Final Report

Ecological Risk Assessment for Seabirds in New Zealand fisheries

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Executive Summary

We examined the risk of fisheries incidental mortality causing population declines for a suite of seabird species in 14 New Zealand fisheries using trawl and longline methods. We applied a method developed by Sharp et al. (2009) that used the available data on species biology, fisheries interactions, and fishing effort in a semi-quantitative Ecological Risk Assessment framework. Data quality was a strong pre-occupation in the study, with species abundance and productivity data being of extremely variable quality. Fishery data on captures were relatively sparse for small longline fisheries. Therefore, the results should be interpreted with caution, and are best used to guide the setting of research and management priorities. Sixty-three species were studied, but the final analysis reports on data for 39, the remainder being excluded due to lack of data in the relevant fisheries at this time.

The primary statistic generated by the study is the risk score, which describes the risk of adverse effects at species level from fishing mortalities – it is the number of likely captures in New Zealand commercial fisheries, over the species-specific index of population productivity. Our primary findings in relation to the likely impacts of fishing mortality on species, by fishery and area were:

1. Nineteen of 39 species (19 species, 90%Confidence Limit (CL)) had risk scores of 0.01 or above, which we define as having more-than-negligible levels of fisheries interaction. 20 species had negligible levels of interactions.

2. For 4 species (7 species, 90%CL) there could be cause for concern as the likely captures exceed the Potential Biological Removals (PBR) index (very high risk) and one other species (4 species, 90% CL) showed high risk. The species of greatest concern, in descending order were: Westland petrel, Chatham albatross, black-browed albatross, northern royal albatross, and southern Buller's albatross.

3. The following species had risk scores of moderate risk for the median value of the risk score, but these changed to high or very high risk with the 90% CL. This indicates considerable uncertainty around the risk scores, and which warrants further research: Kermadec white-faced storm petrel, southern royal albatross, Antipodean albatross (both populations), Salvin's albatross, Campbell albatross, and black petrel.

4. The suite of species identified in points 2 and 3 above are a high priority for research that helps define input parameters to the analysis. In some cases, this may be a greater knowledge of the species-specific catch rates, and for others, of basic biological attributes such as abundance and population growth rate. For some of these species, research is underway that will lead to better definition of biological parameters.

5. Warp strike affecting small albatrosses in trawl fisheries can result in birds being killed but not brought on board the vessel. These cryptic kills are not recorded by fisheries observers. When cryptic kills from trawl warp strike were included, at rates of 2 times (and 10 times) the likely capture values, the following seven species achieved very high risk rankings: Chatham albatross, black-browed albatrosses, southern Buller's albatross, Salvin's albatross, Campbell albatross, northern Buller's albatross, and white-capped albatross. There is considerable

uncertainty around the effect that warp-strikes may have on the risk levels for these birds, which may increase the priority for research on cryptic kills.

6. Four fisheries were identified as having the largest overall impact at species level, both in terms of captures of species with high to very high risk, and the number of overall captures throughout the NZEEZ. These were inshore trawl, small vessel bottom longline, squid trawl, and small vessel surface longline fisheries.

7. The greatest risk overall was in Fishery Management Areas (FMAs) 1 and 2, with high risk for some fisheries in FMAs 3, 4, 5, 6, and 7 and lower risk in FMAs 8,9, and 10.

8. Five fishing groups made little or no contribution to the total seabird bycatch (<1% of the total captures each) or to risk to individual species (<4% for any species each). These were bottom longline autoline, middle depths fresher trawl, southern blue whiting trawl, mackerel trawl, and deepwater trawl fisheries.

9. Those five species ranked with very high or high risk in the study have IUCN threat rankings of Critical to Vulnerable. Of the six species ranked of moderate risk, all were listed by the IUCN as Vulnerable. This indicates that at an international level, conservation concern for the species is high. Of these 11 species, ten breed only in New Zealand. Local loss of these species' populations would lead to global extinction.

10. The species identified as having high to very high risk in the analysis are affected by a number of fisheries. Bycatch management measures currently apply in only a proportion of those fisheries. Monitoring of seabird catch has previously been focused in high-value and mainly southern fisheries, while the areas of greatest risk identified here occur in small vessel fisheries in both trawl and longline fleets, and predominantly in northern areas (in particular FMAs 1 and 2).

11. While ongoing research of this issue is recommended, the current results present the culmination of research and development of methods over several years in Ecological Risk Assessment for seabirds in New Zealand and Pacific fisheries, and make use of the available data. It needs to be acknowledged that the data quality is variable across species, but data were relatively robust for albatross and *Procellaria* petrel species. These were the species identified as most likely to be suffering population effects from fisheries mortality in the study.

12. The study presents the most recent in a series of comprehensive assessments of seabird risk from fishing mortality in New Zealand fisheries. The methods used are responsive to changes in fishing practice, distribution of effort, and improved knowledge of species biology. They will provide a useful tool for assessing risk and targeting measures to manage it in New Zealand fisheries through time.

13. Other fisheries, such as flatfish trawl, set net, troll and purse-seine could be treated with the methods explored in this study as observer data become available for these fisheries. Improved information about a number of species included in the analyses is expected over the next 2-3 years, as long-term research programmes deliver their findings. Therefore, we can optimistically expect improved information, understanding, and finer-scale management of this important environmental risk.

Objective

To provide an assessment of the risk posed by different fisheries to the viability of New Zealand seabirds species, and to assign a risk category to all New Zealand fishing operations.

Introduction

The purpose of this study was to examine the apparent risk of adverse effects of fisheries mortality on seabird populations, resulting from New Zealand fishing. Our brief was to analyze risk to seabirds, using best available information on the biology of their populations, their occurrence as bycatch, and in relation to current fisheries activity, in a semi-quantitative manner.

Ecological risk assessment (ERA) arose from the need to analyse information about systems, in order to identify, manage, or mitigate the effects of deleterious outcomes or events. Sharp (2009:2) notes: "Risk assessment in a natural resource management context arises from the need for managers to make difficult decisions despite incomplete – and at times completely inadequate – actual information upon which those decisions can be based. Properly applied, risk assessment bridges the gap between scientists, who operate in the realm of what is known and attempt to expand on that knowledge, and managers, who do not have the luxury of waiting for the knowledge base to grow".

The methodologies for ecological risk assessment have evolved over time, and in the present day, a hierarchical structure for ERA is described (Hobday et al. 2007):

- Level 1 risk assessments are largely driven by expert opinion, and are helpful in identifying potential management concerns and information gaps, in allowing a overview over a wide spectrum of situations. However, the outcomes of such analyses may be influenced by a) the contributing experts and 'unevenness' in their knowledge or beliefs; b) the variable 'repeatability' of the analysis – i.e. a different group of experts examining the same issue might come up with different responses. Rowe (2009) conducted an expert opinion based Level 1 risk assessment for fishery-seabird interaction in New Zealand.

- Level 3 analyses can be considered the most sophisticated, at least in analytical terms, as they integrate information about very detailed aspects of a system. However, they can be computationally heavy to complete. The types of assessments typically employed in fisheries contexts rely on developing a detailed model of an ecological system or contributing processes, and informing different elements of the analysis with parameter estimates, describing their likelihood. Such analyses often produce outputs that are described in probabilistic terms. They allow exploration of management strategies or scenarios, where 'what-if' questions can be informed by the outcomes of modeling processes, e.g. "what would be the likelihood of the population growth rate of species X exceeding the value Y, if the fishing mortality were reduced to Z in a particular fishery"? These models require high quality information about the systems concerned. For long-lived higher predator species, they often require long-term datasets. Examples of level 3 analyses include determining the impact of fisheries mortalities on albatross populations (Tuck et al. 2001, Lewison and Crowther 2003); determining both the effects of fishing mortalities and alternative management strategies on a sea lion population (Breen et al. 2003), and exploration of the effects of fishing mortalities on southern Buller's albatross populations (Francis et al. 2008).

- Semi-quantitative (or Level 2) risk assessment lies somewhere between the two methods described above. In the types of analyses explored to date in fisheries bycatch contexts, simple models have been developed, that allow different ecological information to be combined and compared, usually to provide outputs exploring the relative likelihood of risk to species (Kirby and Hobday 2007, Kirby 2008). These analyses can incorporate expert opinion as well as quantitative information. For example, in Hawaiian longline fisheries, the risk of shark bycatch in longlining operations under shallow and deep-set fishing strategies was compared using ERA methods (WCPFC 2008). The depth profile of exposure of shark species to hooks, and expert knowledge of preferred depths of these species was used to explore ways to reduce undesirable shark bycatch.

Phillips and Small (2008) explored the relative risk to seabird species of longline fishing mortality in the Atlantic Ocean. They used information on breeding strategies (categories of high- medium- and low-productivity) and the overlap of the distribution of species with fishing effort to derive risk indices for a suite of seabird species and fisheries.

Waugh et al. (2008a) and Kirby et al. (2009) developed an 'exposure effects' method of assessing ecological risk to describe the relative risk to seabirds from longline fishing in New Zealand and Pacific fisheries. This methodology was chosen as bycatch events occur with low frequency, but the cumulative effect of infrequent events can result in important impacts at population levels. The mortality of many individuals may in some cases lead to population declines.

In this case, the exposure is interactions of seabirds with fishing gear, a proportion of which can be fatal. The effects occur both at individual level (through mortality) and at a population level (through reductions in population growth). In the analyses explored by Waugh et al. 2008a and Kirby et al. 2009, exposure was assessed via the spatial overlap of species ranges and fishing effort, where the exposure was assumed to be proportional to the rate of potential interaction. In this case, there was only one fishing method involved, therefore only relative risk between species was identified. The consequences of interaction were not elaborated – i.e. the likelihood of interactions leading to mortality was only explored in a limited way. These analyses identified areas where interactions were most likely to occur, and where information gathering about the captures occurring in those fisheries could be targeted.

The challenge of the current study was to explore the effects of very different fishing methods within the same analysis, and define the relative contribution mortality of each to species risk. This required that the outcome of interactions be codified, so that population effects could be examined. Some fishing methods have a greater chance of causing mortality when interacting with a given species than others, and species have different propensities to be caught and to recover from occasional mortalities, as a result different behaviours and differential inherent population growth rates, respectively.

We apply the methodology developed by Sharp et al. (2009) to examine these effects, and to provide indices of risk to seabird populations from fishing mortality. These indices will be responsive to changes in the likelihood of catching birds in different fisheries through time (e.g. through mitigation), and to changes in the overlap between seabird populations and fishing effort. This will allow long term monitoring of the effect of management interventions.

The reason this approach is currently challenging to implement is because the data relating to seabird populations and interaction with fisheries are variable in quality, patchy, and at times out of date (Taylor 2000a, b; Wilson 2007). Because the risk scores developed in the study are based on information that is at times of poor quality, the results should be interpreted with caution. Furthermore, risk scores are at times based on proxy values, either for species catchability, or species population productivity. The levels of interactions described are best considered to be indicators of where captures may occur (to indicate the uncertainty we refer to these events as 'likely captures'). These likely captures may not be realized in practice. In addition to data quality issues, the systems being studied are relatively poorly known. For example, some species feed aggressively around fishing gear, while others do not. This results in different catch of birds per fishing event even if the numbers of the different species feeding behind vessels are similar. Anecdotally, the influence of behavior on propensity to be caught has been noted, but has been little explored in empirical terms.

Due to the availability of data at the time of the study, the scope of the study is limited to longline and trawl fisheries within New Zealand waters. However, the methods will be applicable to a wider range of fisheries as suitable information becomes available. They could also be applied to other regions. The risk assessment does not address possible indirect fisheries-related impacts, e.g. trophic effects, but is restricted to the consequences of fisheries mortality. The effects of fishing mortality outside of the New Zealand area, and threats that operate on seabird colonies such as predation by invasive alien species, are not treated in this study. However, in the future, the approach could be adapted to include these as the appropriate information becames available.

The risk to seabirds is derived at a species level, and apportioned between fisheries and FMAs within the New Zealand Exclusive Economic Zone (NZEEZ) (Figure 1). This is intended to assist managers of the fisheries (both within industry and government) to implement monitoring or management programmes that aim to reduce risk of adverse effects on seabird populations from fishing mortality.

Methods

In March 2009, the New Zealand Ministry of Fisheries (MFish) hosted a technical workshop to develop methods for ERA for seabird in New Zealand fisheries (ERA Workshop). This report discusses the outcome of a study which implemented the methodology developed at that workshop, and was described by Sharp et al. (2009). The reader is referred to that report for further elaboration of the assumptions and rationale of the research.

Data available for the study

We discuss information available to populate the analysis:

a) Fishing effort distributions
b) Seabird abundance data
c) Species productivity data
d) Potential Biological Removals indices
e) Seabird spatial distributions
f) Vulnerability to capture for seabird groups in specific fisheries
g) Combining a) and e) above to define spatial overlap of birds and fishing effort
h) Risk scores – the statistic determining the risk score for each species.

Fishing effort distributions

The fishing data treated comprised a groomed data set of catch-effort data and observer data for the fishing years 2004-05, 2005-06 and 2006-07[1]. We worked with a groomed dataset provided from analyses used in Ministry of Fisheries project PRO2007/01 and summarized by Abraham and Thompson (2008). These data include both fisher reported effort data; Ministry of Fisheries' observer reported information on seabird bycatch, and autopsy identifications of seabirds.

The fishing effort was divided into 21 groups by experts contributing to the ERA Workshop on the basis of their propensity to interact with seabirds, mainly along the lines of target species, vessel size and fishing method. Data for only 14 of these groups were available at the time of the study from a range of trawl and longline fisheries. Middle depths trawl vessels were further divided into 'fresher' and 'processor' vessels on the basis of a list of vessel keys supplied by the Ministry of Fisheries. Fresher vessels do not carry out any at sea processing. These vessels were expected to generate less offal and fish waste. The fishing effort used by the different fishing groups is described in Table 1.

[1] Fishing years start on 1 October each year for all fisheries except Southern Blue Whiting. However we included this group with the other fisheries, with dataset running 1 October to 30 September each year.

After exploring the dataset, we decided to work with data at the level of fishing events (trawl tows, longline sets). In previous work, the primary drivers for seabird bycatch were found to be strongly influenced by vessel effects, or factors operating at set level (e.g. day or night setting) rather than tow duration or number of hooks (Waugh et al. 2008b). Approximately one third of fishing events were recorded on Catch Effort Landing Return (CELR) forms, which only provide daily summaries of fishing effort and record location at a statistical area level. In data from these forms, a single record may represent several sets or tows. As these data did not provide detailed information on individual tows, we were constrained to work at the level of events to include data from all fisheries. The remainder of the effort data was recorded at an individual fishing event level, and provided the latitude and longitude of fishing events, to 0.1 degree level of precision. The proportion of events recorded with latitude-longitude data is given in Table 1. The majority of the CELR data were in small bottom longline and small trawl vessel fisheries (fishing groups 4, 5, 6). Only 355 (1%) of events in these fisheries were observed.

The study area was bounded by latitudes 23^{o} S and 57^{o} S, and by longitudes 160^{o} E and 170^{o} W. We determined the fishing events per year within a cell of 0.1 x 0.1 degrees longitude and latitude. Where data were available with fisheries statistical area information only, we spread the effort across the area so that each 0.1 degree cell had an equal portion of that effort. In some fishing groups, a combination of latitude-longitude and CELR data were used. Figures 2-14 show the distribution of events for each fishing group, along with the monthly distribution of effort for the 2006 calendar year.

Species data

Our initial selection of seabird species included all marine dependent bird species that are resident in the NZEEZ for at least part of their annual breeding cycle, and for which there was information on species distribution (80 species from 10 families)[2]. We followed the taxonomy and used the associated species information from BirdLife International (BirdLife International 2009), such as threat classifications, and population size information. This was because the database collated by BirdLife International covered the suite of species of interest in a consistent manner, and is updated annually. We were able to populate the species data tables for 63 species.

The biological attributes for the species were collated from the scientific literature. The parameter values used in the study are set out in Appendix 1.

[2] Due to problems of attributing species population within the zone for wandering and yellow-nosed albatrosses in a consistent manner compared with the other species in the study, we removed these non-breeding species from the reported analyses. Initial runs of the analysis indicated that these species had low risk outcomes compared to other species in the study.

Species abundance

For the population size for each species, we used the most recent published estimates of the numbers of individuals for each species. Where a range of values for species abundance is described, we chose a mid-point.

Where estimates of population size in numbers of individuals were not provided in the primary source information, we chose to multiply the number of pairs by a factor of 3 for annual breeding albatrosses and petrels, 3.5 for biennial species, and 4 for species that have more than one offspring per year (e.g. shags, penguins and terns). This mode of calculating population sizes produced similar results to those of a study where the age-structure of the population was modeled (Gilbert 2009).

We examined the data quality for species abundance (Table 2). We did this by assessing how recent the data were, and with a qualification for the methodology used to estimate numbers of birds. We used the methods used by the Agreement for the Conservation of Albatrosses and Petrels to describe survey data quality[3] (ACAP 2009).

