, which was estimated to be between 65 and 154 mortalities per year. There was no significant difference in the vulnerability to capture, in the number of potential fatalities, or in the risk ratio of black petrel between the periods 2003–04 to 2005–06 and 2006–07 to 2008–09. Based on population surveys, Francis & Bell (2010) found that the main black petrel population breeding on Great Barrier Island has been increasing with an average of 1.2% per year, from 1598 breeders in 1988 to 1964 breeders in 2005. This was, however, primarily based on two population surveys that used different methods. The uncertainty associated with these surveys was not taken into account, and it is possible that the population has been declining despite this apparent increase. Fisheries bycatch data were not considered by Francis & Bell (2010). Black petrel migrate to eastern Pacific waters outside of the breeding season, and will also be vulnerable to capture in fisheries there. They may also be caught by recreational fishers in the Hauraki Gulf area (Abraham et al. 2010a). These sources of fisheries mortality were not included in the risk assessment.

4.1.2 Grey-headed albatross (information poor)

The grey-headed albatross (*Thalassarche chrysostoma*) breeds in New Zealand only on Campbell Island, but the 6600 pairs breeding there annually represent only 7% of the world population, estimated to be close to 100 000 pairs distributed around the subantarctic zone. The species is classified as Vulnerable by the IUCN, due to a population decline, suspected to be largely due to incidental mortality in longline fisheries (IUCN 2010). No captures were observed in the NZEEZ between 2003–04 and 2008–09, but it was estimated that between 291 and 912 grey-headed albatrosses were potentially killed annually, exceeding the PBR with a 99% probability (95% c.i. 91 to 327). When a log-normal prior was used, the mean risk ratio was markedly reduced from 3.51 to 0.03. Indeed, for the grey-headed albatross, the risk was mainly driven by the lack of observations in the flatfish trawl and inshore bottom longline fisheries, which overlap with the distribution of this species.

4.1.3 Westland petrel (information poor)

The Westland petrel (*Procellaria westlandica*) only breeds along an eight-kilometre stretch of forested foothills in 1200 ha of coastal forest in the Paparoa Range near Punakaiki on the west coast of the South Island. Because of the small population of approximately 4000 annual breeding pairs, this species is classified as Vulnerable by the IUCN. Ten captures were observed, all close to the breeding colony: seven in trawl fisheries (five when targeting hoki, one when targeting barracouta, and one when targeting jack mackerel) and three in surface longline fisheries targeting southern bluefin tuna. We estimated that between 258 and 1203 Westland petrels were potentially killed annually, exceeding the PBR (95% c.i.: 110 to 282) with a probability of 99%. The vulnerability was found to have increased in trawl fisheries between the periods 2003–04 to 2005–06 and 2006–07 to 2008–09, but the number of annual potential fatalities decreased, reflecting a decrease in trawl fishing effort. The risk ratio for Westland petrel was sensitive to the choice of prior, with the risk ratio decreasing from a mean of 3.31 to a mean of 0.22 if a log-normal prior was used. This was due to many of the estimated potential fatalities being associated with poorly observed small vessel bottom longline and flatfish trawl fisheries. The risk is associated with a lack of observer coverage in these fisheries.

4.1.4 Northern giant petrel (information poor)

The northern giant petrel (*Macronectes halli*) is classified as Least Concern on the IUCN red list. Its breeding range is very large, encompassing the whole subantarctic zone, with a world population of over 10 000 pairs. In New Zealand, an estimated 2500 pairs breed mainly in the Chatham Islands, but also in the Antipodes, Campbell and Auckland Islands. Between 2003–04 and 2008–09, only 4 captures were observed, in trawl fisheries targeting orange roughy, hoki and scampi, and also in the large bottom longline fishery targeting ling. The PBR was estimated to be between 82 and 561 and the mean total annual potential fatalities (95% c.i. 331 to 965) exceeded the PBR with a probability of 94%. The large number of potential fatalities, despite a low number of observed captures, was mainly due to the lack of observations in the flatfish trawl and inshore bottom longline fisheries. The risk ratio decreased when the log-normal prior was used for the vulnerability. Because of the broad distribution of northern giant petrels, observed captures may also have involved birds breeding outside the NZEEZ.

4.1.5 Chatham albatross (information poor)

The Chatham albatross (*Thalassarche eremita*) breeds only at The Pyramid, a small island in the Chatham archipelago. Around 4500 pairs breed there annually. The IUCN status of the Chatham albatross was downgraded in 2010 from Critically Endangered to Vulnerable, as the population has been stable. There were 17 captures observed between 2003–04 and 2008–09, all of them close to the Chatham Islands, and 15 of them occurred in bottom longline fisheries targeting ling. It was estimated that between 463 and 2685 Chatham albatrosses were potentially killed annually, mainly in inshore trawl fisheries, whereas its PBR was estimated to be between 275 and 516. Its risk ratio was estimated to be 2.71, and the uncertainty around this figure (95% c.i.: 1.13 to 7.62) was mainly due to the uncertainty around the mean number of annual potential fatalities. When a log-normal prior was used for the vulnerability, the risk ratio was reduced to less than one. There was no evidence of temporal change in the number of potential fatalities, or in the risk ratio for this species.

4.1.6 Flesh-footed shearwater

In New Zealand, the flesh-footed shearwater (*Puffinus carneipes*) breeds on a number of islands off the north-east coast of the North Island, the Auckland west coast, Taranaki and Cook Straight. It also breeds on Lord Howe Island and on some Indian Ocean islands. Because of its large distribution and world population of over 600 000 pairs, the flesh-footed shearwater is classified as Least Concern by the IUCN. A recent study (Baker et al. 2010) gave an estimate of approximately 10 000 pairs breeding annually in the NZEEZ. There were 58 captures observed between 2003–04 and 2008–09, especially in the bottom longline fisheries targeting snapper and in the trawl fisheries targeting scampi, and we estimated that between 1079 and 1769 birds were potentially killed annually. These potential fatalities exceed the PBR (95% c.i.: 316 to 1226) with a 98% probability. It should be noted that the risk for this species may be overestimated, as a number of birds caught in New Zealand waters may be from populations breeding outside the NZEEZ.

4.1.7 Salvin's albatross

The Salvin's albatross (*Thalassarche salvini*) is classified as Vulnerable by the IUCN and is endemic to New Zealand. It breeds only on the Bounty Islands (96% of the population) and the Western Chain of Snares Islands, with a total of approximately 32 000 annual pairs. There were 134 observed captures between 2003–04 and 2008–09, mainly by large trawl vessels targeting hoki and in bottom longline fisheries targeting ling. It was estimated that between 2873 and 3865 Salvin's albatrosses were potentially killed each year in the NZEEZ, with a PBR between 714 and 3035, and there was a 98% probability that the number of annual potential fatalities exceeded the PBR. The uncertainty around the risk ratio was mainly due to the uncertainty in the number of breeding pairs. There was a decrease in the vulnerability and of the number of annual potential fatalities between the periods 2003–04 to 2005–06 and 2006–07 to 2008–09 in the trawl and bottom longline fisheries, but an increase in the surface longline fishery, although the latter is only responsible for a small proportion of potential fatalities.

4.1.8 Northern royal albatross

The northern royal albatross (*Diomedea sanfordi*) is endemic to New Zealand, breeding predominantly in the Chatham Islands (approximately 5800 pairs), with a few pairs also breeding at Taiaroa Head on the Otago Peninsula, and is classified as Endangered in the IUCN red list. Only two captures were observed: one in trawl fisheries targeting orange roughy and one in surface longline fisheries targeting bigeye tuna. Constraining the vulnerability to be the same for the four *Diomedea* species of the study, it was estimated that between 169 and 590 northern royal albatrosses were potentially killed annually, exceeding the PBR (95% c.i.: 71 to 312) with a 92% probability.

4.1.9 Light-mantled albatross (information poor)

The light-mantled albatross (*Phoebetria palpebrata*) breeds widely on subantarctic islands with a world population of over 20 000 annual breeding pairs, and is considered as Near Threatened by the IUCN. In New Zealand, it breeds at the Auckland, Campbell and Antipodes Islands, and the NZEEZ population is estimated to be less than 7000 pairs. Only one capture was observed in the large surface longline fishery while targeting southern bluefin tuna off the South Island west coast. The average number of annual potential fatalities was estimated between 298 and 922, exceeding the PBR (95% c.i. 182 to 338) with a probability close to 99%. This estimate of the number of potential fatalities was mainly driven by the lack of observations in the flatfish trawl and inshore bottom longline fisheries (other than those targeting snapper). When the log-normal prior was used for the vulnerability the mean risk ratio decreased from 2.18 to 0.02, confirming that the risk for this species is associated with a lack of information.

4.1.10 New Zealand king shag

The distribution of New Zealand king shag (*Phalacrocorax carunculatus*) is restricted to the Marlborough Sounds, with a total population estimated to be 325 breeding pairs, justifying its status as Vulnerable on the IUCN red list. No captures of New Zealand king shags have been observed, but we estimated that between 8 and 81 king shags might be killed annually. This was calculated by applying the same vulnerability to all shag species (primarily driven by the capture of 31 spotted shags during a single fishing event off the Banks Peninsula). It is possible that king shags might not be as vulnerable as spotted shags to capture, but shags are also caught in inshore recreational fisheries (Abraham et al. 2010a) which are active in the Marlborough Sounds, and only a few fatalities a year could exceed the PBR (95 % c.i.: 14 to 23). The uncertainty in the risk was sensitive to assumptions on the distribution of King shags, with the risk being higher for the distribution without explicit colonies.

4.1.11 Campbell albatross

Endemic to New Zealand and classified as Vulnerable by the IUCN, the Campbell albatross (*Thalassarche impavida*) breeds only on Campbell Island, with approximately 20 000 pairs breeding annually. There were 22 captures observed between 2003–04 and 2008–09, mostly in surface longline fisheries targeting southern bluefin tuna off the north-eastern coast of the North Island. The average number of annual potential fatalities was estimated between 594 and 1244, exceeding the PBR (95% c.i.: 298 to 1008) with a 94% probability.

4.1.12 Stewart Island shag

The Stewart Island shag (*Phalacrocorax chalconotus*) breeds only on the southern coastline of New Zealand, with its range extending from the coastal waters of Steward Island to the Otago Peninsula. It is classified as Vulnerable by the IUCN, as its population is relatively small (3000 pairs) and thought to be declining. We estimated that between 186 and 328 Stewart Island shags were potentially killed annually, although no captures have been observed. As for the New Zealand king shag, these fatalities originate from the fact that a single vulnerability was estimated for all shag species, which was driven by the captures of spotted shags. The distribution of Stewart Island shags overlaps with the flatfish trawl fishery, and this results in the large estimate of annual potential fatalities. The PBR was estimated to be between 124 and 228, and there is a 98% probability that the potential fatalities exceed the PBR for this species.

4.1.13 Southern Buller's albatross

The southern Buller's albatross *Thalassarche bulleri bulleri* is endemic to New Zealand and breeds only on the Snares and Solander Islands, with a population of almost 14 000 pairs annually. It is classified as Near-Threatened although it is not considered as distinct from the Northern Buller's albatross *Thalassarche bulleri platei* on the IUCN red list. There were 261 captures observed in the NZEEZ between 2003–04 and 2008–09, predominantly in the large surface longline fishery targeting southern bluefin tuna off the Fiordland coast, but also in trawl fisheries mainly off the South Island west coast, around the Stewart-Snares shelf and on the Chatham rise. We estimated that between 817 and 1521 southern Buller's albatrosses were killed annually, exceeding the PBR (95% c.i. 479– 1716) with a 63% probability. The uncertainty of the risk ratio was almost exclusively driven by the uncertainty in annual adult survival.

4.1.14 Gibson's albatross

The Gibson's albatross (*Diomedea antipodensis gibsoni*), endemic to New Zealand, breeds only on the Auckland Islands (mainly on Adams Island), with a population estimated to approximately 5000 annual breeding pairs. Although not considered separately from the Antipodean albatross (*D. a. antipodensis*) by the IUCN, it was classified as Vulnerable. There were 12 captures observed between 2003–04 and 2008–09, 11 in the surface longline fisheries mainly targeting southern bluefin tuna and swordfish, and 1 in the deepwater trawl fishery targeting orange roughy. We estimated that between 148 and 269 Gibson's albatrosses were potentially killed on average annually, exceeding the PBR (between 95 and 296) with a probability of 65%.

4.1.15 Antipodean albatross

The Antipodean albatross (*Diomedea antipodensis*), classified as Vulnerable on the IUCN red list along with the Gibson's albatross, is endemic to New Zealand with over 6000 annual pairs breeding almost exclusively on Antipodes Island. Six captures were observed from 2003–04 to 2008–09, all in surface longline fisheries targeting southern bluefin tuna, bigeye tuna, and swordfish. We estimated that between 163 and 299 Antipodean albatrosses were potentially killed on average each year, exceeding the PBR (between 148 and 299) with a probability of 65%.

4.2 Risk by fishery type and FMA

We estimated that the risk is highest in the inshore fisheries (Tables A-6 to A-9) in FMA 1, 2, 3, and 7 (Table A-12), primarily due to the distribution, large effort, and lack of observations in these fisheries (Appendix C). In the absence of sufficient data to provide a precise estimate, the number of fatalities was uncertain (i.e., the estimate ranged from very low to very high). This was pronounced in the flatfish trawl fishery, in which albatrosses, petrels of the *Procellaria* genus, king shags, and spotted shags may potentially be killed in large numbers, but all the estimates were very uncertain. For example, annual potential fatalities of Westland petrels in the flatfish trawl fishery were estimated to be between 31 and 932. This large uncertainty arose from a high fishing effort that was poorly observed, but which was occurring where the density of Westland petrels was high. The uncertainty around the estimated number of potential fatalities of Chatham albatrosses by small inshore trawl vessels was also high, with between 51 and 2343 potential fatalities annually, because no observations have been made of the inshore fishing effort around the Chatham Islands. The risk assessment is pessimistic, with a high upper bound in the absence of observer data. Estimates of the risk ratio can be made more precise by making more observations, or by making assumptions on the value of the vulnerability in poorly observed fisheries.

In trawl fisheries, the only fisheries where the mean number of potential fatalities was higher than than 50% of the PBR were inshore and flatfish fisheries. Although there were high numbers of potential fatalities of some species in other fisheries, e.g., white-capped albatross in squid trawl, the PBRs of these species were also higher.

There were low numbers of potential fatalities in large bottom longline fisheries. In the period covered by the data, observed large bottom longliners have predominantly used integrated weight line. This causes the hooks to sink quickly, reducing the time that they are available to birds, and consequently the captures are low (Robertson et al. 2006). Unfortunately, there are large bottom longliners that do not use integrated weight line, but these have been poorly observed (Abraham & Thompson 2011). The method for estimating potential fatalities assumed that the observed fishing effort is representative of all the fishing effort. This is not the case for the large bottom longliners, and so the potential fatalities may be underestimated.

The total number of potential fatalities in surface longline fisheries was lower than either trawl or bottom longline fisheries. Consequently, the risk associated with surface longline fisheries was comparatively low. The group of great albatrosses (*Diomedea* spp.), the two Buller's albatrosses, and the Campbell and black-browed albatrosses, were the seabirds that had most risk associated with surface longline fisheries.

4.3 Variation over time

In principle, the risk assessment method allows for changes in risk to be tracked with time. Whether this can be achieved depends on the availability of sufficient data. We compared the potential fatalities

(Table A-16) between the periods from 2003–04 to 2005–06 and from 2006–07 to 2008–09. This could only be done for the large vessel fisheries groups that had sufficient observations. For these fisheries groups, the overall estimated number of potential fatalities decreased between the two periods. This decrease followed the change in fishing effort (Table 5). On the other hand, the number of potential fatalities in large surface longline fisheries appeared to have increased between the two periods, despite a slight decrease in effort. The uncertainty around the change in vulnerability was large, however. Also, changes in the vulnerabilities were investigated between the periods, however the changes were difficult to interpret, as the vulnerability can not straightforwardly be aggregated across different fisheries. The results have not been included in the report. Changes in capture rates are best explored within the context of specific fisheries. For example, the statistical modelling of seabird captures demonstrated a decrease in the capture rate of white-capped albatross in the Auckland Islands squid trawl fishery (Abraham & Thompson 2011).

4.4 Assessment of the approach

In order to examine the population effects of fisheries bycatch on seabird species in the New Zealand region, we used a level-2 (semi-quantitative) risk assessment framework (Waugh et al. 2009), built on the method set out by Sharp et al. (2011). This method had key advantages over others available (e.g. Kirby et al. 2009, Baird & Gilbert 2010, Waugh et al. 2008b, 2008c). In particular, it allowed all species to be treated within a consistent framework, and included both demographic data and information on observed seabird captures. The use of observer data gives the method a sound empirical basis, and allows the risk index to respond to changes in observed capture rates if they change. We considered uncertainty in most parameters explicitly, and this allowed uncertainty in the final outcomes to be defined. Uncertainties in the parameters were kept through the whole analysis process, as every calculation was made on samples of values instead of point estimates. This approach also allowed changes over time and variations among fishery types to be assessed, and the risk index we calculated is comparable across species.

A number of factors may lead our estimates of risk to be underestimated and some species may be at risk even if their risk ratio was estimated to be lower than one. These factors, as well as the benefits of the approach, are summarised in Table 6.

Table 6: Summary of the benefits and limitations of the seabird risk assessment methodology.

