Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2008–09

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EXECUTIVE SUMMARY

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Seabirds are caught during commercial fishing, most frequently by being hooked during longlining, caught in trawl nets, or struck by trawl warps. In order to understand the impact of fishing on seabird species, estimates of the total mortality from fishing activity must be obtained. In New Zealand commercial fisheries, government observers are present on some vessels, and they record any captures of seabirds and other protected species that occur.

Generalized linear models were used to estimate total captures of seabirds by trawl and longline methods from the observer data. Captures were estimated for trawl, bottom longline, and surface longline fisheries, for the 2002–03 to 2008–09 fishing years (with some models extending back to 1998–99). The estimates were for fishing within the outer boundary of New Zealand Exclusive Economic Zone (EEZ). Statistical models were built of captures of five species groups: white-capped albatross (*Thalassarche steadi*), sooty shearwater (*Puffinus griseus*), white-chinned petrel (*Procellaria aequinoctialis*), other albatross species, and other birds. The models were fitted using Bayesian methods, with the captures represented as samples from a negative binomial distribution.

The total number of seabirds that were estimated to have been caught within New Zealand waters during the 2008–09 fishing year was 3224 (95% c.i.: 2520 to 4412). Of the total estimated captures, 27.5% were albatross species, with the remainder being petrels and shearwaters. The estimate of seabird captures includes captures in all surface longline fishing, in all trawl fishing other than fishing targeting inshore species, in large-vessel (over 34 m long) bottom longline fisheries, and in small vessel bottom longline fisheries targeting snapper in the northern area (FMA1). Observer coverage in the other trawl and longline fisheries was too low to allow for seabird bycatch estimates to be made.

There were 1544 (95% c.i.: 1294 to 1892) estimated seabird captures in offshore trawl fisheries, 591 (95% c.i.: 351 to 987) estimated captures in surface longline fisheries, and 1088 (95% c.i.: 559 to 2719) estimated captures in the bottom longline fisheries for which estimates were made. Of the five species groups used for the modelling, the other birds and other albatross groups had the highest number of estimated captures during 2008–09 (mean estimates of 1207 and 618 captures, respectively). In this year there were also mean estimated captures of 528 sooty shearwaters, 269 white-capped albatrosses, and 601 white-chinned petrels. The results from the estimation were broadly comparable with results from other projects that have estimated seabird bycatch in New Zealand fisheries. An exception was with seabird captures in large-vessel bottom longline fisheries: in this fishery observer coverage has been biased to vessels that use integrated weight lines. Estimation methods that do not take this into account tend to underestimate seabird bycatch in this fishery. Improving observer coverage of the vessels that do not use integrated longline would reduce the uncertainty in the estimates of seabird bycatch in bottom longline fisheries.

Across all included fisheries, there was a significant decrease in the total number of birds caught between 2002–03 and 2008–09, with the total number of captures falling by 47.6% between the 2002–03 and 2008–09 fishing years. This fall was associated with declines in effort in trawl, bottom longline, and surface longline fisheries. Estimated seabird captures increased by 29.3% between 2007–08 and 2008–09. This increase occurred for a range of seabird species, in a range of different fisheries, despite an ongoing decline in the effort. The reasons for this increase are unclear.

The statistical modelling gives insight into the performance of mitigation measures during routine fishing. In large-vessel bottom longline fisheries, the use of integrated weight line was associated with a reduction in the white-chinned petrel capture rate by 87.2% (95% c.i.: 40.6 to 97.6). In 2008–09, only 39% of the effort by large bottom-longline vessels was carried out using integrated weight line. In the squid fishery, the capture rate of white-capped albatross fell to 47.1% (95% c.i.: 20.9 to 98.8) of what it was before the introduction of mandatory warp mitigation in January 2006. The statistical models also showed that seabirds are more likely to be caught in surface longline fisheries during nights close to full moon, than on other nights. Specifically, other albatrosses and other birds were each over 3 times more likely to be caught in surface longline fisheries when the illumination of the moon's disk was more than 90%.

The estimation was based on observer data, and the resulting estimates may be interpreted as the number of captures that would have been reported if there were observers on every vessel. No allowance was made for under-reporting (caused by observers not being able to monitor all fishing activity during observed trips), or cryptic fatalities (caused by birds being killed by the fishing activity, but without the body being brought on board the vessel). In this report, the population consequences of fishing-related seabird fatalities were not considered.

1. INTRODUCTION

This report has been prepared as part of Ministry of Fisheries project PRO2007/01. The project has the specific objective to "estimate capture rates per unit effort and total captures of seabirds for the New Zealand EEZ and in selected fisheries by method, area, target fishery, in relation to mitigation methods in use, and, where possible, by seabird species for the fishing year 2006–07, 2007–08 and 2008–09". The estimation was restricted to trawl, surface longline and bottom longline methods, as it was only for these methods that sufficient data were available. Estimates were made for all marine commercial fishing using these methods within the outer boundary of the New Zealand Exclusive Economic Zone (EEZ). The project objective of estimating captures in relation to mitigation use has also been carried out elsewhere (Abraham & Thompson 2009b).

New Zealand is a global center of seabird diversity (Karpouzi et al. 2007), with over 80 species breeding either on the mainland or on offshore islands. Of these species, 35 are endemic and breed nowhere else, and 47 are considered threatened (Taylor 2000). Seabirds are caught during commercial fishing, most frequently by being hooked during longlining, caught in trawl nets, or struck by trawl warps. In order to understand the commercial impact of fishing on seabird species, estimates of the total mortality from fishing activity must be obtained. Because of the different population sizes and dynamics of different seabirds, mortality estimates are most useful if they are at the species level.

Fisheries observers are present on some fishing vessels, and they record any captures of seabirds or other protected species that occur. These observer data provide a reliable and consistent basis for estimating total captures. Observer data on seabird captures have been presented in a series of reports that give annual summaries of the bycatch data (Baird 2004a, 2004b, Baird & Griggs 2004, Baird 2005, Baird & Griggs 2005, Baird & Smith 2007, 2008, Abraham & Thompson 2009a). Observer coverage varies widely between different fisheries. For example, in the 2008–09 fishing year, over 30% of trawls targeting squid (*Nototodarus sloani*) were observed. In contrast, only 3.4% of trawls targeting inshore fish species were observed. The overall coverage during 2008–09 was 11.2% of tows for trawl fisheries, 26% of hooks for surface longline fisheries, and 10.2% of hooks for bottom longline fisheries, respectively. To estimate the total captures, it is necessary to extrapolate from the captures recorded during observed fishing to all fishing effort. Captures estimated in this way are likely to be less than the total fishing-related fatalities, as some birds may be killed by fishing but not brought on board. The estimates presented in this report can be most literally interpreted as the number of captures that would have been reported had there been observers on all fishing vessels.

In recent years, there has been an increasing use of statistical models to estimate total captures of seabirds in specific well observed fisheries (Manly et al. 2002, Baird & Smith 2007, 2008). The only previous work that has estimated total seabird captures for all main fishing methods was statistical modelling carried out by Waugh et al. (2008). They modelled seabird bycatch from 1997–98 to 2003–04 as a function of fishing year, season, fisheries management area (FMA), and vessel size, for each major fishing method. The use of these broad covariates allowed for extrapolation to be made from well observed to poorly observed fisheries. In this report, related methods are used to extrapolate from the observer data to an estimate of total captures by trawl and longline methods. Rather than modelling all seabirds together, however, the most frequently caught species are treated separately. These include white-capped albatross (*Thalassarche steadi*), sooty shearwater (*Puffinus griseus*) and white-chinned petrel (*Procellaria aequinoctialis*). The captures of the remaining birds are treated in two groups: other albatross species, and other birds. Estimates are made from the 2002–03 to the 2008–09 fishing year, with a particular focus on the most recent year.

The estimation is made with generalised linear models, fitted using Bayesian methods (e.g., Congdon 2003, Gelman et al. 2006). There are many tows or sets without any captures, but there are occasional tows or sets with multiple captures. This overdispersion of the captures is represented by assuming that they are drawn from a negative binomial distribution. The Bayesian methods also allow for random effects to be included. These can be used to represent the fact that observers generally record data from all fishing on entire trips, and so the observations are not a random sample of all fishing effort. Similar methods have previously been used for estimating sea lion captures (Smith & Baird 2007). In principle, the estimates based on statistical modelling have the advantage that they account for any biases in the observer coverage that make the observations non-representative of the fishing effort.

The intention of the work is to provide estimates of total captures, for fisheries that had sufficient observer coverage. The consequences of those captures for the seabird populations is not considered. In related projects (Waugh et al. 2009), the risk to seabird populations from fishing activities was determined. The risk assessment estimated the number of seabirds of over 60 different species that may potentially be killed by fishing activity; they also estimate seabird fatalities in poorly observed fisheries. To allow this level of detail, the risk assessment required a number of assumptions to be made that, while they may have been plausible, did not have direct support from the data.

2. METHODS

2.1 Estimated quantities

The primary aim of the project was to estimate the total captures of seabirds for the New Zealand EEZ, for the fishing years 2002–03 to 2008–09. Estimates were made of captures in trawl fisheries, surface longline fisheries, and bottom longline fisheries. Other methods such as potting, set netting, trolling, or purse seining, were not considered. For some longline fisheries a longer range of years was used, with estimates being made for the fishing years 1998–99 to 2008–09. A summary of the fishing effort that was included in the estimation is given in Table 1, together with the range of years that estimates were made.

Observer coverage in inshore trawl fisheries has been low (with less than 1% of tows observed over all years). Inshore trawl fisheries are geographically widespread and target a range of species, so this coverage could not be considered as representative, and inshore trawl fisheries were not included in the estimation. Observations of bottom longline fishing have been focused on the large vessel ling fishery. Many of this fleet are autoliners, setting over 20 000 hooks a day. They are expected to have different catch rates from the smaller vessels that set hooks manually, which typically set less than 10 000 hooks a day. On smaller bottom longline vessels, observations were focused on the snapper fishery in the north-eastern area of New Zealand (Fisheries Management Area 1). Seabird captures were estimated for fishing by large bottom longliners, and for the northern snapper fishery. In other small-vessel bottom-longline fisheries, observer coverage was low, and no estimation of captures was made in these fisheries. For surface longline fishing, estimation of captures was made across all targets.

The project required estimation of seabird captures over a minimum of a 5 year period. Data from 1998–99 to 2008–09 were used for estimating captures in longline fisheries. A shorter 7 years series, 2002–03 to 2008–09, was used for trawl fisheries. The reduced series was used to make the estimation computationally tractable. A reduced series was also used for estimating seabird captures in the snapper bottom longline fishery, as few observations in this fishery were made before 2002–03. The lengths of these series were sufficient to meet Ministry of Fisheries requirements.

The definitions of the target fisheries that were used are given in Table 2. This table includes species codes that were reported as the target species on more than 100 fishing events. For the relatively few fishing events that reported targeting unusual species, the target fishery was used of the event by the

Table 1: Fishing effort included in the seabird models.

Method	Subset	Years
Trawl	All targets, except inshore species	2002–03 to 2008–09
Bottom longline	Large vessels (> 34 m), all targets	1998–99 to 2008–09
Bottom longline	Northern area, snapper target, vessels < 34 m	2002–03 to 2008–09
Surface longline	All targets	1998–99 to 2008–09

Table 2: Definition of target fisheries used in the estimation, with the common names and three letter codes used by the Ministry of Fisheries. In multi-species target fisheries, species are listed in decreasing order of how frequently they were targeted. Only species and codes that were used on more than 100 fishing events are given.

Method	Target fishery	Target species
Trawl	Squid	Squid (SQU)
	Hoki	Hoki (HOK)
	Deepwater	Orange roughy (ORH), Oreos (OEO, SSO, BOE), Cardinalfish (CDL), Patagonian toothfish (PTO)
	Southern blue whiting	Southern blue whiting (SBW)
	Mackerel	Jack mackerel (JMA), Blue mackerel (EMA)
	Scampi	Scampi (SCI)
	Middle depths	Barracouta (BAR), Warehou (WAR, WWA, SWA), Hake (HAK), Alfonsino (BYX), Ling (LIN), Gemfish (SKI), Bluenose (BNS), Sea perch (SPE), Ghost shark (GSH), Spiny dogfish (SPD), Rubyfish (RBY), Frostfish (FRO)
	Inshore	Tarakihi (TAR), Snapper (SNA), Gurnard (GUR), Red cod (RCO), Trevally (TRE), John dory (JDO), Giant stargazer (STA), Elephantfish (ELE), Queen scallop (QSC), Leatherjacket (LEA), School shark (SCH), Blue moki (MOK), Blue cod (BCO), Rig (SPO), Hapuku (HPB)
Bottom longline	Ling	Ling (LIN)
	Snapper	Snapper (SNA)
	Bluenose	Bluenose (BNS)
	Other	Hapuku & bass (HPB, HAP, BAS), School shark (SCH), Gurnard (GUR), Blue cod (BCO), Ribaldo (RIB), Patagonian toothfish (PTO, ATO), Tarakihi (TAR), Trumpeter (TRU), Silver warehou (SWA), Red snapper (RSN), Gemfish (SKI)
Surface longline	Bigeye	Bigeye tuna (BIG)
	Southern bluefin	Southern bluefin tuna (STN)
	Albacore	Albacore tuna (ALB)
	Swordfish	Swordfish (SWO)
	Other	Yellowfin tuna (YFN), Pacific bluefin tuna (TOR), Snapper (SNA), Northern bluefin tuna (NTU)

same vessel that was closest in time (but within a year), and that had a defined target fishery.

For each of the three fishing methods, models were made of five seabird species or species groups. Over the period of the data, the birds that were most frequently observed caught in New Zealand fisheries were white-capped albatross (*Thalassarche steadi*), white-chinned petrel (*Procellaria aequinoctialis*) and sooty shearwater (*Puffinus griseus*). Separate models were made for each of these three species. In addition models were made for other albatrosses (Diomedeidae), and then for other birds. With few exceptions, reported captures of other birds were all petrels (either Procellariidae, Hydrobatidae, or Pelecanoididae). The raw data on the observed captures, and preliminary ratio estimates of total captures, of these five groups between 1998–99 and 2008–09 are summarised by Abraham et al. (2010). To estimate captures of the five species groups in trawl fisheries, large-vessel bottom-longline fisheries, and surface longline fisheries, 15 models were fitted.

In the northern snapper bottom-longline fishery, the only birds that were observed caught were in the other birds group (with the single exception of a live capture reported by the observer as a white-chinned petrel – in the estimation this capture was included with the other birds). The most frequently caught species was flesh-footed shearwater (*Puffinus carneipes*). A separate model was used to estimate captures of other birds in the northern snapper bottom-longline fishery, resulting in a total of 16 models.

2.2 Data sources

Ministry of Fisheries observers were required to complete an entry on the non-fish bycatch form whenever a seabird was caught by a fishing vessel. In the instructions given to observers, a bycatch event was defined as when an animal became fixed, entangled, or trapped so that it was prevented from moving freely or freeing itself. In particular, the following were not intended to be recorded as bycatch:

- Sightings.
- Birds that struck the warps, unless they were actually caught on the warps.
- Birds that hit the superstructure of the vessel, unless they fell to the deck injured or dead and unable to move freely.
- Birds that were snagged momentarily, but then managed to free themselves because they had not been caught.
- Traces of individuals (such as feathers caught in a trawl warp splice) as it was then unclear whether the animal was caught.
- Birds that landed on the vessel, unless they were unable to take off again under their own power
- Individuals that appeared to have been caught but were then lost before they were brought onboard the vessel, unless they were definitely caught but could not be recovered safely to the deck of the vessel.

Non-fishing related captures (such as birds that had hit the superstructure of the vessel) were excluded from the estimation. Before 2006–07 these captures were identified from observer comments. During the 2006–07 fishing year, the non-fish bycatch form was changed to provide more information on the captures than had previously been noted, including information on where the animals were caught. These additional data were recorded from February 2007 and were used to exclude non-fishing related captures from the reporting. Animals that were reported as live or dead were all included in the estimation, however any animals that were reported by the observer as decomposed were excluded.

Observer data were entered into a database administered by the National Institute of Water and Atmospheric Research (NIWA) on behalf of the Ministry of Fisheries. Fishing effort information was also required for the analysis. Effort data were recorded by fishers on Trawl Catch Effort Processing Return (TCEPR), Tuna Longline Catch Effort Return (TLCER), Catch Effort Landing Return (CELR), and Lining Catch Effort Return (LCE) forms. The effort data were stored on databases administered by the Ministry of Fisheries. Documentation of these databases is available online (Ministry of Fisheries 2008).

The following data from within New Zealand waters from the 1998–99 fishing year to the 2008–09 fishing year provided the basis for the estimation:

1. Data from within New Zealand waters (including all trips with at least one fishing event that started in the EEZ, or within the EEZ keyholes, or within the territorial sea). Reporting was restricted to New Zealand fisheries waters, but whole trip data were required for data grooming.
2. Data spanning the 11 year period from 1 October 1998 to 30 September 2009 (inclusive).
3. All trip and station information for commercial fishing from the *warehou* database within the ranges defined in (1) and (2), with one of the following methods: bottom trawl (BT), bottom pair-trawl (BPT), mid-water trawl (MW), mid-water pair-trawl (MPT), surface longline (SLL), or bottom longline (BLL).
4. All observer records of the capture of seabirds, from the *obs_lfs* and *COD* databases.
5. Observer station data from the *COD* and *l_line* databases for all fishing events on any trips with data selected in (3).
6. Selected vessel information (size, nationality, etc.) for vessels with any trips in (3), from the *vessels* database.