Species productivity

We chose species productivity as an index of responsiveness to pressures such as fishing mortality. The rate of increase of a population at the maximum rate with no resource limitation, predation or competition is termed r_{max} (Sibly and Hone 2003). Niel and Lebreton (2005) demonstrated that for birds, there is a relatively constant relationship between generation length and population growth rate. They established that the maximum annual population growth rate λ_{max} can be estimated for long-lived species using estimates of age at first reproduction (α) and adult annual survival (s). They defined the relationship between these parameters as:

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

Subsequent research into the effects of fishing or harvest on long-lived species populations have used this formulation to produce r_{max} values (where $r_{max} = \lambda_{max} - 1$) and to estimate levels of removals for species that minimize the likely long-term probabilities of population decline (Dillingham & Fletcher 2008, Barbraud et al. 2008, 2009).

We estimated α and s values for each species based on parameter values found in the scientific literature. Where more than one estimate was available for a species, we used the most robustly estimated (e.g. largest sample size, longer-term study). For those

[3] ACAP identified commonly used measures of abundance, and noted their increasing numbers of sources of error: e.g. counts of nesting adults; counts of chicks; counts of nest sites; aerial-photo; ship- or ground- based photo; unknown. They categorized surveys into the following groups High - within 10% of stated figure; Medium - within 50% of stated figure; Low - within 100% of stated figure (e.g. coarsely assessed via area of occupancy and assumed density); Unknown.

species where data were absent, we substituted a value from a closely-related species (Appendix 1).

Calculating PBR index

We calculated a Potential Biological Removals (PBR) index for each species, following Wade (1998), with adaptations for seabirds set out by Dillingham & Fletcher (2008). The formula used to estimate the PBR was:

$$PBR = 0.5 \cdot N_{min} \cdot r_{max} \cdot F$$

In the American resource management context in which the PBR approach was developed, the analysis operates by defining the component of production from a population that is available for take by fisheries (or other human activity) (Wade 1998). The input elements to this calculation are N_{min}, a conservative estimate of population size, r_{max}, and a management-related coefficient, F. The inclusion of F aims to ensure that more vulnerable populations are treated with greater care than larger, or faster growing, ones. The coefficient F for seabirds has been described previously by Dillingham and Fletcher (2006, 2008) and Barbraud et al. (2009), at a value of 0.5 or smaller. A smaller F value leads to a more conservative management response in safeguarding seabird populations from potential over-exploitation. In essence, the PBR formula allows definition of an allowable take of a species equivalent to one half of the annual production under optimum conditions, moderated by F, which allows more conservative levels of take to be set for species for which there is more conservation concern.

We used F values provided by Ministry of Fisheries determined in relation to the IUCN threat status for a species. These were set at the level of 0.1 for species with IUCN ranking of Critical or Endangered, 0.3 for species ranked Vulnerable or Near Threatened, and 0.5 for other species.

Alternative means of setting F values may be explored. For example, it may be equally defensible to use more detailed information about species' populations to generate F values, such as the population trends, size of the population, etc. However, we caution that such data may not be universally available across a suite of species. In this way, the assessment of 'risk of extinction' as an indicator of overall species vulnerability, such as provided by the IUCN threat ranking, may be as good a way as any of linking the concepts of management concern, and the need for caution in managing threats to species.

Species overlap with fisheries

In order to examine the extent to which fishing activity might influence species populations, we explored the zone of spatial overlap between different fishing groups and species. This was calculated by combining information on the species distribution and the effort of the fishery groups. We considered that the distribution maps represent the distribution of the entire population throughout the study zone over the annual periods, and did not attempt to describe their out-of zone distribution.

Data on species distribution was drawn from the NABIS database (Ministry of Fisheries 2009), BirdLife International World Bird Database (range maps, BirdLife International 2009) and the BirdLife International Global Procellariiform Tracking Database (BirdLife International 2005). Using the abundance information, we calculated an annual spatial distribution for each species in the study, defining the species density, *D*, at the level of 0.1 degree squares within the study zone. Data from the different sources were combined as follows:

- NABIS distributions (38 species). Where data compilations in the NABIS database were available, we calculated the species density throughout their range in the NZEEZ, by using the NABIS distributions (three layers). The layers were equated to 10% of the population (in the area of 100% NABIS distribution), 40% of the population (90% distribution) and 50% of the population (NABIS hotspot).

- BirdLife tracking database (1 species). Where no NABIS layers were available, but BirdLife International remote-tracking data layers existed, we used 50, 75 and 95% utility distributions for species for the breeding and non-breeding ranges (see BirdLife 2005 for methods in determining kernel distributions of birds). In order to represent average annual probability distributions of birds spatially, we attributed 40% of each population to the breeding season range, and 60% to the non-breeding range;

- BirdLife Range maps (24 species). Where no data on concentrations of foraging activity were available, we used the BirdLife International Range Maps to describe the species ranges. Within the study area, these provide an even distribution of the species throughout its range.

Examples of the distribution maps for three species are shown in Figure 15. From these distributions, and the fishing effort data, we determined the degree of overlap of each fishing group within the zone of each species' distribution, calculating an overlap matrix on the basis of 0.1 degree squares. This matrix represents the number of birds times units of fishing effort (sets or trawls) per unit area. If *E* is the fishing effort within a square, and *D* the density of birds in that area, then the overlap, *o*, is

$$o = E\,D$$

The total overlap, O, between species and fisheries may be derived by summing *o* over all areas.

Vulnerability

Vulnerability (*V*) relates the density of each species at the location where fishing is taking place, to the number of kills that occur. Depending on the behaviour of the birds, which differs between species (or species groups), different numbers of mortalities are expected for the same seabird density. If there are, on average, *K* birds killed on a fishing event then the vulnerability is

$$K = V\,D$$

The Ministry of Fisheries' observer data provides a consistent data source that can be used to determine the number of birds killed per fishing event. Here captured birds were used (excluding deck captures) and no account is taken of whether or not the birds were released alive. The observers recorded birds that were either brought on board the vessel, or that the observers clearly saw being killed. This follows the methods used for estimating seabird captures in New Zealand fisheries (Waugh et al. 2008b, Abraham and Thompson 2008). Observer data from fishing years 2004-05, 2005-06 and 2006-07 were used to estimate *V*.

In order to calculate *V*, the species were first grouped together in groups of similar behaviours and propensities to be captured in fishing gear, with the following groups: large albatrosses, small albatrosses, small shearwaters, large shearwaters, *Procellaria* petrels; large *Pterodroma* petrels and other petrels. Gannets, shags, terns and gulls were excluded as they have not been observed killed in longline and trawl fisheries at rates that allow estimation of *V*. The species grouping was necessary to reduce the sparseness of the capture dataset. A summary of the observed captures by species group and by fishery group is given in Table 3. There are many species-fisheries combinations where no captures have been observed. The largest number of captures was of small albatross in squid trawl fisheries, with a total of 339 observed captures over the three year period.

The vulnerability*, V,* was then estimated for each species group and fishing group, by fitting a generalized linear model to the captures and density data, for observed fishing events from that fishery. Although capture data are typically over-dispersed, in many of the species-fisheries combinations there were few captures. To increase the stability of the fitting, the observed captures were assumed to be drawn from a Poisson distribution, with a mean proportional to the seabird density at the location of the fishing event. *V* was given by the constant of proportionality. No other covariates were included in the models. An exploration of the model fitting found that neglecting the possibility of over-dispersion had little effect on the model fit. The models were fitted using standard Bayesian methods (e.g., Gelman and Hill 2006), with a diffuse lognormal distribution being assumed as the prior for *V*.

The results of the model fitting are summarised in Table 4. The values in this table are multiplied by 10 000. The highest *V* are for albatrosses in surface longline fisheries, with the *V* for large albatross reaching over 600 x 10^{-4} kills per fishing event per bird per unit area in small surface longline fisheries. Because only few large albatross captures have been observed, the uncertainty in these numbers is high. In contrast, although large shearwaters were caught frequently, their *V* was low (a median value of less than one in all fisheries). The low *V* is because of their relatively high density. Even though they are caught frequently, they are not caught as frequently relative to their density as albatrosses. *Pterodroma* petrels have both low catch rates and low density, and *Procellaria* petrels have high catch rates, but intermediate *V* (between 1 x 10^{-4} and 100 x 10^{-4} kills per event per bird per unit area) across a wide range of fisheries.

In order to inform management decision making in relation to the species for which *V* were not estimated, as captures were too few for the dataset used, we used arbitrary values of 0.1 *V* (large shearwaters) for small shearwaters and other petrels, and 0.1 *V* (small albatrosses) for two species of albatross known infrequently to attend vessels compared to others in that group: grey-headed albatross and light-mantled albatross. We included these values to assess the potential for interactions of these species as they were all known to very occasionally occur in small numbers in bycatch in trawl and longline fisheries.

Overall captures, *C*, for each species within each fishery were calculated by multiplying the vulnerability by the overlap (summed over all areas),

$$C = V\ O$$

Sensitivities

We assessed uncertainty in the input data by running a series of sensitivity tests. This involved choosing alternative values for certain parameter inputs, to examine how these changes affected the overall risk outcomes.

The sensitivities tested were:

1. The influence of some ‘unusual’ survival inputs to the PBR index
2. Using alternative sets of weightings on the distribution maps for species
3. Using vulnerability values at the extremes of the ranges generated (90% Confidence Limit (CL) on *V*)
4. Using cryptic kill values for trawl warp strike.
5. The population size of sooty shearwaters (20 million, 2 million, or 200,000 individuals)

For the fourth factor, above, we tested the effect of adding mortalities from trawl warp strikes, where birds may be fatally injured, but are not recovered on board vessels, and thereby under-estimated in the observer records of species mortalities. These events are thought to affect small albatross species most. An expert group considered that unlanded mortalities from trawl fisheries could result in between 2 and 10 times the number of mortalities recorded by observers. We did this by multiplying the number of likely captures by 2 and 10 for small albatrosses in trawl fisheries, respectively.

We explored the uncertainty associated with the estimated population of sooty shearwaters. The figure of 20 million individuals was estimated by informal methods (data quality low) around 10 years ago (Taylor 2000b). If the population were much smaller (1/10th or 1/100th of the size), the vulnerability of the entire group of shearwaters and small petrels in the analysis would be increased proportionally. We altered the *V* accordingly and assessed the effects on the risk scores for this group of birds.

Risk scores

We generated tables of the likely captures for each species, and compared these with the PBR index (we refer to the ratio of the likely captures over the PBR index as the risk score). Four levels of risk were described by the Ministry of Fisheries: Very High risk, where the likely captures exceeded the PBR index (risk score of >1.1); High risk (0.8 – 1.1); Moderate risk (0.4 – 0.79); and Low risk (< 0.4).

Results

The results are discussed in terms of the overall likely captures by species, and the risk scores. Unless otherwise stated, results use the median *V* values and are for the 2006-07 fishing year. Associated uncertainty values are included in brackets.

Overall captures

The study indicated a major change in overall captures of species from 2004-05 to the two subsequent years. The total likely captures were 10 840, 6845, and 6398 birds (90% CL of 12 924; 8 308 and 7 928 seabirds) respectively (Table 5). As the same *V* was used across all years, these differences in likely captures can only be attributed to changes in the amount and distribution of fishing effort, changing the overlap.

Four fishery groups contributed over 75% of likely captures in 2006-07: Inshore trawl (FG1; 27%); small bottom longline (FG5; 26%), squid trawl (FG18; 14%) and small surface longline fisheries (FG11; 11%).

Species risk scores

The likely captures, PBR index, and risk scores for each species are shown in Table 6. Risk scores decreased through the study period, because of the reduction in fishing effort during this period. The most relevant to current day fisheries is the most recent therefore further discussion is of this one only. The 19 species for which the risk score was greater than 0.09 are shown in descending order of their median risk score

There are 4 species for which risk scores showed extreme risk (>1.1). These were, in descending order: Westland petrel, Chatham albatross, black-browed albatross, and northern royal albatross. Southern Buller's albatross had high levels of risk.

Twenty species did not have detectable levels of interaction (risk scores of less than 0.1) (Table 7). These were mainly small petrels from the genuses *Puffinus* and *Pterodroma*.

When we examined where the likely captures occurred, they were found to be clustered in FMAs, 1 and 2 with other areas of lesser concentration being FMAs 3, 5 and 7. Captures in these areas contributed over 25% of the captures for around one half of the species in the study, and between 10% to 54% of likely captures for each of the species ranked as having high to very high risk.

Fishing group contributions

We next examined the contribution of each fishing group to likely mortalities for each species. The nineteen species for which some level of impact may be occurring are shown in Table 8, with the percentage of likely captures attributed to each fishing group. Four fishing groups stand out in particular. Inshore trawl and small bottom longline are likely to contribute between 25 – 60% of the likely captures for over half the 19 most impacted species. Small surface longline and squid trawl are likely to contribute over 10% of the captures for more than half of those 19 species.

Inshore trawl fisheries (27% of total captures) contributed to a high proportion of likely captures (≥ 25%) for 11 albatross species and one petrel. Most of these captures were concentrated in FMAs 1, 2, 3, with a number for each species in FMA 7 (Table 9).

Small bottom longline vessels (27% of total captures) contributed a high proportion of likely total captures (24 – 48%) for 14 species, mostly albatrosses. These captures were concentrated in FMAs 1, 2, 3, 4 and 7 (Table 10).

Squid trawl fisheries (14% of total captures) contributed between 10 - 25% of total captures for 11 species of albatross and petrel. These captures were concentrated in FMAs 5 and 6, and to a lesser degree in FMA 3 (Table 11).

Small surface longline vessels (11% of total captures) contributed between 30 – 90% of total captures for 4 albatross and one petrel species, and lower proportions (4 – 16%) for thirteen other species. These captures were concentrated in FMAs 1 and 2 (Table 12).

Data quality and sensitivities

The quality of data on albatross and *Procellaria* petrel population ecology were the best available to the study. For 9 of the 17 of these species' populations, data were recent and of high to medium quality. The remainder were of low quality, or were 5 years old or older. Overall, data were particularly poor for the 46 species of other petrels, shearwaters, shags, penguins gulls and terns, and gannets. Only one of these had a high quality, recent estimate of population abundance.

For the data to estimate r_{max}, among the 63 species in the study, 34 had one or more life-history parameter value inferred from other species. Again, the albatross populations had better quality estimates than other species.

Sensitivity tests outcomes are shown in Table 13, for the risk scores and 2006-07 data. We tested the weightings of the layers of seabird distributional data in the analysis, by changing the weightings from a ratio of 0.5:0.4:0.1 (for the 'hotspot', 90% distribution, and 100% distribution layers described in the NABIS database) to 1.0:0.4:0.1. This elevated the density of birds in the hotspots. Overall, this resulted in 3% fewer captures on average for each species. The risk scores for species did not change significantly, and all species retained their original risk rankings.

We used the r_{max} score from the grey petrel to substitute for literature based values for congeneric Westland and white-chinned petrel. The risk scores remained the same for Westland petrel (very high), but changed from moderate to low for white-chinned petrel.

When the effects of warp strike on small albatross were examined, by including cryptic kills, the result was to elevate all small albatrosses to an extreme risk category, with risk scores of between 1.2 and 34.

Changing the population estimate of sooty shearwaters did not affect the risk ratings with a change of 1/10th of the 2000 population estimate (all negligible risk with the exception of the Kermadec white-faced storm petrel). At 1/100th of the population estimate, Hutton's shearwater achieved a risk ranking of moderate, which would have resulted in over 500 captures of this species.

Comparison with estimates of captures

We compared the outputs of the analysis with the estimates of captures of seabirds produced by Abraham and Thompson (2008), who used ratio estimation methods based on observer data for sooty shearwaters, white-capped albatrosses and white-chinned petrels. We found good accord between the likely captures in our study and estimated mortalities for white-chinned petrels, white-capped albatrosses and sooty shearwaters. Strongest divergence was noted for small surface longline fisheries, where our study produced larger estimates than that of Abraham and Thompson (2008) (Figure 16).

Discussion

Overall assessment of the Sharp model

We reviewed a number of methodologies to examine the population effects of fishing mortalities on seabird species in the New Zealand region, in a Level 2 ERA framework. We adopted the methods set out by Sharp et al. (2009) as it had advantages over others available (e.g. Kirby et al 2009., Baird and Gilbert, in press, Waugh et al. 2008a, c). In particular, it used all available data types relating to species biology, fishing activity and the fishery seabird interactions for New Zealand fisheries. It is able to respond to changes in seabird catch in different fisheries through time, and allows comparison of risk levels between species and between distinct fishing methods. The method also allows a directly comparable set of metrics to be developed for different fisheries, and species groups.

However, we found the input data available in New Zealand to be of variable quality, and particularly so for the biological data. This has flow-on effects in any results generated using this or any other methodology. The implications of this are discussed in a later section. With this in mind, the interpretation of the outputs of the study needs to be tempered with caution.

We further note that each parameter estimated in the analysis was done so on the basis that it was the best estimate available. Precaution is applied solely through the use of a management factor *(F)*, used to estimate the PBR index for each species, and designed to allow greater caution to be applied for those species at greatest risk of extinction, according to the IUCN assessments. However, we explored uncertainty in several ways in the analysis. Firstly, we generated a median and upper 90% confidence limit on *V*. Second, we explored alternative input values for parameters describing seabird distribution, productivity, cryptic captures in trawl fisheries (warp strikes), and for population size for a key population in the analysis (sooty shearwater).

Given these points, the approach appears a viable way of addressing the knowledge gap about which fisheries and species require most attention to reduce risk of adverse effects from New Zealand fishing mortality on seabird populations.