Benefits	Limitations
• Risk is quantitative and absolute • Consistent methodology • Use of observer data gives a sound empirical basis • Assessment is data rich, and risk may be attributed to specific fisheries or areas • Information gaps in demographic parameters are high-lighted • Uncertainty in parameters explicitly considered • Risk measure able to respond to changes in the captures • Potential fatalities and associated risk are estimated across a wide range of fisheries	• Not all human-induced mortalities are included • Poor data on cryptic mortalities • Observers are unable to record all captures, observer data may not be representative, and some captures are of live birds • Use of observer data means that values are very uncertain for poorly observed fisheries • PBR method untested for seabirds, and may have biases • Seabirds may range into or out of the NZEEZ • Seabird distributions are poorly understood • Seasonality in seabird distributions was not included • Reliant on using proxy species, and species group vulnerabilities

4.4.1 Not all human-induced mortalities are included

The PBR assumes that all human-caused mortality is taken into account. However, the risk ratio we calculated for each species includes only the mortality caused by the 16 fishery groups we examined. The risk we estimated is therefore not a complete risk, sensu Sharp et al. (2011), as it does not include other human-induced sources of mortality. For instance, setnet and purse seine commercial fisheries were not included in our analysis, because they were poorly observed and quite heterogeneous. The number of birds killed annually in these fisheries is unknown, but the few existing observations indicate that a range of species are caught. In setnet fisheries, observed captures include spotted shags, white-chinned and Westland petrels, fluttering and sooty shearwaters, Cape petrels, and yellow-eyed penguins. Fatalities from non-commercial (e.g., recreational) fishing activities in New Zealand were also excluded. A recent analysis (Abraham et al. 2010a) highlighted the large number of bird captures that might occur in recreational fisheries, estimated to be around 10 000 birds annually in the north-eastern New Zealand region alone. These captures in recreational fisheries would exceed the total number of birds caught in commercial fisheries (although the survival rate may be higher for birds caught in recreational fisheries). Also, sooty shearwater and great-winged petrels (also called grey-faced petrels) chicks are harvested at their colonies in large numbers (over 300 000 chicks annually; Newman et al. 2008) and this removal was not taken into account.

Other human-related factors may also affect the species persistence and were not included in our analysis. Potential issues beyond fishing mortality include pollution, habitat destruction at seabird colonies, depredation by introduced predators, or indirect competition with fisheries (e.g., the decline of krill stocks; Schiermeier 2010).

4.4.2 Cryptic mortality

Observed fatalities during fishing events underestimate the actual number of fatalities. Fatalities may be unobservable (cryptic mortality) as birds can be killed by trawl warp strikes or from injuries by fishing hooks without being brought on board the vessel. Although we included cryptic mortality to estimate the potential number of annual fatalities, the multipliers we used were derived from limited data (Appendix B). Unfortunately, there was no information available from New Zealand fisheries that could be used to quantify the degree of cryptic mortality and the multipliers relied on studies from other countries. These might not be accurate for New Zealand. For some of the parameters, such as aerial warp strikes of large birds, there was no available data. Because of the limited data and the number of assumptions that needed to be made, uncertainty in the multipliers used as a basis for the cryptic mortality was not estimated.

4.4.3 Limitations of observer data

Of the 2700 seabird captures observed between 2003–04 and 2008–09, 191 (7.0%) were recorded using generic identifications (such as ‘small birds’, ‘shearwaters’, ‘gulls’, etc.). These captures were ignored in our calculations as the risk was assessed at the species level, and this may have led to our estimates of the number of potential fatalities being underestimated. Although the majority of birds fatally captured during observed fishing events were necropsied for precise identification (Table 7), not all captured birds are returned for necropsy and the observers’ identifications were used for approximately a third of captures. Species identification by observers is generally correct for common species (around 70% correct; Thompson 2010), but can be unreliable for less common ones (Trebilco et al. 2010), and our estimates of annual seabird fatalities may be prone to errors due to these mistakes.

A further problem with the reliance on observer data is the assumption that the observations are representative of the effort. This may not be the case, particularly if a fishery is poorly observed, and this may then result in biases in the calculation of the potential captures. In bottom longline fisheries, in particular, it is known that the observations are biased towards vessels that use integrated weight line (Abraham & Thompson 2011). These vessels have a lower seabird capture rate, and so potential captures by the unobserved bottom longline vessels may be underestimated.

4.4.4 Potential biases in the PBR calculation

Under-estimates of annual survival result in the PBR being overestimated, via an overestimation of both the maximum population growth rate (Figure 2) and of the ratio of the total population to the number of adults (Figure 2). The calculation of r_{max} assumes that survival is measured in optimal conditions, and methods for estimating survival rates generally result in estimates of local survival, where individuals leaving the study area are considered dead. Moreover, our approach to calculate the ratio of the total population to the number of adults assumes that young birds of over one year old have the same survival rate as older adults, and this ratio may therefore be overestimated. Consequently, the “true” value of the PBR may be lower than the values estimated here.

The PBR was originally developed for managing marine mammal populations (Wade 1998), and its applicability to seabird populations has not been tested. In particular, the choice of parameter values (the selection of f, and determining the quartile of N_{BP} to calculate N_{min}) has not been confirmed as appropriate for seabirds. It will be important to establish that these choices lead to sustainable seabird populations. This could be achieved by comparing the PBR calculation with the results of more detailed seabird population models. There may be other potential biases that could be identified by carrying out simulations of seabird populations

4.4.5 Seabirds may range outside the NZEEZ

Many New Zealand seabirds forage outside the NZEEZ and their capture by foreign fisheries was not included in our analysis. For instance, some species forage off the coast of Chile and Peru during the non-breeding season (e.g. Buller’s albatross, Chatham albatross, Westland petrel), in the eastern tropical Pacific waters (e.g. black petrels), or around South Africa (e.g. white-capped albatrosses). Also, some fisheries such as the Spanish longline fishery targeting swordfish operate in the zone between New Zealand and the South American coast, therefore directly overlapping with many New Zealand seabirds.

Although captures of New Zealand birds outside the NZEEZ underestimate the risk, the opposite process tends to overestimate it: some birds captured within the NZEEZ are likely to belong to breeding populations outside the NZEEZ. For species breeding in New Zealand and also elsewhere, we are currently unable to estimate this proportion due to our poor knowledge of seabirds’ distribution at sea. This problem was evident for the black-browed albatross (*Thalassarche melanophrys*), as the New Zealand breeding population is very small (Table A-1), yet many birds from other populations also forage in New Zealand waters. Because of the small New Zealand breeding population, the few observed captures (Table A-10) led to an unreasonably high risk ratio. It was therefore decided to remove this species from the tables and figures where the risk ratios are presented. It may also explain the high risk estimated for Cape petrel.

4.4.6 Live captures

Around a quarter of birds observed caught in the fisheries considered in this study were released alive (Table 7). Because their fate is unknown, these captures were included in our analysis, therefore treating them as fatal. It is likely that a number of these birds survived their capture, and our estimates of the number of potential captures may therefore be overestimated for some species. Without any information on their fate, including them in the analysis satisfies the precautionary principle.

Table 7: Number of observed annual seabird captures from 2003–04 to 2008–09, percentage of captured birds released alive, and percentage of captured birds necropsied.

Fishing year	Captures	Alive (%)	Necropsied (%)
2003–04	440	22	70
2004–05	713	38	52
2005–06	491	31	64
2006–07	457	19	66
2007–08	318	19	71
2008–09	565	27	63

4.4.7 Poorly understood seabird distributions

To estimate the vulnerability of birds to capture, and to calculate the total number of captures, the number of captures was assumed to follow the bird density at the location of each fishing event. This density was derived from distribution maps created from various sources of data. Two different maps were created to allow some uncertainty in our knowledge of bird distributions to be represented. The first one was a composite map of data from the NABIS database and from satellite tracking when possible, with a few discrete densities. The bird density of the second map directly depended on the distance to the colonies. The first one had the advantage of representing high-foraging areas independently of the colonies, but bird densities may be distorted in some places. For example, the NABIS database indicates two hotspots for the northern royal albatross, a large one around the Otago Peninsula colony and a smaller one around the Chatham Islands, whereas the former colony has approximately 30 pairs and the latter 5800 pairs. The second map may be more realistic for some species, but ignored areas such as the Chatham Rise where many birds forage even if they are breeding on distant islands. Unfortunately, our knowledge of the distribution of most seabirds remains poor, and the consequences of this for the current study are unclear. Improving the quality of data on bird distributions would increase the reliability of our results.

The apparent risk for species such as light-mantled sooty albatross and grey-headed albatross was based on overlap between their distribution and the distribution of inshore and flatfish fisheries. Because of low observer coverage in these fisheries, this resulted in a high risk. Flatfish trawl vessels typically fish in shallow water (a mean depth of less than 20 m). For the albatross species, the NABIS distributions include coastal waters, harbours, and estuaries. It is likely that the abundance of these pelagic birds is low in coastal waters, and that improved understanding of their distribution would result in a decreased overlap with flatfish trawl and other inshore fisheries.

4.4.8 Lack of seasonality

Seasonality in the distribution of seabirds and commercial fishing may be important, but was overlooked in our study. The distribution maps integrating the information on colony locations and sizes were weighted according to the length of the breeding season, but the species' vulnerability to capture was assumed to be constant over time. We did not integrate seasonality into our models as it would have further reduced the precision in the estimates of the number of fatalities, and the seasonality in the distribution of seabirds is only known for few species. However, as more data on seabird distributions are gathered, it may be possible to include seasonality in future analyses. For migratory species, ignoring seasonality may lead to captures being estimated on some fishing effort occurring at times when the birds are not in the New Zealand region. The lack of seasonality is partly mitigated as the potential fatalities were estimated separately for each of the fisheries groups, and many fisheries groups are themselves seasonally restricted.

4.4.9 Grouping of species

Because of the lack of observations for some species, the vulnerability to capture was constrained to be the same for related species. The consequences of this are unknown. The vulnerability within a group of species might vary among species due to differences in behaviour. For example all the shags were grouped together, even though the foraging behaviour of shags is different, with some shag species being group foragers. Some species might therefore be assigned with an overestimated or underestimated vulnerability, which may bias the estimated number of potential fatalities.

4.5 Comparison with other approaches

The risk assessment we carried out here falls at the more quantitative end of the spectrum of Level 2 semi-quantitative risk assessments (Hobday et al. 2007), as we estimate population and capture parameters for individual species, and their associated uncertainty, delivering an absolute measure of risk for each species. Our results are generally in accord with those from previous New Zealand seabird risk assessments. Baird & Gilbert (2010) estimated the risk of fisheries to 17 seabird species from expert knowledge, based on data on species distribution, observed captures, and fishing effort. As in our study, the black petrel had the highest risk score. They defined the risk level as moderate-high for the Westland petrel, the flesh-footed shearwater, and the southern Buller's albatross, also among the species with the highest risk in our study.

Also based on expert knowledge, Rowe (2009) assigned a risk score to each seabird species, considering all relevant species and fisheries. The highest scores, across all fisheries, were found for Salvin's albatross, white-chinned petrel, white-capped albatross, and black petrel. Although her results agreed with ours for black petrel, the Salvin's albatross, and the white-capped albatross, we found that the number of white-chinned petrels potentially killed annually exceeded the PBR with a probability of only 24%. Rowe (2009) also mentioned the potential risk from specific fisheries for yellow-eyed penguin, king shag, and Chatham Island shag, all but the latter in agreement with our results. Differences reflected the fact that we did not consider purse seine and setnet fisheries.

Using an approach similar to ours, but without considering uncertainty, Waugh et al. (2009) found that the species the most at risk from fishing were the Westland petrel, the Chatham albatross, the black-browed albatross, the northern royal albatross, and the southern Buller's albatross, in agreement with our results. Black petrel was only assigned a risk qualified as moderate, but the authors did not include data on the fishing effort of inshore fisheries in their analysis.

The estimates of potential captures are higher than the ratio estimates of seabird captures made following the method of Abraham et al. (2010b) (Figure 7). In the ratio estimation a capture rate was calculated for each combination of species, fishery, year, and fishing area, based on the ratio of the number of observed captures to the number of observed fishing events, and was then multiplied by the fishing effort to get the total number of captures. The calculation of potential captures, using seabird distributions, is more suitable for a risk assessment as we included all fishing effort whereas the ratio estimation could only make the estimates when there was a sufficient number of observations. Indeed, captures in inshore fisheries were typically underrepresented in the ratio estimation (Abraham et al. 2010b).

Seabird risk assessment has been undertaken in a number of international contexts, and was first used routinely to define management actions in fisheries in the Convention for the Conservation of Antarctic Marine Living Resources, for longline and trawl fisheries in the Antarctic and surrounding waters (Waugh et al. 2008a). Required mitigation measures arising from this process led to a reduction of over 99% in the albatross bycatch for the Antarctic fisheries, and was highly precautionary in its application. More quantitative studies have been developed in the Atlantic longline fisheries governed under the ICCAT convention (International Convention for the Conservation of Atlantic Tunas) and the WCPFC fisheries (Western and Central Pacific Fisheries Commission).

For the ICCAT Phillips et al. (2007) developed a risk assessment methodology that will prioritise species in terms of conservation concern in relation to fishing interactions, based on rankings of species derived from indices of species breeding strategy, behavioural characteristics, overlap with ICCAT fisheries, conservation status and population trends. This will lead to a list of species for which greater attention was required. For these species, spatial distribution information will be used to define zones in which fisheries management actions might be differentially applied. A second phase of this programme will to undertake modelling of populations which are at-risk and where data are detailed enough to enable age-structured demographic models to be developed.

For the WCPFC, risk of population effects from tuna fisheries across the Pacific Ocean was examined in relation to the overlap of species and fishing effort. An index of species risk, including species productivity and population sizes was generated (Filippi et al. 2010). This enabled identification of zones with the greatest likelihood of adverse population effects at a cumulative level across a broad suite of species. The assessment was designed to influence the deployment of monitoring by observer programmes, as well as other management measures. Species were ranked in order of the likelihood of population effects from longline fisheries, and contribution to the risk in the region from different fishing nations was computed. The zones defined as high risk were those in which strongest measures for the use of mitigation on vessels were in force (latitudes greater than 20° North or South), where there was a strong likelihood of interactions with albatrosses and petrels or shearwaters (WCPFC 2010). The study confirmed that the zone identified by more informal means (expert knowledge) of high risk for seabird bycatch was the area in which most attention to seabird mitigation needed to be applied.

In all of these international examples, seabird risk assessment has been linked to management and monitoring activity for ongoing management of the incidental capture of seabirds from commercial fishing operations. Although international fisheries conventions can be cumbersome and decision making processes slow, seabird risk assessments are contributing to the improvement of fishing practices, and ensuring that reductions in seabird fatalities continue to be sought. Ultimately, SRA studies like the one we have completed here can highlight information deficiencies, and deliver results that attempt to integrate a great deal of information. For an overall perspective on which areas in a specific region require most attention to reduce seabird fatalities, and which fisheries are contributing most to risk of population decreases, seabird risk assessments of the kind carried out here are ideal for targeting further research, monitoring, and precautionary management activity.

5. ACKNOWLEDGMENTS

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APPENDIX A: RISK ASSESSMENT RESULTS

Table A-1: Age at first reproduction (*A*), adult annual survival (*S*), number of annual breeding pairs (N_{BP}), and proportion of adults breeding in any given year (*P*) used for the PBR calculation of the 64 studied species.