At the time of the data request, February 2010, necropsy data for seabirds (that usually identified the seabird to the species level) had not been included in the database for the 2008–09 fishing year. Seabird necropsy data were obtained from David Thompson (NIWA), and these records were merged into the relevant tables. When birds had been necropsied, the identification from the necropsy was used in preference to the observer's identification.

Data on the number of hooks observed was entered from bottom longline haul forms, as these data had not previously been captured.

2.2.1 Research trips

There have been experiments on bycatch mitigation that required a special permit. In 2002–03 and early 2003–04, experiments were carried out in the bottom longline fishery to test the efficacy of line weighting as a mitigation measure (Robertson et al. 2006). Special longlines were used that had weighted and unweighted sections, and many birds were caught on the unweighted line. Similarly, during 2007–08 a trial was carried out on a surface longline trip to test the efficacy of dyeing bait blue at reducing the number of birds that were hooked. In the analysis, we excluded all captures from these trips and treated them as unobserved.

In 2004–05, an experiment was conducted in the Auckland Islands squid trawl fishery, comparing the performance of different mitigation measures (Middleton & Abraham 2007). As part of this experiment, some observed tows were made without any warp mitigation. The captures that occurred on the unmitigated tows were not included and the tows were treated as unobserved.

In 2008–09, the Ministry of Fisheries initiated the inshore coverage programme, which specifically aimed to improve reporting of protected-species captures in inshore fisheries. Most of the inshore coverage data were collected in fisheries, such as inshore trawl and setnet, that were not included in the seabird estimation. However, there were some observations in inshore bottom-longline and surface longline fisheries. These data have been included in the estimation.

2.3 Matching observer and fisher reported data

There are two approaches that may be taken to the modelling. One is to build the model on the observer data and then apply the model to the effort data to make estimates. This was the method used by Baird & Smith (2008) and Waugh et al. (2008). The second approach, which we follow here, is to first associate the observed captures with the fisher reported effort data, and then build the model directly on the effort data. The second approach has the advantage that the observed component of the effort data is clearly identified. The actual captures can then be used for this component, with the estimation only being necessary for the unobserved effort. Another advantage is that the same dataset is used for model building and model estimation. This means the model is not influenced by any systematic biases in the way that the observers and fishers record their data.

Associating captures with the effort data requires the observer and the fisher recorded data to be linked. There were no keys available in the Ministry of Fisheries data that directly link the two datasets, so heuristic rules were developed that used the position and time of fishing events to associate fisher and observer recorded events with each other. A description of the matching rules, and the number of matches that were made using each rule, is given in Table 3 for trawl and surface longline data.

All matching was made between events with the same vessel key, so accuracy in recorded vessel keys was essential for achieving high match rates. The rules were applied sequentially, beginning with the first listed rule. For the trawl data, events were judged to be at the same time if the start and end times were both within 10 minutes. They were judged to be at similar times if they were within 70 minutes. For trawl events to be at the same position the latitude and longitude were required to both be within one sixth of a degree. For the surface longline data, events were at the same time if the start and end times of the set were within 30 minutes of each other.

Observers recorded times in New Zealand Standard Time and fishers recorded times in New Zealand Daylight time, with daylight savings applied during the summer. This was corrected for, but there was some imprecision in when daylight savings was applied. A small number of events had daylight savings applied when they were in winter, and a small number of events appeared to have had clocks moved backwards rather than forwards. After events were matched that were on the same vessel at similar times, a group of rules were then applied that identified where there were the same number of unmatched events between previously matched events, in both the observer and the effort data. These rules were applied to both the surface longline and the trawl data.

In the surface longline data there was a single trip identified where the fisher had not returned the necessary forms, and so there was no effort data. The required effort data were completed from the observer records. There remained a residual number of events that were unable to be matched using these rules, 1630 tows (1.9% of all observed tows) and 55 surface longline sets (1.3% of all observed sets).

The bottom longline data could not be matched using event level data as some effort was recorded by fishers on CELR forms that provide daily summaries of the fishing. In contrast, observers recorded details of individual sets. Since 2004–05, LCE forms have been used by large-vessel bottom longliners to report fishing effort. These forms provide set level information. To link the observations and the effort the rules summarised in Table 4 were followed. Firstly, the observer data on trips that used LCE forms were linked, using a set of rules similar to those used in trawl fisheries. Sets by the same vessel were found that matched within 5 minutes, in both winter and summer, and then the matching criteria were relaxed, filling in gaps in the sequences. Data from the CELR forms were then matched to groups of observed sets. Matching of the CELR data was difficult, and the majority was matched using the weak rule that the observed fishing was from the same day as the reported fishing. Of the days where observers

Table 3: Summary of matching between observed and fisher reported fishing events. All matching is made between events with the same vessel key. The table gives a description of the rules used to match the data, in the order that they are applied, and the number of events that can be matched between the observer and effort data using each rule.

Description	Trawl (tows)	SLL (sets)
Events at same time, not in summer	40 233	3 698
Events at same time, in summer	1 457	52
Events at same time, adjusted to NZST, and same position, summer	30 003	262
Events at same time, adjusted to NZST, and same position, not summer	49	13
Events at same time, incorrectly adjusted to NZST, same position	58	5
Events at similar time, trip already matched, summer	5 887	
One unmatched event on each dataset on the same day	2 825	
One unmatched event on each dataset, same day, over midnight	560	
Gap of one event between matched events on both datasets	592	
Gap of one event before first matched event at trip start	6	
Gap of one event after last matched event at trip end	35	
Gap of more than one event between matched events on both datasets	761	250
Gap of more than one event before first matched event at trip start	72	9
Gap of more than one event after last matched event at trip end	40	15
Total matched events	82 578	4 304
Effort data missing, completed from observer records		12
Unmatched events	1 630	55
Total observed events	84 208	4 371

recorded bottom longline sets and the fishing effort was reported on CELR forms, the same number of sets were reported by fishers and observers on only 53% of the days. This may reflect different definitions of sets by observers and fishers, with observers treating each set of an individual line as a set, and fishers sometimes treating several lines in the same area as a single set (Craig Loveridge, Ministry of Fisheries, pers. comm.).

In total there were 3809 observed bird captures in the trawl data, 952 observed bird captures in the surface longline data, and 1778 observed bird captures in the bottom longline data. Of these, 22 captures (0.6%) were on tows that could not be matched, 7 captures (0.7%) were on surface longline sets that could not be matched, and 12 captures (0.7%) were during unmatched bottom longline fishing. These unmatched bird captures were not included in the modelling. All presentation of numbers of observed fishing events and captures in this report is based on the matched data only.

2.4 Data grouping

The Bayesian model fitting was computationally intensive, and the trawl data were grouped in order to reduce the data volume. Data from consecutive tows by the same vessel were aggregated, following similar methods to those used by Manly et al. (2002). All tows in a group were in the same target fishery, in the same statistical area, either all observed or all not observed, and all in the same fishing year. A maximum size of 22 was set on the number of tows in any single group, and a maximum time of 10 days between any two tows in a group was set. These limits were arbitrary, and were chosen as a compromise between maintaining similarity between the data within a group and reducing the overall size of the model dataset.

There were an average of 6.3 tows within each group. The total size of the dataset reduced from 576 095

Table 4: Summary of matching between observed and fisher reported bottom longline fishing. All matching is made between events with the same vessel key. The table gives a description of the rules used to match the data, in the order that they are applied, and the number of events that can be matched between the observer and effort data using each rule.

Description	Days	Sets	Hooks ($\times$1000)
Match on LCE forms	898	2 479	17 185
Close match on CELR forms	377	937	6 613
Gap filling between previous matches on CELR forms	277	615	4 822
Match on day and vessel only from CELR forms	1 148	4 090	23 429
Total matched	2 700	8 121	52 050
Unmatched	82	156	299
Percentage matched	97.1	98.1	99.4
Total observed	2 782	8 277	52 349

tows to 91 879 groups, and the number of observations were reduced from 53 811 tows to 6 507 groups. The seabird capture data were sparse: in the full dataset, captures occurred on 1 486 tows, 2.8% of observed tows. By grouping the data the density of the captures was increased: after grouping captures occurred on 830 groups, 12.8% of observed groups.

When modelling the longline data, the set was used as the basic unit, with the number of sets reported on the effort forms being used. Bottom longline data reported on LCE forms, and data from surface longline fishing, were treated as individual sets. Bottom longline data reported on CELR forms was included as groups of sets.

2.5 Statistical modelling

The estimation of captures in unobserved fishing was carried out using Generalised Linear Models (GLMs), that predicted the logarithm of the expected captures during a fishing event as a linear function of a number of covariates. By fitting the model to observed capture data, the coefficients of the covariates could be determined. These were then used to estimate the expected number of captures at unobserved fishing events.

Typically, the capture data were overdispersed, with many events having no captures, and a few events having multiple captures. There are several options for representing overdispersed count data in a GLM. Common methods include using the zero-inflated Poisson distribution (applied to New Zealand seabird data by Waugh et al. (2008)), the negative binomial distribution (used in recent modelling of seabird bycatch by Baird & Smith (2008)) and quasi-Poisson methods (used in the analysis of warp strike data by Middleton & Abraham (2007)). There is no *a priori* theoretical basis for choosing one approach over another, and the suitability of one particular model can only be justified after model fitting, by comparing the distribution of the residuals against the expected distribution.

In this report we followed the most recent work (Baird & Smith 2008) and used the negative binomial distribution, as they found that this gave a good representation of seabird capture data. The negative binomial is parametrised by a mean, μ, and an overdispersion, θ. The variance is given by $\mu + \mu^2/\theta$. As the overdispersion increases to infinity the variance goes to the mean, and the negative binomial distribution converges to a Poisson. As θ gets small relative to the mean, the negative binomial distribution becomes increasingly peaked at zero and develops a long right hand tail. This allows it to represent data with many zeros, and occasional large values. The negative binomial distribution has the convenient property that the sum of n samples drawn from a negative binomial distribution is also negative-binomially distributed, with mean $n\mu$ and overdispersion $n\theta$. This allowed the model to be applied to the grouped event level data.

The negative binomial may be generated by a Poisson mixture distribution, with a gamma distributed mean. The seabird captures, y_i, during a group of n_i fishing events, were generated as

$$y_i \sim \text{Poisson}(n_i \mu_i \delta_i), \tag{1}$$

$$\delta_i \sim \text{Gamma}(n_i \theta, n_i \theta), \tag{2}$$

where the Gamma distribution had shape $n_i\theta$ and a mean of one. In this sense, the negative binomial was a natural choice for modelling the bird captures, as the overdispersion represented the effect of unknown processes on the variation of the mean capture rate. In some of the models, overdispersion was not included as there were insufficient numbers of captures to allow it to be estimated. In these models, the captures were assumed to be Poisson distributed.

The log of the mean catch rate for a single fishing event, μ_i, was assumed to be a linear function of N covariates, x_{ij}, with

$$\log(\mu_i) = \sum_{j=1}^{N} \beta_j x_{ij} + \log(\lambda_{y_i}), \tag{3}$$

where β_j are the coefficients of the covariates, x_{ij}, and λ_{y_i} are year effects. The covariates were all normalised before the model fitting, by subtracting the mean value and dividing by the standard deviation. After fitting, the regression coefficients, β_j, were converted back into standard units for presentation purposes.

The year effects, λ_{y_i}, were indexed by the fishing year of each group of events, y_i. They allowed for variation in the catch rate between years that was not explained by the covariates. They were modelled as log-normally distributed random effects,

$$\log(\lambda_y) \sim \text{Normal}(\log(\mu_\lambda), \sigma_\lambda), \tag{4}$$

where the mean and standard deviation of the year effects, μ_λ and σ_λ, were estimated by the model.

Not only were the captures overdispersed at an individual tow level, but there was also vessel-level variation in the capture rate. This was represented by including vessel-year effects, ν_{vy}. These were a multiplicative correction to the mean rate, μ_i, that could be different for each vessel within each fishing year. They were indexed by the vessel, v_i, and fishing year, y_i, of each group of events. When vessel-year effects were included, the equation for catch on a tow (Equation 1) was modified to be

$$y_i \sim \text{Poisson}(n_i \nu_{v_i y_i} \mu_i \delta_i). \tag{5}$$

The vessel year effects were assumed to be gamma distributed, with mean one and shape θ_ν,

$$\nu_{vy} \sim \text{Gamma}(\theta_\nu, \theta_\nu). \tag{6}$$

The use of a gamma distribution allowed for a skewed distribution in the vessel-year effects, depending on the value of the shape, θ_ν.

The model was closely related to the model used for sea lion captures in the Auckland Islands squid fishery (Smith & Baird 2007). Bayesian modelling was used in the most recent seabird modelling projects (Baird & Smith 2007, 2008), where captures were estimated in specific areas for the hoki and squid trawl fisheries. The model used here was coded in the BUGS modelling language (Spiegelhalter et al. 2003), and model fitting was carried out using the software JAGS (Plummer 2005).

During model fitting, estimates were made for the parameters β_j, λ_1, μ_λ, σ_λ, θ, and θ_v. Prior distributions were required for all these parameters. Diffuse normal priors were used for the mean year effect, μ_λ, the regression coefficients, β_j, and the initial year effect $\log(\lambda_1)$. A half-Cauchy prior (Gelman 2006) was used for the variation between years, σ_λ, and uniform-shrinkage priors were used for the overdispersion parameters (Gelman 2006):

$$\beta_0 \sim \text{Normal}(\mu = 0, \sigma = 10), \tag{7}$$
$$\beta_j \sim \text{Normal}(\mu = 0, \sigma = 10), \tag{8}$$
$$\log(\lambda_1) \sim \text{Normal}(\mu = \log(\bar{y}_i), \sigma = 100), \tag{9}$$
$$\delta_\lambda \sim \text{Normal}(\mu = \log(\bar{y}_i), \sigma = 100), \tag{10}$$
$$\sigma_\lambda \sim \text{Half-Cauchy}(\sigma = \sigma_y), \tag{11}$$
$$\theta \sim \text{Uniform-shrinkage}(\mu = \bar{y}_i), \tag{12}$$
$$\theta_v \sim \text{Uniform-shrinkage}(\mu = \bar{y}_v), \tag{13}$$

where $\bar{y}_i$ was the mean count per event, σ_y was the standard deviation in the captures per year, and $\bar{y}_v$ was the mean number of captures per vessel. The prior for the regression coefficients had a relatively small standard deviation, this reflected a belief that larger absolute values of these coefficients would be unrealistic.

The models were run for 2 000 updates during burn-in, and then run for up to a further 40 000 updates, with every 20th sample being retained for analysis.

2.6 Model selection

The model structure allowed for the seabird capture probability to depend on covariates. A step analysis was used to select the covariates that had explanatory power (Venables & Ripley 2002). Maximum likelihood methods were used to fit a negative binomial GLM to the observed captures. The logarithm of the number of fishing events associated with each observation was included in the linear predictor as an offset term. The models used for the step analysis differed from the full Bayesian models in the following ways: the overdispersion did not depend on the number of events in each observation; no random year or vessel-year effects were included; and the fishing year was presented to the step analysis as a fixed-effect.

At each stage of the step analysis the model was fitted repeatedly, with each of the potential covariates included (or removed) in turn. The covariate was selected that produced the greatest reduction in the AIC (Akaike 1974). Steps continued until the deviance was not reduced by more than 1%. Placing a requirement on the deviance reduction prevented the inclusion of covariates that had little explanatory power. In some cases, the Bayesian models did not converge when the full set of covariates was used. In this case, covariates with low explanatory power were progressively dropped until convergence was achieved. In surface longline fisheries, there were very different rates of observer coverage between small and large vessels, and so a vessel size covariate was included in all models.

In addition to selecting a set of covariates, further modelling choices were made. The most complex models had fishing-year random effects, vessel-year random effects, and overdispersion. These could be dropped to simplify the model, so that the simplest models had no random effects and no overdispersion. Model simplification was necessary to ensure model convergence for species group and fishing method combinations where there had been few captures.

2.7 Diagnostics

The first diagnostic was to check that the MCMC chains appeared to have converged. The Heidelberger & Welch (1983) criterion, applied to the model parameters and hyper-parameters, was used as a guide. This diagnostic checked that the chains were stationary. Two independent chains were run, with similar posterior distributions from the two chains being consistent with model convergence. In making this comparison, the key measure of interest, total captures during the 2008–09 fishing year, was used.