The method is responsive to changes in fishing practice, and the risk scores output will reflect real changes in seabird mitigation efficacy through time. This will principally be via revision of estimates of *V*, which is informed by observer monitoring of seabird catch, and by changes in fishing effort and distribution, affecting the overlap, *O*. Our improving knowledge of the biology and distribution of seabird species over the next few years will also contribute to creating a more accurate picture of species interactions with fisheries and their underlying biological parameters.

We recommend that the appropriate use of the outcomes of the study be limited to addressing the need priorities for targeted research, monitoring and cautious management of the seabird mortality issue in New Zealand fisheries. The outcomes expressed allow an approximate measure of which fisheries, species, and areas are of most concern, with the current state of knowledge of seabird-fishery interactions in New Zealand trawl and longline fisheries. Due to the weaknesses in the dataset discussed above, the outputs do not provide a reliable estimate of how many birds are taken in any particular fishery, nor the level of bycatch of particular species that are sustainable.

Key findings

Over 120 species of seabird frequent New Zealand waters. The fisheries interactions of 39 species of albatross and petrel were examined in relation to likely captures in 14 groups of trawl and longline fisheries. An additional 24 species of shags, terns, gannets, penguins and gulls were examined, but excluded from the findings, as the data from setnet, trawl and pot fisheries with which they are known to interact were unavailable for use[4]. Around 60 of the potential 120 species of petrels and gulls were excluded due to an absence of appropriate information on their distribution or populations in the New Zealand region.

Our primary findings in relation to the risk scores per species and fishery were:

[4] Note that the data required to examine interactions in set net and small vessel trawl fisheries has been collected by MFish observers, but has not been entered into databases to enable it to be processed for analyses such as these.

1. Nineteen of 39 species (19 species, 90%Confidence Limit (CL)) had risk scores of 0.01 or above, which we define as having more-than-negligible levels of fisheries interaction. 20 species had negligible levels of interactions.

2. For 4 species (7 species, 90%CL) there could be cause for concern as the likely captures exceed the Potential Biological Removals (PBR) index (very high risk) and one other species (4 species, 90% CL) showed high risk. The species of greatest concern, in descending order were: Westland petrel, Chatham albatross, black-browed albatross, northern royal albatross, and southern Buller's albatross.

3. The following species had risk scores in the moderate risk category for the median value of the risk score, but these changed to high or very high risk with the 90% CL. This indicates considerable uncertainty around the risk scores, and which warrants further research: Kermadec white-faced storm petrel, southern royal albatross, Antipodean albatross (both populations), Salvin's albatross, Campbell albatross, and black petrel.

4. The suite of species identified in points 2 and 3 above are a high priority for research that helps define input parameters to the analysis. In some cases, this may be a greater knowledge of the species-specific catch rates, and for others, of basic biological attributes such as abundance and population growth rate. For some of these species, research is underway that will lead to better definition of biological parameters.

5. Warp strike affecting small albatrosses in trawl fisheries can result in birds being killed but not brought on board the vessel. These cryptic kills are not recorded by fisheries observers. When cryptic kills from trawl warp strike were included, at rates of 2 times (and 10 times) the likely capture values, the following seven species achieved extreme risk rankings: Chatham albatross, black-browed albatross, southern Buller's albatross, Salvin's albatross, Campbell albatross, northern Buller's albatross, and white-capped albatross. There is considerable uncertainty around the effect that warp-strikes may have on the risk levels for these birds, which may increase the priority for research on cryptic kills.

6. Four fisheries were identified as having the largest overall impact at species level, both in terms of captures of species with high to extreme risk, and the number of overall captures throughout the NZEEZ. These were inshore trawl, small vessel bottom longline, squid trawl and small vessel surface longline fisheries.

7. The greatest risk overall was in FMAs 1 and 2, with high risk for some fisheries in FMAs 3, 4, 5, 6, and 7 and lower risk in FMAs 8,9, and 10.

8. Five fishing groups made little or no contribution to the total seabird bycatch (<1% of the total captures each) or to risk to individual species (<4% for any species each). These were bottom longline autoline, middle depths fresher trawl, southern blue whiting trawl, mackerel trawl, and deepwater trawl fisheries.

9. Those five species ranked with very high or high risk in the study have IUCN threat rankings of Critical to Vulnerable. Of the six species ranked of moderate risk, all were listed by the IUCN as Vulnerable. This indicates that at an international level, conservation concern for the species is high. Of these 11 species, ten breed only in New Zealand. Local loss of these species' populations

would lead to global extinction. We note that the risk scores are influenced by the IUCN ranking via the calculation of F in the analysis.

10. The species identified as having high to very high risk in the analysis are affected by a number of fisheries. Bycatch management measures currently apply in only a proportion of those fisheries. Monitoring of seabird catch has previously been focused in high-value and mainly southern fisheries, while the areas of greatest risk identified here occur in small vessel fisheries in both trawl and longline fleets, and predominantly in northern areas (in particular FMAs 1 and 2).

While ongoing research of this issue is recommended, the current results present the culmination of research and development of methods over several years in Ecological Risk Assessment for seabirds in New Zealand and Pacific fisheries, and make use of the available data. It needs to be acknowledged that the data quality is variable across species, but data were relatively good quality for albatross and *Procellaria* petrel species. These were the species identified as most likely to be suffering population effects from fisheries mortality in the study.

Data quality issues

Data quality is a concern throughout the study. A better quality of data may lead to other research approaches being favourable (e.g. using statistical modeling to estimate captures, species by species). However, in an ERA framework, we aimed to make use of available data, excluding only data of the poorest quality.

Even with our limited requirements, data were lacking for around one half of the 120 or so seabirds that frequent the New Zealand zone. For the 63 species included, we were concerned that many of the key parameters were uncertain in quality, old, or poorly estimated. For example, data required to define the important r_{max} value were inferred for over one half of the species in the study. Data on at-sea distributions is sketchy for many species, with detailed remote-tracking studies to define distributions only available for 10 species[5]. Around one half of the species distributions contained information on foraging hotspots, the rest were represented by a flat distribution.

It is unknown if the likely captures estimated in the study for particular species are realised, due to a poor knowledge of species feeding and ship-following behaviours across all species. From the perspective of data-gathering in the fisheries, information on individual species behaviour around vessels that contribute to capture events is too sparse to be used currently. This area could benefit from enhanced research focus, as it will provide vital leads to help develop effective mitigation approaches.

We chose to exclude fisheries (in particular flatfish trawl) because there was insufficient data to estimate *V*. For others, a complete lack of data on seabird interactions precluded inclusion in the study (purse seine, pot and troll fisheries). A third set of fisheries (using set net method) were not included as data were collected but not available in a format to allow them to be analyzed. These data gaps reduced the comprehensive nature of our study, limiting our inference to only longline and selected trawl fisheries. Four fishery

[5] Note that research programmes are being undertaken or have recently been completed that involve remote tracking studies for a least another five species.

groups included had only small data sets from which to estimate *V*. These were inshore trawl, bluenose bottom longine, small bottom longline and snapper bottom longline groups. Caution should therefore be applied to interpreting the results relating to these groups.

The research did not seek to estimate captures of seabirds in fisheries; there are several detailed research programmes that address this issue (e.g Baird and Smith, 2007a, b; Abraham and Thompson 2008; Waugh et al. 2008b). As a test of reasonableness in the study outputs, we compared the results of the likely captures from this study, to those of Abraham and Thompson (2008) for specific areas of the squid trawl, ling autoline and surface longline fisheries. The results of our study fell within the error bounds of this study in most cases, except for surface longline fisheries, when our study produced higher estimates. This may be because the method applied here becomes less accurate at low levels of interaction. Alternatively the ratio-estimated captures assume a constant availability of seabirds across the zone used by the fishery, whereas our approach took into account differing availability of birds to capture in a spatial sense. Sampling in this particular fishery is relatively low, and therefore differing results may simply be due to the poor representation of the fishery from the observer data.

Seasonality is an important factor in the interactions of species and fisheries. If the seasonal peak of seabird activity and fishery activity coincide during a restricted part of the year, the risk scores presented here could be underestimated. Conversely, if the peak of bird activity in the NZEEZ occurs outside the peak of fishing in a high risk fishery, the risk scores produced here may be overestimated.

Seabirds are not distributed evenly around marine areas, either between years or between seasons. Most petrels and albatrosses migrate outside the NZEEZ for part of the year, but it is poorly known what proportion of the population does so for any species. This is an extremely complex area to analyze, as some species have an annual cycle of activity, and others breed and migrate over periods of two or more years. It is thought that all species have distinct behaviours between breeding and non-breeding groups, and for some species sex-differences in feeding activity are known.

The seasonal distribution of fishing effort is particularly marked for large surface longline fisheries, and squid and southern blue whiting trawl fisheries, all of which have a concentrated period of activity across a few months of each year. It would be appropriate to explore seasonality in future analyses, with a focus on particularly seasonal fisheries and species of concern. Our assessment was that a seasonal analysis across all fisheries was not currently feasible, given the limited data available on seasonal changes in seabird distribution, and on seasonal variation in seabird bycatch rates.

Sensitivities

We examined the influence of input parameters on the study outputs. The factor that had the most influence was that of cryptic kill, which changed the risk scores for 5 species of albatross from high or moderate to very high.

With the current data set, there was little effect of a change in the weighting of the distributional data layers on the overall outcomes, with an average of 3% fewer likely captures per species. This result may be influenced by the fact that for one half of the species, there were no hotspots defined. This area warrants further examination as data become available to more accurately describe species foraging distributions. We would expect that major changes in the location of hotspots, and added information could strongly influence the outcomes of future iterations of this work for particular species.

The change of input parameters to the r_{max} calculation had variable outcomes for the two species for which this was examined. These were Westland petrel and white-chinned petrel. The studies informing the survival estimates for these species were of relatively short duration, and there was high uncertainty around this parameter estimate. Using the same r_{max} values as congeneric species resulted in a reduced risk score for white-chinned petrel (moderate to low), while the Westland petrel stayed in the very high risk category. Adult survival is an important parameter in defining population productivity. Lack of robust estimation of this parameter across the study may be influencing the overall result.

Given that population abundance data are a particular difficulty in the analysis, we tested the effect of one of the populations with greatest leverage in the analysis: sooty shearwater. There is great uncertainty around the estimate of 20 million individuals of this species, and it could be conceivable that the population size is much smaller: e.g. 1/10 of that size. Our sensitivity testing on this parameter showed that the population size would have to be 1/100th of the size estimated by Taylor in 2000 (Taylor 2000b), for there to be any effect of this parameter on the outcomes for this or any other species of petrel (note that the V for shearwaters and other petrels is largely driven by captures of sooty shearwaters). At a population size of 200,000 individuals for sooty shearwaters, the model estimates that over 500 Hutton's shearwaters would be captured. This species distribution overlaps with some of the best observed fisheries in New Zealand around FMA3 and FMA4. This number of unobserved captures of Hutton's shearwaters is unlikely, therefore we conclude that a population size of sooty shearwaters this small is unreasonable. We are therefore confident that the V estimated for shearwaters and other petrels not set at an inappropriate level.

Strengths and weaknesses of the approach

The research has its weak points, and key among these is the lack of reliable data. This is particularly so for biological data on a number of species, both for population productivity and abundance. These factors erode our confidence in the absolute values of the PBR index and risk score. While it is likely that the relative ranking of species within the outputs is robust, biases in the input data defining both the likely captures and the PBR index mean that scaling of the risk score may be poor.

There is a degree of disquiet around the estimation of r_{max}, with some reviewers suggesting we have pushed the bounds of the data beyond reasonable levels. Other studies have approached this aspect differently. For example, Phillips & Small (2008) categorized species into different groups of high, medium or low productivity, based on their breeding frequency and clutch size (biennial breeder, single egg clutch, high; annual breeder, single egg clutch, medium; annual breeder, multiple egg clutch, low). The rationale for this was that for a great number of species, detailed information about population parameters is unknown or poorly estimated, while reproductive output (e.g. clutch size, breeding frequency) is relatively robust information or can be inferred with little error based on taxonomy. The approach taken by Phillips and Small (2008) probably better reflects the state of information about the species studied than the one explored in our work. A similar approach to that used by Phillips and Small (2008) was adopted by Rowe (2009) in determining species productivity.

We recommend that the PBR index developed here is appropriately used to put species into groups of high, medium or low productivity. However, given the poor knowledge of population parameters for most species concerned, we feel it would be over-interpreting the data to assume species level differences in r_{max} were accurate. As the PBR value, in the management context of setting a species catch target, relies on robust information on both population size (N) and species productivity (r_{max}), we caution that the values generated using the current dataset may not be accurate, robust, or scaled appropriately. Thus, we consider that at best, the PBR index should be used to indicate the relative vulnerability of each of the species in the study to fisheries effects, but is unlikely to be an accurate measure of the number of individuals that can be removed from a population before adverse population effects would ensue.

The data to estimate the vulnerability, *V*, were sparse. We were obliged to group species into foraging guilds, in order to generate a sufficient density of data to estimate a fishery- and species-group specific *V* for use in the study. As a result, where one species in the group is more susceptible to capture than others, the risk scores for the entire species group will be affected. This effect may have led to the elevated number of likely captures for some species, such as southern royal albatross and Westland petrel. In these examples, the *V* for each species group may be driven by observations of captures of Antipodean albatross and white-chinned petrel, respectively.

Further monitoring is necessary to determine whether the likely captures for all species ranked high to very high risk are realized. Species may occur rarely in bycatch data because they are themselves rare (yet caught in similar proportions to the population to more common species) or because the fisheries with which they interact are poorly observed. We consider that for Westland petrel, at least, these two instances may apply. Given the small and fragile nature of many of the populations of seabirds studied here, even high apparent risk should warrant serious consideration for management action.

Data on seabird captures from fisheries observer programmes may not be representative of the fishery as a whole, as observer coverage may be concentrated on a subset of vessels or in only some areas in which the fishery operates. For some fisheries, and particularly the small vessel groups, the overall rates of observer coverage were low, and therefore the *V* values may be biased by unusual events. These considerations may have an effect on the likely captures estimated for each species.

Conclusion

This work provides a useful tool for examining seabird mortality across a wide suite of fisheries in a consistent manner. It will inform decision making about where further monitoring, research and possible management activity in fisheries is warranted. It has identified the potential for fisheries effects on species in fisheries that have previously received little observer coverage or mitigation research, such as inshore trawl, and small vessel longline fisheries. It has identified the suite of species for which there should be greatest focus for future research and conservation activity. Chief among these are several species of albatross and *Procellaria* petrels, all of which are listed as threatened with extinction by the IUCN.

Acknowledgements

We are grateful to Nathan Walker, Finlay Thompson and Ben Sharp for discussion and assistance with aspects of the study. Thanks to our many colleagues at BirdLife International who contributed data to the background datasets, and Department of Conservation staff who provided information on species biology. This study was funded by the Ministry of Fisheries under project PRO2008-01. Thanks also to the data management people at the Ministry of Fisheries, the Aquatic Environment Working Group of the Ministry of Fisheries and the Seabird Stakeholder Advisory Group for their input in reviewing the work. Thanks to John Waugh, Cleo Small, Richard Phillips and Christophe Barbraud for reviewing aspects of the work as it progressed.

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Table 1. Fishing effort (number of sets or tows as appropriate) with split of vessels by group in relation to vessel length by fishing group (FG) in the study by fishing year (1October – 30 September) and with the percentage of data points that were recorded with latitudes and longitudes (rather than statistical area).

FG	Fishery description	Vessel length	2004-05	% latlong	2005-06	% latlong	2006-07	% latlong
1	Inshore trawl	≤ 28 m	25601	53%	23431	49%	21802	49%
4	BNS BLL	≤ 36 m	2484	32%	2668	41%	3161	46%
5	Small BLL	≤ 36 m	4909	36%	4168	37%	4979	44%
6	SNA BLL	≤ 36 m	6081	6%	5429	7%	5172	8%
9	BLL Autoline	> 36m	1472	100%	1208	100%	1021	100%
10	SLL Large	> 50m	328	100%	306	100%	722	100%
11	SLL Small	≤ 50 m	3766	99%	3869	100%	3094	100%
12	Middle depth TR – processor	> 36 m	18185	99%	15943	99%	16474	99%
13	Middle depth TR - fresher	> 36 m	6712	100%	5162	100%	4991	100%
15	SBW trawl	> 36 m	919	100%	641	100%	644	100%
16	SCI trawl	> 36 m	4816	100%	5135	100%	5427	100%
17	EMA/JMA trawl	> 36 m	2632	100%	2937	100%	2867	100%
18	SQU trawl	> 36 m	10059	100%	7915	100%	5060	100%
19	Deepwater trawl	> 36 m	8361	96%	9065	97%	7506	98%
Total effort			104748		95180		90389	

Table 2. Data quality of species abundance estimate information. Estimation method quality is based on that of the ACAP Status and Trends Working Group. The number of years ago that a population size was estimated is noted in groups of 5 yearly intervals. Information rated highest quality ((red) within 5 years and of high quality) is limited to 8 species only. Medium quality information ((orange) collected within 5-15 years, and of medium to high quality) is available for 7 species. Data for the remaining 48 species is of low quality.