	A		*S*		N_{BP}		*P*	
	median	95% c.i.	median	95% c.i.	median	95% c.i.	median	95% c.i.
Southern rockhopper penguin	4.4	3.1–5.9	0.84	0.82–0.86	40 900	39 100–55 800	0.90	0.75–0.96
Fiordland crested penguin	4.5	3.1–5.9	0.84	0.82–0.86	2 110	1 430–4 190	0.90	0.74–0.96
Snares crested penguin	5.5	5.0–6.0	0.84	0.82–0.86	21 100	14 000–42 400	0.90	0.75–0.96
Erect-crested penguin	5.5	5.0–6.0	0.84	0.82–0.86	77 900	77 000–84 000	0.90	0.75–0.96
Yellow-eyed penguin	2.5	2.0–3.0	0.87	0.80–0.92	1 770	1 700–2 310	0.60	0.50–0.69
Antipodean albatross	11.5	10.1–12.9	0.96	0.94–0.97	5 600	4 870–7 100	0.60	0.50–0.69
Gibson's albatross	11.0	10.1–12.0	0.96	0.94–0.98	5 070	4 840–7 040	0.60	0.50–0.69
Southern royal albatross	9.5	8.6–10.5	0.95	0.93–0.96	7 000	6 120–8 860	0.60	0.50–0.69
Northern royal albatross	9.5	8.6–10.5	0.94	0.91–0.97	4 100	2 760–8 140	0.61	0.51–0.70
Light-mantled albatross	11.9	10.1–13.9	0.97	0.96–0.98	6 780	6 770–6 880	0.60	0.50–0.69
Grey-headed albatross	10.0	7.2–12.9	0.95	0.93–0.97	4 640	3 060–9 360	0.75	0.64–0.83
Black-browed albatross	9.0	7.1–10.9	0.95	0.93–0.96	102	69–203	0.90	0.75–0.96
Campbell albatross	9.5	6.2–12.8	0.94	0.93–0.96	14 800	9 940–30 100	0.90	0.75–0.96
Northern Buller's albatross	10.5	10.0–11.0	0.93	0.85–0.98	14 500	12 700–18 400	0.90	0.75–0.96
Southern Buller's albatross	10.5	10.0–11.0	0.90	0.86–0.95	12 100	10 600–15 200	0.90	0.74–0.96
White-capped albatross	6.6	5.1–8.2	0.90	0.86–0.95	74 400	74 200–75 400	0.75	0.64–0.83
Chatham albatross	7.0	5.1–8.9	0.87	0.84–0.89	4 670	4 080–5 850	0.90	0.76–0.96
Salvin's albatross	10.5	10.0–11.0	0.90	0.86–0.95	25 300	19 100–40 800	0.90	0.75–0.96
Northern giant petrel	8.0	6.1–9.9	0.89	0.81–0.96	2 020	1 550–3 210	0.90	0.75–0.97
Cape petrel	5.0	3.1–6.9	0.86	0.78–0.94	5 900	3 910–11 700	0.75	0.64–0.83
Great-winged petrel	6.5	6.0–7.0	0.94	0.85–0.98	210 000	200 000–285 000	0.90	0.76–0.96
White-headed petrel	5.5	4.1–6.9	0.94	0.85–0.98	140 000	94 900–275 000	0.60	0.50–0.69
Magenta petrel	6.5	6.0–7.0	0.94	0.85–0.98	62	60–73	0.90	0.75–0.96
Kerm. petrel	6.5	6.0–7.0	0.94	0.85–0.98	5 200	5 010–6 750	0.90	0.75–0.96
Soft-plumaged petrel	6.5	6.0–7.0	0.94	0.84–0.98	1 310	1 010–7 340	0.90	0.75–0.96
Mottled petrel	6.5	6.0–7.0	0.94	0.85–0.98	310 000	301 000–386 000	0.90	0.75–0.96
White-necked petrel	6.5	6.0–7.0	0.94	0.85–0.98	34 800	23 300–68 300	0.90	0.76–0.96
Chatham petrel	6.5	6.0–7.0	0.94	0.85–0.98	235	220–265	0.90	0.75–0.96
Cook's petrel	6.5	6.0–7.0	0.94	0.84–0.98	51 100	50 000–58 800	0.90	0.75–0.96
Pycroft's petrel	6.5	6.0–7.0	0.94	0.85–0.98	2 100	2 000–2 850	0.90	0.75–0.96
Broad-billed prion	4.5	4.0–5.0	0.84	0.77–0.89	700 000	471 000–1 420 000	0.90	0.75–0.97
Antarctic prion	5.5	5.0–6.0	0.84	0.77–0.89	131 000	101 000–783 000	0.90	0.75–0.96
Fairy prion	4.5	4.0–5.0	0.84	0.77–0.89	834 000	707 000–2 440 000	0.90	0.75–0.96
White-chinned petrel	6.5	5.1–7.9	0.94	0.90–0.97	52 100	42 500–198 000	0.90	0.74–0.96
Westland petrel	6.5	5.1–7.9	0.91	0.89–0.93	3 150	2 420–5 050	0.90	0.75–0.96
Black petrel	6.6	6.2–7.0	0.90	0.86–0.94	1 550	1 360–1 960	0.80	0.68–0.88
Grey petrel	7.0	5.1–8.9	0.93	0.90–0.97	35 400	32 200–66 200	0.90	0.75–0.96
Wedge-tailed shearwater	4.0	3.1–5.0	0.90	0.86–0.94	53 400	52 500–59 000	0.90	0.75–0.96
Buller's shearwater	6.4	4.1–8.9	0.92	0.84–0.96	140 000	92 500–283 000	0.90	0.75–0.96
Flesh-footed shearwater	6.5	4.1–8.9	0.92	0.84–0.96	7 050	6 700–9 880	0.90	0.75–0.96
Sooty shearwater	6.0	5.0–6.9	0.92	0.86–0.98	3 510 000	2 360 000–7 020 000	0.90	0.75–0.96
Hutton's shearwater	5.0	4.1–6.0	0.90	0.86–0.94	74 200	56 800–118 000	0.90	0.75–0.96
Little shearwater	5.0	4.0–6.0	0.90	0.86–0.94	110 000	100 000–201 000	0.90	0.76–0.96
NZ white-faced storm petrel	4.0	3.1–4.9	0.90	0.82–0.95	836 000	707 000–2 580 000	0.90	0.75–0.96
Kerm. white-faced storm petrel	4.0	3.0–5.0	0.90	0.83–0.95	25	20–98	0.90	0.75–0.96
NZ storm petrel	4.5	4.0–5.0	0.90	0.82–0.95	32	21–644	0.75	0.64–0.83
Black-bellied storm petrel	4.5	4.0–5.0	0.90	0.82–0.95	54 200	50 200–90 900	0.75	0.64–0.83
White-bellied storm petrel	4.5	4.0–5.0	0.90	0.82–0.94	699	471–1 400	0.75	0.65–0.84
Common diving petrel	2.5	2.0–3.0	0.81	0.75–0.87	378 000	303 000–1 690 000	0.90	0.75–0.96
South Georgia diving petrel	2.5	2.0–3.0	0.81	0.75–0.87	45	31–92	0.90	0.75–0.96
Australasian gannet	5.0	3.1–6.9	0.94	0.85–0.98	32 300	21 800–63 300	0.75	0.64–0.83
Masked booby	3.0	2.0–4.0	0.85	0.78–0.90	297	243–1 120	0.90	0.75–0.96
NZ king shag	4.0	3.0–4.9	0.91	0.90–0.93	306	286–343	0.90	0.76–0.96
Stewart Island shag	4.0	3.0–5.0	0.91	0.90–0.93	2 640	2 510–3 760	0.90	0.75–0.96
Chatham Island shag	4.0	3.0–5.0	0.91	0.90–0.93	254	238–287	0.90	0.75–0.96
Bounty Island shag	4.0	3.1–5.0	0.91	0.90–0.93	275	241–347	0.90	0.76–0.96
Auckland Island shag	4.0	3.0–4.9	0.91	0.90–0.93	890	781–1 120	0.90	0.76–0.96
Campbell Island shag	4.0	3.1–5.0	0.91	0.90–0.93	3 560	3 110–4 510	0.90	0.75–0.96
Spotted shag	2.0	1.1–3.0	0.91	0.90–0.93	20 800	17 700–61 300	0.90	0.74–0.96
Pitt Island shag	4.0	3.0–5.0	0.91	0.90–0.93	469	312–947	0.90	0.76–0.96
Brown skua	8.0	7.6–8.4	0.94	0.91–0.97	452	450–467	0.90	0.76–0.96
Black-backed gull	4.0	3.1–4.9	0.81	0.75–0.86	832 000	707 000–2 480 000	0.75	0.64–0.84
Common white tern	4.0	3.1–4.9	0.81	0.78–0.83	12	10–49	0.90	0.75–0.96
Caspian tern	3.0	2.0–4.0	0.87	0.82–0.93	791	608–1 270	0.90	0.75–0.96

Table A-2: Estimated species vulnerability in trawl fisheries (x1000).

	Small inshore trawl		Large processer 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.
Penguins (spp)	0.03	0.00–0.20	0.02	0.00–0.10	0.00	0.00–0.02	0.11	0.00–0.67	0.00	0.00–0.03
Great albatrosses (spp)	0.14	0.00–0.84	0.08	0.00–0.68	0.04	0.00–0.25	0.39	0.01–2.12	0.29	0.01–1.67
Light-mantled sooty albatross	0.73	0.03–3.91	0.62	0.02–3.38	0.14	0.01–0.76	1.72	0.06–9.72	0.94	0.04–5.57
Grey-headed albatross	1.41	0.05–9.37	1.07	0.03–7.40	0.24	0.01–1.82	3.03	0.11–19.58	0.25	0.01–1.98
Black-browed albatrosses (spp)	0.35	0.01–2.36	0.34	0.05–3.42	0.07	0.00–0.57	3.01	0.09–35.08	0.15	0.02–0.67
Buller's albatrosses (spp)	0.14	0.02–0.76	0.51	0.19–1.42	0.37	0.16–0.96	0.14	0.01–0.83	1.28	0.02–79.66
White-capped albatross	1.15	0.53–2.54	1.48	0.96–2.15	0.44	0.32–0.61	0.29	0.04–1.24	0.08	0.00–0.40
Chatham albatross	1.95	0.04–56.48	0.36	0.01–1.89	0.08	0.00–0.48	0.51	0.02–4.05	6.59	0.17–92.66
Salvin's albatross	2.61	1.31–4.86	1.13	0.45–2.58	0.88	0.47–1.61	0.30	0.01–1.64	0.32	0.04–1.11
Northern giant petrel	1.75	0.06–9.73	1.25	0.04–6.67	1.14	0.27–3.16	3.17	0.12–17.74	2.15	0.09–11.68
Cape petrel	1.42	0.19–4.75	0.95	0.13–3.50	2.06	1.00–4.20	3.82	0.56–12.81	2.23	0.32–7.46
Pterodroma petrels (spp)	0.01	0.00–0.03	0.00	0.00–0.03	0.00	0.00–0.01	0.02	0.00–0.10	0.01	0.00–0.07
Prions (spp)	0.00	0.00–0.01	0.00	0.00–0.01	0.00	0.00–0.00	0.00	0.00–0.01	0.00	0.00–0.01
White-chinned petrel	0.06	0.00–0.32	0.60	0.27–1.14	0.40	0.25–0.64	0.15	0.01–0.84	0.07	0.00–0.38
Westland petrel	0.11	0.00–0.59	0.26	0.04–1.53	0.07	0.01–0.42	0.43	0.01–3.79	49.78	2.27–97.79
Black petrel	2.32	0.31–9.75	7.78	0.16–95.40	1.40	0.03–29.47	2.25	0.09–12.38		–
Grey petrel	0.14	0.00–0.76	0.11	0.00–0.61	0.14	0.04–0.36	0.34	0.01–1.94	1.21	0.50–2.47
Wedge-tailed shearwater		–		–		–	2.24	0.07–12.24		–
Shearwaters (spp)	0.00	0.00–0.02	0.01	0.00–0.03	0.00	0.00–0.01	0.01	0.00–0.05	0.08	0.00–0.45
Flesh-footed shearwater	1.86	0.41–5.62	1.38	0.20–4.58	0.13	0.00–0.70	1.18	0.04–7.26	6.53	0.20–60.13
Sooty shearwater	0.01	0.00–0.03	0.02	0.01–0.03	0.02	0.01–0.02	0.00	0.00–0.02	0.00	0.00–0.01
Storm petrels (spp)	0.01	0.00–0.05	0.00	0.00–0.05	0.01	0.00–0.02	0.01	0.00–0.10	0.16	0.01–0.83
Diving petrels	0.01	0.00–0.04	0.01	0.00–0.03	0.01	0.00–0.02	0.02	0.00–0.09	0.01	0.00–0.07
Boobies and gannets	0.04	0.00–0.24	0.05	0.00–0.29	0.01	0.00–0.07	0.16	0.01–0.80	2.46	0.11–13.57
Shags (spp)	0.01	0.00–0.03	0.03	0.00–0.17	0.01	0.00–0.04	0.02	0.00–0.13	0.25	0.01–1.38
Gulls, terns & skua	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.01

Table A-3: Estimated species vulnerability in trawl fisheries (x1000) (cont.).

	SCI trawl		Mackerel trawl		SQU 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.
Penguins (spp)	0.01	0.00–0.08	0.04	0.00–0.23	0.00	0.00–0.01	0.00	0.00–0.02	0.09	0.00–0.52
Great albatrosses (spp)	0.11	0.00–0.84	0.18	0.01–1.25	0.09	0.02–0.70	0.06	0.01–0.33	0.20	0.00–3.21
Light-mantled sooty albatross	0.69	0.03–3.93	0.44	0.02–2.64	0.14	0.00–0.76	0.15	0.01–0.85	2.92	0.11–17.56
Grey-headed albatross	1.18	0.04–9.17	0.87	0.03–6.50	0.24	0.01–2.46	0.20	0.01–1.04	5.66	0.18–42.37
Black-browed albatrosses (spp)	0.36	0.03–1.60	0.26	0.01–1.52	0.16	0.05–0.53	0.08	0.00–0.42	1.09	0.04–8.17
Buller's albatrosses (spp)	0.46	0.16–1.05	0.25	0.04–0.92	0.23	0.11–0.51	0.04	0.01–0.14	0.13	0.00–1.17
White-capped albatross	0.34	0.13–0.83	0.03	0.00–0.19	4.70	2.21–8.17	0.03	0.00–0.10	0.18	0.01–1.30
Chatham albatross	1.37	0.20–4.71	1.37	0.03–44.94	1.52	0.02–93.35	0.04	0.00–0.31	8.60	0.19–93.46
Salvin's albatross	3.81	1.99–7.26	0.07	0.00–0.42	0.71	0.37–1.31	0.11	0.03–0.30	0.49	0.02–2.68
Northern giant petrel	3.71	0.53–12.27	1.09	0.04–6.05	1.71	0.39–4.69	0.42	0.05–1.99	7.35	0.26–42.59
Cape petrel	3.36	1.00–7.88	1.45	0.33–4.00	0.16	0.02–1.05	3.03	1.80–4.62	2.20	0.09–12.29
Pterodroma petrels (spp)	0.01	0.00–0.04	0.00	0.00–0.02	0.00	0.00–0.01	0.00	0.00–0.01	0.02	0.00–0.12
Prions (spp)	0.00	0.00–0.01	0.00	0.00–0.01	0.00	0.00–0.01	0.00	0.00–0.00	0.00	0.00–0.02
White-chinned petrel	0.22	0.04–0.66	0.20	0.06–0.51	4.14	2.90–6.05	0.01	0.00–0.06	0.25	0.01–1.22
Westland petrel	0.60	0.02–4.69	0.26	0.04–0.86	3.21	0.13–17.04	0.17	0.01–1.09	0.81	0.03–4.52
Black petrel	3.53	0.41–19.43	0.52	0.02–2.87	34.91	1.38–95.88	0.66	0.02–4.10	19.41	0.73–86.40
Grey petrel	0.15	0.01–0.84	0.08	0.00–0.49	0.08	0.01–0.29	0.11	0.03–0.28	0.56	0.02–3.12
Wedge-tailed shearwater		–		–		–	0.26	0.01–1.52		–
Shearwaters (spp)	0.01	0.00–0.04	0.00	0.00–0.02	0.01	0.00–0.05	0.00	0.00–0.01	0.03	0.00–0.15
Flesh-footed shearwater	22.10	12.26–38.88	0.31	0.01–1.78	0.33	0.01–3.14	0.14	0.00–0.74	2.56	0.10–14.31
Sooty shearwater	0.02	0.01–0.09	0.00	0.00–0.01	0.04	0.02–0.07	0.00	0.00–0.00	0.01	0.00–0.04
Storm petrels (spp)	0.01	0.00–0.06	0.00	0.00–0.03	0.11	0.04–0.26	0.00	0.00–0.03	0.03	0.00–0.19
Diving petrels	0.01	0.00–0.05	0.01	0.00–0.04	0.01	0.00–0.02	0.00	0.00–0.01	0.02	0.00–0.14
Boobies and gannets	0.05	0.00–0.38	0.03	0.00–0.19	0.02	0.00–0.13	0.03	0.00–0.18	0.23	0.01–1.23
Shags (spp)	0.02	0.00–0.11	0.01	0.00–0.07	0.01	0.00–0.08	0.04	0.00–0.22	0.71	0.50–0.98
Gulls, terns & skua	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.00	0.00	0.00–0.00

Table A-4: Estimated species vulnerability in bottom longline fisheries (x1000).

	Bluenose BLL		Small BLL		Snapper BLL		Large BLL	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Penguins (spp)	0.63	0.02–3.47	0.19	0.01–1.00	2.03	0.28–7.36	0.02	0.00–0.06
Great albatrosses (spp)	3.04	0.38–14.23	0.48	0.02–3.02	2.09	0.05–44.35	0.34	0.06–1.60
Light-mantled sooty albatross	8.23	0.26–49.15	2.67	0.09–16.31	2.83	0.10–16.11	0.67	0.03–3.88
Grey-headed albatross	12.00	0.45–61.96	4.91	0.16–31.45	5.44	0.17–38.15	1.08	0.04–6.93
Black-browed albatrosses (spp)	41.08	7.18–96.34	10.42	1.10–66.04	6.74	0.14–90.76	0.79	0.11–2.78
Buller’s albatrosses (spp)	2.76	0.82–7.16	0.18	0.01–1.00	0.37	0.01–2.58	0.17	0.05–0.42
White-capped albatross	0.72	0.02–4.06	0.57	0.08–2.03	0.24	0.01–1.34	0.12	0.02–0.44
Chatham albatross	1.03	0.03–11.52	9.10	3.09–29.46	6.54	0.17–87.10	0.62	0.12–2.97
Salvin’s albatross	1.33	0.05–7.64	12.95	6.85–23.97	0.46	0.02–2.73	1.36	0.63–2.67
Northern giant petrel	9.91	0.37–67.98	3.75	0.13–25.74	7.12	0.28–39.62	3.41	0.70–11.98
Cape petrel	17.71	2.38–53.49	16.27	5.89–36.44	2.45	0.09–13.39	4.30	1.63–9.97
Pterodroma petrels (spp)	0.07	0.00–0.39	0.24	0.10–0.48	0.02	0.00–0.09	0.00	0.00–0.03
Prions (spp)	0.01	0.00–0.07	0.00	0.00–0.03	0.01	0.00–0.03	0.00	0.00–0.01
White-chinned petrel	2.82	0.67–8.12	1.26	0.38–3.15	0.26	0.01–1.37	3.94	2.55–6.06
Westland petrel	3.47	0.11–27.68	1.03	0.04–6.50	1.16	0.04–12.82	0.55	0.02–3.62
Black petrel	57.83	18.23–98.33	21.31	5.61–66.61	39.37	18.00–80.99	4.78	0.17–31.19
Grey petrel	1.64	0.06–9.18	2.77	0.73–7.26	0.52	0.02–3.05	0.87	0.36–1.77
Wedge-tailed shearwater		–		–		–		–
Shearwaters (spp)	0.05	0.00–0.29	0.04	0.01–0.16	0.14	0.05–0.39	0.01	0.00–0.04
Flesh-footed shearwater	6.39	0.25–37.73	10.43	2.88–28.31	48.29	26.27–87.17	0.66	0.03–3.40
Sooty shearwater	0.01	0.00–0.07	0.01	0.00–0.05	0.00	0.00–0.04	0.02	0.01–0.03
Storm petrels (spp)	0.02	0.00–0.54	0.01	0.00–0.17	0.03	0.00–0.18	0.01	0.00–0.09
Diving petrels	0.06	0.00–0.41	0.03	0.00–0.14	0.03	0.00–0.15	0.01	0.00–0.07
Boobies and gannets	0.66	0.02–4.29	0.25	0.01–1.45	0.35	0.05–2.13	0.12	0.00–0.60
Shags (spp)	0.20	0.01–1.08	0.10	0.00–0.51	0.02	0.00–0.12	0.02	0.00–0.09
Gulls, terns & skua	0.00	0.00–0.02	0.00	0.00–0.01	0.00	0.00–0.00	0.00	0.00–0.00

Table A-5: Estimated species vulnerability in surface longline fisheries (x1000).