It was also checked whether there was evidence that the assumptions underlying the model were not being met. The captures were estimated on observed groups of fishing events. It was checked whether randomised quantile residuals (derived from the difference between the modelled and the observed captures) had the expected distribution (Dunn & Smyth 1996). In the case of the most general model (Equation 5), the captures on a group of fishing events, i, were drawn from a negative binomial distribution, with mean $n_i \nu_{v_i y_i} \mu_i$ and overdispersion $n_i \theta$. The randomised quantile residuals were calculated from the beta distribution (Murray Smith, NIWA, pers. comm.),

$$b(c_i) \sim \mathrm{Beta}(\theta/(\nu_{v_i y_i}\mu_i + \theta);\ n_i\theta,\ c_i), \tag{14}$$

where c_i were the observed captures, by drawing from the uniform distribution.

$$u_i \sim \mathrm{Uniform}(b(c_i),\ b(c_i+1)). \tag{15}$$

If the data were represented by a negative binomial model, then the quantile residuals, u_i, would have been normally distributed with zero mean and unit standard deviation. Normal quantile-quantile plots were used to inspect whether this held. Confidence intervals were obtained by calculating the quantile residuals for 1000 randomly drawn samples from the MCMC chain, and taking the 2.5% and 97.5% percentiles.

2.8 Prediction

To make predictions of captures, the number of captures that occurred during each group of fishing events was estimated. For observed fishing events, the number of captures was simply the observed captures. For unobserved fishing events, an estimate was made by sampling from the Poisson distribution (following Equation 1 or Equation 5), where the parameters of these equations were derived from the covariates and from the posterior distributions of the parameters. The event-group estimates were then summed within strata to obtain total captures by year, by fishery, or in other aggregates. A consistent set of areas and fisheries was used for reporting on the data, following those used by Abraham et al. (2010). In many cases, the areas and fisheries used as covariates during the modelling differed from those used during model fitting.

By repeating the estimate for all samples from the MCMC chains, a posterior distribution of estimated captures was obtained. The posterior distributions are summarised by their mean, median, and 95% confidence interval (determined from the 2.5% and 97.5% quantiles).

2.8.1 Model summaries

For each of the 16 models, a summary is included in the Appendices. A consistent set of the following tables and plots is given for each model:

- Estimated captures and capture rate for each fishery. For trawl fisheries, estimated captures and rates are listed for the fisheries that had the highest number of captures.

- The number of captures within each fishery-area combinations. The areas used in this summary are the areas that were used by Abraham et al. (2010), rather than the areas used as model covariates. This allows comparison between the model estimates, and with the early ratio estimates.
- A summary of the step-analysis that gives the deviance explained by the sequential addition of covariates to the maximum likelihood model.
- Time-series plots showing the captures estimated by applying the model to observed fishing effort, and to all fishing effort. The number of observed captures is indicated for comparison. As a simple diagnostic, it is expected that the observed captures should generally be within the range of estimates made by applying the model to the observed effort.
- A summary of the Bayesian model parameters is given (the median, mean, 2.5% and 97.5% percentiles). The base rates and model covariates are given in exponentiated form, so that they can be interpreted as multiplicative effects.

3. RESULTS

3.1 Trawl fisheries

3.1.1 Summary of trawl fisheries

Trawl fisheries were diverse and geographically widespread. During the 7-year period used for the modelling, 2002–03 to 2008–09, over 570 000 tows were made by trawlers (Tables 5 and 6). During this period, the most frequently targeted offshore species were hoki and squid. These fisheries, together with those for deepwater species (orange roughy, oreos, and cardinal fish), mackerel (jack mackerel and english mackerel), and southern blue whiting, all had over 10% observer coverage. In contrast, while over 44% of tows targeted inshore species (including flatfish), only 0.9% of these tows were observed. Both the highest number of observed seabird captures, and the highest observed capture rate (14.0 birds per 100 tows), were in the squid fishery. The deepwater, southern blue whiting and mackerel fisheries all had observed capture rates of less than 1 bird per 100 tows.

Variations in trawl effort between 1998–99 and 2007–08 period were summarised by Abraham et al. (2010). The total number of tows fell from 130 177 in 2002–03, to 87 213 in 2008–09. In the model dataset, the number of tows targeting offshore species fell from 60 735 to 35 899. Effort in the squid fishery increased from 8199 tows in 2002–03 to a peak of 10 241 tows in 2004–05. By 2008–09, the number of tows targeting squid had fallen to 3864.

Table 5: Summary of observations, effort and seabird captures in offshore trawl fisheries for the seven years 2002–03 to 2008–09. This is the model dataset.

Fishery	Effort (Tows)	Obs. (Tows)	Coverage (%)	Captures (All birds)	Rate (Birds/100 tows)
Squid	48 502	10 692	22.0	1 493	14.0
Hoki	100 545	13 974	13.9	307	2.2
Middle depths	64 414	5 230	8.1	243	4.6
Scampi	31 907	2 678	8.4	93	3.5
Deepwater	51 592	12 809	24.8	40	0.3
Mackerel	18 262	4 168	22.8	20	0.5
S. blue whiting	5 505	1 911	34.7	10	0.5
Total	320 727	51 462	16.0	2 206	4.3

Trawl vessels ranged in length from less than 10 m to over 100 m (Figure 1). The largest trawlers were 104.5 m long. When viewed by number of tows, the vessel size classes where there was the most effort were the 10 m, 15 m and 20 m vessels. These largely targeted inshore species. Observer coverage increased with vessel size, reaching a maximum of 24% of all tows for vessels over 100 m. The smallest observed vessel was 11.9 m long, and out of a total of over 210 000 trawls made by vessels of 20 m or less, only 0.5% were observed.

3.1.2 Model covariates

The covariates assessed for inclusion in the final models are listed in Table 7. The covariates were related to the location of the fishing (area), the target of the fishing (fishery), the time of the fishing (day of year, moon phase), characteristics of fishing events (duration, gear type), or characteristics of the vessels (size, processing type) (Figure 2). Of the offshore fisheries, middle-depths fisheries had the lowest observer coverage. Most effort by trawlers targeting offshore species was carried out by vessels that were recorded as having a meal plant installed. Vessels with meal plants were disproportionately represented amongst the observed tows. The distribution of fishing duration was similar between all effort and the observed tows, with most tows being between 2 and 8 hours long.

The area factors were made by grouping Ministry of Fisheries' statistical areas that had similar observed capture rates. Separate groups were made for each species (Figure 3). Capture rates of white-capped albatross were highest in the Auckland Islands and Snares areas. Capture rates of sooty shearwater were highest on the inner Chatham Rise and to the south and east of Stewart Island. White-chinned petrel

Table 6: Summary of observations, effort and seabird captures in inshore and flatfish trawl fisheries for the seven years 2002–03 to 2008–09. These trawl data were excluded from the estimation.

Fishery	Effort (Tows)	Obs. (Tows)	Coverage (%)	Captures (All birds)	Rate (Birds/100 tows)
Flatfish	78 551	774	1.0	36	4.7
Inshore	176 817	1 575	0.9	28	1.8
Total	255 368	2 349	0.9	64	2.7

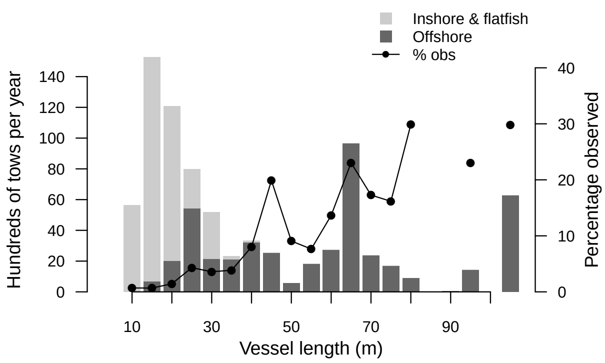

Figure 1: Average number of trawls per year by vessels of different lengths. The vessel length is divided into 5 m length classes. Inshore and other fisheries are shown separately. The percentage of tows observed was calculated for length classes with a total of more than 100 tows per year.

Table 7: Covariates used in estimating seabird captures in trawl fisheries.

Vessel size	Four groups, vessels less or equal to than 28 m, 29 m to 45 m, 46 m to 85 m, 86 m and over.
Area	Groups of statistical areas, based on the observed capture rates. Different groupings were used for each species group (Figure 3).
Fishery	Classification of each group of tows based on target species. Includes deepwater species, hoki, mackerel, southern blue whiting, scampi, squid, and other middle-depths species (see Table 2). When grouping tows, the fishery was taken as the most frequent fishery of all the tows in a group.
Day of year	First and second harmonics of the day of the year ($\sin(2d\pi/366)$, $\cos(2d\pi/366)$, $\sin(4d\pi/366)$, $\cos(4d\pi/366)$, where d is the day of the year) included as continuous variables, allowing for smooth variation in the seabird bycatch rates with the season. Averaged over all trawls within a group.
Gear type	Midwater or bottom trawl.
Processing type	Freezer, freezer with meal plant, or neither. Derived from the meal plant and freezer indicators from the vessels database. Vessels for which this information was missing were assigned to the 'neither' class.
Duration	The logarithm of the average duration of the trawls within a group.
Moon phase	Fractional illumination of the moon's disk (between 0 and 1). Averaged over all trawls within a group.

captures had a restricted range, with no captures being reported north of the Chatham Rise, and with the capture rate being highest in the Auckland Islands and Snares areas. Capture rates of other albatrosses were highest on the Chatham Rise, with some captures also being reported from the subantarctic and northern areas. Captures of other birds were also widespread, with high capture rates in statistical areas close to Stewart Island, the inner Chatham Rise, and the Bay of Plenty.

3.1.3 Model results

A summary of the configuration of each of the trawl models, and a list of the covariates included in each model, is given in Table 8. The area covariates are included in all models, with fishery being included as a covariate in the white-capped albatross, white-chinned petrel, and other albatross models. Covariates relating to the time of year were included in the white-capped albatross, sooty shearwater, and other albatross models. The only other covariate included was processing type, and this only appeared in the other albatross model. A summary of the automated step analysis, showing the deviance explained by the addition of each covariate to the maximum likelihood model, is given as one of the tables in each section of Appendix A. For example, for white-capped albatross, the summary is given in Table A-4. In this case, the fishery was the covariate that explained the largest portion of the deviance.

In the models of captures in trawl fisheries, fishing year was always included as a random effect. For the white-capped albatross and sooty shearwater models, that had the highest number of observed captures, both overdispersion and vessel-year random effects were included. When there were relatively few observed captures, vessel-year effects and overdispersion could not be estimated separately, and vessel-year effects were not included in the models. The MCMC chains from models of captures in trawl

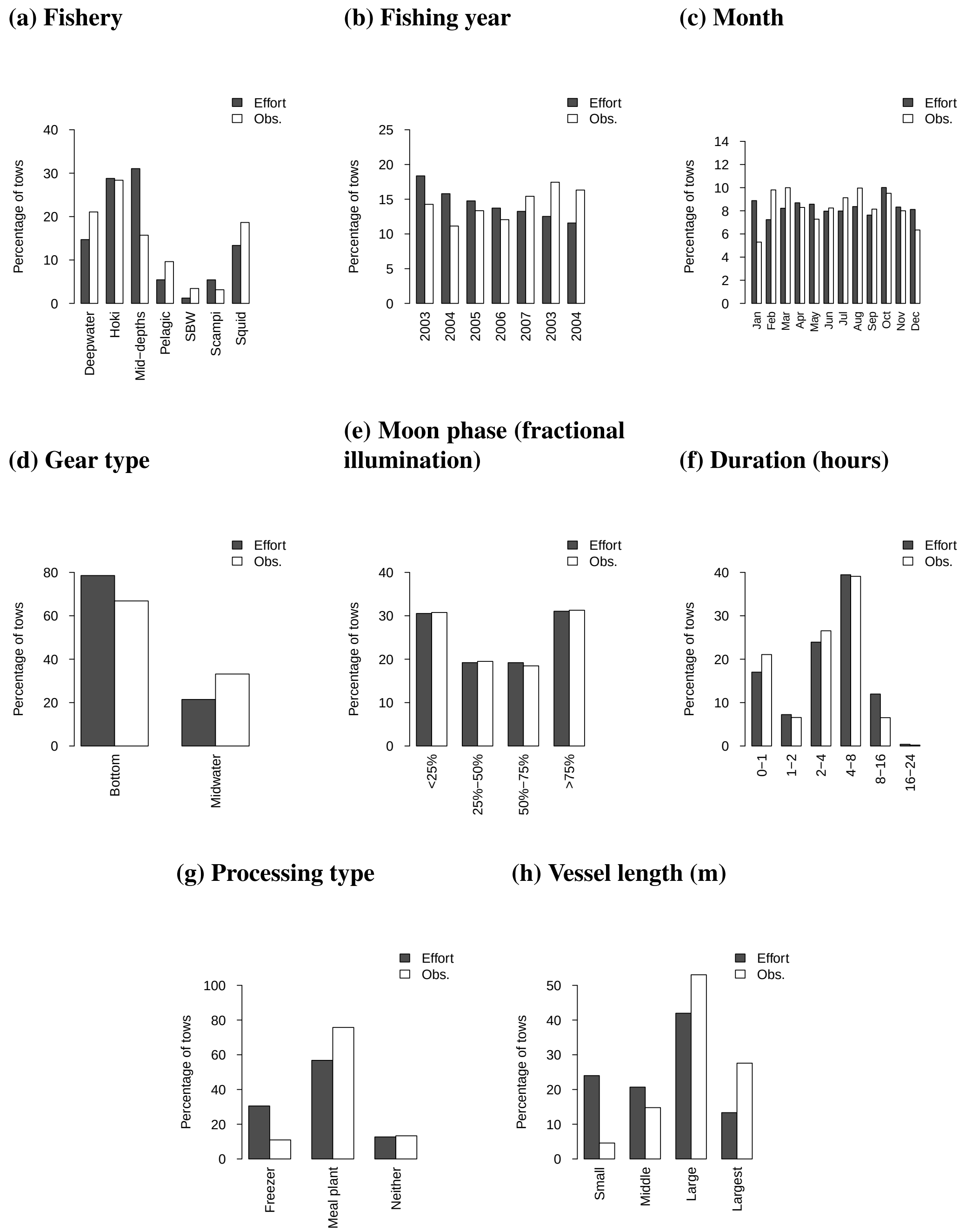

Figure 2: Frequency distributions of covariates for all tows (Effort) and observed tows (Obs.). The data are from all tows from the years 2002–03 to 2008–09 that targeted offshore species.

fisheries showed no evidence of a lack of convergence. The randomised quantile residuals showed a tendency for there to be some larger capture events than were predicted by the model, but for all species there was agreement between the observed and modelled distributions of captures, within the 95% confidence interval, to at least 3 standard deviations.

Estimated captures for the 2008–09 fishing year are given in Table 9. This table gives captures for the three fisheries with the highest total number of seabird captures, and for all other offshore fisheries combined. The model results are also summarised in more detail in Appendix A. The squid, hoki, and middle-depths trawl fisheries were the target fisheries with the highest number of captures. During the

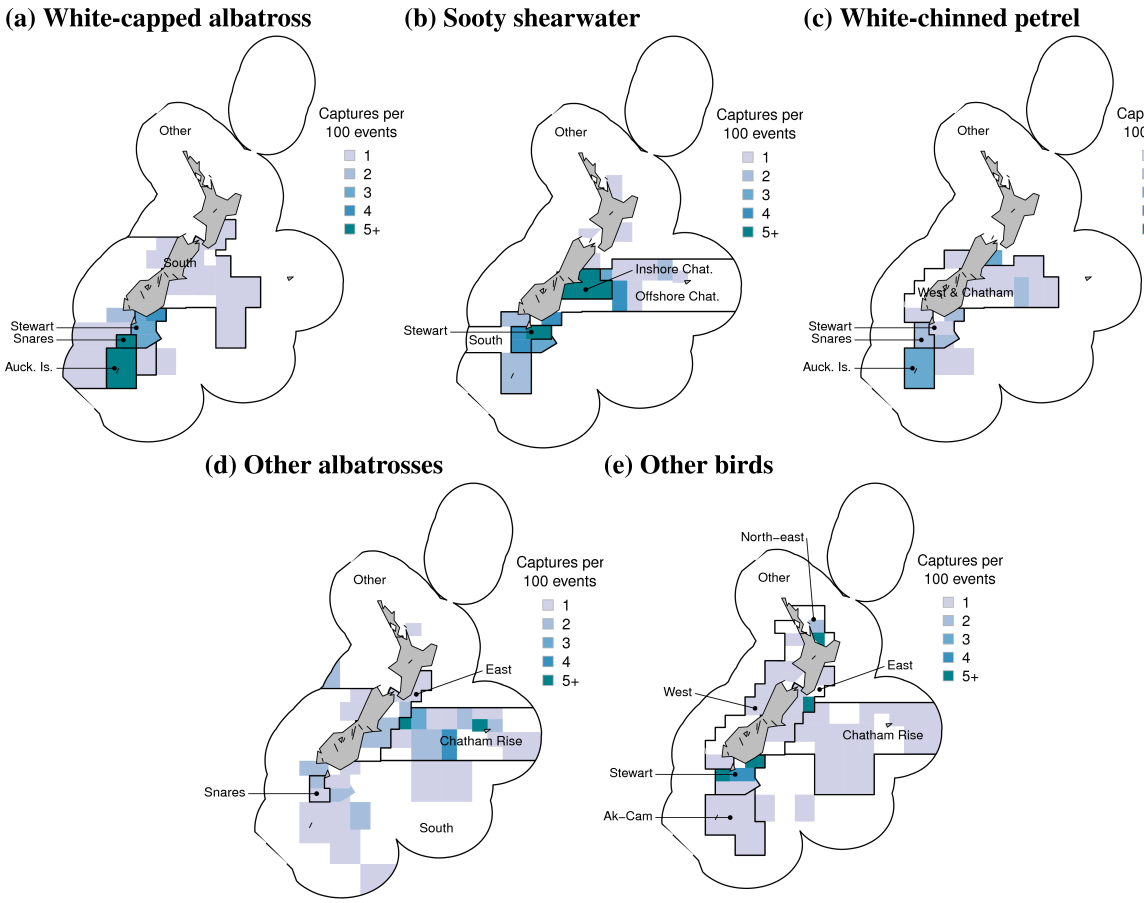

Figure 3: Areas used as covariates in the trawl fisheries models. The colours give the capture rate (birds per 100 tows) for each of the species groups within each statistical area. Capture rates are only shown if more than 100 observed tows were in a statistical area.