Species group	**Years since study**	**Quality of estimate**		
		High	**Medium**	**Low**
Albatrosses (13 species)	<5 yrs	5		
	5 – 10 yrs	1		
	older	5	1	1
Procellaria petrels (4 species)	<5 yrs	2	1	
	5 – 10 yrs			1
	older			
Shearwaters (6 species)	<5 yrs	1		
	5 – 10 yrs			1
	older		1	3
All other species (40 species)	<5 yrs		5	1
	5 – 10 yrs			2
	older		5	27

Table 3. The number of observed seabird captures, and number of observations for each observed fishing group (FG). Species-fisheries groups without captures are left empty.

FG	Fishery description	Species groups					Observed events
		Pterodroma petrels	large shearwaters	large albatrosses	small albatrosses	*Procellaria* petrels	
1	Inshore trawl small vessel		29		19	2	1213
2	Bluenose BLL					5	96
3	BLL small vessel				35	11	300
4	SNA BLL		9			3	309
9	BLL autoline		7		3	28	1039
10	SLL large vessel		1	5	118	18	629
11	SLL domestic	2	9	8	14	19	414
12	Middle depths processer		45		62	10	6942
13	Middle depths trawl fresher		49		22	26	2152
15	SBW trawl					5	777
16	SCI trawl				3		127
17	Mackerel trawl		2				2044
18	SQU trawl		233		339	143	5084
19	Deepwater trawl			1	2	1	4107
	Total	2	384	14	617	271	25233

Table 4. Vulnerability estimated from a generalised linear model, multiplied by 10,000 for each fishing event in a given fishing group. The table gives the median and 90% upper confidence limit from the posterior distribution of the vulnerability, *V*. Results are shown for the 14 fishing groups for which data were available during the study, and for 5 species groups for wich vulnerability information was able to be calculated.

FG	**Fishery description**	**Species Groups**									
	Fishing Group	*Pterodroma* petrels		large shearwaters		large albatrosses		small albatrosses		*Procellaria* petrels	
		Med.	90% CL	Med.	90% CL	Med	90% CL	Med.	90% CL.	Med.	90% CL
1	Inshore trawl small vessel	0	0.17	0.28	0.35	0	5.4	19	25	1	3.5
4	Bluenose BLL	0.02	2.3	0	0.07	0	68	0	3.9	86	150
5	BLL small vessel	0	0.62	0	0.02	0	19	156	190	69	100
6	SNA BLL	0	0.53	0.27	0.41	0	24	0	1.5	17	33
9	BLL autoline	0	0.27	0.07	0.12	0	5.6	2	4.5	54	68
10	SLL large vessel	0	0.47	0.06	0.21	262	450	329	370	70	94
11	SLL domestic	3.67	8.3	0.94	1.4	654	1000	57	80	95	130
12	Middle depths processer	0	0.04	0.11	0.13	0	0.88	10	11	3	4.3
13	Middle depths trawl fresher	0	0.11	0.34	0.4	0	3	11	14	24	31
15	SBW trawl	0	0.8	0	0.01	0	9.2	0	0.49	17	30
16	SCI trawl	0.01	2.2	0	0.05	0	45	25	50	0	4.8
17	Mackerel trawl	0	0.1	0.01	0.03	0	3.3	0	0.21	0	0.22
18	SQU trawl	0	0.07	0.69	0.75	0	0.98	74	79	70	78
19	Deepwater trawl	0	0.06	0	0	6	20	1	1.3	0	1.5

Table 5. Summary of likely captures by fishing group for three fishing years, and by % in each of the fisheries studied. Figures include part birds and therefore totals may differ slightly from sum of fishing group totals due to rounding errors.

Fishing year	Inshore trawl	BNS BLL	Small BLL	SNA BLL	BLL Autoline	SLL Large	SLL Small	Middle depth TR - processor	Middle depth TR - fresher	SBW trawl	SCI trawl	EMA/JMA trawl	SQU trawl	Deepwater trawl	Grand Total
Median	**FG 1**	**FG 4**	**FG 5**	**FG 6**	**FG 9**	**FG 10**	**FG 11**	**FG 12**	**FG 13**	**FG 15**	**FG 16**	**FG 17**	**FG 18**	**FG 19**	
2004/05	1933	172	4938	252	58	134	859	551	0	6	202	0	1719	16	10840
2005/06	1864	177	1469	213	51	117	880	483	0	5	214	0	1356	17	6845
2006/07	1719	230	1681	194	43	289	684	439	0	5	225	0	878	13	6398
Median															
2004/05	18%	2%	46%	2%	1%	1%	8%	5%	0%	0%	2%	0%	16%	0%	10840
2005/06	27%	3%	21%	3%	1%	2%	13%	7%	0%	0%	3%	0%	20%	0%	6845
2006/07	27%	4%	26%	3%	1%	5%	11%	7%	0%	0%	4%	0%	14%	0%	6398
90%CL	**FG 1**	**FG 4**	**FG 5**	**FG 6**	**FG 9**	**FG 10**	**FG 11**	**FG 12**	**FG 13**	**FG 15**	**FG 16**	**FG 17**	**FG 18**	**FG 19**	**Grand Total**
2004/05	2581	374	5741	441	76	137	1150	610	64	13	362	2	1333	41	12924
2005/06	2481	389	1625	373	66	120	1174	522	49	9	387	3	1066	44	8308
2006/07	2285	504	1879	342	56	292	908	472	46	9	411	3	686	35	7928
90%CL															
2004/05	24%	3%	53%	4%	1%	1%	11%	6%	1%	0%	3%	0%	12%	0%	12924
2005/06	36%	6%	24%	5%	1%	2%	17%	8%	1%	0%	6%	0%	16%	1%	8308
2006/07	36%	8%	29%	5%	1%	5%	14%	7%	1%	0%	6%	0%	11%	1%	7928

Table 6. The 19 most at risk species of 63 included in the study are shown in this table, ranked by the median risk score (2nd column). The 90% CL for the risk score is shown in column 3. Risk score cells are coloured dark red for Very High risk, red for High risk, Orange for moderate risk, and green for Low risk. The contribution of risk from fishing in each FMA is shown in columns 4 – 13, with cells coloured orange when risk by FMA was 25% or greater, and yellow when it was 10 – 24% of the total for a species. The likely captures computed from the analysis and the calculated PBR index for each species are shown in the right hand columns, with the IUCN threat rating.

Species	Median risk score	90% CL Risk score	FMA1	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	FMA10	Likely captures 2006-07	PBR index	IUCN rating
Westland Petrel	3.0	4.9	28%	30%	11%	6%	2%	0%	17%	3%	3%	0%	238	79	VU
Chatham Albatross	2.5	3.3	12%	23%	15%	28%	6%	0%	10%	3%	3%	0%	96	38	CR
Black-browed Albatross	1.4	1.8	14%	17%	14%	13%	13%	6%	15%	3%	4%	0%	1	1	EN
Northern Royal Albatross	1.2	3.2	30%	54%	0%	1%	3%	0%	4%	0%	6%	1%	63	51	EN
Buller's Albatross (Southern)	0.8	0.7	0%	8%	31%	12%	29%	0%	19%	2%	0%	0%	760	976	VU
Salvin's Albatross	0.7	0.9	13%	17%	17%	15%	12%	6%	14%	3%	4%	0%	478	700	VU
Campbell Albatross	0.6	0.8	10%	14%	21%	8%	18%	9%	14%	2%	3%	0%	209	344	VU
Southern Royal Albatross	0.5	1.2	32%	52%	0%	1%	4%	1%	4%	0%	6%	2%	90	165	VU
Parkinson's Petrel	0.5	0.8	43%	39%	0%	0%	0%	0%	4%	4%	8%	1%	46	93	VU
Antipodean Albatross (Auckland I)	0.5	1.0	30%	52%	0%	1%	3%	0%	4%	0%	6%	4%	50	101	VU
Buller's Albatross (Northern)	0.5	0.6	26%	33%	12%	25%	0%	0%	2%	0%	3%	0%	350	733	VU
White-capped Albatross	0.4	0.6	12%	16%	17%	11%	12%	8%	18%	3%	3%	0%	1210	2780	NT
Antipodean Albatross (Antipodes I)	0.4	0.9	30%	52%	0%	1%	3%	0%	4%	0%	6%	4%	70	171	VU
Kermedec White-faced storm-petrel	0.4	1.9	28%	21%	21%	3%	5%	0%	14%	2%	5%	2%	4	11	LC
Northern giant-petrel	0.4	0.5	14%	17%	13%	14%	12%	9%	14%	3%	4%	0%	33	92	NT
White-chinned Petrel	0.3	0.5	19%	19%	10%	11%	16%	11%	8%	2%	3%	0%	292	956	VU
Grey Petrel	0.2	0.4	21%	23%	10%	11%	13%	7%	8%	2%	3%	0%	478	2044	NT
Light-mantled Albatross	0.2	0.3	14%	18%	14%	12%	12%	8%	15%	3%	4%	0%	491	212	TN
Grey-headed Albatross	0.1	0.1	14%	18%	14%	12%	13%	6%	15%	3%	4%	0%	12	141	VU

Table 7. The percent of risk for each species, distributed by FMA for the 20 least at risk species for which data were available, listed in alphabetical order. Column definitions and symbols are as for Table 6.

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Species	Median risk score	90% CL Risk score	FMA1	FMA2	FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9	FMA10	Likely captures 2006-07	PBR index	IUCN rating
Antarctic Prion	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	0%	1	11137	LC
Broad-billed Prion	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	1	11137	LC
Buller's Shearwater	0	0	28%	23%	22%	3%	5%	0%	12%	2%	5%	0%	15	24717	VU
Cape Petrel	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	0	346	LC
Chatham Petrel	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0	16	EN
Cook's Petrel	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	0	1222	EN
Fairy Prion	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	9	73174	LC
Flesh-footed Shearwater	0	0	34%	23%	15%	2%	6%	1%	11%	2%	5%	0%	1	324	LC
Great-winged Petrel	0	0	35%	55%	0%	0%	0%	0%	0%	0%	6%	4%	11	12398	CL
Hutton's Shearwater	0	0	35%	18%	29%	1%	0%	0%	8%	4%	5%	0%	5	1071	EN
Kermadec Petrel	0	0	36%	27%	9%	2%	0%	0%	17%	3%	6%	2%	0	310	LC
Little Shearwater	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	1	10381	LC
Magenta Petrel	0	0	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0	0	CR
Mottled Petrel	0	0	23%	18%	19%	3%	14%	6%	12%	2%	3%	1%	2	18597	NT
Pycroft's Petrel	0	0	84%	12%	0%	0%	0%	0%	0%	0%	2%	1%	0	78	VU
Soft-plumaged Petrel	0	0	25%	74%	0%	0%	0%	0%	0%	0%	1%	0%	0	310	CL
Sooty Shearwater	0	0	32%	11%	19%	2%	14%	6%	11%	2%	3%	0%	1210	438405	NT
South Georgia Diving-petrel	0	0	0%	2%	32%	4%	39%	10%	13%	0%	0%	0%	2	48307	LC
White-headed petrel	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0	9215	CL
White-necked Petrel	0	0	45%	0%	0%	0%	0%	0%	0%	0%	22%	33%	0	1222	VU

Table 8. Contribution of each fishing group to the likely captures for the 20 species with highest levels of likely impact. These are shown by Fishing Group for those species with greater than 1% captures in any fishing group. Cells for FMA are coloured orange when the contribution of risk for the species is greater than or equal to 25%, and yellow when it is between 10-24% of the total risk for a species.

Species with greater than negligible fisheries effects	**Likely captures (Total)**	**Inshore trawl**	**BNS BLL**	**Small BLL**	**SNA BLL**	**BLL Autoline**	**SLL Large**	**SLL Small**	**Middle depth TR - processor**	**Middle depth TR - fresher**	**SBW trawl**	**SCI trawl**	**EMA /JMA trawl**	**SQU trawl**	**Deep water trawl**
		1	**4**	**5**	**6**	**9**	**10**	**11**	**12**	**13**	**15**	**16**	**17**	**18**	**19**
Antipodean Albatross (Antipodes I)	70	0%	0%	0%	0%	0%	8%	90%	0%	0%	0%	0%	0%	0%	2%
Chatham Albatross	96	25%	0%	48%	0%	0%	3%	7%	6%	0%	0%	6%	0%	5%	0%
Buller's Albatross (Southern)	760	25%	0%	33%	0%	0%	6%	0%	8%	0%	0%	4%	0%	25%	0%
Grey-headed Albatross	12	26%	0%	36%	0%	0%	8%	5%	6%	0%	0%	6%	0%	13%	0%
Black-browed Albatross	1	24%	0%	35%	0%	0%	8%	6%	6%	0%	0%	7%	0%	13%	0%
Southern Royal Albatross	90	0%	0%	0%	0%	0%	9%	88%	0%	0%	0%	0%	0%	0%	2%
Northern Royal Albatross	63	0%	0%	0%	0%	0%	8%	89%	0%	0%	0%	0%	0%	0%	3%
Salvin's Albatross	478	26%	0%	37%	0%	0%	7%	5%	6%	0%	0%	7%	0%	12%	0%
Buller's Albatross (Northern)	350	27%	0%	48%	0%	0%	3%	9%	3%	0%	0%	8%	0%	1%	0%
Antipodean Albatross (Auckland I)	50	0%	0%	0%	0%	0%	8%	90%	0%	0%	0%	0%	0%	0%	2%
Kermedec White-faced Storm-petrel	4	60%	0%	0%	9%	0%	0%	16%	11%	0%	0%	0%	0%	3%	0%
Northern giant-petrel	33	24%	0%	36%	0%	0%	7%	5%	5%	0%	0%	7%	0%	14%	0%
Grey Petrel	478	2%	21%	25%	5%	3%	3%	16%	7%	0%	1%	0%	0%	18%	0%
Westland Petrel	238	3%	25%	36%	9%	3%	2%	13%	7%	0%	0%	0%	0%	2%	0%
Sooty Shearwater	1210	58%	0%	0%	10%	0%	0%	5%	11%	0%	0%	0%	0%	15%	0%
Light-mantled Albatross	491	25%	0%	35%	0%	0%	8%	5%	5%	0%	0%	6%	0%	14%	0%
Parkinson's Petrel	46	2%	28%	25%	11%	1%	1%	30%	2%	0%	0%	0%	0%	0%	0%
White-chinned Petrel	292	2%	19%	24%	5%	3%	3%	13%	7%	0%	1%	0%	0%	24%	0%
Campbell Albatross	209	27%	0%	30%	0%	0%	6%	4%	7%	0%	0%	7%	0%	19%	0%
White-capped Albatross	1210	27%	0%	36%	0%	0%	7%	5%	6%	0%	0%	6%	0%	13%	0%

Table 9. For fishing group 1 (Inshore Trawl) the 16 species which are likely to interact with the fishery and have highest levels of likely impact (from Table 6) are shown. Species data by row shows the likely contribution of this fishing group to the total captures of that species (column 2), and the contribution of fishing effort in each FMA to those captures (columns 3 – 12). Cells for FMA are coloured orange when the value for the species is greater than or equal to 25% of risk, and yellow when it is between 10-24%.

Selected species	**Selected fishery**	**FMA**									
	Inshore trawl	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chatham Albatross	25%	21%	29%	23%	1%	5%	0%	14%	3%	4%	0%
Buller's Albatross (Southern)	25%	0%	6%	55%	0%	15%	0%	22%	1%	0%	0%
Grey-headed Albatross	26%	24%	22%	24%	1%	6%	0%	16%	3%	5%	0%
Black-browed Albatross	24%	23%	21%	26%	1%	5%	0%	17%	3%	5%	0%
Salvin's Albatross	26%	22%	20%	29%	0%	5%	0%	15%	3%	5%	0%
Buller's Albatross (Northern)	27%	41%	37%	16%	1%	0%	0%	2%	0%	3%	0%
Kermedec White-faced Storm-petrel	60%	24%	22%	24%	1%	5%	0%	17%	3%	5%	0%
Northern giant-petrel	24%	24%	22%	24%	1%	6%	0%	16%	3%	5%	0%
Grey Petrel	2%	23%	23%	24%	1%	6%	0%	16%	3%	5%	0%
Westland Petrel	3%	26%	23%	15%	0%	2%	0%	26%	3%	4%	0%
Sooty Shearwater	58%	34%	15%	23%	1%	6%	0%	14%	3%	4%	0%
Light-mantled Albatross	25%	24%	22%	24%	1%	6%	0%	16%	3%	5%	0%
Parkinson's Petrel	2%	44%	35%	0%	0%	0%	0%	9%	5%	8%	0%
White-chinned Petrel	2%	24%	22%	24%	1%	6%	0%	16%	3%	5%	0%
Campbell Albatross	27%	15%	15%	40%	0%	10%	0%	15%	2%	3%	0%
White-capped Albatross	27%	19%	18%	28%	0%	7%	0%	21%	2%	4%	0%
Total captures		415	286	474	9	117	0	269	41	61	0

Table 10. For fishing group 5 (small bottom longline) the 14 species which are likely to interact with the fishery and have highest levels of likely impact (from Table 6) are shown. Species data by row shows the likely contribution of this fishing group to the total captures of that species (column 2), and the contribution of fishing effort in each FMA to those captures (columns 3 – 12). Cells for FMA are coloured orange when the value for the species is greater than or equal to 25% of risk, and yellow when it is between 10-24%.