	Large SLL		Small SLL	
	mean	95% c.i.	mean	95% c.i.
Penguins (spp)	0.05	0.00–0.29	0.56	0.02–3.14
Great albatrosses (spp)	3.64	1.71–6.83	40.13	21.71–75.38
Light-mantled sooty albatross	2.91	0.41–10.83	2.17	0.08–12.05
Grey-headed albatross	2.32	0.08–15.83	4.40	0.16–36.13
Black-browed albatrosses (spp)	7.01	2.40–19.46	58.18	23.54–104.03
Buller’s albatrosses (spp)	35.16	27.56–44.98	5.20	2.23–11.99
White-capped albatross	7.96	5.59–11.34	1.32	0.45–3.06
Chatham albatross	7.27	0.20–88.69	4.74	0.14–65.55
Salvin’s albatross	1.04	0.29–2.91	1.94	0.54–5.05
Northern giant petrel	11.45	2.60–33.87	5.53	0.19–31.21
Cape petrel	0.94	0.04–4.75	7.34	1.82–20.16
Pterodroma petrels (spp)	0.01	0.00–0.05	0.08	0.02–0.21
Prions (spp)	0.00	0.00–0.01	0.00	0.00–0.02
White-chinned petrel	2.13	1.15–3.63	1.39	0.48–3.26
Westland petrel	3.48	0.85–9.69	2.45	0.30–13.12
Black petrel	8.97	0.37–52.64	11.29	3.19–27.58
Grey petrel	5.73	3.01–10.37	12.74	7.07–21.57
Wedge-tailed shearwater	9.91	0.37–55.22	1.63	0.06–14.94
Shearwaters (spp)	0.02	0.00–0.10	0.02	0.00–0.12
Flesh-footed shearwater	1.56	0.05–9.65	25.43	12.05–48.88
Sooty shearwater	0.02	0.00–0.05	0.01	0.00–0.05
Storm petrels (spp)	0.01	0.00–0.08	0.02	0.00–0.09
Diving petrels	0.01	0.00–0.06	0.03	0.00–0.14
Boobies and gannets	0.10	0.00–0.55	0.17	0.01–0.93
Shags (spp)	0.42	0.01–2.20	0.33	0.01–1.73
Gulls, terns & skua	0.01	0.00–0.04	0.00	0.00–0.01

Table A-6: Annual potential seabird fatalities by trawl fisheries. The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	Small inshore trawl		Large processer trawl		Large meal trawl		Large fresher trawl		SBW trawl		SCI trawl	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	4	1–11	1	0–1	0	0–0	2	0–7	0	0–0	1	0–2
Fiordland crested penguin	**5**	2–11	0	0–1	0	0–0	1	0–4	0	0–0	0	0–0
Snares crested penguin	6	1–16	1	0–3	1	0–1	2	0–5	0	0–0	1	0–1
Erect-crested penguin	0	0–0	0	0–0	0	0–0	0	0–0	0	0–2	2	0–7
Yellow-eyed penguin	**4**	0–14	0	0–1	0	0–0	**2**	0–8	0	0–0	0	0–1
Antipodean albatross	**17**	3–50	2	0–5	1	0–4	**6**	1–15	1	0–3	**3**	1–6
Gibson's albatross	**15**	3–44	2	0–4	1	0–3	**5**	1–14	1	0–3	**2**	0–6
Southern royal albatross	**27**	2–74	**5**	1–15	**5**	2–11	**5**	0–19	1	0–4	**5**	1–16
Northern royal albatross	**50**	10–192	**4**	1–9	**3**	1–7	**16**	2–50	0	0–2	**4**	1–13
Light-mantled albatross	**115**	42–231	**11**	4–25	**5**	2–10	**27**	8–65	**3**	0–12	**14**	4–31
Grey-headed albatross	**116**	43–233	**12**	4–25	**5**	2–12	**27**	7–66	**3**	0–12	**13**	3–32
Black-browed albatross	**1**	0–2	**0**	0–0	**0**	0–0	**1**	0–4	0	0–0	**0**	0–0
Campbell albatross	**78**	8–203	**40**	18–68	**12**	4–22	**46**	9–146	**7**	1–19	**29**	3–76
Northern Buller's albatross	**103**	31–225	**31**	9–69	**41**	14–76	**21**	5–53	0	0–2	**36**	19–60
Southern Buller's albatross	**139**	53–286	**137**	91–196	**185**	139–242	9	2–22	3	0–8	**26**	10–48
White-capped albatross	**1 820**	1 420–2 290	**303**	249–365	**182**	154–212	54	22–107	3	0–12	**100**	58–164
Chatham albatross	**511**	51–2 340	**16**	1–61	**6**	0–18	**31**	2–99	1	0–9	**30**	7–77
Salvin's albatross	**1 830**	1 470–2 230	**102**	73–136	**161**	132–196	**26**	8–62	6	1–17	**320**	256–393
Northern giant petrel	**119**	44–233	**12**	4–29	**16**	8–27	**28**	7–72	**3**	0–11	**27**	11–54
Cape petrel	**130**	67–218	**13**	6–25	**46**	36–58	**30**	13–58	4	0–10	**30**	17–48
Great-winged petrel	22	5–58	2	0–5	1	0–2	5	2–12	0	0–2	3	1–6
White-headed petrel	18	5–41	2	1–5	1	0–2	6	2–14	1	0–3	3	1–7
Magenta petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Soft-plumaged petrel	0	0–1	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Mottled petrel	23	6–72	4	1–16	1	0–3	4	1–9	1	0–2	2	0–4
White-necked petrel	0	0–0	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	0	0–0
Cook's petrel	8	2–32	0	0–1	0	0–0	1	0–3	0	0–0	1	0–3
Pycroft's petrel	0	0–2	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Broad-billed prion	19	5–48	3	1–6	4	3–7	4	1–14	1	0–3	3	1–7
Antarctic prion	7	2–19	1	0–2	2	1–3	1	0–5	0	0–1	2	0–6
Fairy prion	37	11–97	3	1–8	5	3–8	9	2–29	1	0–3	3	1–7
White-chinned petrel	**75**	28–150	**68**	48–90	**88**	73–104	18	5–43	2	0–8	**27**	13–46
Westland petrel	**54**	10–137	**19**	5–39	**7**	2–15	**25**	5–73	0	0–0	**9**	2–21
Black petrel	**169**	67–339	**13**	2–32	**3**	1–8	**13**	3–35	0	0–0	**16**	4–37
Grey petrel	**77**	28–151	7	2–16	13	8–20	18	5–44	14	6–26	9	3–20
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	2	0–5	0	0–0	0	0–0
Buller's shearwater	25	9–52	3	1–8	2	0–5	5	1–14	0	0–0	4	1–9
Flesh-footed shearwater	**237**	134–377	**15**	7–28	3	1–7	**18**	5–45	2	0–6	**176**	136–222
Sooty shearwater	935	633–1 400	290	233–373	429	342–513	20	6–48	2	0–8	170	133–212
Hutton's shearwater	**43**	11–102	3	1–8	2	0–5	14	3–38	0	0–0	3	1–9
Little shearwater	5	2–11	1	0–2	0	0–1	1	0–3	2	0–6	1	0–3
NZ white-faced storm petrel	66	24–132	6	2–15	8	4–15	13	2–37	0	0–0	6	1–16
Kerm. white-faced storm petrel	0	0–0	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	0	0–0
Black-bellied storm petrel	5	1–12	0	0–1	1	0–2	1	0–3	2	0–7	1	0–2
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	70	25–149	7	2–18	11	6–17	15	4–37	2	0–7	8	2–17
South Georgia diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	26	8–62	2	1–5	1	0–2	6	1–15	1	0–4	3	1–7
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ king shag	**0**	0–2	0	0–0	0	0–0	**1**	0–3	0	0–0	0	0–0
Stewart Island shag	1	0–4	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	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0	0	0–0	**0**	0–1	0	0–0
Auckland Island shag	0	0–0	0	0–0	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	0–1	0	0–0
Spotted shag	20	7–41	3	1–7	1	0–2	6	1–17	0	0–0	2	0–7
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Brown skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-backed gull	71	24–146	8	3–19	2	0–5	19	4–51	1	0–5	8	2–19
Common white tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Total	7 110	4 290–12 600	1 150	772–1 740	1 260	940–1 650	566	143–1 470	70	9–219	1 100	694–1 720

Table A-7: Annual potential seabird fatalities by trawl fisheries (cont.). The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	Mackerel trawl		SQU trawl		Deepwater trawl		Flatfish trawl		Total	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	0	0–1	0	0–0	0	0–0	10	1–34	18	5–46
Fiordland crested penguin	0	0–1	0	0–0	0	0–0	**8**	2–20	**15**	7–29
Snares crested penguin	0	0–1	0	0–1	0	0–1	18	3–51	**29**	11–64
Erect-crested penguin	0	0–0	0	0–1	0	0–1	0	0–0	3	1–8
Yellow-eyed penguin	0	0–0	0	0–0	0	0–0	**10**	1–43	**16**	2–55
Antipodean albatross	1	0–2	**4**	1–9	**3**	1–5	**29**	1–117	**65**	16–170
Gibson's albatross	1	0–2	**3**	1–8	**2**	1–4	**26**	0–110	**59**	15–156
Southern royal albatross	2	0–6	**16**	6–37	3	1–6	**68**	3–204	**137**	53–283
Northern royal albatross	**1**	0–5	**6**	3–11	**5**	2–11	**82**	7–325	**170**	61–468
Light-mantled albatross	**4**	1–11	**4**	1–11	**4**	1–10	**251**	54–630	**439**	212–827
Grey-headed albatross	**4**	1–10	**4**	1–11	**4**	1–10	**245**	52–615	**435**	210–818
Black-browed albatross	**0**	0–0	**0**	0–0	**0**	0–0	**1**	0–5	**4**	2–7
Campbell albatross	4	0–12	**29**	16–48	4	1–8	**211**	35–564	**460**	233–841
Northern Buller's albatross	1	0–3	3	1–8	9	3–18	**31**	2–141	**276**	131–498
Southern Buller's albatross	**10**	4–19	**157**	109–220	5	2–12	**194**	37–520	**864**	623–1 260
White-capped albatross	4	1–10	**2 200**	1 850–2 560	8	4–15	**249**	52–627	**4 920**	4 380–5 500
Chatham albatross	**6**	1–19	**14**	1–40	**8**	1–20	**144**	17–545	**767**	248–2 520
Salvin's albatross	4	1–10	**79**	59–104	**17**	10–26	**251**	54–623	**2 800**	2 350–3 330
Northern giant petrel	**4**	1–10	**14**	6–25	**8**	2–17	**247**	53–630	**478**	252–874
Cape petrel	7	4–13	5	1–11	**40**	32–50	**137**	30–340	**443**	304–659
Great-winged petrel	1	0–2	1	0–2	1	0–2	31	3–109	66	21–160
White-headed petrel	1	0–2	1	0–2	1	0–2	35	4–114	67	27–154
Magenta petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0	0	0–1	1	0–1
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0	1	0–4	**2**	0–5
Mottled petrel	1	0–1	1	0–5	1	0–1	67	10–218	105	36–270
White-necked 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
Cook's petrel	0	0–1	0	0–0	0	0–0	6	1–20	18	8–39
Pycroft's petrel	0	0–0	0	0–0	0	0–0	0	0–0	1	0–2
Broad-billed prion	4	1–9	6	3–11	1	0–4	41	6–130	86	34–193
Antarctic prion	1	0–3	5	2–10	0	0–1	16	2–50	36	18–74
Fairy prion	9	4–18	6	3–11	1	0–2	123	15–521	198	72–610
White-chinned petrel	11	6–19	**798**	723–875	3	1–6	**163**	34–410	**1 250**	1 080–1 510
Westland petrel	**5**	1–11	**19**	3–58	**4**	1–10	**274**	31–932	**416**	151–1 070
Black petrel	**3**	1–8	**11**	0–54	**3**	1–9	**250**	45–639	**483**	224–899
Grey petrel	3	1–7	6	2–13	11	6–17	**164**	35–422	**322**	172–584
Wedge-tailed shearwater	0	0–0	0	0–0	1	0–4	0	0–0	3	0–7
Buller's shearwater	1	0–3	2	0–7	2	1–5	**78**	15–207	**122**	55–252
Flesh-footed shearwater	3	1–7	4	1–12	3	1–7	**174**	39–439	**636**	437–932
Sooty shearwater	6	2–13	1 140	973–1 290	3	1–7	362	118–800	**3 360**	2 970–3 940
Hutton's shearwater	1	0–4	3	0–13	1	0–5	**91**	14–261	**162**	67–347
Little shearwater	0	0–1	2	0–4	1	0–1	14	3–37	26	13–49
NZ white-faced storm petrel	2	1–5	28	11–56	7	1–14	130	28–332	266	138–480
Kerm. white-faced 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
Black-bellied storm petrel	0	0–1	8	4–15	1	0–1	10	2–33	29	13–58
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	5	2–9	8	3–16	7	3–13	144	31–364	277	144–505
South Georgia diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	1	0–2	1	0–3	1	0–3	**58**	13–140	**100**	45–187
Masked booby	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	**33**	7–73	**34**	7–75
Stewart Island shag	0	0–0	0	0–1	0	0–0	**247**	182–324	**249**	184–326
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**	0–1
Auckland Island shag	0	0–0	1	0–2	0	0–0	0	0–0	**1**	0–2
Campbell Island shag	0	0–0	0	0–0	0	0–0	0	0–0	0	0–1
Spotted shag	1	0–2	1	0–2	3	1–6	**1 420**	1 140–1 730	**1 460**	1 180–1 770
Pitt Island shag	0	0–0	0	0–0	0	0–0	0	0–0	**0**	0–1
Brown skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-backed gull	2	1–6	2	0–6	5	2–11	437	197–786	556	307–900
Common white tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Total	119	38–270	4 600	3 780–5 580	180	84–346	6 580	2 380–15 200	22 700	16 500–33 800

Table A-8: Annual potential seabird fatalities by bottom longline fisheries. The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	Bluenose BLL		Small BLL		Snapper BLL		Large BLL		Total	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	8	2–23	5	1–12	0	0–1	0	0–1	13	5–31
Fiordland crested penguin	**10**	3–23	**6**	2–13	**49**	6–135	0	0–0	**64**	19–153
Snares crested penguin	12	2–33	8	2–18	0	0–0	1	0–1	20	8–43
Erect-crested penguin	0	0–1	0	0–0	0	0–0	1	0–3	1	0–3
Yellow-eyed penguin	1	0–5	**2**	0–8	0	0–0	0	0–0	**4**	1–11
Antipodean albatross	**15**	6–28	**4**	1–7	**11**	0–45	1	0–2	**30**	14–65
Gibson’s albatross	**13**	5–26	**3**	1–7	**9**	0–40	1	0–2	**27**	12–56
Southern royal albatross	**15**	1–42	**4**	0–11	**4**	0–24	2	1–3	**25**	4–65
Northern royal albatross	**29**	10–74	**8**	2–24	**4**	0–17	**2**	1–5	**42**	18–90
Light-mantled albatross	**40**	13–85	**19**	8–37	**23**	1–84	2	1–5	**84**	40–158
Grey-headed albatross	**35**	10–78	**19**	7–37	**23**	1–85	**2**	1–5	**79**	36–150
Black-browed albatross	**2**	1–4	**1**	0–3	**2**	0–8	**0**	0–0	**5**	1–13
Campbell albatross	**111**	65–180	**110**	24–363	**17**	1–67	4	1–8	**241**	127–484
Northern Buller’s albatross	**102**	46–181	**9**	3–21	**23**	1–83	3	1–6	**137**	71–229
Southern Buller’s albatross	**32**	12–70	7	2–21	0	0–1	5	2–10	**44**	19–88
White-capped albatross	41	14–87	43	23–74	23	1–83	4	2–7	**111**	62–186
Chatham albatross	**25**	2–76	**149**	75–215	**19**	1–69	**8**	3–16	**200**	108–301
Salvin’s albatross	**39**	13–84	**406**	339–479	**23**	1–85	**22**	15–29	**490**	407–590
Northern giant petrel	**32**	7–75	**16**	4–36	**23**	1–85	**6**	2–11	**76**	29–151
Cape petrel	**78**	37–133	**97**	68–132	**23**	1–85	**13**	8–19	**211**	148–293
Great-winged petrel	13	3–34	43	27–63	7	0–32	0	0–2	64	37–106
White-headed petrel	11	4–25	40	29–52	4	0–17	0	0–1	56	40–76
Magenta petrel	0	0–0	**0**	0–0	0	0–0	0	0–0	**0**	0–0
Kerm. petrel	0	0–0	1	0–1	0	0–0	0	0–0	1	0–2
Soft-plumaged petrel	0	0–1	1	1–1	0	0–1	0	0–0	**1**	1–2
Mottled petrel	10	3–22	38	26–54	3	0–15	1	0–3	52	37–71
White-necked 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
Cook’s petrel	5	1–20	16	6–34	7	0–36	0	0–0	**27**	9–71
Pycroft’s petrel	0	0–2	**1**	0–2	0	0–2	0	0–0	**2**	1–4
Broad-billed prion	17	5–42	9	3–19	10	0–35	2	1–3	37	17–72
Antarctic prion	4	1–12	3	1–5	4	0–14	0	0–1	11	4–23
Fairy prion	15	5–34	23	4–81	10	1–36	2	1–3	50	20–110
White-chinned petrel	**119**	65–194	**78**	52–110	23	1–81	**109**	94–125	**329**	255–427
Westland petrel	**38**	11–85	**34**	9–100	**24**	1–86	**2**	1–5	**98**	43–189
Black petrel	**158**	91–256	**81**	39–143	**292**	160–466	**2**	0–6	**534**	372–725
Grey petrel	**41**	13–89	**78**	52–110	**23**	1–83	12	7–19	**153**	100–233
Wedge-tailed shearwater	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Buller’s shearwater	15	4–40	16	8–26	56	19–119	1	0–3	**89**	48–148
Flesh-footed shearwater	**44**	13–100	**80**	52–116	**513**	328–737	2	1–5	**639**	442–873
Sooty shearwater	38	13–84	43	22–71	23	1–86	50	32–71	154	102–234
Hutton’s shearwater	13	3–39	23	11–41	**64**	18–146	1	0–2	**101**	45–194
Little shearwater	3	1–9	3	2–6	19	4–50	0	0–1	26	11–56
NZ white-faced storm petrel	31	4–82	21	6–60	22	1–79	5	1–15	78	31–156
Kerm. white-faced 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
Black-bellied storm petrel	2	0–8	1	0–3	2	0–7	0	0–1	5	1–15
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	36	10–85	20	8–40	23	1–85	5	2–10	84	38–160
South Georgia diving petrel	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	**45**	11–108	24	9–48	**67**	15–161	3	1–6	**138**	66–248
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
NZ king shag	0	0–1	**3**	0–10	0	0–0	0	0–0	**3**	0–10
Stewart Island shag	1	0–2	1	0–3	0	0–0	0	0–1	**2**	1–4
Chatham Island shag	**1**	0–2	**0**	0–1	0	0–0	0	0–0	**1**	0–2
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	34	9–85	**48**	16–105	23	1–86	1	0–3	**107**	49–199
Pitt Island shag	**1**	0–5	**1**	0–3	0	0–0	0	0–0	**2**	0–7
Brown skua	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Black-backed gull	41	13–92	30	11–61	46	6–128	1	0–3	118	58–213
Common white tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0	0	0–0
Total	1 380	529–2 870	1 670	957–2 890	1 540	575–3 580	276	178–423	4 870	2 960–7 800