Table 8: Summary of the configuration of the trawl fisheries models. The bullets indicate the inclusion of random year effects, random vessel-year effects, and overdispersion.

Method	Species group	Years	Vessels	Over.	Covariates
Trawl	White capped albatross	•	•	•	Annual sine, area, fishery
	Sooty shearwater	•	•	•	Annual sine, area, six-monthly cosine
	White chinned petrel	•	-	•	Annual cosine, annual sine, area, fishery
	Other albatross	•	-	•	Area, fishery
	Other birds	•	-	•	Area, fishery, log(fishing duration)

2008–09 fishing year, a total of 625 (95% c.i.: 522 to 776) seabirds were estimated to have been caught in the squid fishery. The squid fishery had the highest number of captures of white-capped albatross, sooty shearwater, and white-chinned petrel. Of the estimated captures in the squid fishery, 210 (95% c.i.: 135 to 347) were of sooty shearwater. The next most frequently caught species were white-capped albatross and white-chinned petrel. The fishery with the second highest number of total captures was the middle-depths target fishery, with an estimated total of 356 (95% c.i.: 246 to 543) bird captures. In middle-depths fisheries, sooty shearwater was also the most frequently caught species with 164 (95% c.i.: 74 to 352) captures. However, there were more captures of other albatrosses than either white-capped albatross or white-chinned petrel. In 2008–09, observed captures of other albatrosses in middle-depths fisheries were of Buller's albatross (3 captures), Salvin's albatross (1 capture), and unidentified albatrosses (4

Table 9: Summary of results from all trawl models, showing the estimated total seabird captures during the 2008–09 fishing year. The mean and 95% confidence intervals of the posterior distribution of the totals are given.

Group	Squid		Middle depths		Hoki		Other offshore	
	Mean	c.i.	Mean	c.i.	Mean	c.i.	Mean	c.i.
White-capped alb.	156	(118 – 205)	44	(28 – 68)	18	(9 – 31)	39	(18 – 75)
Other albatross	40	(26 – 59)	107	(68 – 159)	84	(50 – 131)	114	(74 – 167)
Total albatross	196	(154 – 247)	151	(107 – 208)	102	(66 – 150)	154	(105 – 216)
Sooty shearwater	210	(135 – 347)	164	(74 – 352)	82	(36 – 190)	58	(27 – 123)
White-chinned petr.	155	(118 – 207)	17	(7 – 30)	15	(6 – 28)	27	(14 – 49)
Other birds	65	(48 – 89)	24	(12 – 44)	33	(16 – 58)	93	(47 – 167)
Total petrel	429	(338 – 570)	205	(112 – 390)	130	(77 – 236)	178	(115 – 276)
Total birds	625	(522 – 776)	356	(246 – 543)	232	(163 – 345)	332	(247 – 441)

captures)(Abraham et al. 2010). In hoki trawl fisheries, there were an estimated 232 (95% c.i.: 163 to 345) seabird captures, with sooty shearwater and other albatrosses again being the most frequently caught species groups.

3.2 Bottom longline fisheries

3.2.1 Summary of bottom longline fisheries

There were two main fleets that carried out bottom longlining in New Zealand waters, large vessels that set their lines using mechanical equipment (autoliners), and smaller vessels that set their hooks manually. There was no record of whether or not a vessel was autolining in the Ministry of Fisheries databases, and so the two fleets were defined on the basis of vessel size (Figure 4). A threshold length of 34 m separated the vessels into two classes. With the exception of a single vessel over 90 m long that carried out only 2 sets, all 12 vessels over 34 m set a median number of more than 20 000 hooks per day. In contrast, all vessels less than 34 m in length set a median of less than 15 000 hooks per day. Over the 11-year period of the data there were 487 distinct vessel keys for smaller vessels.

The large vessels targeted ling on 98% of all sets. In contrast, the small vessels targeted snapper on 60.3% of sets, ling on 11.3% of sets and bluenose on 14.2% of sets. The remaining bottom longline effort targeted a range of species including hapuku, school shark, gurnard and blue cod. Of all sets that targeted snapper, 97.6% were in the northern area (FMA 1). Seabird captures in bottom longline fisheries are summarised in Table 10. Observer effort was primarily focused on the large-vessel ling fishery, and consequently most observed seabird captures were in this fishery. Although observer coverage was otherwise low, there was no evidence that capture rates in other fisheries were higher than the capture rate of 23.6 birds per 100 sets that was observed in the large-vessel ling fishery.

3.2.2 Model covariates

The potential covariates used in the modelling are given in Table 11. Only a small number of covariates were considered. For each of the 5 seabird groups, customized areas were defined by grouping statistical areas that had similar catch rates (birds per 100 observed sets). Because it was important to include data from before the 2004–05 fishing year, only information available on CELR forms was used in the

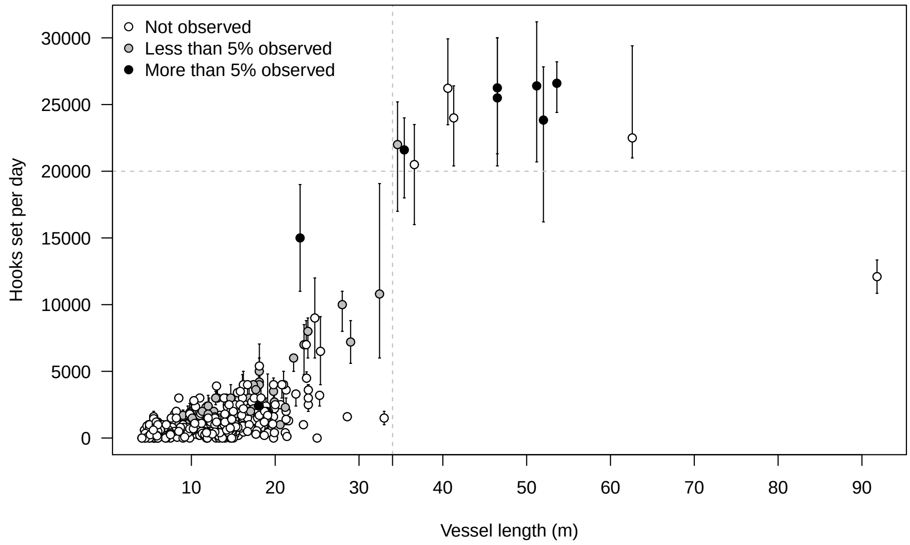

Figure 4: Relationship between vessel length and hooks set per day for bottom longliners. The points mark the median number of hooks set per day of fishing for each vessel, with the bars indicating the upper and lower quartiles. The shading of the points indicates the percentage of sets made by each vessel that have been observed.

Table 10: Summary of observations, effort and seabird captures in bottom longline fisheries. All data between 1998–99 and 2008–09 are included.

Fishery	Effort (Sets)	Obs. (Sets)	Coverage (%)	Captures (All birds)	Rate (Birds/100 sets)
Ling, large vessel	32 307	6 678	20.7	1 579	23.6
Snapper, small vessel, northern	104 659	496	0.5	79	15.9
Ling, small vessel	26 415	520	2.0	75	14.4
Other species, small vessel	74 225	322	0.4	27	8.4
Other species, large vessel	584	74	12.7	6	8.1
Snapper, small vessel, not northern	3 588	0	0.0		
Total	241 778	8 090	3.3	1 766	21.8

modelling. In particular, a possible effect of time of day on seabird captures could not be included.

For each seabird species, area factors were made for the large-vessel bottom longline models by grouping contiguous statistical areas that had similar capture rates (Figure 5). There was little effort by the large-vessel fishery in the north of the New Zealand region, and no recorded seabird captures there. In all cases the ‘Other’ area was excluded from the modelling. White-capped albatrosses had a sporadic capture distribution (Figure 5(a)). The highest capture rates for sooty shearwater were in the keyhole area, where the Solander trough approaches the South Island (Figure 5(b)). The highest capture rates of white-chinned petrel were on the Chatham Rise (Figure 5(c)). In bottom longline fisheries, other albatrosses were most frequently caught close to the Bounty Islands, while capture rates of other birds were highest in the areas surrounding the Auckland and Campbell Islands, and on the Campbell Plateau (Figure 5(d)).

Following experiments by Robertson et al. (2006), carried out in 2002 and 2003, integrated weight lines

Table 11: Covariates used in estimating seabird captures in bottom longline fisheries

Covariate	Definition
Target species	Target species fishery, either ling, snapper, bluenose, or other target species.
Area	Areas were defined based on grouping statistical areas with similar observed capture rates, for each seabird species group.
Season	Either a two-level factor (summer and winter), with summer defined as being between the beginning of October and the end of March, or a three-level factor with the breeding season of the bird species. Breeding season was used for sooty shearwater and white-chinned petrel. For sooty shearwater the levels were breeding (November to March), shoulder (April to June and October), and off-season (July to September). For white-chinned petrel the levels were breeding (October to April), shoulder (May and September), and off-season (June to August). For both sooty shearwater and white-chinned petrel no captures have been observed in bottom longline fisheries during the off season, and so the catch rate was assumed to be zero during these months.
Integrated weight line	Whether or not the vessel was using an integrated weight line at the time of the fishing.
Moon phase	A value between 0 and 1 defined as the fractional illumination of the moon's disk. Calculated following algorithms by Meeus (1991).
Hook number	The logarithm of the total number of hooks set, from the fisher data. This allows for a bycatch that is a power law of the number of hooks.

were adopted by some of the large-vessel bottom longline vessels. Integrated weight lines have a lead core and sink rapidly. Because of this the baited hooks are only briefly available to the birds, and during the experiments the use of weighted lines was found to reduce seabird captures (in particular, the capture of white-chinned petrels was reduced by over 98%). For each of the large vessels, the Ministry of Fisheries provided a date for when the vessel started using integrated weight line.

Integrated weight lines were first introduced during the 2002–03 fishing year (Figure 6). Although use of integrated weight line increased between 2002–03 and 2006–07, it has since decreased slightly. In 2008–09, there were five large bottom longline vessels fishing, and of these two used integrated weight line. Of all the sets by large bottom longline vessels in 2008–09, 39.9% used integrated weight line. Since 2004–05, observer coverage has been biased towards vessels that use integrated weight line and in 2008–09, 82.2% of observed sets used integrated weight line.

3.2.3 Model results

A summary of the model configuration for the bottom longline models is given in Table 12. Because of the small number of vessels, models that included separate year and vessel-year effects had convergence problems, and so only vessel-year random effects were included. Overdispersion was included in the models for all species, other than white-capped albatross. Because of the low number of white-capped albatross captures, separate overdispersion and vessel-year effects could not be estimated. Covariates included in the models were area, integrated weight line, moon phase, and season. The snapper model was the simplest, with no covariates being included. This model is essentially reduced to a ratio estimate, although with vessel-year random effects and overdispersion. For each of the models of captures in

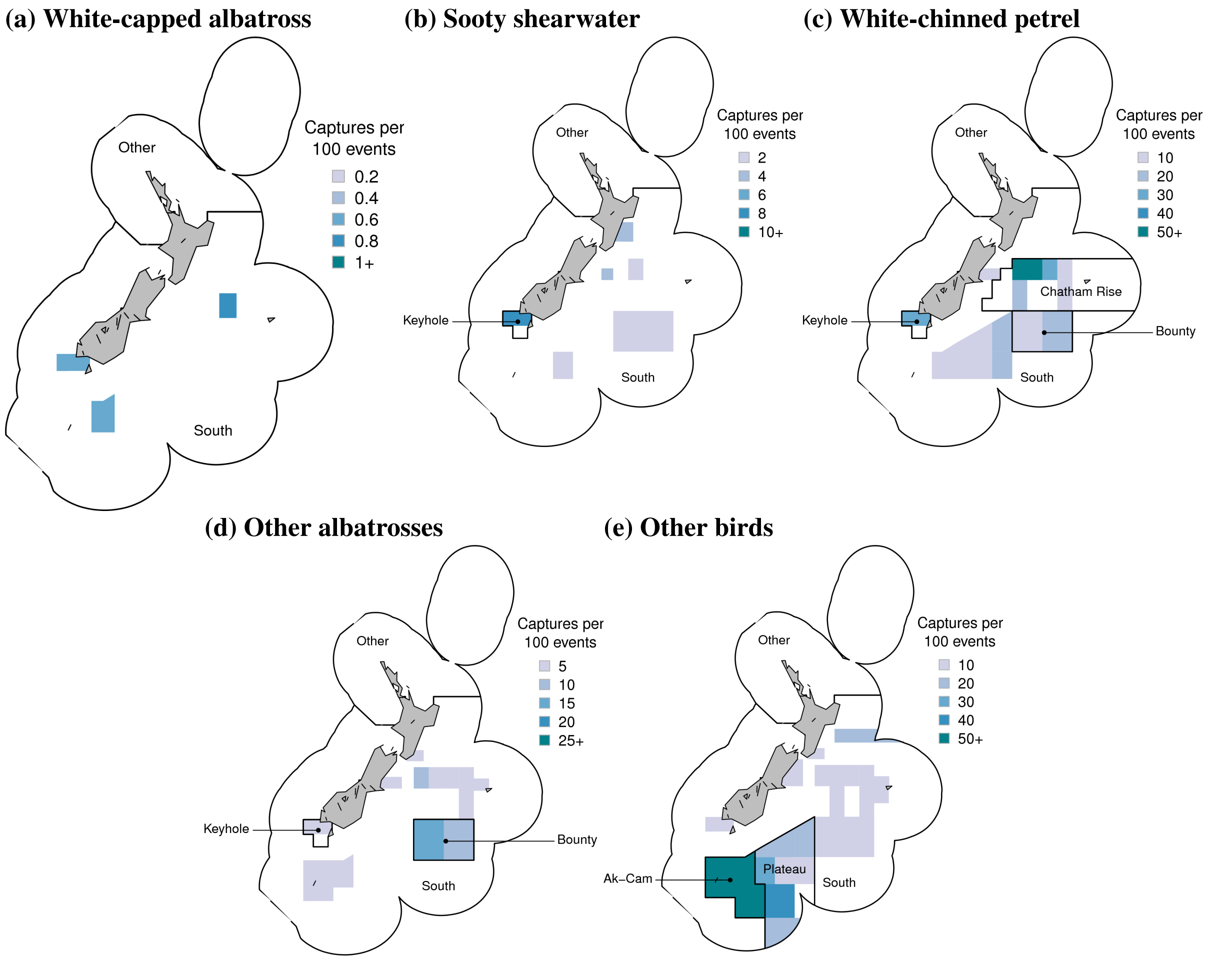

Figure 5: Areas used as covariates in the large-vessel bottom longline fisheries models. The colours give the capture rate (birds per 100 tows) for each of the species groups within each statistical area.

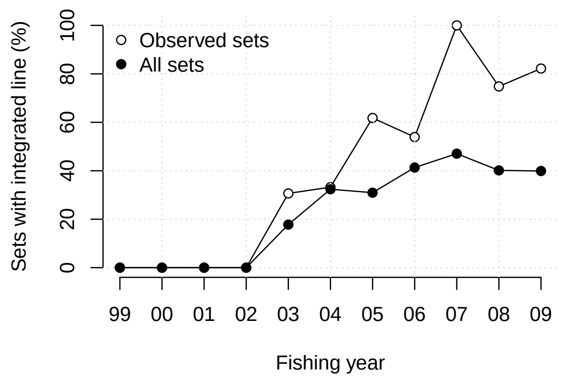

Figure 6: Use of integrated weight line by large bottom longline vessels (longer than 34 m).

Table 12: Summary of the configuration of the bottom longline models. The bullets indicate the inclusion of random year effects, random vessel-year effects, and overdispersion.

Method	Species group	Years	Vessels	Over.	Covariates
Bottom longline	White capped albatross	-	-	-	Integrated weight line, moon phase
	Sooty shearwater	-	•	•	Area, integrated weight line, moon phase, season
	White chinned petrel	-	•	•	Area, integrated weight line, moon phase, season
	Other albatross	-	-	•	Area, integrated weight line, moon phase, season
	Other birds	-	•	•	Area, integrated weight line, season
	Other birds (snapper)	-	•	•	

bottom longline fisheries, similar posterior distributions of estimated captures were derived from both chains. The randomised quantile residuals showed a tendency for there to be some larger capture events than were predicted by the model. For all species, other than the other albatross group, there was agreement between the observed and modelled distributions of captures, within the 95% confidence interval, to at least 3 standard deviations.