Selected species	Selected fishery	FMA									
	Small BLL	1	2	3	4	5	6	7	8	9	10
Chatham Albatross	48%	9%	18%	12%	44%	1%	0%	10%	4%	3%	0%
Buller's Albatross (Southern)	33%	0%	14%	29%	24%	2%	0%	26%	4%	0%	0%
Grey-headed Albatross	36%	14%	20%	12%	24%	2%	0%	17%	6%	6%	0%
Black-browed Albatross	35%	15%	18%	12%	26%	2%	0%	16%	6%	6%	0%
Salvin's Albatross	37%	13%	18%	14%	27%	1%	0%	16%	6%	5%	0%
Buller's Albatross (Northern)	48%	20%	26%	11%	37%	0%	0%	3%	0%	4%	0%
Northern giant-petrel	36%	13%	18%	11%	29%	1%	0%	16%	6%	5%	0%
Grey Petrel	25%	14%	21%	12%	23%	2%	0%	17%	6%	5%	0%
Westland Petrel	36%	15%	26%	12%	9%	2%	0%	29%	6%	3%	0%
Light-mantled Albatross	35%	14%	20%	12%	24%	2%	0%	17%	6%	6%	0%
Parkinson's Petrel	25%	29%	37%	0%	0%	0%	0%	12%	12%	11%	0%
White-chinned Petrel	24%	14%	19%	13%	24%	2%	0%	17%	6%	5%	0%
Campbell Albatross	30%	12%	20%	17%	19%	2%	0%	20%	5%	5%	0%
White-capped Albatross	36%	12%	19%	14%	20%	2%	0%	22%	6%	5%	0%
Total captures		190	315	248	389	25	0	300	81	62	0

Table 11. For fishing group 18 (squid trawl) the 14 species which are likely to interact with the fishery and have highest levels of likely impact (from Table 6) are shown. Species data by row shows the likely contribution of this fishing group to the total captures of that species (column 2), and the contribution of fishing effort in each FMA to those captures (columns 3 – 12). Cells for FMA are coloured orange when the value for the species is greater than or equal to 25% of risk, and yellow when it is between 10-24%.

Selected species	**Selected fishery**	**FMA**									
	SQU trawl	1	2	3	4	5	6	7	8	9	10
Chatham Albatross	5%	0%	0%	32%	2%	63%	3%	0%	0%	0%	0%
Buller's Albatross (Southern)	25%	0%	0%	18%	0%	82%	0%	0%	0%	0%	0%
Grey-headed Albatross	13%	0%	0%	13%	1%	57%	28%	0%	0%	0%	0%
Black-browed Albatross	13%	0%	0%	13%	1%	57%	28%	0%	0%	0%	0%
Salvin's Albatross	12%	0%	0%	17%	1%	55%	27%	0%	0%	0%	0%
Kermedec White-faced Storm-petrel	3%	1%	0%	68%	4%	27%	0%	0%	0%	0%	0%
Northern giant-petrel	14%	0%	0%	11%	1%	47%	41%	0%	0%	0%	0%
Grey Petrel	18%	0%	0%	13%	1%	56%	30%	0%	0%	0%	0%
Westland Petrel	2%	2%	0%	89%	0%	8%	0%	0%	0%	0%	0%
Sooty Shearwater	15%	0%	0%	15%	1%	53%	31%	0%	0%	0%	0%
Light-mantled Albatross	14%	0%	0%	12%	1%	50%	38%	0%	0%	0%	0%
White-chinned Petrel	24%	0%	0%	10%	1%	53%	36%	0%	0%	0%	0%
Campbell Albatross	19%	0%	0%	17%	0%	61%	22%	0%	0%	0%	0%
White-capped Albatross	13%	0%	0%	14%	1%	46%	39%	0%	0%	0%	0%
Total captures		1	0	135	6	507	224	0	0	0	0

Table 12. For fishing group 11 (small surface longline) the 19 species which are likely to interact with the fishery and have highest levels of likely impact (from Table 6) are shown. Species data by row shows the likely contribution of this fishing group to the total captures of that species (column 2), and the contribution of fishing effort in each FMA to those captures (columns 3 – 12). Cells for FMA are coloured orange when the value for the species is greater than or equal to 25% of risk, and yellow when it is between 10-24%.

Selected species	Selected fishery	FMA									
	SLL Small	1	2	3	4	5	6	7	8	9	10
Antipodean Albatross (Antipodes I)	90%	34%	55%	0%	0%	0%	0%	0%	0%	7%	4%
Chatham Albatross	7%	25%	70%	0%	0%	0%	0%	0%	0%	4%	1%
Grey-headed Albatross	5%	35%	57%	0%	0%	0%	0%	0%	0%	6%	2%
Black-browed Albatross	6%	35%	54%	0%	0%	0%	0%	0%	0%	7%	5%
Southern Royal Albatross	88%	35%	56%	0%	0%	0%	0%	0%	0%	6%	2%
Northern Royal Albatross	89%	34%	58%	0%	0%	0%	0%	0%	0%	7%	1%
Salvin's Albatross	5%	36%	56%	0%	0%	0%	0%	0%	0%	6%	1%
Buller's Albatross (Northern)	9%	33%	63%	0%	0%	0%	0%	0%	0%	2%	1%
Antipodean Albatross (Auckland I)	90%	34%	55%	0%	0%	0%	0%	0%	0%	7%	4%
Kermedec White-faced Storm-petrel	16%	32%	48%	0%	0%	0%	0%	0%	0%	7%	12%
Northern giant-petrel	5%	36%	56%	0%	0%	0%	0%	0%	0%	5%	2%
Grey Petrel	16%	33%	61%	0%	0%	0%	0%	0%	0%	4%	1%
Westland Petrel	13%	33%	66%	0%	0%	0%	0%	0%	0%	1%	0%
Sooty Shearwater	5%	39%	49%	0%	0%	0%	0%	0%	0%	9%	4%
Light-mantled Albatross	5%	36%	56%	0%	0%	0%	0%	0%	0%	7%	0%
Parkinson's Petrel	30%	35%	52%	0%	0%	0%	0%	0%	0%	8%	4%
White-chinned Petrel	13%	33%	60%	0%	0%	0%	0%	0%	0%	4%	2%
Campbell Albatross	4%	35%	54%	0%	0%	0%	0%	0%	0%	7%	5%
White-capped Albatross	5%	36%	56%	0%	0%	0%	0%	0%	0%	6%	2%
Total captures		213	354	0	0	0	0	1	1	35	13

Table 13. Sensitivity test results for risk scores for nine species for which there were changes in risk score as a result of sensitivity testing. The risk score described in the results in Table 6 is shown in column 2. Outcomes from changing the weightings of NABIS layer weights are next. Two levels of cryptic kill resulting from trawl warp strike mortality of non-landed birds are included, with rates of 2 times and 10 x the observed mortality rates. Risk scores as a result of changes in r_{max} values are shown for two species in the right hand column. N/A indicates where the sensitivity test was not applied to that species.

Selected species	Median risk score 2006-07	NABIS	Risk score Cryptic x2	Risk score Cryptic x10	Risk score RMAX
Westland Petrel	3.0	3.6	N/A	N/A	3.4
Chatham Albatross	2.5	2.5	6.9	34.3	N/A
Black-browed Albatross	1.4	1.4	5.1	25.3	N/A
Buller's Albatross (Southern)	0.8	0.8	3.6	17.9	N/A
Salvin's Albatross	0.7	0.7	2.4	12.2	N/A
Campbell Albatross	0.6	0.6	2.6	12.9	N/A
Buller's Albatross (Northern)	0.5	0.6	1.2	6.2	N/A
White-capped Albatross	0.4	0.5	1.6	8.0	N/A
White-chinned Petrel	0.6	0.7	N/A	N/A	0.3

Figure 1. The New Zealand EEZ showing major Fishery Management Areas (numbered 1-10).

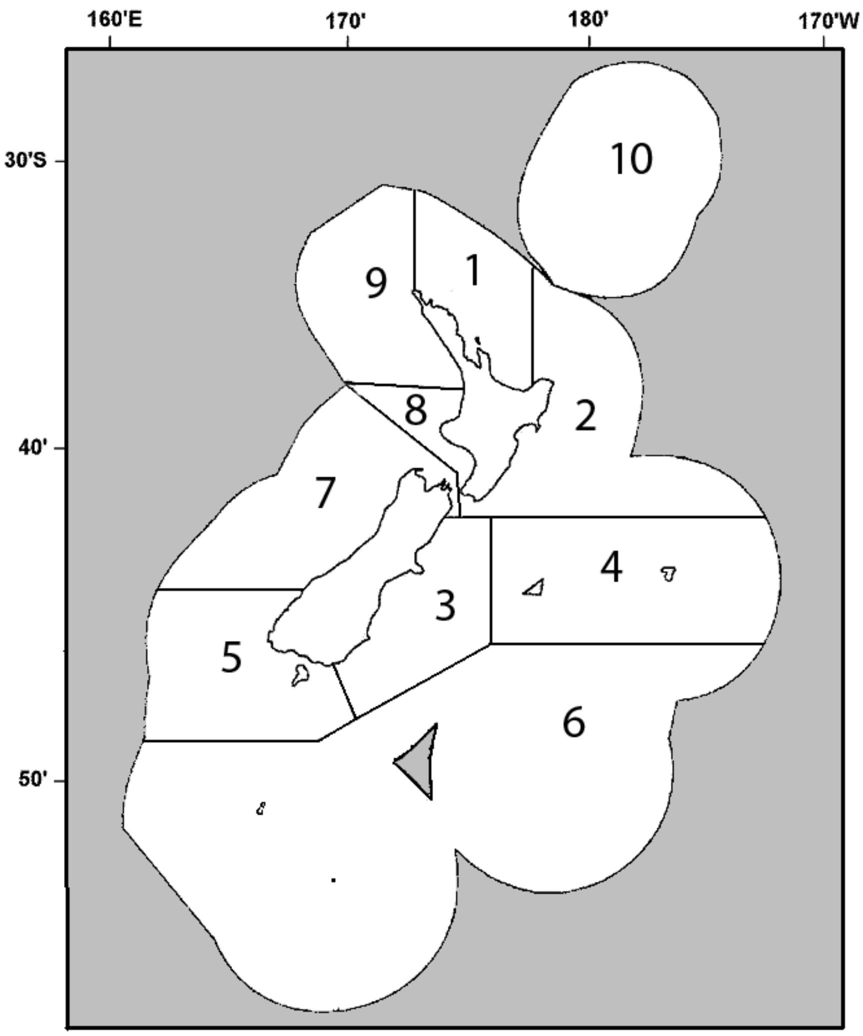
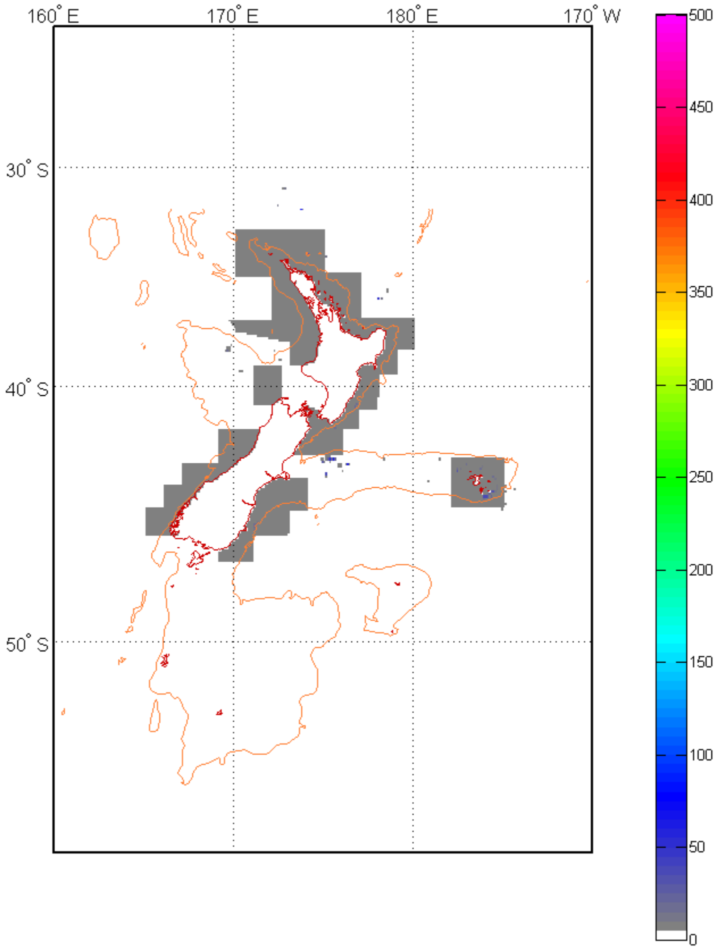


Figure 2. Map of the distribution of fishing effort within the NZEEZ for bluenose bottom longline fisheries (FG4). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



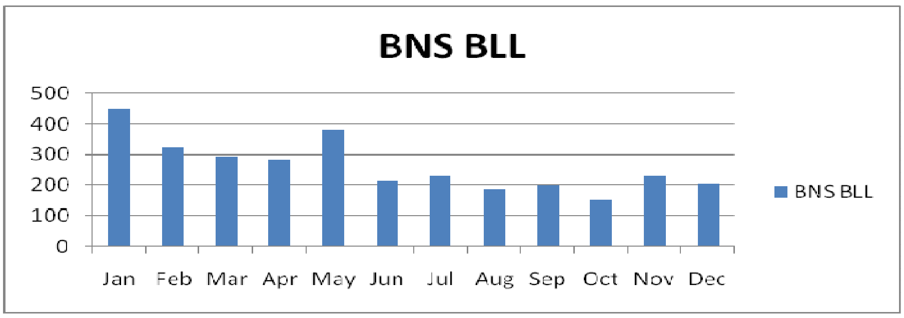
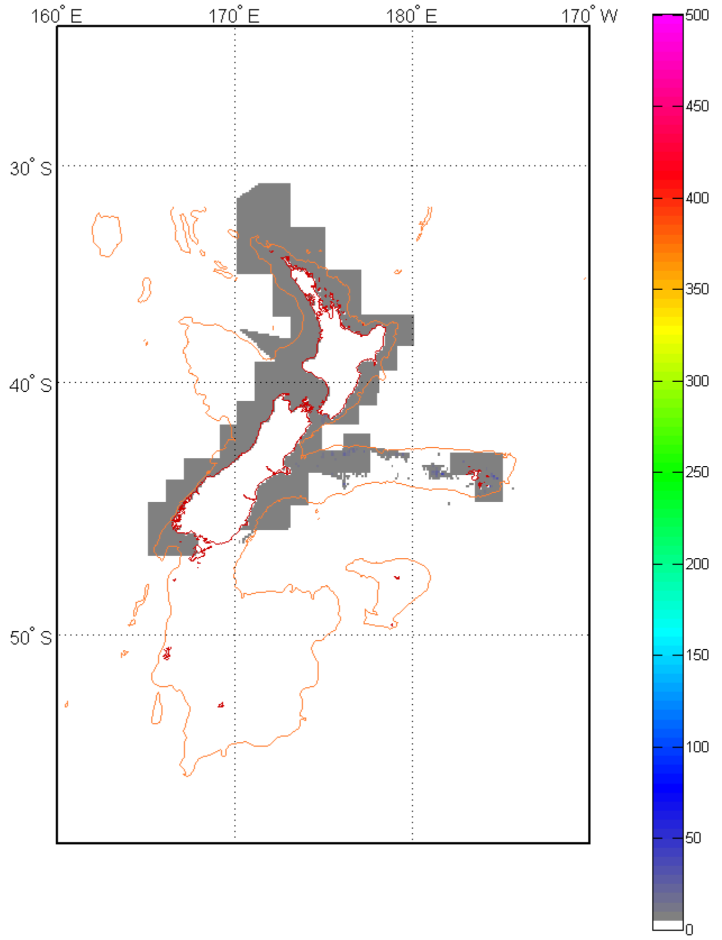


Figure 3. Map of the distribution of fishing effort within the NZEEZ for small bottom longline fisheries (FG5). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