Table A-9: Annual potential seabird fatalities by surface longline fisheries. The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	Large SLL		Small SLL		Total	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	0	0–0	3	0–10	3	0–10
Fiordland crested penguin	0	0–0	**7**	1–20	**7**	1–20
Snares crested penguin	0	0–1	2	0–6	2	0–7
Erect-crested penguin	0	0–0	0	0–0	0	0–0
Yellow-eyed penguin	0	0–0	0	0–0	0	0–0
Antipodean albatross	2	1–4	**131**	66–216	**133**	68–219
Gibson’s albatross	2	1–3	**117**	60–194	**119**	61–196
Southern royal albatross	**3**	1–7	**61**	1–142	**64**	4–144
Northern royal albatross	1	0–2	**73**	51–95	**74**	51–96
Light-mantled albatross	1	0–3	**10**	2–25	**11**	3–27
Grey-headed albatross	1	0–2	**10**	2–26	**11**	3–27
Black-browed albatross	**0**	0–0	**3**	1–5	**3**	1–5
Campbell albatross	**7**	5–11	**147**	102–196	**154**	110–203
Northern Buller’s albatross	**10**	5–16	**108**	72–152	**117**	79–163
Southern Buller’s albatross	**172**	138–213	**15**	9–24	**188**	155–227
White-capped albatross	37	31–44	51	27–83	**88**	64–121
Chatham albatross	1	0–2	**11**	2–32	**12**	2–33
Salvin’s albatross	3	1–5	**40**	20–69	**43**	23–72
Northern giant petrel	2	1–4	**10**	2–26	**12**	4–28
Cape petrel	1	0–2	**29**	13–53	**30**	14–53
Great-winged petrel	0	0–0	9	4–17	10	4–17
White-headed petrel	0	0–0	9	4–16	9	4–16
Magenta petrel	0	0–0	0	0–0	0	0–0
Kerm. petrel	0	0–0	0	0–0	0	0–0
Soft-plumaged petrel	0	0–0	0	0–0	0	0–0
Mottled petrel	0	0–2	6	3–13	7	3–13
White-necked petrel	0	0–0	0	0–1	0	0–1
Chatham petrel	0	0–0	0	0–0	0	0–0
Cook’s petrel	0	0–0	4	1–10	4	1–10
Pycroft’s petrel	0	0–0	0	0–1	0	0–1
Broad-billed prion	0	0–1	4	1–11	4	1–11
Antarctic prion	0	0–0	2	0–4	2	0–4
Fairy prion	0	0–1	4	1–11	5	1–11
White-chinned petrel	10	7–14	**51**	27–84	**61**	37–94
Westland petrel	**2**	1–4	**23**	8–48	**25**	10–50
Black petrel	1	0–2	**39**	19–68	**39**	19–69
Grey petrel	12	9–16	**221**	166–286	**233**	179–298
Wedge-tailed shearwater	0	0–1	4	0–13	4	0–13
Buller’s shearwater	1	0–1	6	1–14	6	2–15
Flesh-footed shearwater	1	0–2	**108**	73–151	**109**	73–152
Sooty shearwater	4	2–6	20	8–40	24	11–44
Hutton’s shearwater	0	0–0	3	1–8	3	1–8
Little shearwater	0	0–0	1	0–4	2	0–4
NZ white-faced storm petrel	1	0–2	8	2–21	9	2–21
Kerm. white-faced storm petrel	0	0–0	0	0–0	0	0–0
NZ storm petrel	0	0–0	0	0–0	0	0–0
Black-bellied storm petrel	0	0–0	1	0–1	1	0–2
White-bellied storm petrel	0	0–0	0	0–0	0	0–0
Common diving petrel	1	0–2	10	2–25	11	3–26
South Georgia diving petrel	0	0–0	0	0–0	0	0–0
Australasian gannet	1	0–2	11	2–27	11	3–28
Masked booby	0	0–0	0	0–0	0	0–0
NZ king shag	0	0–0	0	0–0	0	0–0
Stewart Island shag	0	0–1	0	0–0	0	0–1
Chatham Island shag	0	0–0	0	0–0	0	0–0
Bounty Island shag	0	0–0	0	0–0	0	0–0
Auckland Island shag	0	0–0	0	0–0	0	0–0
Campbell Island shag	0	0–0	0	0–0	0	0–0
Spotted shag	1	0–4	14	3–37	16	4–38
Pitt Island shag	0	0–0	0	0–0	0	0–0
Brown skua	0	0–0	0	0–0	0	0–0
Black-backed gull	1	0–3	10	2–25	11	3–26
Common white tern	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0
Total	280	205–386	1 400	761–2 310	1 680	1 010–2 630

Table A-10: Number of annual potential bird fatalities in trawl, bottom long-line, and surface long-line fisheries. The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	Trawl		BLL		SLL		Total	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	18	5–46	13	5–31	3	0–10	35	14–72
Fiordland crested penguin	**15**	7–29	**64**	19–153	**7**	1–20	**87**	38–176
Snares crested penguin	**29**	11–64	20	8–43	2	0–7	**52**	28–91
Erect-crested penguin	3	1–8	1	0–3	0	0–0	4	2–10
Yellow-eyed penguin	**16**	2–55	**4**	1–11	0	0–0	**20**	3–61
Antipodean albatross	**65**	16–170	**30**	14–65	**133**	68–219	**227**	163–299
Gibson’s albatross	**59**	15–156	**27**	12–56	**119**	61–196	**205**	148–269
Southern royal albatross	**137**	53–283	**25**	4–65	**64**	4–144	**227**	66–438
Northern royal albatross	**170**	61–468	**42**	18–90	**74**	51–96	**286**	169–590
Light-mantled albatross	**439**	212–827	**84**	40–158	**11**	3–27	**534**	298–922
Grey-headed albatross	**435**	210–818	**79**	36–150	**11**	3–27	**525**	291–912
Black-browed albatross	**4**	2–7	**5**	1–13	**3**	1–5	**12**	6–21
Campbell albatross	**460**	233–841	**241**	127–484	**154**	110–203	**855**	594–1 240
Northern Buller’s albatross	**276**	131–498	**137**	71–229	**117**	79–163	**531**	369–752
Southern Buller’s albatross	**864**	623–1 260	**44**	19–88	**188**	155–227	**1 100**	817–1 520
White-capped albatross	**4 920**	4 380–5 500	**111**	62–186	**88**	64–121	**5 120**	4 570–5 720
Chatham albatross	**767**	248–2 520	**200**	108–301	**12**	2–33	**980**	463–2 680
Salvin’s albatross	**2 800**	2 350–3 330	**490**	407–590	**43**	23–72	**3 330**	2 870–3 860
Northern giant petrel	**478**	252–874	**76**	29–151	**12**	4–28	**567**	331–965
Cape petrel	**443**	304–659	**211**	148–293	**30**	14–53	**684**	523–910
Great-winged petrel	66	21–160	64	37–106	10	4–17	139	74–251
White-headed petrel	67	27–154	56	40–76	9	4–16	132	85–221
Magenta petrel	0	0–0	**0**	0–0	0	0–0	**0**	0–0
Kerm. petrel	1	0–1	1	0–2	0	0–0	2	1–3
Soft-plumaged petrel	**2**	0–5	**1**	1–2	0	0–0	**3**	1–7
Mottled petrel	105	36–270	52	37–71	7	3–13	164	89–331
White-necked petrel	0	0–0	0	0–0	0	0–1	0	0–1
Chatham petrel	0	0–0	**0**	0–0	0	0–0	**0**	0–0
Cook’s petrel	18	8–39	**27**	9–71	4	1–10	**49**	22–102
Pycroft’s petrel	1	0–2	**2**	1–4	0	0–1	**3**	1–6
Broad-billed prion	86	34–193	37	17–72	4	1–11	128	65–236
Antarctic prion	36	18–74	11	4–23	2	0–4	49	26–89
Fairy prion	198	72–610	50	20–110	5	1–11	253	109–678
White-chinned petrel	**1 250**	1 080–1 510	**329**	255–427	**61**	37–94	**1 640**	1 450–1 920
Westland petrel	**416**	151–1 070	**98**	43–189	**25**	10–50	**539**	258–1 200
Black petrel	**483**	224–899	**534**	372–725	**39**	19–69	**1 060**	725–1 520
Grey petrel	**322**	172–584	**153**	100–233	**233**	179–298	**709**	531–979
Wedge-tailed shearwater	3	0–7	0	0–0	4	0–13	7	2–16
Buller’s shearwater	**122**	55–252	**89**	48–148	6	2–15	**217**	129–361
Flesh-footed shearwater	**636**	437–932	**639**	442–873	**109**	73–152	**1 380**	1 080–1 770
Sooty shearwater	**3 360**	2 970–3 940	154	102–234	24	11–44	**3 540**	3 150–4 110
Hutton’s shearwater	**162**	67–347	**101**	45–194	3	1–8	**266**	135–482
Little shearwater	26	13–49	26	11–56	2	0–4	54	30–93
NZ white-faced storm petrel	266	138–480	78	31–156	9	2–21	353	212–579
Kerm. white-faced 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
Black-bellied storm petrel	29	13–58	5	1–15	1	0–2	35	15–69
White-bellied storm petrel	0	0–0	0	0–0	0	0–0	0	0–0
Common diving petrel	277	144–505	84	38–160	11	3–26	371	223–602
South Georgia diving petrel	0	0–0	0	0–0	0	0–0	0	0–0
Australasian gannet	**100**	45–187	**138**	66–248	11	3–28	**249**	153–383
Masked booby	0	0–0	0	0–0	0	0–0	0	0–0
NZ king shag	**34**	7–75	**3**	0–10	0	0–0	**37**	8–81
Stewart Island shag	**249**	184–326	**2**	1–4	0	0–1	**251**	186–328
Chatham Island shag	**0**	0–0	**1**	0–2	0	0–0	**1**	0–3
Bounty Island shag	**0**	0–1	0	0–0	0	0–0	**0**	0–1
Auckland Island shag	**1**	0–2	0	0–0	0	0–0	**1**	0–2
Campbell Island shag	0	0–1	0	0–0	0	0–0	0	0–1
Spotted shag	**1 460**	1 180–1 770	**107**	49–199	16	4–38	**1 580**	1 290–1 910
Pitt Island shag	**0**	0–1	**2**	0–7	0	0–0	**3**	1–7
Brown skua	0	0–0	0	0–0	0	0–0	0	0–0
Black-backed gull	556	307–900	118	58–213	11	3–26	685	421–1 040
Common white tern	0	0–0	0	0–0	0	0–0	0	0–0
Caspian tern	0	0–0	0	0–0	0	0–0	0	0–0
Total	22 700	16 500–33 800	4 870	2 960–7 800	1 680	1 010–2 630	29 300	22 200–40 900

Table A-11: Annual potential fatalities, Potential Biological Removal (PBR), risk ratio (RR), and the probability that the risk ratio is greater or equal to one.

	Potential fatalities		PBR		Risk ratio		
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	$p(RR \geq 1)$ %
Black petrel	1 056	725-1 524	99	65-154	11.15	5.92-18.57	100.00
Grey-headed albatross	525	291-912	164	91-327	3.51	1.34-7.18	99.42
Westland petrel	539	258-1 203	172	110-282	3.31	1.28-7.83	99.29
Northern giant petrel	567	331-965	251	82-561	3.00	0.82-7.86	94.07
Chatham albatross	980	463-2 685	372	275-516	2.71	1.13-7.62	99.11
Flesh-footed shearwater	1 384	1 079-1 769	622	316-1 226	2.51	1.07-4.54	98.25
Salvin's albatross	3 330	2 873-3 865	1 568	714-3 035	2.49	1.07-4.72	98.26
Northern royal albatross	286	169-590	149	71-312	2.21	0.74-5.42	92.07
Light-mantled albatross	534	298-922	252	182-338	2.18	1.08-4.01	98.74
NZ king shag	37	8-81	18	14-23	2.05	0.42-4.77	50.06
Campbell albatross	855	594-1 244	505	298-1 008	1.84	0.78-3.21	93.82
Stewart Island shag	251	186-328	160	124-228	1.60	1.01-2.29	97.77
Southern Buller's albatross	1 096	817-1 521	979	479-1 716	1.28	0.57-2.51	63.13
Gibson's albatross	205	148-269	181	95-296	1.25	0.62-2.30	65.39
Antipodean albatross	227	163-299	211	148-299	1.11	0.68-1.69	64.53
White-capped albatross	5 123	4 571-5 718	6 678	3 882-10 113	0.83	0.50-1.33	24.77
White-chinned petrel	1 642	1 446-1 915	2 575	1 146-8 234	0.79	0.20-1.44	23.66
Northern Buller's albatross	531	369-752	870	330-2 371	0.79	0.21-1.76	25.35
Cape petrel	684	523-910	1 094	438-2 448	0.76	0.27-1.62	22.25
Southern royal albatross	227	66-438	316	225-447	0.74	0.19-1.56	29.01
Spotted shag	1 580	1 291-1 906	3 665	2 007-9 328	0.50	0.17-0.83	0.10
Fiordland crested penguin	87	38-176	210	128-405	0.45	0.15-0.98	2.37
Grey petrel	709	531-979	2 000	1 053-3 872	0.39	0.18-0.73	0.08
Chatham Island shag	1	0-3	5	4-6	0.20	0.04-0.54	0.04
Pitt Island shag	3	1-7	19	12-38	0.14	0.03-0.40	0.01
Yellow-eyed penguin	20	3-61	172	116-251	0.12	0.02-0.39	0.00
Hutton's shearwater	266	135-482	2 951	1 711-5 055	0.10	0.04-0.20	0.00
Australasian gannet	249	153-383	3 114	1 263-7 211	0.10	0.03-0.22	0.00
Soft-plumaged petrel	3	1-7	125	40-482	0.04	0.00-0.12	0.00
Pycroft's petrel	3	1-6	90	41-204	0.04	0.01-0.10	0.00
Chatham petrel	0	0-0	7	3-15	0.03	0.01-0.09	0.00
Buller's shearwater	217	129-361	7 616	3 306-17 785	0.03	0.01-0.08	0.00
Magenta petrel	0	0-0	1	0-2	0.03	0.00-0.07	0.00
Snares crested penguin	52	28-91	2 079	1 268-4 069	0.03	0.01-0.05	0.00
Cook's petrel	49	22-102	2 189	1 015-4 892	0.03	0.01-0.07	0.00
Kerm. white-faced storm petrel	0	0-0	1	0-2	0.02	0.00-0.04	0.00
Bounty Island shag	0	0-1	16	13-22	0.02	0.00-0.06	0.00
Sooty shearwater	3 542	3 147-4 112	242 407	91 870-548 326	0.02	0.01-0.04	0.00
Auckland Island shag	1	0-2	53	41-71	0.02	0.00-0.05	0.00
Great-winged petrel	139	74-251	14 838	7 068-32 019	0.01	0.00-0.03	0.00
Mottled petrel	164	89-331	17 727	8 218-39 760	0.01	0.00-0.03	0.00
White-headed petrel	132	85-221	15 874	6 459-36 746	0.01	0.00-0.02	0.00
Southern rockhopper penguin	35	14-72	3 986	3 203-5 447	0.01	0.00-0.02	0.00
Kerm. petrel	2	1-3	370	170-795	0.01	0.00-0.01	0.00
Black-bellied storm petrel	35	15-69	7 237	4 227-12 833	0.01	0.00-0.01	0.00
Little shearwater	54	30-93	11 384	6 717-20 394	0.01	0.00-0.01	0.00
Common diving petrel	371	223-602	98 908	51 101-332 148	0.00	0.00-0.01	0.00
South Georgia diving petrel	0	0-0	10	5-20	0.00	0.00-0.01	0.00
NZ white-faced storm petrel	353	212-579	109 031	55 295-293 080	0.00	0.00-0.01	0.00
NZ storm petrel	0	0-0	2	0-17	0.00	0.00-0.01	0.00
Black-backed gull	685	421-1 040	218 294	125 674-553 678	0.00	0.00-0.01	0.00
Caspian tern	0	0-0	116	64-198	0.00	0.00-0.01	0.00
Antarctic prion	49	26-89	29 340	12 025-119 549	0.00	0.00-0.01	0.00
Fairy prion	253	109-678	153 921	84 930-397 769	0.00	0.00-0.01	0.00
Campbell Island shag	0	0-1	211	163-283	0.00	0.00-0.01	0.00
Wedge-tailed shearwater	7	2-16	5 616	3 651-7 883	0.00	0.00-0.00	0.00
Broad-billed prion	128	65-236	117 342	62 427-241 119	0.00	0.00-0.00	0.00
Brown skua	0	0-0	27	16-39	0.00	0.00-0.00	0.00
Erect-crested penguin	4	2-10	4 917	4 043-6 181	0.00	0.00-0.00	0.00
Masked booby	0	0-0	59	32-179	0.00	0.00-0.00	0.00
White-necked petrel	0	0-1	1 523	625-3 633	0.00	0.00-0.00	0.00
White-bellied storm petrel	0	0-0	94	47-191	0.00	0.00-0.00	0.00
Common white tern	0	0-0	3	2-9	0.00	0.00-0.00	0.00

Table A-12: Mean annual potential bird fatalities estimated by FMA. The cell colour represents the mean ratio of the number of potential fatalities to the PBR. Light yellow: potential fatalities between 1 and 50% of the PBR; light orange: between 50% and 100%; dark orange: exceeding PBR.