Full model results are given in Appendix B, and a summary of model estimates for the 2008–09 fishing year are given in Table 13. In the large-vessel fishery, seabird captures were dominated by captures of white-chinned petrel, with a mean estimate of 371 white-chinned petrel captures during 2008–09. The uncertainty in the white-chinned petrel captures was high (with the confidence interval corresponding to a c.v. of 104%). In the northern snapper fishery, there were estimated to have been be 673 seabirds caught, with a c.v. of 31.5%, all in the other birds group. Captures of albatrosses and sooty shearwater were lower than the estimated number of captures in offshore trawl fisheries.

The model for the capture of white-chinned petrel is summarised in Appendix B-2. The median estimated number of captures (Table B-6), and the median capture rate (Table B-7), appeared to have decreased since the 2002–03 fishing year when integrated weight lines were first used. However, because of the high uncertainty in the estimates, the decrease was not significant at the 95% confidence level. The coefficient of the integrated weight line effect had a median value of 0.128 (95% c.i.: 0.024 to 0.594), with a significant reduction in the capture rate when integrated weight line is used. As expected, the capture rate was lower during the shoulder months (May and September). The capture rate was significantly higher when there was more moon illumination, and the median effect was positive for fishing in the keyhole and southern areas, relative to the Chatham Rise.

For all of the five species groups, the median estimated number of captures in the large-vessel ling fishery decreased between 1998–99 and 2008–09. Because of the high uncertainties, this decrease was only significant for the other birds and other albatrosses groups. In all cases, the median value of the integrated weight line effect was less than one (although the effect was not significantly less than one for the sooty shearwater and other birds groups).

The model for other bird captures in the northern snapper fishery was only fitted for five years of data (Appendix B-6). There were no year effects included in the model, and the capture rates were similar across the period of the data.

Table 13: Summary of results from all bottom longline models, showing the estimated total seabird captures by fishery during the 2008–09 fishing year. The mean and 95% confidence intervals of the posterior distribution of the totals are given.

Group	Large ling		Nth. snapper		All fisheries	
	Mean	c.i.	Mean	c.i.	Mean	c.i.
White-capped alb.	2	(0 – 5)	0	(0 – 0)	2	(0 – 5)
Other albatross	17	(4 – 42)	0	(0 – 0)	17	(4 – 42)
Total albatross	18	(5 – 44)	0	(0 – 0)	19	(5 – 45)
Sooty shearwater	12	(2 – 30)	0	(0 – 0)	12	(2 – 30)
White-chinned petr.	369	(34 – 1 366)	0	(0 – 0)	371	(36 – 1 366)
Other birds	13	(3 – 46)	673	(375 – 1 173)	687	(387 – 1 187)
Total petrel	395	(57 – 1 389)	673	(375 – 1 173)	1 070	(538 – 2 154)
Total birds	413	(75 – 1 407)	673	(375 – 1 173)	1 088	(559 – 2 179)

3.3 Surface longline fisheries

3.3.1 Summary of surface longline fisheries

Over the period covered by the estimation, 1998–99 to 2008–09, there were two main surface longline fleets fishing in New Zealand waters, a charter fleet consisting mainly of Japanese vessels, and including some Philippines vessels, and a New Zealand domestic fleet. The charter fishery mainly targeted southern bluefin tuna (*Thunnus maccoyi*) in waters to the south and west of New Zealand. The vessels in this fleet were all over 50 m long, and the number of sets made on single trips ranged from 24 to 119, with a median of 64. In contrast, all of the New Zealand domestic fleet were less than 35 m long, with the exception of a single 54 m long vessel. The small-vessel New Zealand fleet mainly fished for bigeye tuna (*Thunnus obesus*) and albacore (*Thunnus alalunga*) in waters to the north and east of New Zealand. Trips by these domestic vessels were mostly short, with a median of 4 sets per trip (range 1 to 47).

In addition to the Japanese charter and the New Zealand domestic fleet, there were a small number of trips (15) made by two Australian charter vessels. These vessels mainly targeted swordfish (*Xiphias gladius*) in northern and Kermadec waters. They were both small vessels, less than 35 m in length. They only fished in New Zealand waters in the 2005–06 and 2006–07 fishing years.

A summary of fishing effort and seabird captures in surface longline fisheries is given in Table 14. When viewed by numbers of sets, surface long line effort was dominated by the bigeye tuna fishery, which had over 36 000 sets over the 11 year period covered by the modelling. This fishery had low observer coverage, with less than 2% of sets being observed. Most of the observations were made in the large vessel southern bluefin fishery, which had over 84% of sets observed. Because of the high observer coverage, most of the observed seabird captures were in this fishery.

A swordfish fishery developed between 2004–05 and 2006–07 (Table 15). Swordfish entered the Quota Management System (QMS) in 2004–05. Before that, swordfish were only occasionally reported as the target species on surface longline sets. By 2006–07 the fishery had increased to 255 sets, of which 17.6% were observed. The vessels that targeted swordfish in 2006–07 were smaller vessels (less than 40 m) including New Zealand domestic and Australian charter vessels. Most swordfish fishing was carried out in Area 1, which includes the Fisheries Management Area surrounding the Kermadec Islands. Across all the surface-longline observer data, there are only three trips where the number of captured albatrosses was greater than the number of sets. These three trips were one trip targeting big-eye tuna in 2001–02

Table 14: Summary of effort, observations, and seabird captures in surface longline fisheries, covering the period 1998–99 to 2008–09. The table is ordered by the number of observed seabird captures. Large vessels were longer than 40 m, and small vessels were less than 40 m.

Fishery	Effort (Sets)	Obs. (Sets)	Coverage (%)	Captures (All birds)	Rate (Birds/100 sets)
Bluefin, Large vessel	3 396	2 873	84.6	533	18.6
Bigeye	36 318	696	1.9	177	25.4
Albacore	4 192	251	6.0	80	31.9
Swordfish	809	92	11.4	76	82.6
Bluefin, Small vessel	10 613	406	3.8	49	12.1
Other	1 331	41	3.1	8	19.5
Total	56 659	4 359	7.7	923	21.2

Table 15: Development of the surface longline swordfish fishery.

	Before 2004–05	2004–05	2005–06	2006–07	2007–08	2008–09
Sets	28	129	224	255	129	44
Trips	15	49	81	53	44	19
Observed sets		14	4	45	25	4
Observed trips		5	1	7	7	2
Captured albatross		1	2	60	0	0

and two trips targeting swordfish in 2006–07. During one of these swordfish trips, by an Australian charter vessel in the Kermadec area, there were 12 sets and 51 albatrosses were caught. Although this trip was much shorter than typical trips made by Japanese charter vessels, this was the highest number of albatross caught on any single trip in the surface longline dataset. The second trip targeting swordfish in 2006–07 that had a high albatross capture rate caught nine albatrosses from only three sets. This trip was made by a New Zealand vessel within Area 1. Both of the swordfish trips with high catch rates set all their lines during the day. In response to the high bycatch by the Australian vessel, the Minister of Fisheries prohibited the day-setting of surface longlines, in all surface longline fisheries, unless suitable line weighting measures were used (Department of Internal Affairs 2008).

The 2006–07 trip with the largest number of captures was problematic. It was unclear how to generalise from this trip to other observed effort. A contributing factor to the high catch rate was suggested to have been the shallow set depth of the lines (Anderton 2006). This information was not directly available from the commercial effort data, and so was not used in the modelling. We assumed that the practice followed on this trip could have also been followed during other unobserved swordfish target sets, by both New Zealand and Australian vessels. The Australian charter vessels were not treated separately from the smaller New Zealand vessels. A further difficulty was that swordfish effort before 2004–05 may not have been reported, as swordfish were not a quota species before then. In the estimation, only the declared target species was used to define the fishery.

Observed captures of seabirds in surface longline fisheries from 1998–99 to 2007–08 were summarised by Abraham et al. (2010). Most observed captures in 2008–09 were of other albatrosses in the southern bluefin fishery. Across all years 58% of the identified seabird captures in the southern bluefin fishery have been Buller's albatross, with a total of 337 observed captures between 1998–99 and 2008–09. Observed captures in the bigeye tuna fishery have mainly been of other birds, with 70% of identified observed seabird captures being of flesh-footed shearwaters. Over the period of the data, there were 84 observed captures of white-capped albatross in surface longline fisheries. All white-capped albatrosses were caught in the southern bluefin fishery, with the exception of a single capture on a set targeting swordfish in Area 3. Although the captures of white-capped albatross were mainly in the southern area (Area 3), there were also some white-capped albatross on captures on southern bluefin sets in other areas (three in Area 1, and two in Area 2). There were few observed captures of either white-chinned petrel (36 captures) or sooty shearwater (18 captures) in surface longline fisheries.

3.3.2 Model covariates

The set of covariates was relatively simple (Table 16), being restricted to covariates related to the time and place of the fishing (area, day of year, and set time), covariates related to the nature of the fishing event (total hook number, duration, and target species), and vessel size.

Target species were grouped into four targets, with minor target species (such as yellowfin tuna) being included with bigeye tuna. There were no records of vessels longer than 40 m targeting species other than southern bluefin tuna, bigeye tuna, or albacore. In surface longline fisheries effort is dispersed within regions to the southwest and northeast of New Zealand. The areas used as covariates were Area 1 and Area 4, to the northeast of New Zealand; Kermadec (FMA 10); and Area 2 and Area 3, to the southwest of New Zealand. Seasonal variation in the catch rates was modelled using sine and cosine functions of the day of the year.

The marked differences between the observations and the effort that are seen, for example, in target fishery (Figure 7(a)), area (Figure 7(b)), and vessel size (Figure 7(c)), were due to the observations being disproportionately on the Area 3 southern bluefin tuna fishery. The observations were also more strongly peaked in the winter months when the southern bluefin tuna fishery was operational (Figure 7(e)).

3.3.3 Surface longline model results

A summary of the configuration of the surface longline models is given in Table 17. Vessel size was included as a covariate in all models, to allow for the non-representative nature of the observer coverage. Otherwise, the most frequently included covariates were related to time of day and time of year. The only other covariates were target fishery, in the white-capped albatross model, and area in the other birds model. The other albatross and other birds models included random year effects, random vessel-year effects, and overdispersion. Random vessel-year effects and overdispersion were included in the white-capped albatross model. The other two models (sooty shearwater and white-chinned petrel) were Poisson models, without overdispersion or any random effects. The total number of captures of these birds were too low to allow more complex models to be fitted. Similar posterior distributions of estimated captures were derived from both chains of each of the models. The randomised quantile residuals showed a tendency for there to be some larger capture events than were predicted by the model. For all species, there was agreement between the observed and model distributions of captures, within the 95% confidence interval, to at least 3 standard deviations.

A summary of captures in the 2008–09 fishing year is given in Table 18. Of the median total estimated captures for 2006–07, 43% were of other albatrosses and 51% were of other birds, with only relatively few white-capped albatrosses, sooty shearwaters, or white-chinned petrels estimated to have been caught. Most (75%) of the estimated bird captures were in the bigeye tuna fishery, with 21% of the captures being in the southern bluefin tuna fishery. In 2008–09, there were few estimated captures in other target fisheries. Full summaries of the model fitting are given in Appendix C.

Table 16: Covariates used in estimating seabird captures in surface longline fisheries

Covariate	Definition
Target species	Southern bluefin tuna, bigeye tuna, albacore and swordfish. A number of other species were targeted relatively infrequently, such as yellowfin tuna (*Thunnus albacares*). For the modelling, these other target species are included with bigeye tuna. Other species were primarily targeted on trips that also targeted bigeye, and sets targeting other species were only infrequently observed.
Area	Northern, southern and Kermadec. The northern area includes Area 1 and Area 4, with the exception of FMA10 surrounding the Kermadec Islands. The southern area includes Area 2 and Area 3. The Kermadec area, FMA10, is treated separately.
Vessel size	Two groups, vessels less than 40 m in length and vessels over 40 m in length. This divides the fleet into domestic and charter fisheries, with the exception of two Australian charter vessels that are less than 40 m long, and a single New Zealand flagged vessel that is over 50 m in length and that mainly fishes for bluefin tuna in Area 3.
Day of year	The sine and cosine of the day of year ($\sin(2d\pi/366)$, $\cos(2d\pi/366)$) are included as continuous variables, allowing for smooth variation in the seabird bycatch rates with the season.
Set time	Night, day, full moon. The start and end times of the set, and vessel position, are used to calculate whether the set falls entirely in the night, or is partly in the day. Astronomical algorithms were used to calculate the sun's angle relative to the horizon, with night being defined by when the sun was below the horizon at both the start and the end of the set (Meeus 1991). For night sets, the fractional illumination of the moon's disc was used to define a full moon, with an illumination of more than 90% being defined as full. Other categorisations were also tried, including using separate categories for dawn and dusk sets, using continuous functions of the set time, and using haul times rather than set times.
Hook number	The logarithm of the total number of hooks set. This allows for a bycatch that is proportional to the number of hooks.
Duration	The logarithm of the duration of the setting. The logarithm transform allows for a bycatch proportional to the duration. The duration was of the set time only, as it was assumed that the highest risk to birds is during line setting.

Estimated captures for white-capped albatross in 2008–09 were strongly skewed, with high upper confidence intervals for the annual cosine and sine exponents, and to a lesser extent for the swordfish fishery factor (see Table Appendix C-5). This resulted in wide confidence intervals for the number of captures, particularly in the swordfish fishery (see Table C-1).

Only a restricted number of covariates were included in the full model of other albatross captures (see Table Appendix C-20). The included covariates were vessel length, set time of day, and an annual sine exponent (with a March-April peak in the capture rate). Nationality was also selected as a covariate during maximum likelihood fitting (see Table C-17), but if this was included, then the model appeared to suffer from over-fitting, with high uncertainties in the estimates related to correlations between the covariates. The covariates associated with setting during the day, or during full moon, had values that were significantly higher than one. Not setting at these times is likely to reduce the number of other

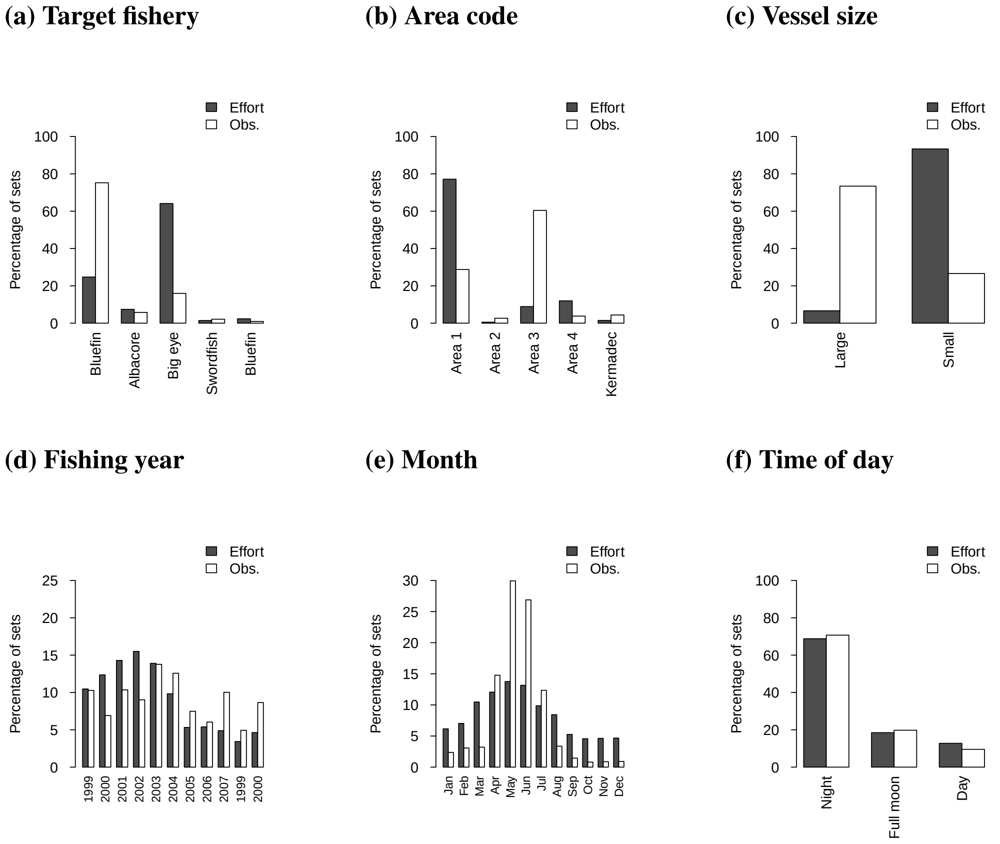

Figure 7: Comparison between the distribution of covariates on all sets (Effort) and observed sets (Obs.).

Table 17: Summary of the configuration of surface longline fisheries models. The bullets indicate the inclusion of random year effects, random vessel-year effects, and overdispersion.