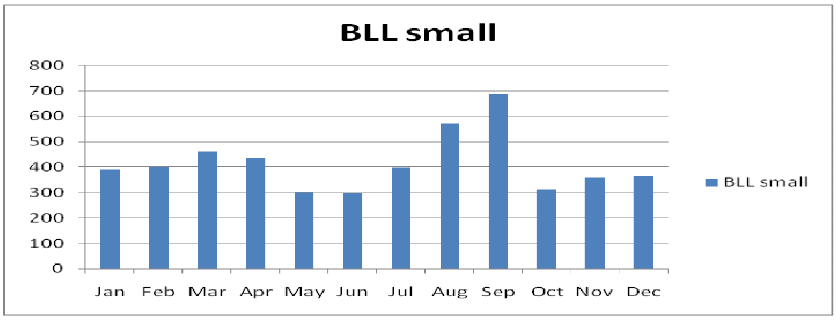
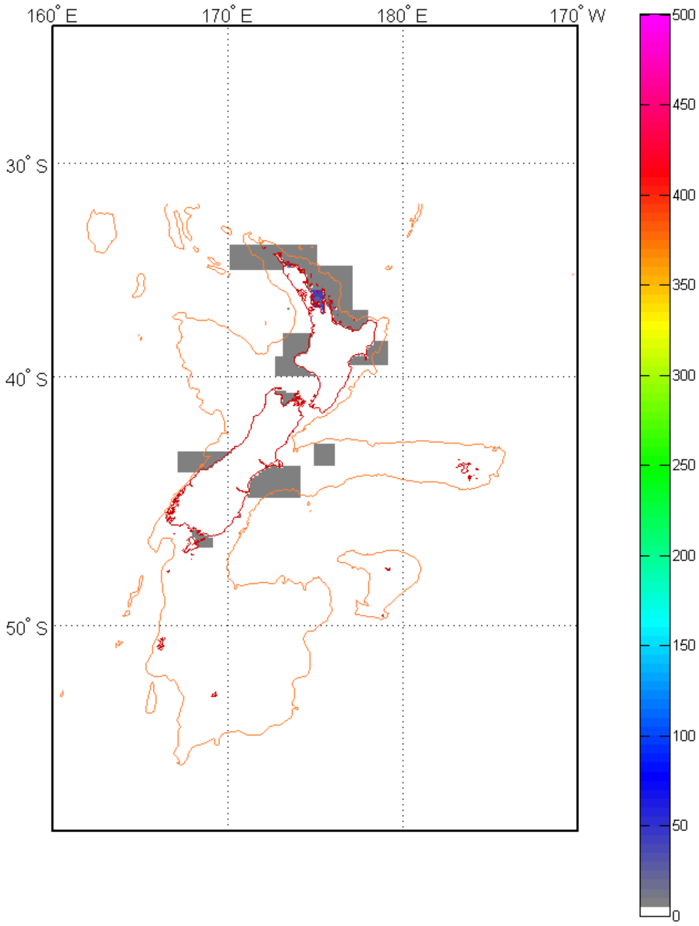


Figure 4. Map of the distribution of fishing effort within the NZEEZ for snapper bottom longline fisheries (FG6). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



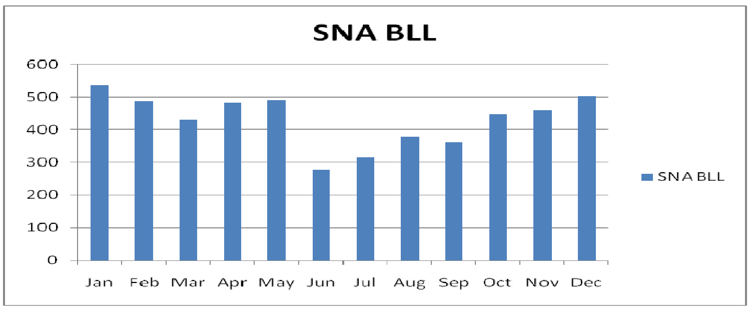
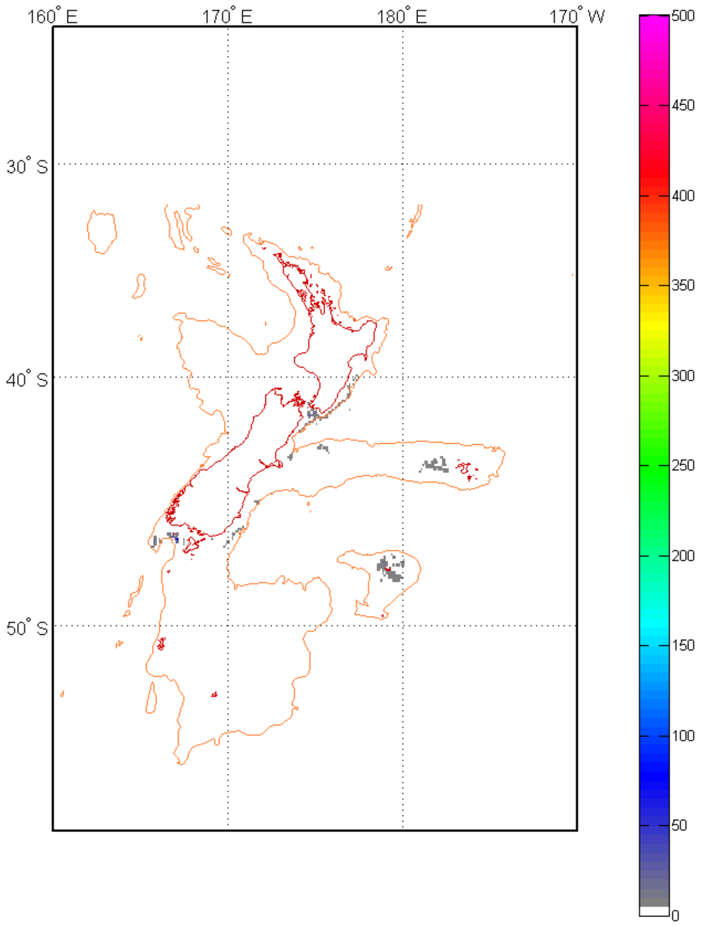


Figure 5. Map of the distribution of fishing effort within the NZEEZ for ling autoline fisheries (FG9). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



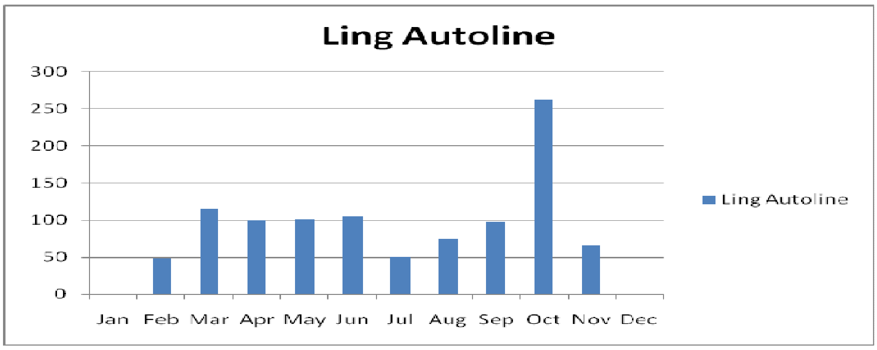
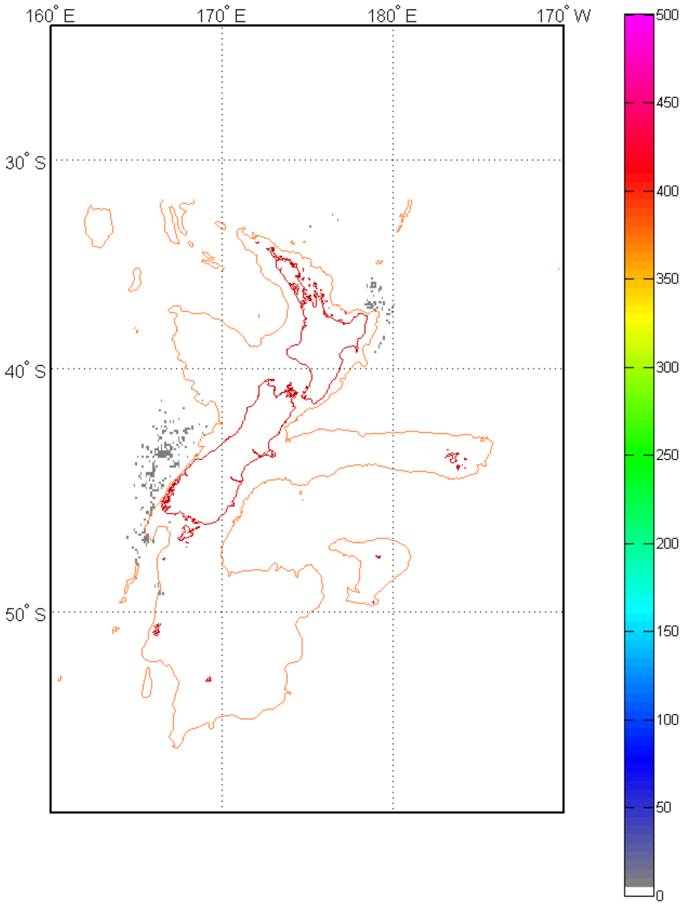


Figure 6. Map of the distribution of fishing effort within the NZEEZ for large surface longline fisheries (FG10). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



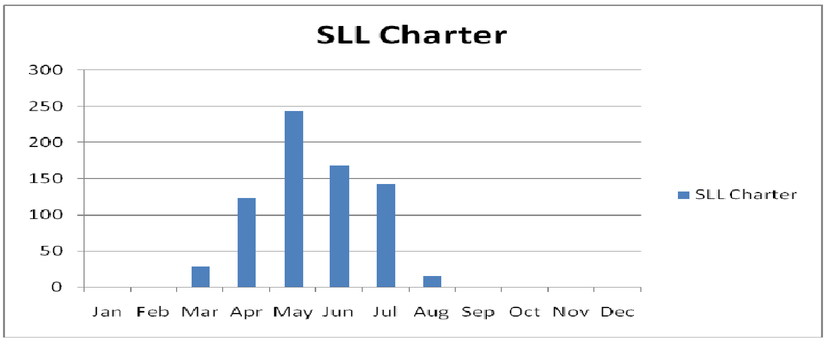
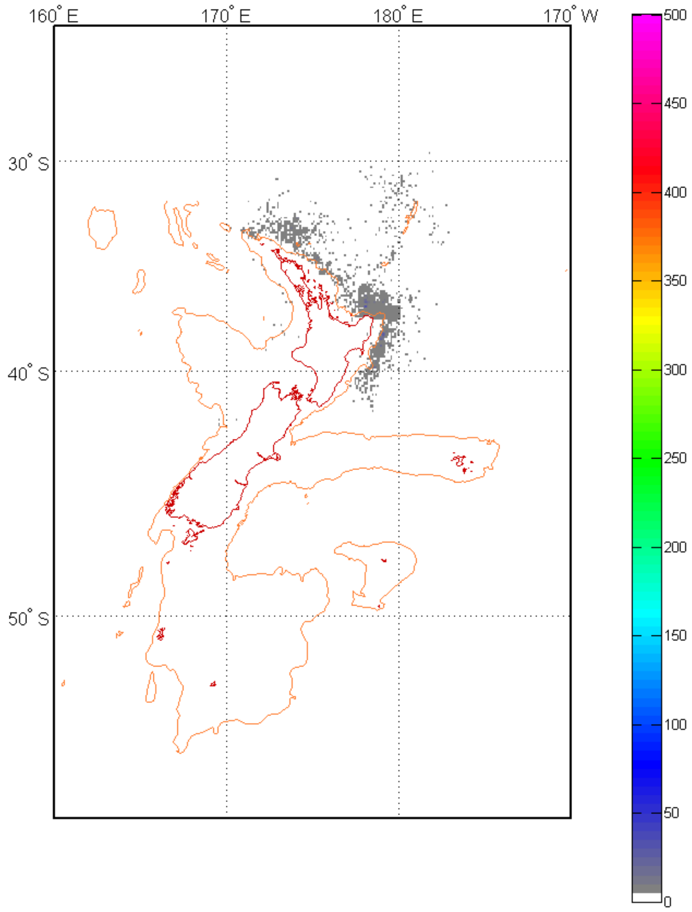


Figure 7. Map of the distribution of fishing effort within the NZEEZ for small surface longline fisheries (FG11). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



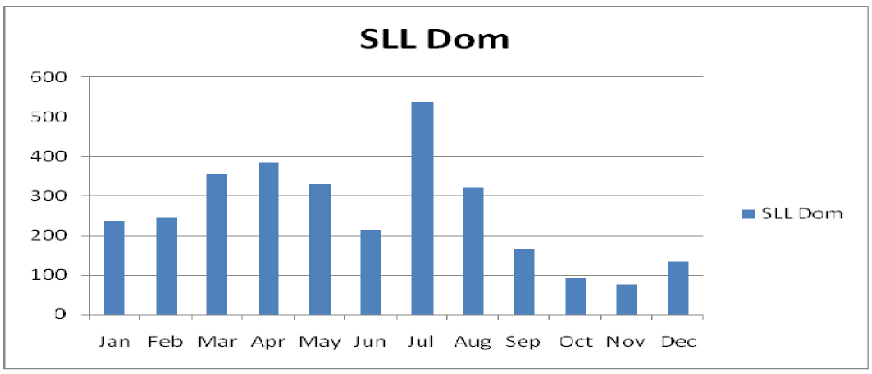
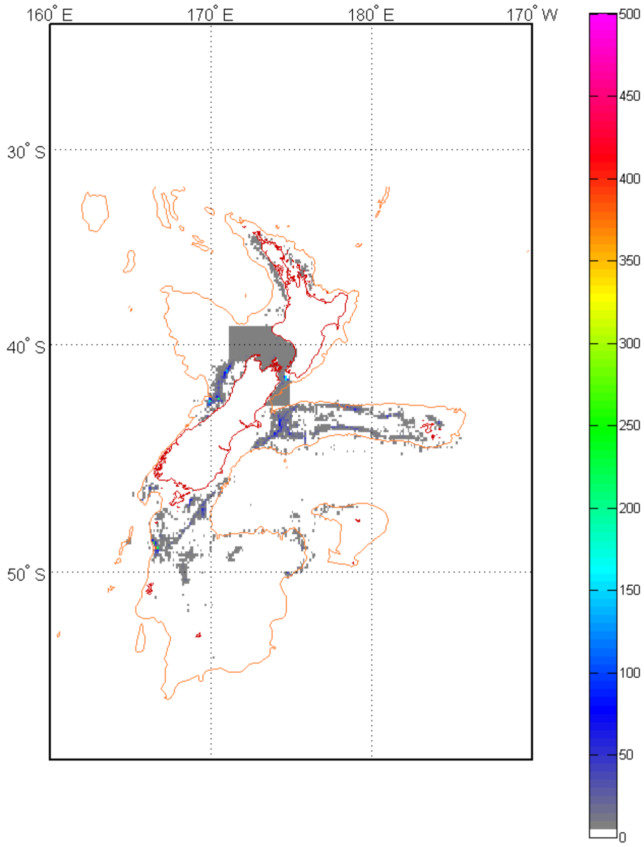


Figure 8a. Map of the distribution of fishing effort within the NZEEZ for middle depths trawl (processor) fisheries (FG12). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



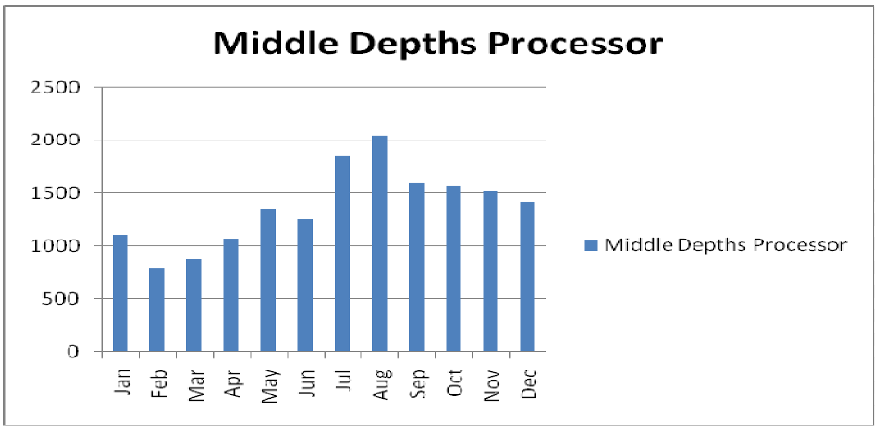
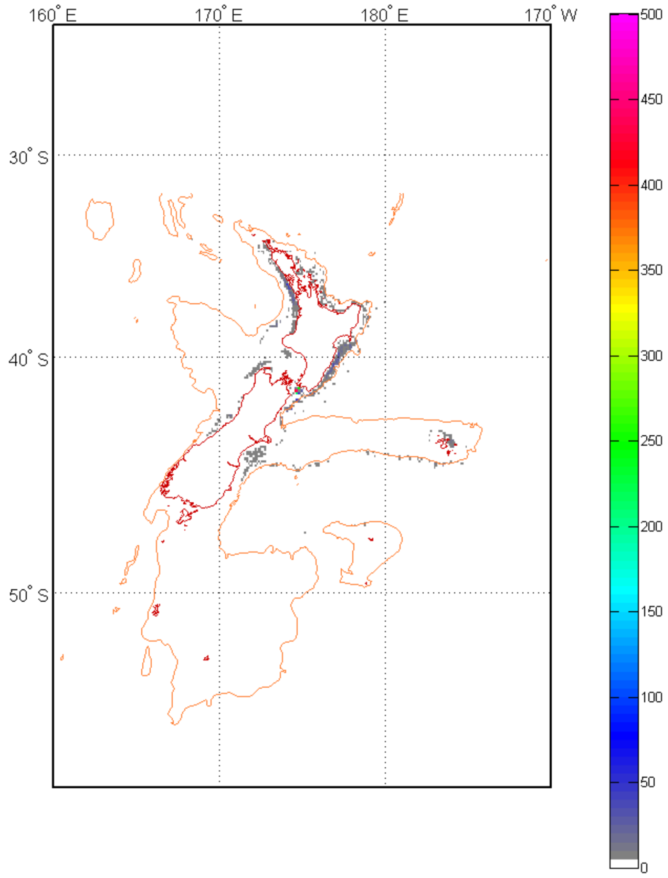


Figure 9. Map of the distribution of fishing effort within the NZEEZ for middle depths trawl (fresher) fisheries (FG13). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