	1	2	3	4	5	6	7	8	9	10	Total
Southern rockhopper penguin	0	8	8	5	2	1	9	1	0	0	35
Fiordland crested penguin	**55**	**12**	**5**	0	**3**	0	**9**	2	1	0	**87**
Snares crested penguin	0	0	19	12	7	1	12	0	0	0	**52**
Erect-crested penguin	0	0	0	0	0	4	0	0	0	0	4
Yellow-eyed penguin	0	**3**	**13**	0	**3**	0	2	0	0	0	**20**
Antipodean albatross	**59**	**85**	**19**	**12**	**8**	**4**	**24**	2	**15**	1	**228**
Gibson's albatross	**53**	**76**	**17**	**11**	**7**	**4**	**22**	2	**13**	1	**206**
Southern royal albatross	**39**	**43**	**61**	**8**	**27**	**10**	**27**	2	**8**	1	**227**
Northern royal albatross	**27**	**68**	**116**	**35**	**7**	**2**	**23**	**2**	**6**	1	**287**
Light-mantled albatross	**77**	**74**	**142**	**24**	**34**	**13**	**140**	**12**	**17**	0	**534**
Grey-headed albatross	**73**	**69**	**138**	**35**	**33**	**14**	**136**	**12**	**16**	0	**525**
Black-browed albatross	**4**	**3**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**12**
Campbell albatross	**91**	**89**	**166**	**43**	**82**	**60**	**297**	**9**	**19**	1	**857**
Northern Buller's albatross	**142**	**147**	**75**	**140**	0	1	**11**	2	**13**	0	**531**
Southern Buller's albatross	1	**23**	**298**	**34**	**507**	**63**	**163**	7	0	0	**1 100**
White-capped albatross	**473**	**473**	**883**	**131**	**1 100**	**1 190**	**652**	**75**	**148**	0	**5 120**
Chatham albatross	**79**	**110**	**87**	**571**	**21**	3	**86**	**11**	**13**	0	**980**
Salvin's albatross	**637**	**596**	**583**	**295**	**196**	**146**	**566**	**111**	**201**	0	**3 330**
Northern giant petrel	**72**	**66**	**143**	**65**	**39**	**18**	**137**	**11**	**15**	0	**567**
Cape petrel	**116**	**114**	**117**	**70**	**67**	**36**	**112**	**21**	**30**	0	**684**
Great-winged petrel	37	27	21	9	5	1	24	5	9	0	139
White-headed petrel	24	25	24	10	6	3	28	5	7	0	132
Magenta petrel	0	0	0	**0**	0	0	0	0	0	0	**0**
Kerm. petrel	0	0	0	0	0	0	0	0	0	0	2
Soft-plumaged petrel	1	1	1	0	0	0	1	0	0	0	**3**
Mottled petrel	17	17	41	7	50	2	22	4	5	0	164
White-necked petrel	0	0	0	0	0	0	0	0	0	0	1
Chatham petrel	0	0	0	**0**	0	0	0	0	0	0	**0**
Cook's petrel	**27**	5	4	2	1	0	5	1	3	0	**49**
Pycroft's petrel	**2**	0	0	0	0	0	0	0	0	0	**3**
Broad-billed prion	22	16	26	15	9	4	26	4	4	0	128
Antarctic prion	9	6	10	2	4	5	10	2	2	0	49
Fairy prion	23	27	30	8	10	5	130	17	4	0	253
White-chinned petrel	**117**	**124**	**271**	**124**	**470**	**334**	**155**	22	26	0	**1 640**
Westland petrel	**59**	**54**	**64**	**11**	**9**	0	**326**	**7**	**8**	0	**539**
Black petrel	**523**	**179**	**50**	**8**	0	0	**207**	**34**	**55**	0	**1 060**
Grey petrel	**157**	**178**	**106**	**36**	**35**	**28**	**122**	14	**32**	1	**710**
Wedge-tailed shearwater	2	0	0	0	0	0	0	0	5	1	8
Buller's shearwater	73	27	45	9	10	0	41	4	7	0	**217**
Flesh-footed shearwater	**710**	**206**	**127**	**95**	**31**	4	**138**	**23**	**49**	1	**1 380**
Sooty shearwater	279	197	563	173	1 580	341	321	33	51	0	**3 540**
Hutton's shearwater	**82**	**34**	**83**	2	0	0	**51**	7	7	0	**266**
Little shearwater	24	5	8	2	3	3	8	1	1	0	54
NZ white-faced storm petrel	52	38	96	56	22	0	74	7	10	0	353
Kerm. white-faced storm petrel	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
Black-bellied storm petrel	4	3	8	2	6	5	6	1	1	0	35
White-bellied storm petrel	0	0	0	0	0	0	0	0	0	0	0
Common diving petrel	57	40	74	35	76	9	62	8	10	0	371
South Georgia diving petrel	0	0	0	0	0	0	0	0	0	0	0
Australasian gannet	**109**	**45**	**33**	3	9	2	**32**	5	9	0	**249**
Masked booby	0	0	0	0	0	0	0	0	0	0	0
NZ king shag	0	**1**	0	0	0	0	**34**	**1**	0	0	**37**
Stewart Island shag	0	0	**210**	0	**41**	0	0	0	0	0	**251**
Chatham Island shag	0	0	0	**1**	0	0	0	0	0	0	**1**
Bounty Island shag	0	0	0	0	0	**0**	0	0	0	0	**0**
Auckland Island shag	0	0	0	0	0	**1**	0	0	0	0	**1**
Campbell Island shag	0	0	0	0	0	0	0	0	0	0	0
Spotted shag	**58**	**115**	**635**	0	**126**	0	**623**	20	4	0	**1 580**
Pitt Island shag	0	0	0	**3**	0	0	0	0	0	0	**3**
Brown skua	0	0	0	0	0	0	0	0	0	0	0
Black-backed gull	94	82	209	10	47	5	215	11	12	0	685
Common white tern	0	0	0	0	0	0	0	0	0	0	0
Caspian tern	0	0	0	0	0	0	0	0	0	0	0
Total	4559	3512	5632	2113	4696	2323	5092	517	836	12	29292

Table A-13: Sensitivity of the risk ratio to the uncertainty in the age at first reproduction (*A*), the adult annual survival rate (*S*), the number of annual breeding pairs (*N*), the proportion of adults breeding in a given year (*P*), the mean number of annual potential fatalities (*F*), and to the distribution map (*D*). The sensitivity is expressed as the reduction (%) of the 95% confidence interval of the risk ratio induced by sequentially fixing each parameter (except *D*, see text) to its mean value. The parameter with the highest sensitivity for each species is marked in bold.

	A	*S*	*N*	*P*	*F*	*D*
Southern rockhopper penguin	0	4	6	1	**56**	40
Fiordland crested penguin	0	2	19	0	**49**	1
Snares crested penguin	1	3	25	1	**37**	2
Erect-crested penguin	0	2	1	1	**80**	1
Yellow-eyed penguin	2	8	0	1	**64**	39
Antipodean albatross	1	19	10	7	**22**	4
Gibson's albatross	0	**49**	5	4	12	4
Southern royal albatross	1	12	2	4	**50**	35
Northern royal albatross	1	24	16	2	**25**	14
Light-mantled albatross	0	9	1	4	**57**	1
Grey-headed albatross	0	10	25	1	**33**	1
Black-browed albatross	0	7	**37**	2	20	28
Campbell albatross	0	5	**36**	0	19	1
Northern Buller's albatross	0	**67**	3	1	7	6
Southern Buller's albatross	1	**57**	4	1	13	5
White-capped albatross	2	**69**	1	6	3	1
Chatham albatross	0	6	3	0	**62**	25
Salvin's albatross	0	**52**	15	2	3	1
Northern giant petrel	2	**53**	8	1	20	1
Cape petrel	1	**41**	22	1	8	0
Great-winged petrel	1	**53**	3	0	14	22
White-headed petrel	2	**34**	18	3	11	8
Magenta petrel	1	**41**	0	1	24	30
Kerm. petrel	0	**53**	3	1	12	24
Soft-plumaged petrel	1	31	**39**	0	10	27
Mottled petrel	0	**43**	2	1	26	11
White-necked petrel	1	**25**	15	0	25	0
Chatham petrel	1	**37**	2	0	28	18
Cook's petrel	1	**47**	1	0	21	25
Pycroft's petrel	1	**43**	4	1	24	25
Broad-billed prion	1	15	**25**	1	24	16
Antarctic prion	1	14	**46**	0	19	12
Fairy prion	1	11	28	1	**42**	22
White-chinned petrel	2	32	**45**	2	3	0
Westland petrel	1	7	9	0	**59**	2
Black petrel	0	**26**	4	2	25	4
Grey petrel	1	**35**	16	2	12	1
Wedge-tailed shearwater	1	10	1	0	**72**	0
Buller's shearwater	0	**27**	18	1	19	3
Flesh-footed shearwater	2	**52**	4	1	7	1
Sooty shearwater	0	**49**	24	0	2	1
Hutton's shearwater	1	20	12	1	**34**	12
Little shearwater	1	22	13	1	**26**	13
NZ white-faced storm petrel	0	13	**28**	0	24	1
Kerm. white-faced storm petrel	0	12	**37**	0	25	2
NZ storm petrel	1	12	**75**	1	14	18
Black-bellied storm petrel	1	24	11	1	26	**31**
White-bellied storm petrel	0	10	15	1	**51**	29
Common diving petrel	0	7	**41**	0	26	1
South Georgia diving petrel	0	7	20	0	**46**	2
Australasian gannet	3	**29**	20	1	16	1
Masked booby	1	8	**39**	0	22	14
NZ king shag	6	8	2	6	41	**64**
Stewart Island shag	5	7	12	5	**29**	1
Chatham Island shag	2	3	1	0	**85**	0
Bounty Island shag	1	2	1	0	**87**	1
Auckland Island shag	1	2	2	1	**84**	0
Campbell Island shag	0	2	3	0	**90**	0
Spotted shag	17	3	**38**	1	7	1
Pitt Island shag	1	3	14	2	**67**	0
Brown skua	1	24	1	0	**51**	1
Black-backed gull	0	11	**30**	1	25	1
Common white tern	0	4	**51**	1	18	29
Caspian tern	3	21	13	1	**25**	1

Table A-14: Sensitivity of the risk ratio to the two different distribution maps (with and without colonies; see Methods section). The final risk ratio was obtained by merging the two risk ratios.

	Without colonies		With colonies		Final	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Black petrel	11.96	6.42-19.64	10.34	5.63-16.90	11.15	5.92-18.57
Grey-headed albatross	3.50	1.36-7.24	3.53	1.32-7.12	3.51	1.34-7.18
Westland petrel	3.06	1.30-6.64	3.57	1.26-8.79	3.31	1.28-7.83
Northern giant petrel	2.99	0.83-7.75	3.01	0.81-7.96	3.00	0.82-7.86
Chatham albatross	3.45	1.13-8.80	1.96	1.15-3.31	2.71	1.13-7.62
Flesh-footed shearwater	2.60	1.11-4.69	2.41	1.04-4.35	2.51	1.07-4.54
Salvin's albatross	2.49	1.07-4.76	2.48	1.07-4.67	2.49	1.07-4.72
Northern royal albatross	2.72	0.93-6.34	1.71	0.66-3.37	2.21	0.74-5.42
Light-mantled albatross	2.19	1.07-4.06	2.16	1.09-3.96	2.18	1.08-4.01
NZ king shag	3.52	2.34-5.11	0.59	0.39-0.84	2.05	0.42-4.77
Campbell albatross	1.83	0.77-3.22	1.84	0.81-3.19	1.84	0.78-3.21
Stewart Island shag	1.59	1.02-2.29	1.61	1.01-2.29	1.60	1.01-2.29
Southern Buller's albatross	1.42	0.65-2.69	1.15	0.54-2.18	1.28	0.57-2.51
Gibson's albatross	1.32	0.70-2.35	1.18	0.59-2.19	1.25	0.62-2.30
Antipodean albatross	1.18	0.76-1.73	1.04	0.63-1.63	1.11	0.68-1.69
White-capped albatross	0.85	0.51-1.36	0.81	0.49-1.30	0.83	0.50-1.33
White-chinned petrel	0.78	0.20-1.43	0.80	0.20-1.47	0.79	0.20-1.44
Northern Buller's albatross	0.67	0.19-1.43	0.91	0.24-1.93	0.79	0.21-1.76
Cape petrel	0.76	0.27-1.64	0.76	0.27-1.61	0.76	0.27-1.62
Southern royal albatross	0.41	0.18-0.90	1.07	0.65-1.71	0.74	0.19-1.56
Spotted shag	0.50	0.16-0.82	0.50	0.17-0.83	0.50	0.17-0.83
Fiordland crested penguin	0.43	0.15-0.95	0.46	0.16-1.02	0.45	0.15-0.98
Grey petrel	0.40	0.18-0.73	0.39	0.18-0.71	0.39	0.18-0.73
Chatham Island shag	0.20	0.04-0.53	0.20	0.04-0.55	0.20	0.04-0.54
Pitt Island shag	0.14	0.03-0.40	0.14	0.02-0.41	0.14	0.03-0.40
Yellow-eyed penguin	0.20	0.07-0.46	0.04	0.02-0.10	0.12	0.02-0.39
Hutton's shearwater	0.12	0.05-0.23	0.08	0.03-0.15	0.10	0.04-0.20
Australasian gannet	0.10	0.03-0.22	0.10	0.03-0.22	0.10	0.03-0.22
Soft-plumaged petrel	0.06	0.01-0.13	0.02	0.00-0.05	0.04	0.00-0.12
Pycroft's petrel	0.02	0.01-0.05	0.05	0.02-0.12	0.04	0.01-0.10
Chatham petrel	0.02	0.01-0.05	0.05	0.01-0.10	0.03	0.01-0.09
Buller's shearwater	0.03	0.01-0.06	0.04	0.01-0.08	0.03	0.01-0.08
Magenta petrel	0.01	0.00-0.03	0.04	0.01-0.09	0.03	0.00-0.07
Snares crested penguin	0.03	0.01-0.05	0.03	0.01-0.06	0.03	0.01-0.05
Cook's petrel	0.02	0.01-0.03	0.04	0.01-0.08	0.03	0.01-0.07
Kerm. white-faced storm petrel	0.02	0.00-0.04	0.02	0.00-0.04	0.02	0.00-0.04
Bounty Island shag	0.02	0.00-0.06	0.02	0.00-0.06	0.02	0.00-0.06
Sooty shearwater	0.02	0.01-0.04	0.02	0.01-0.04	0.02	0.01-0.04
Auckland Island shag	0.02	0.00-0.05	0.02	0.00-0.05	0.02	0.00-0.05
Great-winged petrel	0.01	0.01-0.03	0.01	0.00-0.01	0.01	0.00-0.03
Mottled petrel	0.01	0.00-0.02	0.01	0.00-0.03	0.01	0.00-0.03
White-headed petrel	0.01	0.00-0.03	0.01	0.00-0.02	0.01	0.00-0.02
Southern rockhopper penguin	0.01	0.00-0.01	0.01	0.01-0.02	0.01	0.00-0.02
Kerm. petrel	0.00	0.00-0.01	0.01	0.00-0.01	0.01	0.00-0.01
Black-bellied storm petrel	0.01	0.00-0.01	0.00	0.00-0.01	0.01	0.00-0.01
Little shearwater	0.00	0.00-0.01	0.01	0.00-0.01	0.01	0.00-0.01
Common diving petrel	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
South Georgia diving petrel	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
NZ white-faced storm petrel	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
NZ storm petrel	0.01	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
Black-backed gull	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
Caspian tern	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
Antarctic prion	0.00	0.00-0.01	0.00	0.00-0.00	0.00	0.00-0.01
Fairy prion	0.00	0.00-0.00	0.00	0.00-0.01	0.00	0.00-0.01
Campbell Island shag	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00-0.01
Wedge-tailed shearwater	0.00	0.00-0.00	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	0.00	0.00-0.00
Brown skua	0.00	0.00-0.00	0.00	0.00-0.00	0.00	0.00-0.00
Erect-crested penguin	0.00	0.00-0.00	0.00	0.00-0.00	0.00	0.00-0.00
Masked booby	0.00	0.00-0.00	0.00	0.00-0.00	0.00	0.00-0.00
White-necked petrel	0.00	0.00-0.00	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	0.00	0.00-0.00
Common white tern	0.00	0.00-0.00	0.00	0.00-0.00	0.00	0.00-0.00

Table A-15: Comparison of annual potential fatalities and risk ratios when using different priors for calculating species vulnerability: a uniform distribution between 0 and 0.1 (used in this study), and a log-normal distribution (log of vulnerability normally distributed, with a mean of 0 and a standard deviation of 100). Species for which the number of potential fatalities estimated using the uniform prior was significantly greater than from the log-normal prior are indicated using a light orange colour. When the significance was high (when the confidence intervals were non-overlapping), the species are indicated using a dark orange colour.