Method	Species group	Years	Vessels	Over.	Covariates
Surface longline	White capped albatross	-	•	•	Annual cosine, annual sine, set time (day, night, full moon), target fishery, vessel size
	Sooty shearwater	-	-	-	Annual cosine, sine start time, vessel size
	White chinned petrel	•	-	-	Vessel size
	Other albatross	•	•	•	Annual sine, set time (day, night, full moon), vessel size
	Other birds	•	•	•	Annual cosine, area, set time (day, night, full moon), vessel size

albatross captures. This supports the use of a restriction on day setting as a measure to reduce albatross captures in surface longline fisheries.

Across the whole series, from 1998–99 to 2008–09, changes in the number of estimated captures broadly followed changes in the number of observed captures (see Figure Appendix C-7), with a peak in 2006–07 associated with captures in the swordfish fishery. In 2008–09, the number of estimated other albatross captures in surface longline fisheries was 235 (95% c.i.: 135 to 467). This was similar to the number estimated to have been caught in 2007–08.

Table 18: Summary of results from all surface longline models, showing the estimated total seabird captures by fishery during 2008–09. The mean and 95% confidence intervals of the posterior distribution of the totals are given.

Group	Bluefin		Bigeye		Swordfish		Other		Total	
	Mean	c.i.	Mean	c.i.	Mean	c.i.	Mean	c.i.	Mean	c.i.
White-capped alb.	8	(3 – 23)	0	(0 – 1)	2	(0 – 14)	0	(0 – 0)	10	(3 – 29)
Other albatross	87	(60 – 133)	163	(68 – 330)	3	(0 – 11)	3	(0 – 11)	256	(135 – 467)
Total albatross	95	(66 – 141)	163	(68 – 330)	6	(0 – 19)	3	(0 – 11)	266	(145 – 478)
Sooty shearwater	0	(0 – 1)	2	(0 – 7)	0	(0 – 0)	0	(0 – 0)	2	(0 – 7)
White-chinned petr.	6	(2 – 12)	10	(2 – 24)	0	(0 – 1)	0	(0 – 1)	16	(5 – 35)
Other birds	27	(12 – 58)	270	(100 – 627)	4	(0 – 14)	6	(0 – 19)	307	(120 – 693)
Total petrel	32	(16 – 63)	282	(110 – 641)	4	(0 – 14)	6	(0 – 19)	325	(136 – 711)
Total birds	127	(93 – 180)	445	(235 – 804)	10	(2 – 28)	9	(1 – 24)	591	(351 – 987)

In 2008–09, captures of other birds in surface longline fisheries were estimated at 307 (95% c.i.: 120 to 693). This was significantly fewer captures than the peak of 2016 (95% c.i.: 1032 to 3917) other bird captures that were estimated for 2001–02. From the fitted covariates (see Table Appendix C-25), capture rates of other birds were low in the southern area, and increased during daylight and full moon. The full moon covariate was significantly higher than 1, and had a mean value that was higher than the daylight covariate. There was a significant seasonal cycle to the capture rate, with the seasonal variation being represented by a cosine term, peaking at new year.

4. DISCUSSION

4.1 Seabird captures during the 2008–09 fishing year

The total number of seabirds that were estimated to have been caught was 3224 (95% c.i.: 2520 to 4412) (Table 19). This estimate includes captures in all surface longline fishing, in all trawl fishing other than fishing targeting inshore species, in large-vessel (over 34 m long) bottom longline fisheries, and in small vessel bottom longline fisheries targeting snapper in the northern area (FMA1). Of the total estimated captures, 27.5% were albatross species, with the remainder being petrels and shearwaters.

In trawl fisheries, sooty shearwater was the most frequently caught species, with an estimated 514 (95% c.i.: 335 to 829) captures. Out of the three methods, trawl fishing was the method that was estimated to have caught the most sooty shearwaters, white-capped albatrosses (257 (95% c.i.: 199 to 337) captures) , and other albatrosses (345 (95% c.i.: 246 to 467) captures). Captures of individual albatross species were not estimated separately, however over the period 1998–99 to 2008–09, there were a total of 487 observed captures of other albatrosses in trawl fisheries. These captures were of the following species: Salvin's albatross (171), Buller's albatross (142), unidentified albatrosses (94), black-browed and Campbell albatross (49), southern royal albatross (10), Chatham albatross (7), Pacific albatross (5), grey-headed albatross (3), wandering albatrosses (4), and northern royal albatross (2). If it is assumed that the estimated captures occur with the same species ratio, then it follows that 43% of the estimated other albatross captures in trawl fisheries would be Salvin's albatross (where the unidentified albatrosses were excluded when calculating the ratio).

In surface longline fisheries, the other birds group was the group with the highest estimated bycatch (307 (95% c.i.: 120 to 693) captures). These captures were largely in the bigeye tuna fishery. Over the

Table 19: Summary of results from all models, showing the estimated total seabird captures during the 2008–09 fishing year. The mean and 95% confidence intervals of the posterior distribution of the totals are given. The trawl fisheries include all target species except inshore species, and the bottom longline fisheries include fishing from large vessels and from FMA 1 snapper.

Group	Trawl		SLL		BLL		Total	
	Mean	c.i.	Mean	c.i.	Mean	c.i.	Mean	c.i.
White-capped alb.	257	(199 – 337)	10	(3 – 29)	2	(0 – 5)	269	(210 – 351)
Other albatross	345	(246 – 467)	256	(135 – 467)	17	(4 – 42)	618	(452 – 853)
Total albatross	602	(483 – 745)	266	(145 – 478)	19	(5 – 45)	887	(705 – 1 128)
Sooty shearwater	514	(335 – 829)	2	(0 – 7)	12	(2 – 30)	528	(350 – 845)
White-chinned petr.	214	(162 – 285)	16	(5 – 35)	371	(36 – 1 366)	601	(253 – 1 590)
Other birds	214	(145 – 312)	307	(120 – 693)	687	(387 – 1 187)	1 207	(809 – 1 842)
Total petrel	942	(734 – 1 267)	325	(136 – 711)	1 070	(538 – 2 154)	2 337	(1 670 – 3 518)
Total birds	1 544	(1 294 – 1 892)	591	(351 – 987)	1 088	(559 – 2 179)	3 224	(2 520 – 4 412)

years 1998–99 to 2008–09, there were a total of 160 observed captures of other birds in this fishery. These observed captures were of the following species: flesh-footed shearwater (133), black petrel (21), great-winged petrel (2), Cape petrel (1), and 1 unidentified petrel. The group with the next highest estimated captures in surface longline fisheries was the other albatross group (256 (95% c.i.: 135 to 467) captures). Again, most of these estimated captures were in the bigeye tuna target fishery. From 1998–99 to 2008–09 there were 27 observed other albatross captures in the bigeye fishery. These were of the following species: wandering albatrosses (8), Salvin's albatross (7), Buller's albatross (6), black-browed albatross or Campbell albatross (4), northern royal albatross (1), and 1 unidentified albatross.

In the bottom longline fisheries where capture estimates could be made, there were few albatross captures. The species group with the highest number of estimated captures was the other birds group, with estimated captures of 687 (95% c.i.: 387 to 1187) birds. These other bird captures were almost entirely in the northern snapper fishery. Over the years covered by the data, there were 80 observed other bird captures in this fishery. These captures were of the following species: flesh-footed shearwater (34), black petrel (13), grey petrel (11), Buller's shearwater (6), Australasian gannet (2), fluttering shearwater (2), penguin (1), pied shag (1), black-backed gull (1), and 10 unidentified birds. The next highest estimated number of captures in bottom longline fisheries were of white-chinned petrel (371 (95% c.i.: 36 to 1366) captures). These were in the large-vessel bottom longline fishery, which primarily targeted ling.

4.2 Trends

Across all offshore trawl fisheries, there was a decrease in the total number of birds caught between 2003–03 and 2008–09, (Figure 8, Table 20) with the captures falling by 42% over this period. Over the same years, the total number of tows in offshore fisheries fell by 46%, and so the overall decrease was similar to the decrease in the trawl effort.

In surface longline fisheries, there was also a significant decrease in the number of estimated seabird captures between 2002–03 and 2008–09, although the number of estimated captures in 2008–09 was higher than in 2004–05. Between 2002–03 and 2008–09, the percentage decrease was 69%. Over that same period the number of hooks set in surface longline fisheries fell by 71%, so the overall decrease in seabird captures was similar to the decrease in the effort.

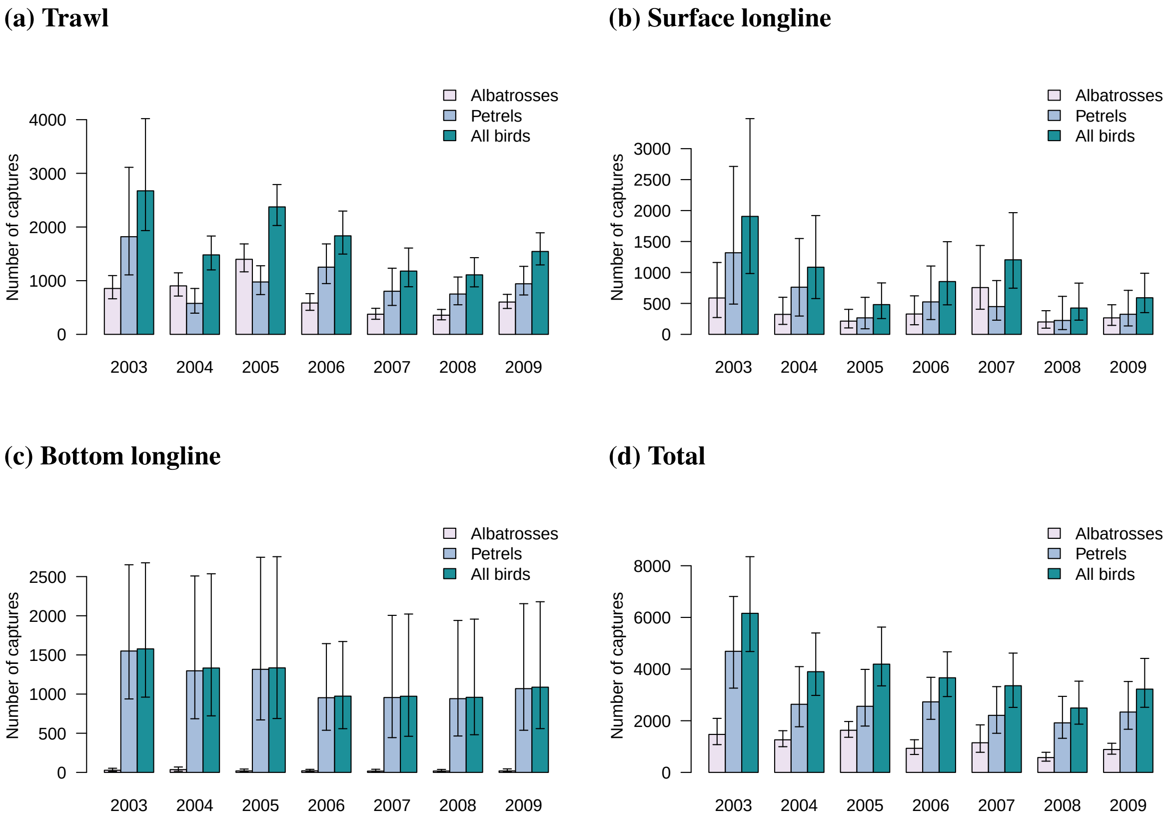

Figure 8: Time series of estimated seabird captures, for each of the three fishing methods (a) trawl, (b) surface longline, and (c) bottom longline. A time series of total captures is shown in (d). The bars indicate the mean of the posterior distributions, while the error-bars indicate the 95% confidence intervals.

Most of the estimated seabird captures in bottom longline fisheries were of petrel species. Uncertainties in the total captures in bottom longline fisheries were high, driven primarily by the inclusion of the northern snapper fishery, and by large uncertainties in the model of white-chinned petrel captures in the large-vessel fishery. Although the uncertainties were large, there was a 31% decrease in the mean estimated captures over the seven year period. This was associated with a 43% decline in the number of hooks set in the large-vessel ling longline fishery, and a 35% decline in the number of hooks set in the snapper longline fishery.

Although the long term trends in the total number of seabird captures appear to have been mainly associated with changes in the fishing effort, there was an increase in the estimated total seabird captures between 2007–08 and 2008–09. The 2008–09 mean estimate was 29.3% higher than the 2007–08 estimate (the increase was not significant at the 95% confidence level, however). An increase in the mean number of estimated captures was recorded for both albatrosses and petrels in each of the three methods, with a significant 69% increase in the mean number of albatross captures in trawl fisheries. The increase in trawl fisheries occurred despite an 8% decrease in the trawl effort in the fisheries included in the models, including decreases in effort in squid, hoki, middle-depths, and scampi trawl fisheries. An increase in the number of estimated captures in trawl fisheries was found for each of the five species groups, with significant increases for white-capped albatrosses (see Table Appendix A-1), other albatrosses (see Table Appendix A-16), and other birds (see Table Appendix A-21). In the observer data an increase in the seabird capture rate was recorded in each of the Chatham Rise, Stewart-Snares, and Auckland Islands areas where most observed bird captures occur, and in the same four trawl fisheries.

Table 20: Summary of results from all models, showing the estimated total seabird captures. The mean and 95% confidence intervals of the posterior distribution of the totals are given. The trawl fisheries include all target species except inshore species, and the bottom longline fisheries include fishing from large vessels and from FMA 1 snapper. The table summarises captures in the modelled trawl, surface longline (SLL), and bottom longline (BLL) fisheries. Totals are provided for albatrosses (Alb. – white capped albatross and other albatrosses), and the remaining species groups (Petr. – white-chinned petrel, sooty shearwater and other birds).

Birds	Year	Trawl		SLL		BLL		All	
		Mean	c.i.	Mean	c.i.	Mean	c.i.	Mean	c.i.
Alb.	2002–03	855	(663 – 1 095)	588	(272 – 1 161)	27	(12 – 53)	1 470	(1 075 – 2 091)
	2003–04	903	(714 – 1 146)	323	(161 – 599)	36	(15 – 69)	1 262	(995 – 1 614)
	2004–05	1 399	(1 165 – 1 685)	214	(104 – 404)	19	(5 – 43)	1 631	(1 359 – 1 970)
	2005–06	584	(448 – 758)	329	(155 – 622)	20	(9 – 39)	932	(694 – 1 264)
	2006–07	375	(281 – 485)	756	(406 – 1 436)	16	(3 – 40)	1 148	(778 – 1 840)
	2007–08	357	(271 – 464)	201	(100 – 382)	17	(5 – 38)	575	(435 – 778)
	2008–09	602	(483 – 745)	266	(145 – 478)	19	(5 – 45)	887	(705 – 1 128)
Petr.	2002–03	1 819	(1 108 – 3 112)	1 318	(489 – 2 713)	1 550	(938 – 2 651)	4 687	(3 262 – 6 809)
	2003–04	577	(395 – 855)	762	(296 – 1 548)	1 297	(685 – 2 508)	2 637	(1 767 – 4 094)
	2004–05	976	(741 – 1 278)	267	(90 – 598)	1 316	(670 – 2 747)	2 559	(1 794 – 3 987)
	2005–06	1 252	(946 – 1 685)	524	(239 – 1 104)	954	(538 – 1 644)	2 730	(2 054 – 3 681)
	2006–07	804	(539 – 1 232)	449	(229 – 869)	956	(444 – 2 005)	2 208	(1 514 – 3 320)
	2007–08	752	(551 – 1 068)	225	(77 – 614)	941	(465 – 1 940)	1 918	(1 320 – 2 943)
	2008–09	942	(734 – 1 267)	325	(136 – 711)	1 070	(538 – 2 154)	2 337	(1 670 – 3 518)
All birds	2002–03	2 674	(1 933 – 4 019)	1 906	(983 – 3 485)	1 577	(961 – 2 676)	6 157	(4 679 – 8 350)
	2003–04	1 481	(1 201 – 1 832)	1 085	(578 – 1 919)	1 333	(722 – 2 536)	3 899	(2 980 – 5 397)
	2004–05	2 375	(2 028 – 2 791)	481	(255 – 831)	1 335	(688 – 2 754)	4 190	(3 349 – 5 625)
	2005–06	1 836	(1 496 – 2 297)	853	(477 – 1 497)	974	(558 – 1 671)	3 662	(2 936 – 4 668)
	2006–07	1 179	(887 – 1 608)	1 205	(746 – 1 966)	972	(461 – 2 022)	3 356	(2 516 – 4 618)
	2007–08	1 109	(885 – 1 429)	425	(230 – 828)	959	(481 – 1 957)	2 493	(1 867 – 3 532)
	2008–09	1 544	(1 294 – 1 892)	591	(351 – 987)	1 088	(559 – 2 179)	3 224	(2 520 – 4 412)

The general increase in seabird bycatch in trawl fisheries, and also in fishing using other methods, is striking. As it is found for a range of seabird groups, and in a range of fisheries, it is not caused by an unusual single fishing event or trip with high bycatch. The reasons for this increase is unclear. One possibility is that annual changes in oceanic productivity are driving changes in seabird foraging behaviour. In one seabird study, it was shown that a decrease in the availability of natural prey led to an increase in the use of fisheries' waste (Hamer et al. 1991). An assumption of the modelling was that there was independent variation in the capture rates between different species, and between different fishing methods. If environmental variation is leading to correlated changes in catch rates, then this would result in the uncertainties in the total captures being underestimated. The correlation in annual capture rates between seabird species and between different fishing methods could be explored in future work.