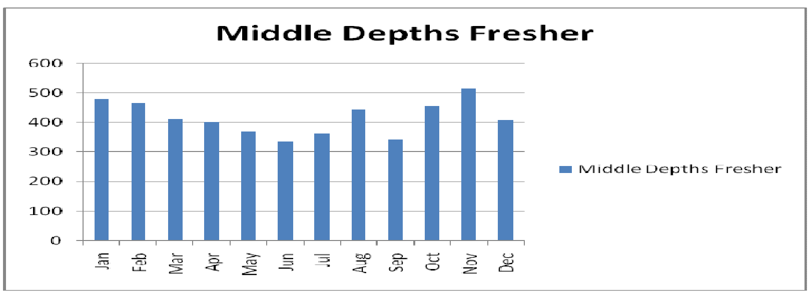
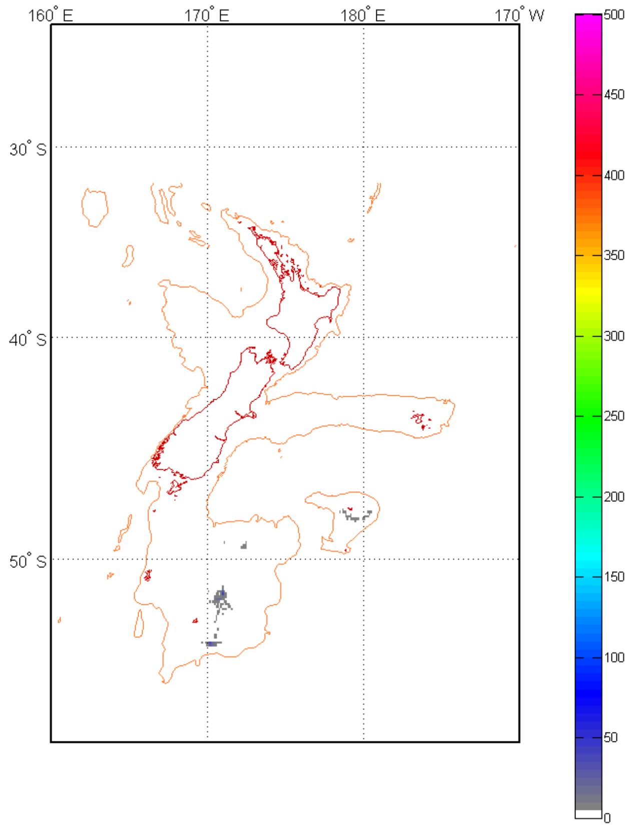


Figure 10. Map of the distribution of fishing effort within the NZEEZ for southern blue whiting trawl fisheries (FG15). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



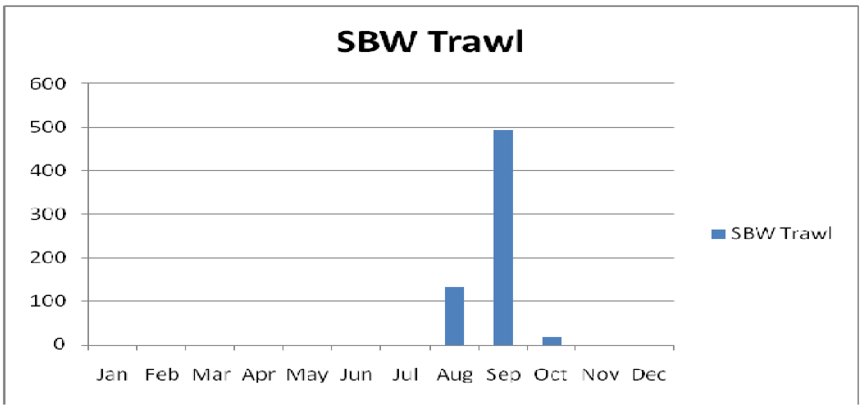
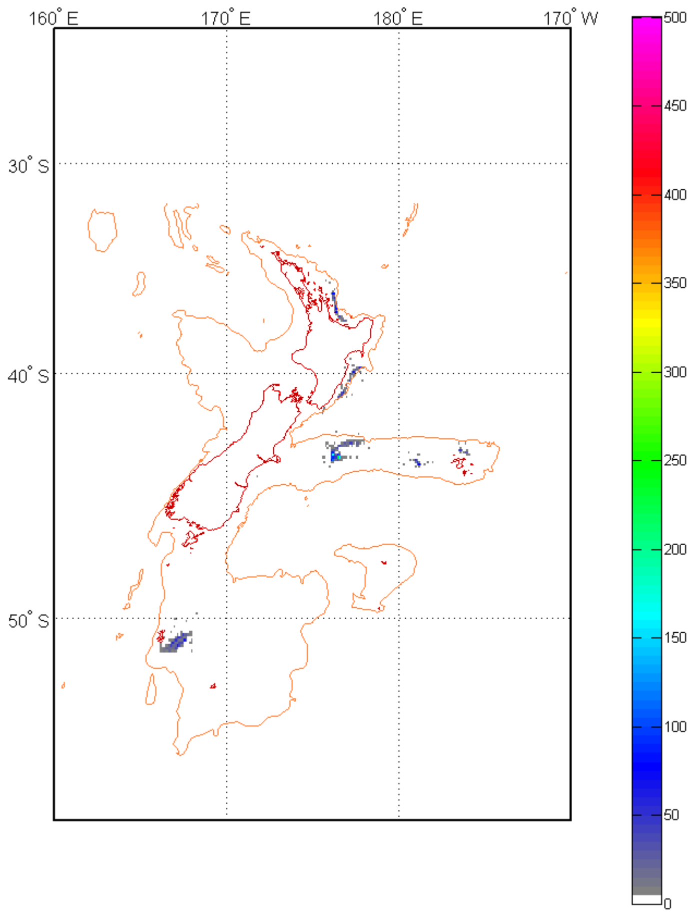


Figure 11. Map of the distribution of fishing effort within the NZEEZ for scampi trawl fisheries (FG16). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



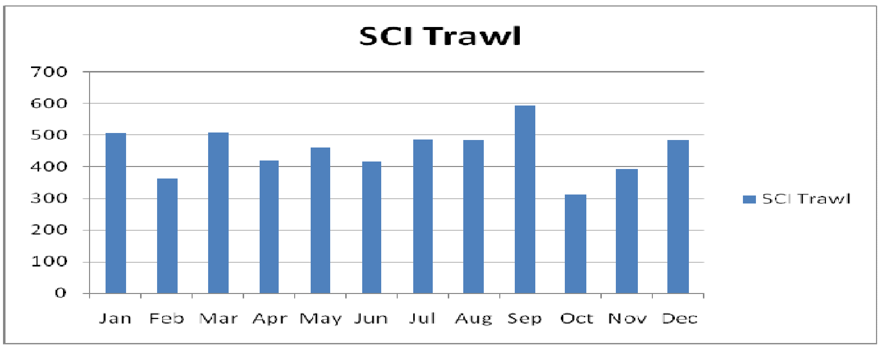
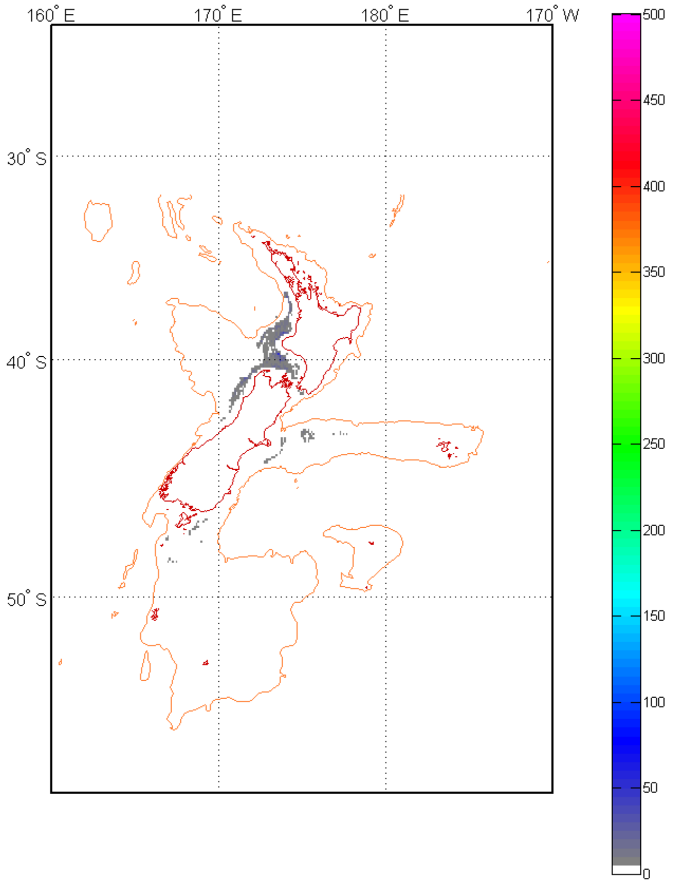


Figure 12. Map of the distribution of fishing effort within the NZEEZ for mackerel trawl fisheries (FG17). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



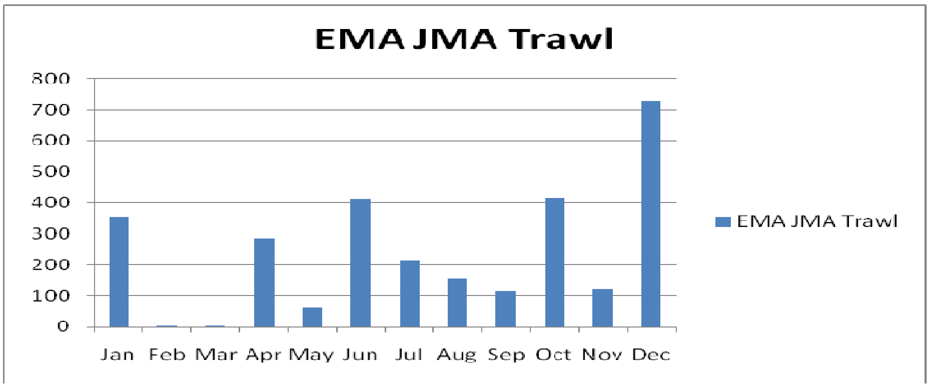
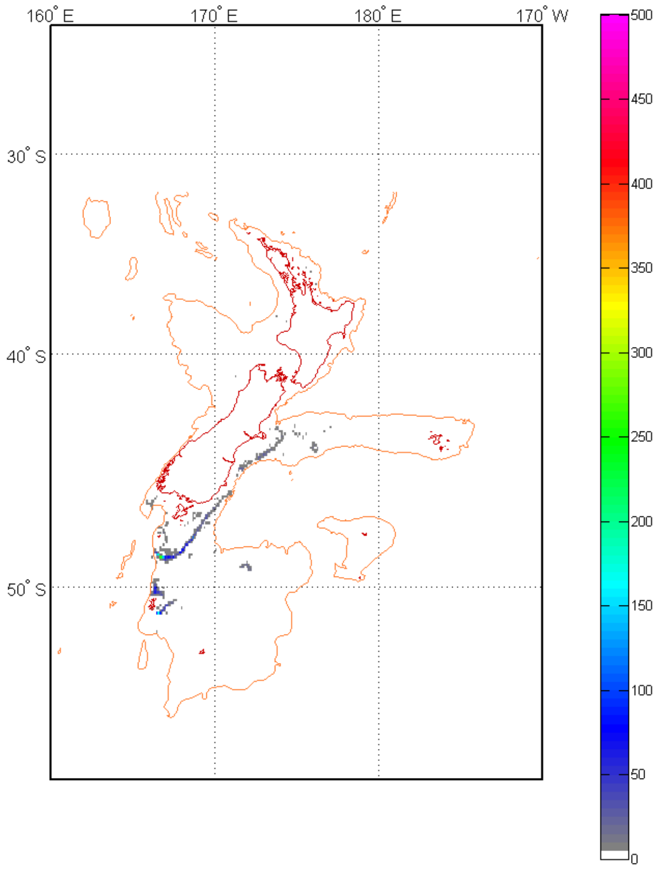


Figure 13. Map of the distribution of fishing effort within the NZEEZ for squid trawl fisheries (FG18). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



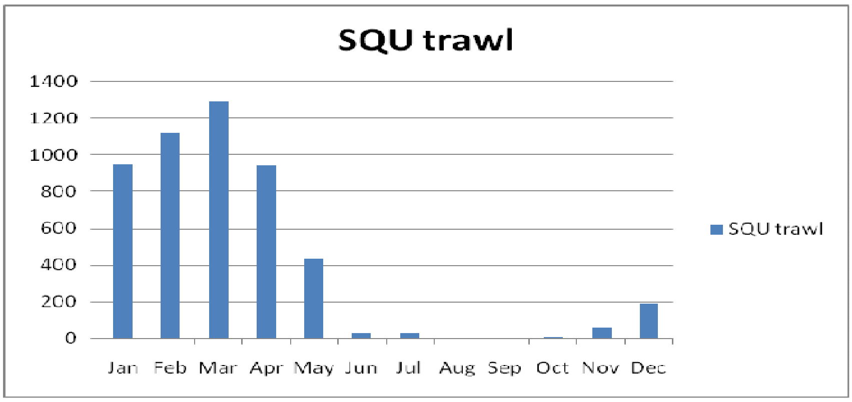
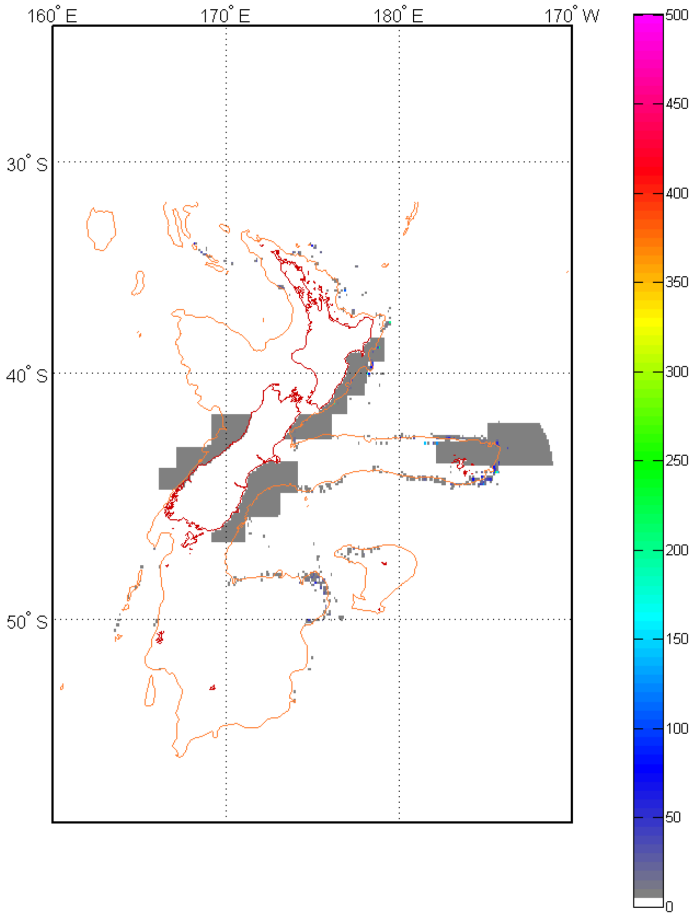


Figure 14. Map of the distribution of fishing effort within the NZEEZ for deep water trawl fisheries (FG19). The colourway shown on the right shows the number of events per 0.1 degree longitude by 0.1 degree latitude square or by larger squares when data were reported by statistical area. The spread of fishing effort for 2006-07 across calendar month is shown in the lower plot.