	Annual potential fatalities				Risk ratio			
	Uniform		Log-normal		Uniform		Log-normal	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	35	14-72	1	0-2	0.01	0.00-0.02	0.00	0.00-0.00
Fiordland crested penguin	87	38-176	24	0-88	0.45	0.15-0.98	0.12	0.00-0.47
Snares crested penguin	52	28-91	1	0-3	0.03	0.01-0.05	0.00	0.00-0.00
Erect-crested penguin	4	2-10	1	0-2	0.00	0.00-0.00	0.00	0.00-0.00
Yellow-eyed penguin	20	3-61	0	0-1	0.12	0.02-0.39	0.00	0.00-0.01
Antipodean albatross	227	163-299	142	80-222	1.11	0.68-1.69	0.69	0.32-1.27
Gibson's albatross	205	148-269	128	73-200	1.25	0.62-2.30	0.78	0.30-1.69
Southern royal albatross	227	66-438	87	17-172	0.74	0.19-1.56	0.28	0.05-0.65
Northern royal albatross	286	169-590	96	69-128	2.21	0.74-5.42	0.74	0.29-1.43
Light-mantled albatross	534	298-922	4	0-28	2.18	1.08-4.01	0.02	0.00-0.12
Grey-headed albatross	525	291-912	4	0-28	3.51	1.34-7.18	0.03	0.00-0.18
Campbell albatross	855	594-1 244	380	270-590	1.84	0.78-3.21	0.82	0.35-1.50
Northern Buller's albatross	531	369-752	349	247-477	0.79	0.21-1.76	0.52	0.14-1.14
Southern Buller's albatross	1 096	817-1 521	682	549-856	1.28	0.57-2.51	0.80	0.37-1.51
White-capped albatross	5 123	4 571-5 718	4 587	4 120-5 057	0.83	0.50-1.33	0.74	0.45-1.19
Chatham albatross	980	463-2 685	166	87-247	2.71	1.13-7.62	0.46	0.22-0.74
Salvin's albatross	3 330	2 873-3 865	2 810	2 439-3 223	2.49	1.07-4.72	2.10	0.90-4.00
Northern giant petrel	567	331-965	41	22-74	3.00	0.82-7.86	0.22	0.06-0.58
Cape petrel	684	523-910	326	258-412	0.76	0.27-1.62	0.36	0.13-0.77
Great-winged petrel	139	74-251	44	28-64	0.01	0.00-0.03	0.00	0.00-0.01
White-headed petrel	132	85-221	40	29-54	0.01	0.00-0.02	0.00	0.00-0.01
Magenta petrel	0	0-0	0	0-0	0.03	0.00-0.07	0.01	0.00-0.04
Kerm. petrel	2	1-3	1	0-1	0.01	0.00-0.01	0.00	0.00-0.01
Soft-plumaged petrel	3	1-7	1	1-1	0.04	0.00-0.12	0.01	0.00-0.03
Mottled petrel	164	89-331	37	26-54	0.01	0.00-0.03	0.00	0.00-0.00
White-necked petrel	0	0-1	0	0-1	0.00	0.00-0.00	0.00	0.00-0.00
Chatham petrel	0	0-0	0	0-0	0.03	0.01-0.09	0.02	0.00-0.05
Cook's petrel	49	22-102	16	6-35	0.03	0.01-0.07	0.01	0.00-0.02
Pycroft's petrel	3	1-6	1	0-2	0.04	0.01-0.10	0.01	0.00-0.04
Broad-billed prion	128	65-236	13	7-23	0.00	0.00-0.00	0.00	0.00-0.00
Antarctic prion	49	26-89	7	5-12	0.00	0.00-0.01	0.00	0.00-0.00
Fairy prion	253	109-678	19	12-31	0.00	0.00-0.01	0.00	0.00-0.00
White-chinned petrel	1 642	1 446-1 915	1 263	1 159-1 374	0.79	0.20-1.44	0.61	0.15-1.11
Westland petrel	539	258-1 203	35	17-65	3.31	1.28-7.83	0.22	0.08-0.45
Black petrel	1 056	725-1 524	619	399-901	11.15	5.92-18.57	6.53	3.35-11.05
Grey petrel	709	531-979	325	263-400	0.39	0.18-0.73	0.18	0.08-0.32
Wedge-tailed shearwater	7	2-16	0	0-0	0.00	0.00-0.00	0.00	0.00-0.00
Buller's shearwater	217	129-361	56	22-114	0.03	0.01-0.08	0.01	0.00-0.02
Flesh-footed shearwater	1 384	1 079-1 769	986	762-1 248	2.51	1.07-4.54	1.79	0.77-3.25
Sooty shearwater	3 542	3 147-4 112	3 109	2 758-3 555	0.02	0.01-0.04	0.02	0.01-0.03
Hutton's shearwater	266	135-482	66	23-148	0.10	0.04-0.20	0.02	0.01-0.06
Little shearwater	54	30-93	17	5-46	0.01	0.00-0.01	0.00	0.00-0.00
NZ white-faced storm petrel	353	212-579	31	16-60	0.00	0.00-0.01	0.00	0.00-0.00
Kerm. white-faced storm petrel	0	0-0	0	0-0	0.02	0.00-0.04	0.00	0.00-0.00
NZ storm petrel	0	0-0	0	0-0	0.00	0.00-0.01	0.00	0.00-0.00
Black-bellied storm petrel	35	15-69	7	3-14	0.01	0.00-0.01	0.00	0.00-0.00
White-bellied storm petrel	0	0-0	0	0-0	0.00	0.00-0.00	0.00	0.00-0.00
Common diving petrel	371	223-602	26	16-44	0.00	0.00-0.01	0.00	0.00-0.00
South Georgia diving petrel	0	0-0	0	0-0	0.00	0.00-0.01	0.00	0.00-0.00
Australasian gannet	249	153-383	46	6-127	0.10	0.03-0.22	0.02	0.00-0.06
Masked booby	0	0-0	0	0-0	0.00	0.00-0.00	0.00	0.00-0.00
NZ king shag	37	8-81	32	6-71	2.05	0.42-4.77	1.77	0.34-4.20
Stewart Island shag	251	186-328	239	173-314	1.60	1.01-2.29	1.52	0.95-2.18
Chatham Island shag	1	0-3	0	0-0	0.20	0.04-0.54	0.00	0.00-0.01
Bounty Island shag	0	0-1	0	0-0	0.02	0.00-0.06	0.00	0.00-0.00
Auckland Island shag	1	0-2	0	0-0	0.02	0.00-0.05	0.00	0.00-0.00
Campbell Island shag	0	0-1	0	0-0	0.00	0.00-0.01	0.00	0.00-0.00
Spotted shag	1 580	1 291-1 906	1 378	1 104-1 686	0.50	0.17-0.83	0.44	0.14-0.73
Pitt Island shag	3	1-7	0	0-0	0.14	0.03-0.40	0.00	0.00-0.01
Brown skua	0	0-0	0	0-0	0.00	0.00-0.00	0.00	0.00-0.00
Black-backed gull	685	421-1 040	318	126-621	0.00	0.00-0.01	0.00	0.00-0.00
Common white tern	0	0-0	0	0-0	0.00	0.00-0.00	0.00	0.00-0.00
Caspian tern	0	0-0	0	0-0	0.00	0.00-0.01	0.00	0.00-0.00

Table A-16: Change in the number of seabird potential fatalities between the periods 2003 to 2006 and 2006 to 2009, expressed as the ratio of the 2006–07 to 2008–09 estimate over the 2003–04 to 2005–06 estimate. Green cells indicate a decrease over time, and red an increase. The colour intensity indicates the significance level of the difference (α = 0.2, 0.1, and 0.05, from light to intense).

	Large offshore trawl		Large BLL		Large SLL		All	
	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.	mean	95% c.i.
Southern rockhopper penguin	0.55	0.24 – 1.34	2.41	0.62 – 10.04	1.54	0.18 – 13.37	0.63	0.28 – 1.40
Fiordland crested penguin	0.48	0.16 – 1.45	2.96	0.72 – 16.03	1.47	0.19 – 12.49	0.53	0.20 – 1.49
Snares crested penguin	0.52	0.25 – 1.09	2.57	0.67 – 11.46	1.53	0.16 – 14.22	0.64	0.34 – 1.24
Erect-crested penguin	0.87	0.17 – 4.58	3.36	0.27 – 90.58		–	1.15	0.29 – 4.53
Yellow-eyed penguin	0.49	0.11 – 1.84	2.83	0.69 – 13.70	0.01	0.00 – 13.65	0.52	0.13 – 1.85
Antipodean albatross	0.65	0.33 – 1.42	0.33	0.08 – 1.16	3.9	1.54 – 11.17	0.71	0.40 – 1.48
Gibson's albatross	0.65	0.33 – 1.41	0.33	0.08 – 1.18	3.9	1.52 – 11.23	0.71	0.39 – 1.47
Southern royal albatross	0.61	0.28 – 1.19	0.24	0.04 – 0.98	4.03	1.49 – 14.76	0.66	0.34 – 1.23
Northern royal albatross	0.6	0.29 – 1.24	0.35	0.07 – 1.61	2.03	0.48 – 7.85	0.61	0.29 – 1.20
Light-mantled albatross	0.62	0.31 – 1.22	1.16	0.25 – 5.19	0.73	0.13 – 3.43	0.63	0.33 – 1.21
Grey-headed albatross	0.65	0.33 – 1.34	1.08	0.23 – 5.17	1.53	0.22 – 11.17	0.67	0.35 – 1.33
Black-browed albatross	0.62	0.26 – 3.32	0.52	0.13 – 1.84	0.99	0.42 – 2.26	0.62	0.28 – 3.22
Campbell albatross	0.51	0.25 – 1.21	0.31	0.04 – 1.43	0.91	0.38 – 2.11	0.52	0.27 – 1.18
Northern Buller's albatross	0.67	0.33 – 1.20	7.13	1.31 – 53.47	5.68	3.76 – 8.37	0.8	0.49 – 1.31
Southern Buller's albatross	0.73	0.52 – 1.05	7.28	1.80 – 40.40	2.41	1.67 – 3.56	0.99	0.71 – 1.38
White-capped albatross	0.31	0.28 – 0.36	0.56	0.15 – 1.83	2.34	1.63 – 3.39	0.32	0.29 – 0.37
Chatham albatross	0.81	0.28 – 5.07	0.63	0.10 – 3.09	1.65	0.28 – 9.79	0.81	0.29 – 4.86
Salvin's albatross	0.78	0.61 – 0.99	0.2	0.08 – 0.44	6.85	1.76 – 36.38	0.76	0.60 – 0.96
Northern giant petrel	0.87	0.45 – 1.84	0.33	0.07 – 1.37	0.46	0.09 – 1.84	0.83	0.45 – 1.72
Cape petrel	0.33	0.23 – 0.49	0.42	0.17 – 1.00	1.6	0.22 – 12.30	0.34	0.24 – 0.49
Great-winged petrel	0.6	0.30 – 1.22	1.76	0.29 – 9.29	1.72	0.25 – 11.42	0.62	0.32 – 1.24
White-headed petrel	0.6	0.29 – 1.25	1.7	0.31 – 9.09	1.68	0.24 – 11.56	0.63	0.31 – 1.26
Magenta petrel	0.61	0.14 – 2.63	1.72	0.05 – 24.83	1.02	0.03 – 46.42	0.64	0.16 – 2.45
Kerm. petrel	0.56	0.23 – 1.41	1.8	0.21 – 16.19	2.14	0.20 – 20.30	0.59	0.25 – 1.42
Soft-plumaged petrel	0.62	0.29 – 1.32	1.76	0.40 – 9.40	1.72	0.25 – 12.35	0.65	0.32 – 1.33
Mottled petrel	0.61	0.25 – 1.38	1.57	0.24 – 20.34	1.62	0.17 – 16.27	0.67	0.30 – 1.45
White-necked petrel	0	0.00 – 0.00		–	0.39	0.01 – 5.56	0.15	0.01 – 1.33
Chatham petrel	0.63	0.14 – 2.73	1.56	0.10 – 34.52		–	0.67	0.17 – 2.65
Cook's petrel	0.58	0.26 – 1.28	1.7	0.32 – 8.80	1.75	0.25 – 11.78	0.61	0.28 – 1.29
Pycroft's petrel	0.56	0.10 – 3.13		–	4.12	0.23 – 43.91	0.58	0.12 – 3.18
Broad-billed prion	0.54	0.32 – 0.91	2.36	0.54 – 10.62	1.61	0.23 – 10.83	0.59	0.36 – 0.98
Antarctic prion	0.5	0.26 – 0.93	2.38	0.67 – 9.42	1.58	0.23 – 10.46	0.54	0.29 – 0.97
Fairy prion	0.55	0.29 – 1.05	2.56	0.70 – 9.80	1.57	0.24 – 10.38	0.6	0.33 – 1.09
White-chinned petrel	0.88	0.77 – 1.02	0.53	0.40 – 0.71	2.53	1.31 – 5.03	0.85	0.75 – 0.97
Westland petrel	0.52	0.23 – 1.15	1.11	0.22 – 5.44	0.46	0.08 – 1.99	0.53	0.24 – 1.12
Black petrel	0.79	0.36 – 1.97	1.17	0.08 – 20.74	1.37	0.13 – 10.79	0.81	0.38 – 1.94
Grey petrel	0.62	0.36 – 1.06	3.65	1.55 – 9.08	8.51	3.85 – 19.92	0.87	0.54 – 1.36
Wedge-tailed shearwater	0.52	0.06 – 5.08		–	0	0.00 – 0.00	0.47	0.05 – 3.47
Buller's shearwater	0.48	0.24 – 0.96	1.04	0.19 – 5.85	1.52	0.22 – 10.56	0.52	0.27 – 0.99
Flesh-footed shearwater	0.76	0.50 – 1.18	1.26	0.26 – 5.89	1.75	0.27 – 10.56	0.77	0.51 – 1.19
Sooty shearwater	0.85	0.74 – 1.02	0.58	0.26 – 2.01	0.61	0.17 – 1.98	0.84	0.73 – 1.02
Hutton's shearwater	0.5	0.19 – 1.29	0.98	0.17 – 5.88	3.01	0.17 – 31.60	0.51	0.20 – 1.28
Little shearwater	0.58	0.26 – 1.35	0.99	0.21 – 4.48	1.53	0.22 – 10.52	0.6	0.29 – 1.35
NZ white-faced storm petrel	0.52	0.26 – 1.68	0.49	0.06 – 2.81	1.66	0.24 – 10.40	0.53	0.27 – 1.58
Kerm. white-faced storm petrel	0.42	0.21 – 0.82	0.63	0.13 – 2.62	1.66	0.26 – 10.04	0.44	0.22 – 0.82
NZ storm petrel	0.35	0.14 – 0.90	0.61	0.15 – 2.14	1.64	0.24 – 11.17	0.36	0.15 – 0.90
Black-bellied storm petrel	0.35	0.15 – 0.89	0.61	0.16 – 2.17	1.63	0.24 – 10.76	0.36	0.15 – 0.89
White-bellied storm petrel	0.39	0.05 – 2.92		–	2.32	0.15 – 22.56	0.58	0.08 – 3.13
Common diving petrel	0.57	0.30 – 1.15	0.48	0.11 – 2.88	1.74	0.20 – 16.12	0.57	0.32 – 1.15
South Georgia diving petrel	0.48	0.25 – 0.93	0.5	0.10 – 3.05	1.59	0.15 – 19.46	0.49	0.27 – 0.94
Australasian gannet	0.55	0.26 – 1.14	1.24	0.31 – 4.79	1.56	0.24 – 10.65	0.65	0.33 – 1.21
Masked booby	0.18	0.06 – 1.03	1.24	0.26 – 5.69	1.6	0.24 – 10.89	0.22	0.07 – 1.08
NZ king shag	0.44	0.10 – 2.21	3.68	0.30 – 45.61		–	0.48	0.12 – 2.25
Stewart Island shag	0.44	0.13 – 1.47	2.22	0.18 – 25.82	3.2	0.09 – 89.06	0.96	0.30 – 3.14
Chatham Island shag	0.46	0.10 – 2.40	1.47	0.04 – 64.50		–	0.54	0.13 – 2.36
Bounty Island shag	1.38	0.06 – 21.83	2.43	0.06 – 118.09		–	1.6	0.17 – 13.23
Auckland Island shag	0.53	0.07 – 4.41	0	0.00 – 0.00	4.66	0.29 – 65.57	0.54	0.07 – 4.42
Campbell Island shag	0.88	0.02 – 22.00	0	0.00 – 0.00		–	0.84	0.02 – 16.49
Spotted shag	0.38	0.16 – 0.90	2.52	0.37 – 17.93	2.23	0.21 – 21.22	0.5	0.22 – 1.09
Pitt Island shag	0.46	0.09 – 2.34	1.46	0.04 – 63.85		–	0.54	0.13 – 2.30
Brown skua	0.5	0.17 – 1.49	1.15	0.11 – 12.91	0.87	0.06 – 14.85	0.51	0.18 – 1.48
Black-backed gull	0.43	0.19 – 0.96	2.11	0.48 – 9.44	1.54	0.22 – 10.54	0.47	0.22 – 0.99
Common white tern	0.45	0.22 – 0.92	2.11	0.37 – 12.35	1.4	0.22 – 8.62	0.55	0.29 – 1.05
Caspian tern	0.41	0.17 – 0.98	2.13	0.38 – 11.25	1.55	0.23 – 11.16	0.45	0.20 – 1.02

Table A-17: Mean annual potential fatalities (captures) and risk ratios when no cryptic mortality is considered. The species for which the lower 95% confidence limit exceeds 1 are highlighted in dark orange, in light orange when the mean exceeds 1, and in yellow when the upper 95% confidence limit exceeds 1.