4.3 Warp mitigation

While the overall trends in seabird captures over the seven years largely follow changes in effort, there has been significant effort to reduce seabird capture rates in many fisheries. In trawl fisheries, seabirds may be killed by being caught in nets, or by being struck by the warps while they are feeding behind vessels. Albatrosses, with their long wingspan, are prone to life-threatening injuries if they are struck by trawl warps. In order to reduce the number of albatrosses that are killed by the warps, mitigation devices have been developed. These devices deter birds from entering the region between the stern of a trawler and where the warps enter the water. They have been shown to be effective under experimental settings (Sullivan et al. 2006, Middleton & Abraham 2007). In January 2006, warp mitigation devices were made mandatory for all trawlers over 28 m long, fishing in New Zealand waters (Department of Internal Affairs 2006). Since then, there has been a reduction in the proportion of observed albatross captures that were from the trawl warps (Abraham 2010). In all years following the introduction of mandatory warp mitigation (from 2005–06 on), the estimated capture rate of white-capped albatross in trawl fisheries has been lower than before (see Table Appendix A-2). The estimated capture rate of other albatrosses in trawl fisheries decreased between 2004–05 and 2005–06, but the estimated capture rate in 2008–09 was higher than the capture rate in either 2002–03 or 2003–04 (see Table Appendix A-2).

A difficulty with considering changes in the estimated capture rate across all fisheries, is that the changes may reflect shifts in the location of fishing, or changes in the relative proportion of effort targeting different species. To understand the effect of the introduction of mandatory mitigation, it is most useful to restrict the analysis to a specific fishery and area. White-capped albatross were most frequently caught in the squid fishery, with capture rates being highest in the Auckland Islands fishery. Before the 2005–06 fishing year, the estimated capture rate in the Auckland Islands squid fishery was 9.4 (95% c.i.: 4.7 to 14.6) birds per 100 tows, whereas after the introduction of mandatory mitigation it reduced to 4.1 (95% c.i.: 2.4 to 6.4) birds per 100 tows (Figure 9). From the densities of the posterior distributions of the capture rate (Figure 9(b)), it follows that the capture rate after the introduction of mitigation is less than the capture rate before the introduction of mitigation, with a probability of 97.7%. The ratio of the mean capture rate after mandatory mitigation to the mean capture rate before mitigation is 47.1% (95% c.i.: 20.9–98.8). This is a measure of the efficacy of the mitigation at reducing the overall number of captures of white-capped albatross in the Auckland Islands squid fishery.

Early data on the capture of white-capped albatross in the Auckland Islands squid fishery were reported by Bartle (1991), with an analysis of the dataset being carried out by Hilborn & Mangel (1997). At this time, trawlers were using netsondes, communicating with the vessel through a 'third wire' that was associated with high fatality rates. In the 1990–91 season, observers recorded the capture of 250 white-capped albatross from 897 tows, a rate of 27.9 captures per 100 tows. This fatality rate compares with the estimated capture rate of 4.1 (95% c.i.: 2.4 to 6.4) white-capped albatrosses per 100 tows in the Auckland Islands squid fishery, in the years since 2005–06. From the 1991 data, it was estimated that a total of

(a) White-capped albatross capture rate **(b) Capture rate distribution**

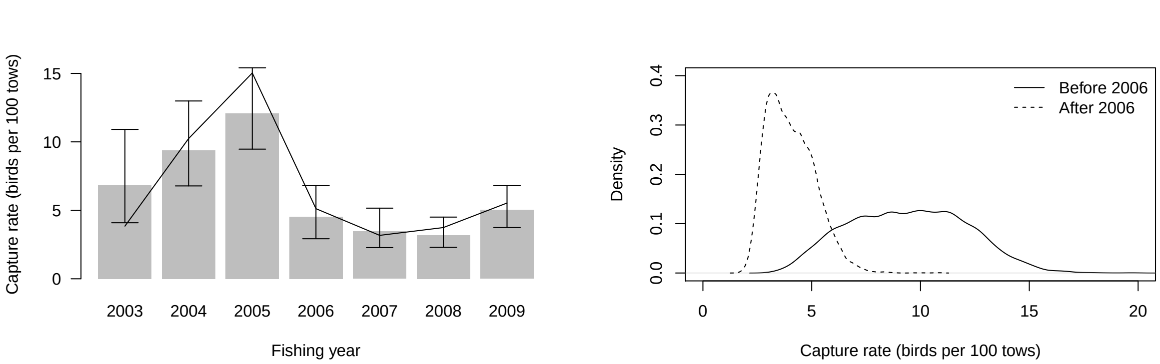

Figure 9: Capture rate of white-capped albatross in the Auckland Islands squid fishery. In (a) the estimated captures are given by fishing year. The error bars indicate the 2.5% and 97.5% percentiles, with the solid bars indicating the mean. The line indicates the observed capture rate. In (b) the posterior distributions of the estimated capture rates are summarised, for all years before 2005–06, and for the years from and including 2005–06.

1212 white-capped albatrosses were caught from the 4349 tows made during that season. This compares with estimated captures of 96.8 (95% c.i.: 72 to 131) white-capped albatrosses in the Auckland Islands squid fishery from 1925 tows during 2008–09. Over the 18 year period from 1990–91 to 2008–09, the elimination of the use of a third-wire, the introduction of warp mitigation, and other changes in vessel practice, have reduced the capture rates of white-capped albatross considerably.

Global estimates of white-capped albatross bycatch were made by Baker et al. (2007). They estimated that a total of over 8000 white-capped albatrosses were killed in global fisheries annually. Of these, over half were attributed to fatalities in South African trawl fisheries, while 450 were estimated to be killed in the New Zealand squid fishery. This figure of 450 fatalities is within the range of estimates calculated here for captures during 2002–03 and 2003–04, before the introduction of warp mitigation. Substantially reducing the impact of fishing on white-capped albatross populations will require a reduction in the fatality of albatrosses in South African trawl fisheries, and in other fisheries throughout their southern ocean range.

4.4 Model covariates

The use of statistical modelling to estimate captures provides insight into the factors that are associated with increased capture rates. The prime purpose of the models was to estimate total captures, and so covariates could only be used that were available from all the effort data. Most of the covariates related to the location or timing of the fishing event.

Seasonal effects were often selected for inclusion in the models. The seasonal peak was most pronounced for sooty-shearwater captures in trawl fisheries (Figure 10), with the capture rate reaching about 6 times the annual average capture rate during April. In this case, annual and six-monthly harmonics were fitted, and in addition to the autumn peak, there is a smaller peak in spring. These two peaks coincide with sooty shearwater migration: the larger peak being associated with the start of northward migration, at the end of the breeding season. In bottom longline fisheries, the highest capture rates of sooty shearwater also occurred at either end of the breeding season (March to May, and October), with no captures recorded during winter (July to September). In trawl fisheries, white-capped albatross and white-chinned petrel also had peak capture rates between February and May.

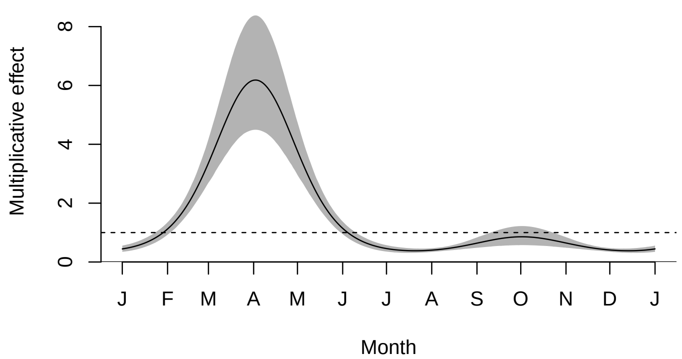

Figure 10: Seasonality in sooty shearwater capture rate, in trawl fisheries. The multiplicative effect from the fitted seasonal covariates is shown, with the line indicating the mean value, and the shading indicating the 95% c.i.

In large-vessel bottom longline fisheries, a key covariate was whether or not the vessel used integrated weight line. From the model of white-chinned petrel captures in bottom longline fisheries, the use of integrated weight line was found to reduce the capture rate by 87.2% (95% c.i.: 40.6 to 97.6). The efficacy of line-weighting has been demonstrated during experimental trials (Robertson et al. 2006), and the analysis here shows that integrated weight line is an effective mitigation measure during routine fishing. The estimated capture of white-chinned petrels in bottom longline fisheries remains high, as only 39% of the effort in the large-vessel fleet was carried out with integrated weight line. The uncertainty in the estimates of captures in large-vessel bottom longline fisheries is high, as the fishing without integrated weight lines has been poorly observed.

In surface longline fisheries, set time was available as a covariate. It was presented as a three level factor with sets either entirely at night, or during the day, and with the night-time sets further classified by whether or not they were close to full moon. For the two species-groups with the most captures (other albatrosses and other birds), set time was a significant effect. For other albatrosses, sets close to full moon had a capture rate that was 3.0 (95% c.i.: 2.3 to 3.9) times higher than during other night sets (see Table Appendix C-20). Similarly, for other birds, sets during full moon had a capture rate that was 3.3 (95% c.i.: 1.9 to 5.3) times higher than during other night sets (see Table Appendix C-25). A similar increase in catch rate during full moon was also found for white-capped albatross. Setting surface longlines during the day is currently restricted, as a measure to reduce seabird bycatch, however capture rates close to full moon may be similarly high. This is supported by observer data (Figure 11). When the moon is less than quarter-phase (50% illuminated), the capture rate is about one-third of the capture-rate that was observed when the moon was full. Across all the observed night-time surface longline sets, 75% of captures occurred when the moon was more than 50% illuminated, and 43% of captures occurred when the moon was more than 90% illuminated.

4.5 Comparison with previous models

Seabird captures in New Zealand fisheries have previously been estimated by Waugh et al. (2008). The aim of this work was to estimate seabird captures in all trawl, surface longline and bottom longline fisheries between the 1998–99 and 2003–04 fishing years. A zero-inflated Poisson model was used, fitted with similar Bayesian methods to those used here. A fixed set of covariates was included in each model (season, area, fishing year, vessel size), with separate models being fitted for vessels over 28 m

(a) Number of annual captures **(b) Capture rate**

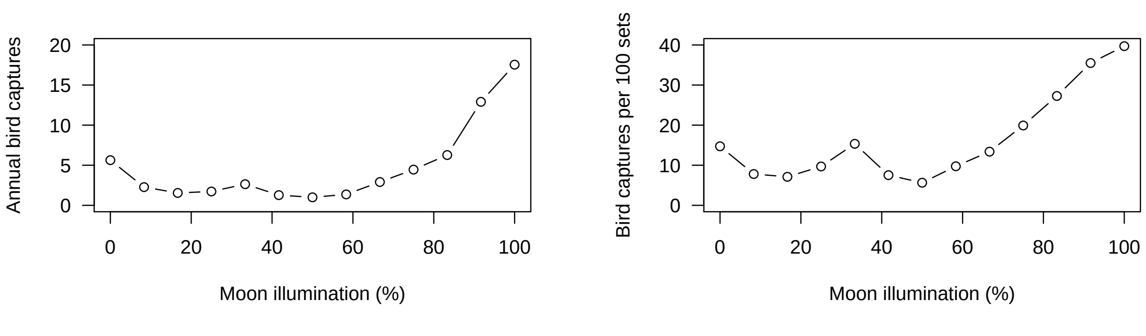

Figure 11: Variation in seabird captures and capture rate with moon illumination. The data are from all bird captures during observed surface longline sets that were set during the night. They are plotted against the percentage illumination of the moon's disk (0% is new moon, 50% is quarter moon, and 100% is full moon), binned into equal bins. In (a) the average annual number of captures is shown, and in (b) the average capture rate (birds per 100 sets) is shown.

in length and for vessels less than 28 m in length. The models directly estimated total seabird captures, with additional estimates being made of albatross captures of trawl fisheries.

One key difference between the methodology used in this report and the methods used by Waugh et al. (2008) was that we estimated captures for each of five species groups. We also used a different model structure, with a negative binomial model of the captures that included vessel-year random effects where there had been sufficient capture events. A comparison between the two sets of model estimates is given in Figure 12. There are some differences in the effort that was included in the two sets of estimates, as Waugh et al. (2008) split their estimates by vessel length. In the models presented here, this was only done for bottom longline fisheries, with a length of 34 m being used. The values shown in the figure are the total seabird captures estimated by Waugh et al. (2008), and the sum of captures from all five species groups for the estimates from this report. For trawl fisheries, and for snapper bottom longline, there are only two years of overlap between the estimates, otherwise there are six years of overlapping estimates. In general, there is good agreement between the two sets of estimates. The 2003–04 estimates of captures in the squid and hoki trawl fisheries Figure 12(a, b) are lower than were estimated by Waugh et al. (2008), and there are two years (2000–01 and 2002–03) where the large-vessel bottom longline estimates are lower than were estimated by Waugh et al. (2008). None of the other estimates are significantly different.

Many of the estimates given by Waugh et al. (2008) had very large uncertainties. These all occurred in models of the small vessel fisheries. It is likely that the combination of low observer coverage in the small vessel fisheries, and the use of a fixed set of covariates, meant that these models suffered from over-fitting. In the surface longline estimates made here, these problems are masked by fitting all the effort within a single model framework. In contrast, in the trawl fisheries and large-vessel bottom longline fisheries, the uncertainties from the models presented here are larger. It is likely that the larger uncertainties are due both to the use of the negative binomial model, and to the inclusion of vessel-year random effects. The negative binomial model allows for more skewed distributions than can be represented with the zero-inflated Poisson model, and the vessel-year random effects allow for correlations between observations made on the same vessel and in the same year. Whether or not vessels used integrated weight line was not included as a covariate in the bottom longline modelling of Waugh et al. (2008).

Other authors have made estimates of captures in selected fisheries. Baird & Smith (2007) and Baird & Smith (2008) gave model based estimates of seabird captures in squid and hoki trawl fisheries. They used a model with a similar structure to the ones developed here, using a negative binomial model, and including vessel-year random effects. They fitted separate models for albatross, petrel, and total seabird captures. They selected covariates from a similar set to those used here, but with a different spatial division of the New Zealand region. For the three years where there was overlap, the estimates for total seabird captures in the squid and hoki fisheries are comparable with those presented here (Figure 12(a, b)), with the estimates of captures in the 2004–05 squid fishery being just outside each-other's 95% confidence intervals. Baird & Smith (2007) also made ratio estimates of captures in longline fisheries. For surface longline fisheries they gave estimates for the charter and domestic surface longline fisheries, and these do not correspond to any of the quantities estimated here. Their estimates of captures in the bottom longline ling autoline and snapper fisheries are given in Figure 12(e, f). The estimates are similar to those calculated here, within the range of the confidence intervals. The model based estimates of captures in the large-vessel bottom longline fishery have higher uncertainty than the ratio estimates.

The overall agreement between the three different sets of estimates gives confidence in the results. All of these estimates were produced entirely independently, using different methods (although all based on observer data). The total seabird captures derived from models presented in this paper are obtained by summing the results from the five species groups. There is no evidence from this comparison of any structural problems with the modelling.