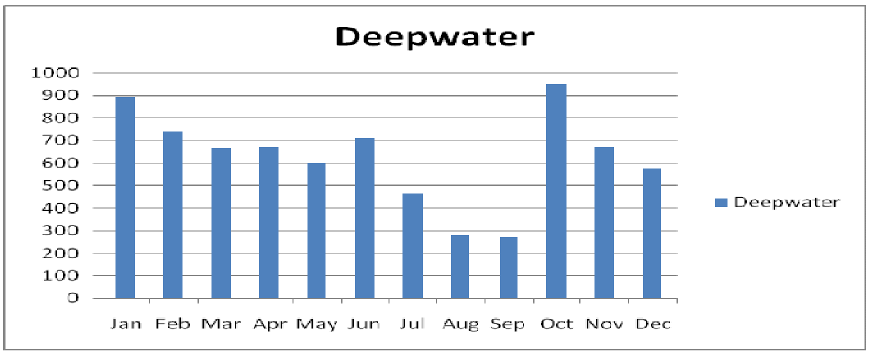
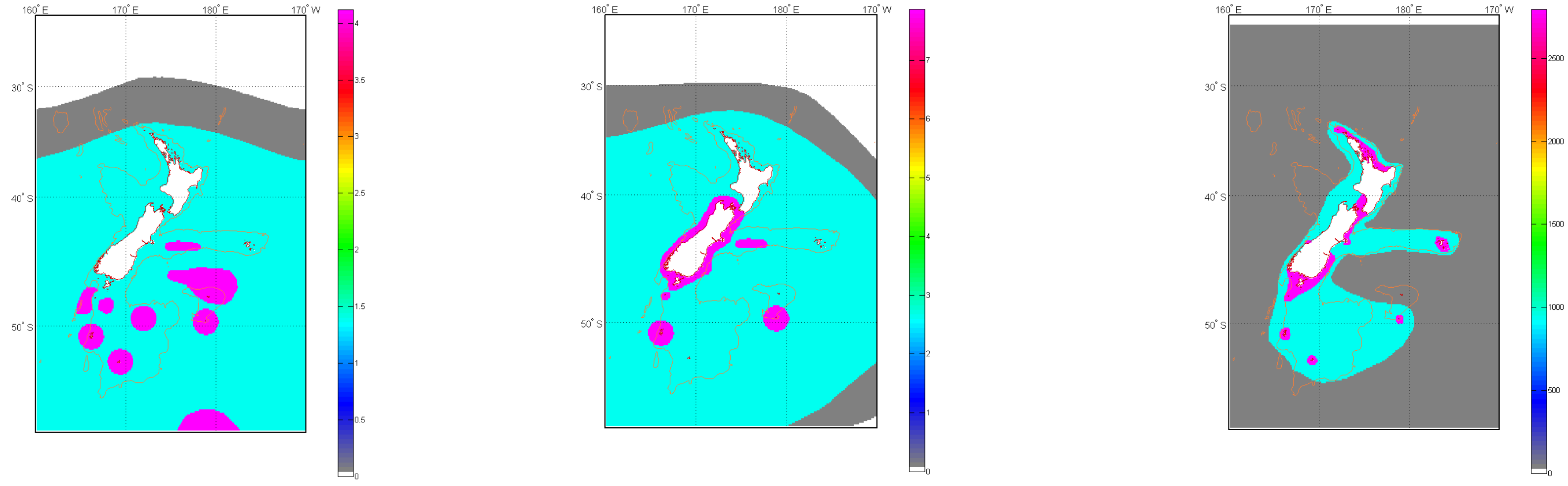


Figure 15. Three examples of species distributions, using NABIS data, with bird density per 0.1 degree square. For white chinned petrel, white-capped albatross and sooty shearwater

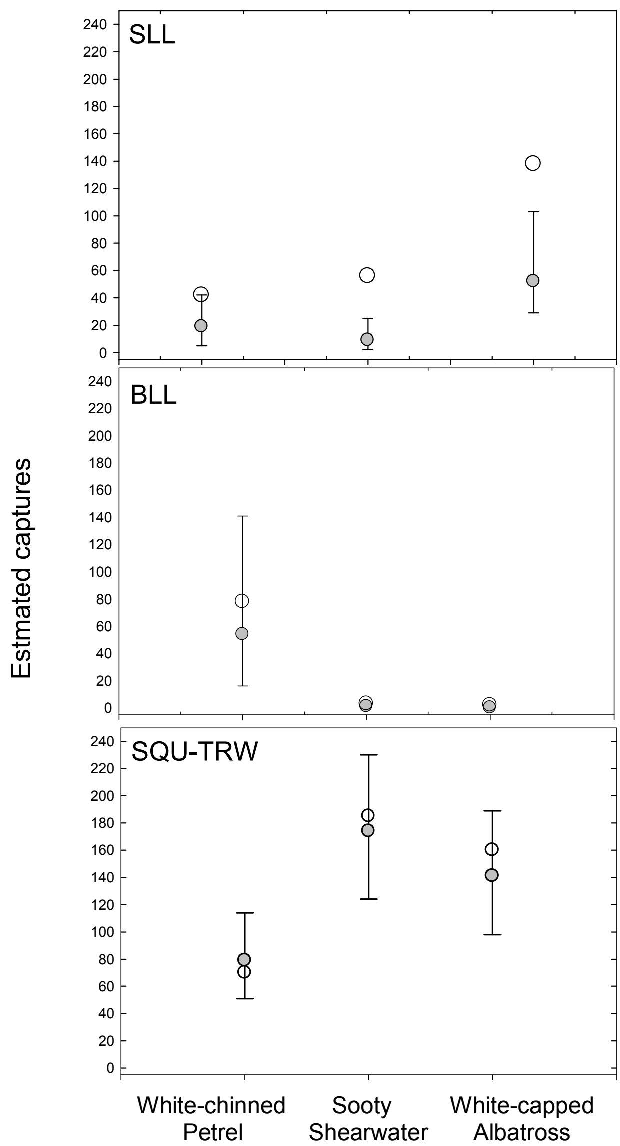


White-chinned petrel

White-capped albatross

Sooty shearwater

Figure 16. Estimated captures of white chinned petrels, sooty shearwaters and white-capped albatrosses in three fisheries compared between this study (2006-07 fishing year, open circles) and those of Abraham and Thompson (2008) (filled circles and error bars). These fisheries combine fishing groups differently depending on the available data from Abraham and Thompson (2008). All surface longline fisheries (FG10 and 11) are compared across all species. For bottom longline, estimated captures were available for all fisheries in this fishing group for white-chinned petrels, but Ling Autoline only (FG9) for sooty shearwater and white-capped albatross estimates. Squid trawl fishery capture estimates for FMA5 and 6 from this study were used to compare with figures for the Snares-Stewart Shelf and SQU6T fisheries from Abraham and Thompson (2008) for all species.



Appendix 1. Biological attributes for 63 species of seabird used in the Ecological Risk Assessment. Species are classed by species group then alphabetically by species within those groups. Data fields are species names, scientific and common, species group, IUCN ranking, the species code used in the analysis, the average age at maturity (age mat), average adult survival, r_{max}, years since population survey (<5 yrs, 5-10 years, older), population (see methods), population data quality assessment, source for population size, individual population size used in study, F value based on IUCN ranking and PBR index calculated in this study.

BLI Scientific name	Common name	Species group	IUCN	Species code in this study	Age at maturity	Surv.	r_{max}	Species proxy value used	Population estimate category (yrs)	Population estimate method	Population data quality assessment	Popn size source	Number of individuals	F value	PBR index
Phalacrocorax campbelli	Campbell Island Shag	Cormorants	VU	CSG	3	86	0.197	Y	older	Low	Low	Robertson & Bell 1984	4000	0.3	78
Phalacrocorax carunculatus	New Zealand King Shag	Cormorants	VU	KSG	3	86	0.197	Y	older	Medium	Med-Low	Schuckard 1994	550	0.3	11
Phalacrocorax chalconotus	Stewart Island Shag	Cormorants	VU	SSG	3	86	0.197	Y	<5	Low	Low	Lalas & Perriman 2009	4600	0.3	136
Phalacrocorax colensoi	Auckland Islands Shag	Cormorants	VU	ASG	3	86	0.197	Y	older	Low	Low	Taylor 2000a	3472	0.3	67
Phalacrocorax featherstoni	Pitt Island Shag	Cormorants	EN	PSG	2	95	0.175	Y	<5	Medium	Medium	Bell & Charteris unpublished	2076	0.1	12
Phalacrocorax onslowi	Chatham Islands Shag	Cormorants	CR	CHS	3	86	0.97	Y	<5	Medium	Medium	Bell & Charteris unpublished	270	0.1	9
Phalacrocorax punctatus	Spotted Shag	Cormorants	LC	NSG	2	86	0.175	Y	5_10	Low	Low	Taylor 2000a,. BirdLife WBDB	35000	0.5	1006
Phalacrocorax ranfurlyi	Bounty Islands Shag	Cormorants	VU	BSG	3	86	0.197	Y	older	Low	Low	Clark et al 1998	480	0.3	9
Diomedea antipodensis antipodensis	Antipodean Albatross	Diomedea	VU	ANA	7	95.4	0.066848		older	High	Med-Low	Walker et al 2002	25960	0.3	171
Diomedea antipodensis gibsoni	Gibsons Albatross	Diomedea	VU	GBA	7	97	0.056395		5_10	High	High	Walker & Elliot 2002	18151	0.3	101
Diomedea epomophora	Southern Royal Albatross	Diomedea	VU	DIP	7	97	0.056395		older	High	Med-Low	Moore et al. 1997	29694	0.3	165
Diomedea sanfordi	Northern Royal Albatross	Diomedea	EN	DIS	7	94.6	0.071078		<5	High	High	ACAP	22025.5	0.1	51
Morus serrator	Australasian Gannet	Gannets	LC	MOS	5	90	0.113		older	Medium	Med-Low	Wodzicki et al. 1984	157992	0.5	2933
Sula dactylatra	Masked Booby	Gannets	LC	MBO	3	92.5	0.151		older	Low	Low	Bell (1970)	400	0.5	10
Gygis alba	Common White Tern	Gulls&terns	LC	GAL	5	84	0.136	Y	older	Low	Low	Taylor 2000b	75	0.5	3
Larus dominicanus	Kelp Gull	Gulls&terns	LC	XBG	4	81	0.173		older	Low	Low	Robertson & Bell 1984	3000000	0.5	85252
Sterna caspia	Caspian Tern	Gulls&terns	LC	CAT	3	89	0.18		older	Low	Low	Taylor 2000b	3000	0.5	89
Pterodroma lessonii	White-headed Petrel	Large Pterodroma	LC	XWH	5.5	93	0.093496		older	Low	Low	Taylor 2000b	600000	0.5	9215
Pterodroma macroptera	Great-winged Petrel	Large Pterodroma	LC	PDM	6.5	93	0.082652		older	Low	Low	Taylor 2000b	600000	0.5	12398
Pterodroma mollis	Soft-plumaged Petrel	Large Pterodroma	LC	PTS	6.5	93	0.082652		older	Low	Low	Taylor 2000b	15000	0.5	310
Puffinus carneipes	Flesh-footed Shearwater	Large shearwater	LC	PFC	5	93	0.100317		<5	High	High	Baker et al. 2008	12924	0.5	324
Puffinus griseus	Sooty Shearwater	Large shearwater	NT	PFG	6	93	0.087681		5_10	Low	Low	Taylor 2000a	20000000	0.5	438405
Puffinus pacificus	Wedge-tailed Shearwater	Large shearwater	LC	PUP	4	93	0.118407		older	Low	Low	Tennyson et al. 1989, Taylor 2000b	157500	0.5	3063
Catharacta lonnbergi	Brown Skua	Other birds	LC	CAQ	6	93	0.087		older	Low	Low	Taylor 2000b	1335	0.5	19
Daption capense	Cape Petrel	Other birds	LC	DAC	6	94	0.08268		older	Low	Low	Taylor 2000b	25500	0.5	346
Fregetta grallaria	White-bellied Storm-petrel	Other birds	LC	FGR	4	91	0.132	Y	older	Low	Low	Robertson & Bell 1984	3000	0.5	65
Fregetta tropica	Black-bellied Storm-petrel	Other birds	LC	FGQ	4	91	0.132	Y	older	Low	Low	Robertson & Bell 1984	150000	0.5	4950
Macronectes halli	Northern Giant-petrel	Other birds	NT	MAH	7.5	93	0.074359	Y	older	Low	Low	Taylor 200b, ACAP	7500	0.5	92
Oceanites maorianus	New Zealand Storm-petrel	Other birds	CR	NZS	5	86	0.129	Y	older	Low	Low	www.birdlife.org	75	0.1	0
Pachyptila desolata	Antarctic Prion	Other birds	LC	PWD	4.5	84	0.14849	Y	older	Low	Low	Robertson & Bell 1984	300000	0.5	11137
Pachyptila turtur	Fairy Prion	Other birds	LC	XFP	4.5	84	0.14849	Y	older	Low	Low	Robertson & Bell 1984, Tennyson 1989	3000000	0.5	73174
Pachyptila vittata	Broad-billed Prion	Other birds	LC	XPV	4.5	84	0.14849	Y	older	Low	Low	Robertson & Bell 1984	300000	0.5	11137
Pelagodroma marina	Kermedec White-faced Storm-petrel	Other birds	LC	KSP	5	86	0.129936	Y	older	Low	Low	West & Nilsson 1994, Taylor 2000b	2550000	0.5	54426
Pelecanoides georgicus	South Georgia Diving-petrel	Other birds	LC	GDP	2	81	0.322049	Y	older	Low	Low	Robertson & Bell 1984	600000	0.5	48307
Pelecanoides urinatrix	Common Diving-petrel	Other birds	LC	GDU	2	81	0.322049		older	Low	Low	Taylor 2000b	1500000	0.5	120768
Pterodroma axillaris	Chatham Petrel	Other birds	EN	PTA	6.5	93	0.082652	Y	<5	Medium	Medium	DoC unpublished report	6000	0.1	16

BLI Scientific name	Common name	Species group	IUCN	Species code in this study	A Age at maturity	Surv.	r_{max}	Species proxy value used	Population estimate category (yrs)	Population estimate method	Population data quality assessment	Popn size source	Number of individuals	F value	PBR index
Pterodroma cervicalis	White-necked Petrel	Other birds	VU	WNP	6.5	93	0.082652	Y	older	Low	Low	Taylor 2000a	150000	0.3	1222
Pterodroma cookii	Cook's Petrel	Other birds	EN	PTC	6.5	93	0.082652	Y	older	Low	Low	Taylor 2000a	150000	0.1	407
Pterodroma inexpectata	Mottled Petrel	Other birds	NT	XMP	6.5	93	0.082652	Y	5_10	Low	Low	Imber pers comm.	900000	0.5	18597
Pterodroma magentae	Magenta Petrel	Other birds	CR	PTM	6.5	93	0.082652	Y	<5	Medium	Medium	DoC unpublished report	135	0.1	0
Pterodroma neglecta	Kermadec Petrel	Other birds	LC	PVB	6.5	93	0.082652	Y	older	Low	Low	Taylor 2000b	15000	0.5	310
Pterodroma pycrofti	Pycroft's Petrel	Other birds	VU	PTP	6.5	92	0.086782	Y	older	Low	Low	Taylor 2000a	6000	0.3	78
Eudyptes filholi	Rockhopper Penguin	Penguins	VU	EVC	6	86	0.112	Y	older	Medium	Med-Low	Taylor 2000a	162600	0.1	911
Eudyptes pachyrhynchus	Fiordland Penguin	Penguins	VU	EVF	3.5	85	0.177		older	Low	Low	McLean et al. 1997	7500	0.3	199
Eudyptes robustus	Snares Penguin	Penguins	VU	EVS	4	85	0.16	Y	<5	Medium	Medium	D.Houston pers comm	60000	0.3	946
Eudyptes sclateri	Erect-crested Penguin	Penguins	EN	EVE	5	85	0.134	Y	older	Medium	Med-Low	www.birdlife.org	56000	0.1	247
Megadyptes antipodes	Yellow-eyed Penguin	Penguins	EN	XYP	2	87	0.272		older	Medium	Med-Low	Moore 1992	4800	0.1	65
Procellaria aequinoctialis	White-chinned Petrel	Procellaria petrels	VU	PRO	6.5	89	0.097024		<5	High	High	Sagar & Thompson 2008, ACAP	100000	0.3	956
Procellaria cinerea	Grey Petrel	Procellaria petrels	NT	PCI	7	93	0.078251		5_10	Low	Low	Bell 2002	159000	0.5	2044
Procellaria parkinsoni	Parkinson's Petrel	Procellaria petrels	VU	PRK	7	88	0.094199		<5	Medium	Medium	Bell & Sim 2004	10000	0.3	93
Procellaria westlandica	Westland Petrel	Procellaria petrels	VU	PCW	6	88	0.106444		<5	High	High	Baker et al. 2008	7500	0.3	79
Phoebetria palpebrata	Light-mantled Albatross	Small albatross	NT	PHE	7	97.3	0.054009		older	Low	Low	ACAP	23859.5	0.5	212
Thalassarche bulleri bulleri	Buller's Albatross Northern	Small albatross	VU	DIB	5	91.3	0.109125		older	High	Med-Low	Taylor 2000	54474	0.5	976
Thalassarche bulleri platei	Buller's Albatross Southern	Small albatross	VU	DNB	5	91.3	0.109125		<5	High	High	Sagar and Stahl 2005	40875	0.5	733
Thalassarche chrysostoma	Grey-headed Albatross	Small albatross	VU	DIC	10	95.3	0.052371		older	High	Med-Low	Moore 2004	27300	0.3	141
Thalassarche eremita	Chatham Albatross	Small albatross	CR	DER	7	91.3	0.084536		<5	High	High	ACAP	13725	0.1	38
Thalassarche impavida	Campbell Albatross	Small albatross	VU	TQW	10	94.5	0.055345		older	High	Med-Low	Moore 2004	63000	0.3	344
Thalassarche melanophrys	Black-browed Albatross	Small albatross	EN	DIM	7	95.1	0.068496		older	Medium	Med-Low	Taylor 2000b	420	0.1	1
Thalassarche salvini	Salvin's Albatross	Small albatross	VU	DLS	7	94	0.073944		<5	High	High	Miskelly et al. 2001	96000	0.3	700
Thalassarche steadi	White-capped Albatross	Small albatross	NT	XWM	7	94	0.073944		<5	High	High	ACAP	228900	0.5	2780
Puffinus assimilis	Little Shearwater	Small shearwaters	LC	PUA	5	93	0.100317		older	Low	Low	Imber 1983	630000	0.5	10381
Puffinus bulleri	Buller's Shearwater	Small shearwaters	VU	PBU	5	93	0.100317		older	Low	Low	Harper 1983, 1986).	2500000	0.3	24717
Puffinus huttoni	Hutton's Shearwater	Small shearwaters	EN	HSW	5	93	0.100317		older	Medium	Med-Low	Taylor 2000a	325000	0.1	1071