	Potential captures		Risk ratio	
	mean	95% c.i.	mean	95% c.i.
Black petrel	404	290-545	**4.27**	2.35-6.87
NZ king shag	27	6-61	1.54	0.31-3.58
Westland petrel	163	86-328	1	0.42-2.17
Stewart Island shag	193	143-252	1.23	0.77-1.76
Flesh-footed shearwater	529	411-669	0.96	0.41-1.73
Northern giant petrel	122	74-190	0.64	0.18-1.64
Grey-headed albatross	115	69-184	0.77	0.31-1.49
Chatham albatross	230	133-499	0.64	0.33-1.42
Northern royal albatross	85	61-141	0.66	0.25-1.37
Gibson's albatross	83	53-121	0.5	0.22-1.02
Salvin's albatross	718	633-814	0.54	0.23-1.01
Campbell albatross	272	200-390	0.58	0.25-1.00
Light-mantled albatross	118	72-190	0.48	0.26-0.84
Antipodean albatross	92	59-135	0.45	0.24-0.75
Spotted shag	1182	965-1428	0.38	0.12-0.62
Cape petrel	247	192-319	0.27	0.10-0.58
Southern Buller's albatross	256	197-337	0.3	0.13-0.58
Northern Buller's albatross	172	130-226	0.26	0.07-0.54
Fiordland crested penguin	48	22-93	0.24	0.09-0.52
Southern royal albatross	67	15-132	0.22	0.04-0.49
White-chinned petrel	501	439-579	0.24	0.06-0.44
Yellow-eyed penguin	14	2-45	0.09	0.01-0.29
Chatham Island shag	1	0-1	0.1	0.03-0.28
Grey petrel	272	214-348	0.15	0.07-0.27
White-capped albatross	895	800-998	0.14	0.09-0.23
Pitt Island shag	1	0-3	0.07	0.02-0.21
Australasian gannet	151	93-235	0.06	0.02-0.13
Hutton's shearwater	91	48-159	0.03	0.01-0.07
Bounty Island shag	0	0-1	0.01	0.00-0.05
Pycroft's petrel	1	0-3	0.02	0.00-0.05
Soft-plumaged petrel	1	1-2	0.02	0.00-0.04
Chatham petrel	0	0-0	0.02	0.00-0.04
Snares crested penguin	34	17-62	0.02	0.01-0.04
Auckland Island shag	1	0-2	0.01	0.00-0.04
Magenta petrel	0	0-0	0.01	0.00-0.03
Cook's petrel	21	9-45	0.01	0.00-0.03
Buller's shearwater	77	48-121	0.01	0.00-0.03
Kerm. white-faced storm petrel	0	0-0	0.01	0.00-0.01
Southern rockhopper penguin	22	9-48	0.01	0.00-0.01
Sooty shearwater	909	808-1047	0	0.00-0.01
Great-winged petrel	53	30-87	0	0.00-0.01
Mottled petrel	59	36-108	0	0.00-0.01
White-headed petrel	49	34-72	0	0.00-0.01
Kerm. petrel	1	0-1	0	0.00-0.01
Campbell Island shag	0	0-1	0	0.00-0.01
Little shearwater	21	12-38	0	0.00-0.00
Black-bellied storm petrel	11	5-22	0	0.00-0.00
NZ storm petrel	0	0-0	0	0.00-0.00
Common diving petrel	126	78-197	0	0.00-0.00
South Georgia diving petrel	0	0-0	0	0.00-0.00
NZ white-faced storm petrel	120	74-190	0	0.00-0.00
Black-backed gull	224	142-332	0	0.00-0.00
Antarctic prion	17	9-30	0	0.00-0.00
Caspian tern	0	0-0	0	0.00-0.00
Fairy prion	84	38-210	0	0.00-0.00
Erect-crested penguin	3	1-7	0	0.00-0.00
Wedge-tailed shearwater	3	1-7	0	0.00-0.00
Broad-billed prion	45	24-78	0	0.00-0.00
Brown skua	0	0-0	0	0.00-0.00
Masked booby	0	0-0	0	0.00-0.00
White-bellied storm petrel	0	0-0	0	0.00-0.00
White-necked petrel	0	0-0	0	0.00-0.00
Common white tern	0	0-0	0	0.00-0.00

APPENDIX B: ESTIMATION OF CRYPTIC FATALITIES

Document provided by Ben Sharp, Ministry of Fisheries

B.1 Introduction

'Capture' refers to any bird (or portion of a whole bird) that comes into the physical possession of observers or fishers onboard the vessel. Cryptic fatality F_{cryp} refers to birds that are fatally injured in an encounter with fishing effort but are not observable as 'captures', because they are not recovered onboard the fishing vessel. Risk is properly a function of total fatalities F_{tot}, and the proper estimation of risk requires that the relationship between observable captures C_{tot} and total fatalities F_{tot} be explored. For some fishery groups this relationship may be simple; for others, estimating total fatalities F_{tot} as a function of captures relies on a complex series of calculations based on assumptions subject to considerable uncertainty.

In this section we disaggregate the various types of observed and cryptic fatalities for the main fishery groups and outline a method to estimate cryptic fatalities from available data. We also summarise available published sources informing these estimates and highlight the assumptions to which the overall estimation of risk remains particularly sensitive. For many fisheries it is likely that cryptic fatalities will remain a major source of uncertainty in seabird risk assessments until further information is available.

B.2 Longline fisheries

Total fatalities in longline fisheries is calculated as the sum of total captures and cryptic fatalities, less the number of birds released alive:

$$F_{tot} = C_{tot} + F_{crypt} - C_{live} \tag{B-1}$$

The potential for cryptic fatalities in longline fisheries arises from i) the potential for hooked birds to fall off the line prior to or during line retrieval and ii) undetected actions to undermine observation effectiveness (i.e. deliberate covert discards). In a major multi-year study in which the fate of individual birds diving for longline baits was recorded during the set and haul and subsequently compared with observed captures, Brothers et al. (2010) reported that total fatalities F_{tot} exceeded observed captures C_{tot} by a factor of 2. In this study observation methods were designed to eliminate the possibility of covert discards, and live releases were negligible. On this basis we can assume that

$$F_{tot} = 2C_{tot} \tag{B-2}$$

for all surface longline fisheries. In the absence of other information it may be reasonable to assume a similar cryptic fatality multiplier of two for bottom longline fisheries. However, whereas seabird bycatch for surface longlines is observed mainly on the set rather than the haul (ensuring that hooked seabirds actually drown), for bottom longlines there may be a higher proportion caught during the haul, with less opportunity for carcasses to be lost, and implying that a greater proportion of birds may be recovered alive, some of which may be expected to survive (i.e. C_{live}). Obtaining data indicative of relative rates of capture on the set versus the haul for bottom longline fisheries, and of live releases, would enable estimation of a cryptic fatality multiplier specifically for bottom longlines.

B.3 Trawl fisheries

Cryptic fatalities in trawl fisheries potentially represent a major source of fisheries mortality, but very little data available. The calculations required to estimate cryptic fatalities as a function of observed captures in trawl fisheries are subject to considerable uncertainty, with significant implications for total risk. New research to reduce this uncertainty should be a high priority.

To estimate total fatalities in trawl fisheries, it is first necessary to distinguish between three distinct categories of seabird-trawler interaction:

- 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 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 moving warp.

The total fatalities are therefore:

$$F_{tot} = F_{net} + F_{surf} + F_{air} \quad \text{(B-3)}$$
$$= C_{net} + F_{cryp-net} + C_{surf} + F_{cryp-surf} + C_{air} + F_{cryp-air} - C_{live} \quad \text{(B-4)}$$
$$\text{(B-5)}$$

where F_{net} are the total fatalities in the net; C_{net} are observed captures in the net; $F_{cryp-net}$ are the cryptic net fatalities, and so on.

B.3.1 Net entanglement

Net entanglements can occur either on shooting the net or on hauling, with the majority caught on 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 meshes tighten and close during hauling. In the latter instance birds may be released alive and unharmed (i.e., C_{live}). Cryptic net fatalities $F_{cryp-net}$ arises either from birds entangled in the trawl wings during setting or the outside of the net during hauling that subsequently fall off and are not recorded, or birds caught inside the net that are subsequently lost through the slack meshes during the haul.

At a New Zealand National Plan of Action Risk Assessment workshop, it was agreed that cryptic net fatality $F_{cryp-net}$ is likely to be lower than observed captures C_{net} and that C_{live} for trawl fisheries likely consists exclusively of net-caught birds. A cryptic fatality multiplier of 1.5 was proposed. However it is likely that some net-captured birds caught on the haul and released alive will survive (i.e. C_{live}). In the absence of further information we propose a cryptic fatality multiplier of 1.3:

$$F_{net} = C_{net} + F_{cryp-net} - C_{live} \quad \text{(B-6)}$$
$$= 1.3 C_{net} . \quad \text{(B-7)}$$
$$\text{(B-8)}$$

B.3.2 Warp strikes

Warp strike rates for different species of seabird have been observed and modelled as a function of total fishing effort, gear configuration, fisher behaviour and at-sea conditions (e.g., Watkins et al. 2008, Abraham & Thompson 2010b), primarily as a means of evaluating mitigation options. However these data are largely unavailable for most fishing effort; the risk assessment framework instead estimates vulnerability to trawl gear as a function of observed captures. The nature of seabird-warp interactions is such that the number of interactions will far exceed the number of seabirds physically recovered (i.e., recorded as 'captured'). Consequently the cryptic fatality multiplier for trawls may be very high, but will be subject to considerable uncertainty, being based on a relatively small number of observed captures and several hard-to-test assumptions about the fate of non-captured birds. Limited data are available from the Watkins et al. (2008) and Abraham & Thompson (2010b) studies to relate observed warp captures to estimated warp fatalities; the purpose of the risk assessment is to carefully apply best available information and make explicit the remaining uncertainties. It is first necessary to carefully 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 interactions, warp strike parameter estimates are calculated independently for large versus small seabirds. Small birds are in turn segregated into 'flying', 'hovering', or 'diving' species, with distinct assumptions about their relative susceptibility to different kinds of capture (Table Appendix B-18). In general, 'flying' birds are larger than 'hovering' 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 are assumed to be killed only in the net.

B.3.3 Surface warp strikes

The total cryptic fatalities from surface warp strikes are:

$$F_{surf} = C_{surf} + F_{crypt-surf} \tag{B-9}$$

Surface warp strikes occur when birds either 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 birds' 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 process (i.e., $F_{crypt-surf}$); alternately they may be impaled on a sprag (loose warp splice) or pulled all the way to the trawl door (800 – 900 m), and subsequently retrieved (i.e. C_{surf}). Non-lethal warp captures (C_{live}) 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 'flying' and 'hovering' small birds are assumed to be susceptible to surface warp capture; the lower susceptibility of the hovering birds will be reflected in lower observed capture rates, so requires no mathematical adjustment. In contrast, diving birds (penguins and shags) are assumed not to be captured or killed in warp interactions; all diving bird fatalities are assumed to occur in the net, with no cryptic surface or aerial warp fatalities.

For large birds, Watkins et al. (2008) observed 26.8 presumed fatalities arising from 137 surface warp strikes, with only two corresponding captures, implying a surface cryptic fatality multiplier of 13.4 for large birds. The Abraham & Thompson (2010b) data do not distinguish between surface strikes and

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

Species	Size	Behaviour
Antipodean albatross	Large	
Black-browed albatross	Large	
Brown skua	Large	
Campbell albatross	Large	
Chatham albatross	Large	
Gibson’s albatross	Large	
Grey-headed albatross	Large	
Light-mantled albatross	Large	
Northern Buller’s albatross	Large	
Northern giant-petrel	Large	
Northern royal albatross	Large	
Salvin’s albatross	Large	
Southern Buller’s albatross	Large	
Southern royal albatross	Large	
White-capped albatross	Large	
Black (Parkinson’s) petrel	Small	Flying
Buller’s shearwater	Small	Flying
Flesh-footed shearwater	Small	Flying
Great-winged petrel	Small	Flying
Grey petrel	Small	Flying
Hutton’s shearwaters	Small	Flying
Kermadec petrel	Small	Flying
Sooty shearwater	Small	Flying
Wedge-tailed shearwater	Small	Flying
Westland petrel	Small	Flying
White-chinned petrel	Small	Flying
White-headed petrel	Small	Flying
Antarctic prion	Small	Hovering
Black-backed gull	Small	Hovering
Black-bellied storm-petrel	Small	Hovering
Broad-billed prion	Small	Hovering
Cape petrel	Small	Hovering
Caspian tern	Small	Hovering
Chatham petrel	Small	Hovering
Common Diving-petrel	Small	Hovering
Common white tern	Small	Hovering
Cook’s petrel	Small	Hovering
Fairy prion	Small	Hovering
Kermadec white-faced storm-petrel	Small	Hovering
Little shearwater	Small	Hovering
Magenta petrel	Small	Hovering
Mottled petrel	Small	Hovering
New Zealand storm-petrel	Small	Hovering
New Zealand white-faced storm-petrel	Small	Hovering
Pycroft’s petrel	Small	Hovering
Soft-plumaged petrel	Small	Hovering
South Georgia Diving-petrel	Small	Hovering
White-bellied storm-petrel	Small	Hovering
White-necked petrel	Small	Hovering
Auckland Island shag	Small	Diving
Australasian gannet	Small	Diving
Bounty Island shag	Small	Diving
Campbell Island shag	Small	Diving
Chatham Island shag	Small	Diving
Erect-crested penguin	Small	Diving
Fiordland crested penguin	Small	Diving
Masked booby	Small	Diving
New Zealand king shag	Small	Diving
Pitt Island shag	Small	Diving
Snares crested penguin	Small	Diving
Southern rockhopper penguin	Small	Diving
Spotted shag	Small	Diving
Stewart Island shag	Small	Diving
Yellow-eyed penguin	Small	Diving

aerial strikes; however their estimated total (surface and aerial) interaction rate of 208 strikes per warp capture compares favourably with the 179 strikes per capture observed by (Watkins et al. 2008). Applying Watkins et al. (2008) fatality rates to the interaction rates of Abraham & Thompson (2010b) yields:

$$F_{surf} = 15.6C_{surf} \tag{B-10}$$

For small birds, Watkins et al. (2008) observed 6.48 presumed fatalities arising from 124 surface warp strikes, with no corresponding captures. Applying an estimated 7610 total warp strikes per warp capture (Abraham & Thompson 2010b) yields:

$$F_{surf} = 80.6C_{surf} \tag{B-11}$$

for small 'flying' and 'hovering' birds. For small diving birds, it is assumed that there are no cryptic warp fatalities, i.e., $F_{surf} = C_{surf}$.

B.3.4 Aerial warp strikes

The total cryptic fatalities from aerial warp strikes are:

$$F_{air} = C_{air} + F_{crypt-air} \tag{B-12}$$

Aerial warp strikes occur when flying birds collide with the moving warps. Aerial strikes are in this study 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 above the wrist (Abraham & Thompson 2010b), coinciding with the definition of 'heavy' collisions used by Watkins et al. (2008). 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 is 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 'flying' bird (white-chinned petrel) in 728 observed heavy collisions. It is to be expected that fatality rates will be highest for large birds, moderate for small 'flying' birds which may collide under their own forward momentum, and lowest for small 'hovering' birds for which the birds' forward momentum will be minimal and strikes are more likely to arise from the lateral movement of the warp itself. However without dedicated efforts to assess the post-collision status of affected birds any conclusion about associated fatality rates are highly speculative.

Because impacts occur primarily on the front surface of the wings, aerial strikes do not result in entanglement in the warp with a subsequent chance of body recovery, i.e., $C_{air} = 0$, and aerial strike fatality arises exclusively from cryptic fatalities.

$$F_{air} = F_{crypt-air} \tag{B-13}$$

Because $C_{air} = 0$, a cryptic fatality multiplier cannot be defined relative to aerial captures; instead, available warp strike observations enable estimation of aerial fatalities as the product of observed surface captures (C_{surf}), aerial strike interactions per observed surface capture (X_{air}/C_{surf}) and estimated fatalities per interaction, F_{air}/X_{air}). Fatality rates for aerial warp strikes are thought to be low (e.g., 0 – 5%). Applying estimated aerial strike interaction rates per observed capture estimated by Abraham & Thompson (2010b) and estimated proportions of aerial versus surface interactions by Watkins et al. (2008) and assuming aerial strike fatality rates of 2% for large birds, 1% for small 'flying' birds, and 0.5% for small 'hovering' birds, yields:

Large birds:	$F_{air} = 2.56 C_{surf}$
Small 'flying' birds:	$F_{air} = 60.8 C_{surf}$
Small 'hovering' birds:	$F_{air} = 30.4 C_{surf}$

For small diving birds, it is assumed that there are no cryptic warp fatalities, i.e., $F_{air} = 0$. We acknowledge that the fatality rate estimates are highly speculative, and further research to resolve these estimates should be a high priority.

B.4 Total fatality estimation

The proportion of observed captures attributable to each category of interaction is expressed as follows:

$$P_{net} + P_{surf} = 1, \qquad \text{(B-14)}$$

where $P_{net} = C_{net}/C_{tot}$ and $P_{surf} = C_{surf}/C_{surf}$.

Because the subsequent estimation of cryptic fatalities occurs with respect to each category separately and the cryptic fatality multipliers for each are likely to be very different, estimation of total fatalities may be highly sensitive to assumptions about these proportions. The following simplifying assumptions are possible: i) warp captured birds will be mostly dead, or fatally injured, such that C_{live} refers exclusively to net-captured birds; ii) warp captured birds will arise exclusively from surface strikes; it is assumed to be unlikely that aerial warp strikes will result in captures iii) small diving birds are killed only in the net (i.e., $P_{net} = 1$; $F_{crypt-surf} = 0$; $F_{crypt-air} = 0$)

From data on warp captures (Abraham & Thompson 2010b), it follows that for large birds $P_{net} = 0.71$, and for small 'flying' and 'hovering' birds $P_{net} = 0.980$. This enables estimation of total fatalities for each category of bird:

Large birds:

$$\begin{aligned}
F_{tot} &= C_{net} + F_{cryp-net} + C_{surf} + F_{cryp-surf} + F_{cryp-air} && \text{(B-15)}\\
&= [P_{net} + 0.3P_{net} + (1-P_{net}) + 14.6(1-P_{net}) + 2.56(1-P_{net})]\,C_{tot} && \text{(B-16)}\\
&= 6.19C_{tot} && \text{(B-17)}
\end{aligned}$$

Small 'flying' birds:

$$\begin{aligned}
F_{tot} &= C_{net} + F_{cryp-net} + C_{surf} + F_{cryp-surf} + F_{cryp-air} && \text{(B-18)}\\
&= [P_{net} + 0.3\,P_{net} + (1-P_{net}) + 79.6\,(1-P_{net}) + 60.8\,(1-P_{net})]\,C_{tot} && \text{(B-19)}\\
&= 4.10C_{tot} && \text{(B-20)}
\end{aligned}$$

Small 'hovering' birds:

$$\begin{aligned}
F_{tot} &= C_{net} + F_{cryp-net} + C_{surf} + F_{cryp-surf} + F_{cryp-air} && \text{(B-21)}\\
&= [P_{net} + 0.3\,P_{net} + (1-P_{net}) + 79.6\,(1-P_{net}) + 30.4\,(1-P_{net})]C_{tot} && \text{(B-22)}\\
&= 3.49C_{tot} && \text{(B-23)}
\end{aligned}$$

Small 'diving' birds:

$$\begin{aligned}
F_{tot} &= C_{net} + F_{cryp-net} + C_{surf} + F_{cryp-surf} + F_{cryp-air} && \text{(B-24)}\\
&= [P_{net} + 0.3\,P_{net}]C_{tot} && \text{(B-25)}\\
&= 1.3C_{tot} && \text{(B-26)}
\end{aligned}$$

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