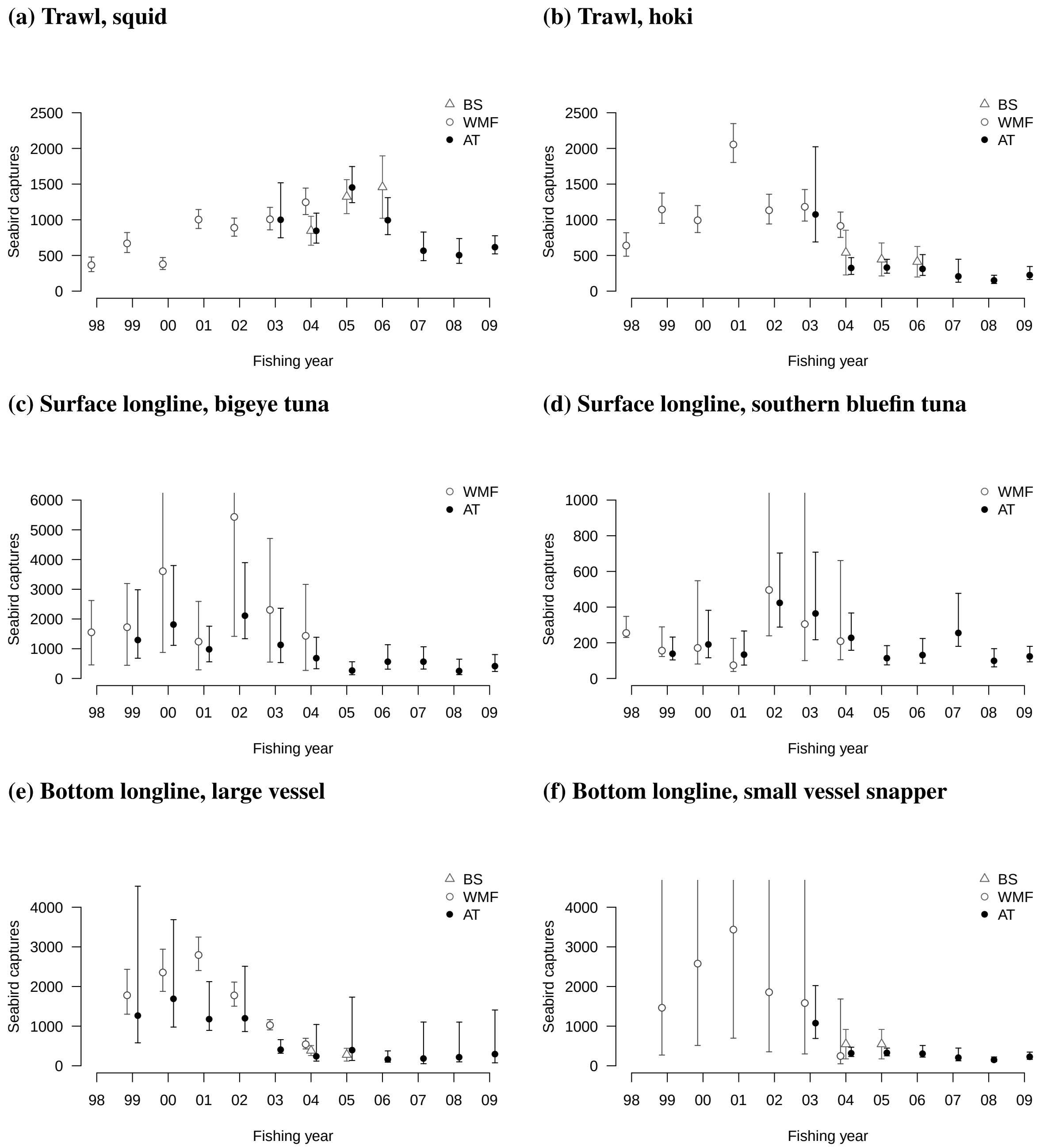

Figure 12: Comparison of selected estimates of total seabird captures made by Waugh et al. (2008) (WMF) and Baird & Smith (2007, 2008)(BS), with estimates presented in this report (AT). The plots give the median and 95% c.i. of the posterior distributions, with some upper confidence intervals from the report by Waugh et al. (2008) being truncated. The following estimates by Waugh et al. (2008) are used: (a, b) vessels over 28 m in length; (c) vessels less than 28 m in length; (d) the sum of estimates for both size classes of vessel; (e) vessels over 28 m in length; (f) vessels less than 28 m in length. Estimates from this report for trawl and surface longline include effort from vessels of all sizes. The estimates of captures in bottom longline fisheries from this report are captures by vessels over 34 m in length (e), and captures by vessels less than 34 m in length targeting snapper in FMA 1 (f). Model estimated captures were available from Baird and Smith (2007, 2008) for squid and hoki trawl fisheries, covering the 2003–04 to 2005–06 fishing years. They also provided ratio estimates for bottom longline fisheries for 2003–04 and 2004–05.

4.6 Under-reporting and cryptic fatalities

The estimates in this report were based on observer data. They can be pragmatically interpreted as the number of seabirds that would have been reported caught, if observers had been placed on every vessel in the modelled fisheries. Observers only report captures that they either see or that they are made aware of. The extent of under-reporting is unknown. Often, not all of a fishing operation can be observed by a single observer, especially if they have other duties to carry out in addition to recording bycatch. For example, in the large-vessel bottom longline fisheries only 49% of the hooks were observed during monitoring of the haul (in contrast, in the northern snapper fishery, 96% of hooks were observed during monitored hauls). In informal discussions, observers said that sometimes, but not always, crew would notify them of birds that had been caught during the unobserved portion of the haul. In trawl fisheries, a similar under-reporting may occur: observers may not be on duty when tows are hauled, or they may be on the wrong part of the vessel to see the captures.

In many cases, the longer series of estimated captures (Figure 12) show lower number of captures in the first three years of the series (1998–99 to 1999–2000). During informal discussions with observers, it was stated by one observer that there was an increased focus by the Ministry of Fisheries on seabird captures from 2000–01 onwards. They felt that this would have resulted in more complete reporting of seabird captures by observers from the 2000–01 fishing year, than in the years before that.

A further problem with the observer data is that cryptic fatalities may be occurring. These are fatalities that are difficult to detect because the dead bird is not brought on board the vessel. For example, in a South African trawl fishery the trawl warps were watched and fatal interactions between the warps and seabirds were recorded (Watkins et al. 2008). During the time that the warps were watched, there were 30 interactions between seabirds and the warps that were assessed as fatal, but only 2 of these birds were brought on board the vessel. The other 28 interactions would not have been recorded by an observer during normal operations. A similar study aimed to quantify the number of seabirds that were hooked during surface longlining, but not retrieved on the haul as the body had fallen off the hook during the set (Brothers et al. 2010). It was estimated that around 50% of the birds killed during surface longlining are lost, and so would not be recorded in observer data. No attempt has been made to adjust the estimates for either under-reporting or for these cryptic fatalities.

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APPENDIX A: TRAWL FISHERIES MODELS

A.1 Model summary, white-capped albatross, trawl fisheries

Table A-1: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
2002–03	345	(234 – 494)	81	(44 – 141)	23	(7 – 52)	46	(22 – 83)	505	(353 – 709)
2003–04	519	(382 – 706)	57	(30 – 97)	19	(5 – 46)	38	(18 – 68)	645	(478 – 860)
2004–05	776	(624 – 968)	36	(17 – 65)	40	(9 – 110)	55	(28 – 96)	930	(741 – 1 174)
2005–06	252	(170 – 364)	19	(9 – 34)	18	(4 – 48)	38	(24 – 56)	341	(242 – 478)
2006–07	148	(104 – 205)	12	(5 – 23)	14	(4 – 34)	26	(13 – 45)	212	(151 – 291)
2007–08	86	(62 – 120)	10	(4 – 18)	8	(1 – 23)	22	(9 – 43)	137	(96 – 194)
2008–09	156	(118 – 205)	18	(9 – 31)	20	(5 – 48)	44	(28 – 68)	257	(199 – 337)

Table A-2: Capture rate (birds per 100 trawls) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
2002–03	4.2	(2.9 – 6.0)	0.3	(0.2 – 0.5)	0.5	(0.1 – 1.1)	0.6	(0.3 – 1.1)	0.9	(0.6 – 1.2)
2003–04	6.3	(4.6 – 8.5)	0.3	(0.1 – 0.5)	0.5	(0.1 – 1.2)	0.6	(0.3 – 1.1)	1.3	(1.0 – 1.8)
2004–05	7.6	(6.1 – 9.5)	0.3	(0.1 – 0.5)	0.9	(0.2 – 2.4)	0.9	(0.5 – 1.6)	2.1	(1.6 – 2.6)
2005–06	3.0	(2.1 – 4.4)	0.2	(0.1 – 0.3)	0.4	(0.1 – 1.0)	0.6	(0.4 – 0.9)	0.8	(0.6 – 1.2)
2006–07	2.7	(1.9 – 3.8)	0.1	(0.0 – 0.2)	0.3	(0.1 – 0.7)	0.5	(0.2 – 0.8)	0.6	(0.4 – 0.8)
2007–08	2.0	(1.5 – 2.8)	0.1	(0.0 – 0.2)	0.2	(0.0 – 0.5)	0.3	(0.1 – 0.6)	0.4	(0.3 – 0.5)
2008–09	4.0	(3.1 – 5.3)	0.2	(0.1 – 0.4)	0.5	(0.1 – 1.2)	0.6	(0.4 – 0.9)	0.8	(0.6 – 1.0)

Table A-3: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-capped albatross captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	35 899	22.1	73	0.9	257	(199 – 337)
Squid	Auckland Islands	1 925	39.4	42	5.5	97	(72 – 131)
Squid	Stewart-Snares	1 805	29.3	11	2.1	58	(37 – 86)
Middle-depths	Stewart-Snares	1 015	24.7	12	4.8	26	(17 – 40)
Scampi	Auckland Islands	1 457	4.2	1	1.6	17	(4 – 43)
Middle-depths	Chatham Rise	2 706	9.1	0	0	9	(2 – 19)
Hake	Stewart-Snares	274	28.5	1	1.3	8	(2 – 18)
Hoki	Chatham Rise	4 012	14.2	1	0.2	6	(2 – 13)
Hoki	Stewart-Snares	789	35.4	2	0.7	5	(2 – 12)

Table A-4: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		2156.5		
Fishery	4	1176.8	979.7	45.4
Area	4	1089.3	87.5	7.4
Fishing year	6	1033.8	55.5	5.1
Annual sine exponent	1	1011.4	22.5	2.2
Vessel length	3	1001.1	10.2	1.0

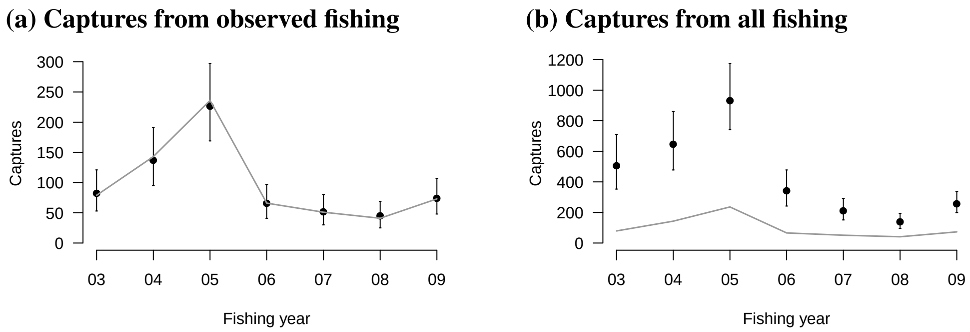

Figure A-1: Estimated captures of white-capped albatross in all trawl fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-5: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Auckland Islands (Area) and Squid (Fishery).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.119	0.129	0.034	0.280
Base rate, $100 \times \lambda_{03-04}$	0.124	0.132	0.035	0.285
Base rate, $100 \times \lambda_{04-05}$	0.153	0.162	0.043	0.340
Base rate, $100 \times \lambda_{05-06}$	0.076	0.082	0.020	0.179
Base rate, $100 \times \lambda_{06-07}$	0.061	0.066	0.017	0.147
Base rate, $100 \times \lambda_{07-08}$	0.048	0.052	0.013	0.118
Base rate, $100 \times \lambda_{08-09}$	0.082	0.088	0.022	0.191
Area, Snares	0.866	0.869	0.669	1.097
Area, Southern	0.201	0.209	0.123	0.331
Area, Stewart-Snares	0.628	0.646	0.391	0.980
Area, Other	0.009	0.015	0.000	0.061
Fishery, Mid-depths	0.780	0.804	0.489	1.243
Fishery, Hoki	0.268	0.283	0.148	0.500
Fishery, Scampi	0.303	0.333	0.118	0.738
Fishery, Deepwater	0.035	0.056	0.001	0.232
Annual sine exponent	2.116	2.140	1.521	2.944
Vessel-year s.d., $\exp(\sigma_v)$	2.270	2.291	1.939	2.747
Overdispersion, θ	0.100	0.103	0.072	0.149

A.2 Model summary, white-chinned petrel, trawl fisheries

Table A-6: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
2002–03	67	(32 – 121)	23	(11 – 43)	6	(1 – 16)	7	(2 – 15)	108	(56 – 183)
2003–04	65	(38 – 107)	10	(3 – 22)	5	(1 – 11)	4	(0 – 10)	86	(50 – 140)
2004–05	164	(116 – 230)	14	(6 – 26)	11	(4 – 22)	7	(2 – 16)	201	(142 – 280)
2005–06	254	(168 – 380)	19	(10 – 33)	16	(5 – 31)	14	(6 – 27)	311	(209 – 457)
2006–07	78	(51 – 117)	10	(4 – 20)	8	(2 – 16)	9	(4 – 17)	108	(72 – 161)
2007–08	124	(85 – 181)	21	(12 – 34)	13	(5 – 26)	20	(11 – 34)	191	(136 – 268)
2008–09	155	(118 – 207)	15	(6 – 28)	15	(5 – 31)	17	(7 – 30)	214	(162 – 285)

Table A-7: Capture rate (birds per 100 trawls) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
2002–03	0.8	(0.4 – 1.5)	0.1	(0.0 – 0.2)	0.1	(0.0 – 0.3)	0.1	(0.0 – 0.2)	0.2	(0.1 – 0.4)
2003–04	0.8	(0.5 – 1.3)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.3)	0.1	(0.0 – 0.2)	0.2	(0.1 – 0.3)
2004–05	1.6	(1.1 – 2.2)	0.1	(0.0 – 0.2)	0.2	(0.1 – 0.5)	0.1	(0.0 – 0.3)	0.5	(0.4 – 0.7)
2005–06	3.1	(2.0 – 4.6)	0.2	(0.1 – 0.3)	0.3	(0.1 – 0.6)	0.2	(0.1 – 0.5)	0.9	(0.6 – 1.3)
2006–07	1.4	(0.9 – 2.2)	0.1	(0.0 – 0.2)	0.1	(0.0 – 0.3)	0.2	(0.1 – 0.3)	0.3	(0.2 – 0.5)
2007–08	2.9	(2.0 – 4.3)	0.2	(0.1 – 0.4)	0.3	(0.1 – 0.5)	0.3	(0.1 – 0.5)	0.6	(0.4 – 0.8)
2008–09	4.0	(3.1 – 5.4)	0.2	(0.1 – 0.3)	0.4	(0.1 – 0.8)	0.2	(0.1 – 0.4)	0.7	(0.6 – 1.0)

Table A-8: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-chinned petrel captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	35 899	22.1	86	1.1	214	(162 – 285)
Squid	Auckland Islands	1 925	39.4	47	6.2	87	(62 – 125)
Squid	Stewart-Snares	1 805	29.3	33	6.2	67	(47 – 98)
Scampi	Auckland Islands	1 457	4.2	0	0	10	(2 – 24)
Hoki	Chatham Rise	4 012	14.2	0	0	9	(2 – 19)
Middle-depths	Stewart-Snares	1 015	24.7	2	0.8	6	(2 – 14)
Middle-depths	Chatham Rise	2 706	9.1	0	0	5	(1 – 12)
Mackerel	Stewart-Snares	83	42.2	3	8.6	4	(3 – 7)
Hake	Stewart-Snares	274	28.5	0	0	3	(0 – 10)
Hoki	Stewart-Snares	789	35.4	1	0.4	3	(1 – 9)
Scampi	Chatham Rise	1 306	15.6	0	0	2	(0 – 7)

Table A-9: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		1005.9		
Fishery	1	712.0	294.0	29.2
Fishing year	6	653.5	58.5	8.2
Annual sine exponent	1	629.7	23.8	3.6
Annual cosine exponent	1	612.8	16.9	2.7
Log(fishing duration)	1	602.3	10.6	1.7
Area	4	587.9	14.4	2.4

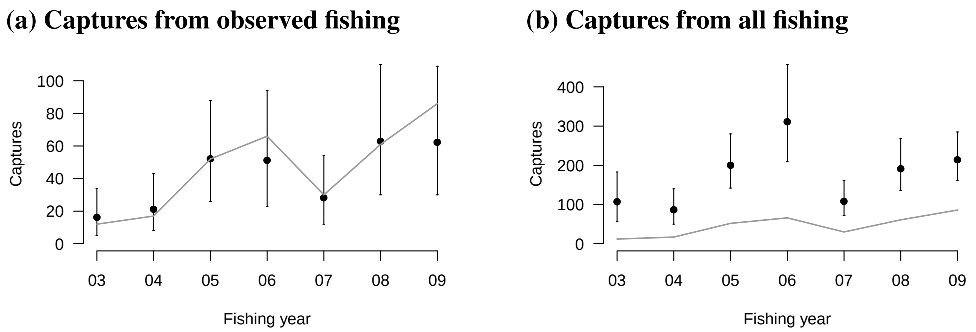

Figure A-2: Estimated captures of white-chinned petrel in all trawl fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-10: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Squid (Fishery) and Auckland Islands (Area).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.088	0.092	0.042	0.165
Base rate, $100 \times \lambda_{03-04}$	0.066	0.070	0.032	0.129
Base rate, $100 \times \lambda_{04-05}$	0.129	0.132	0.074	0.215
Base rate, $100 \times \lambda_{05-06}$	0.228	0.237	0.131	0.382
Base rate, $100 \times \lambda_{06-07}$	0.113	0.118	0.062	0.199
Base rate, $100 \times \lambda_{07-08}$	0.230	0.237	0.137	0.373
Base rate, $100 \times \lambda_{08-09}$	0.241	0.249	0.145	0.394
Fishery, Mid-depths	0.384	0.402	0.205	0.689
Annual sine exponent	3.071	3.173	1.916	5.000
Annual cosine exponent	2.172	2.222	1.470	3.306
Area, Snares	0.701	0.718	0.462	1.065
Area, Stewart-Snares	0.581	0.609	0.304	1.082
Area, Chatham Rise	0.234	0.251	0.103	0.502
Area, Other	0.231	0.251	0.101	0.516
Overdispersion, θ	0.014	0.014	0.010	0.019

A.3 Model summary, sooty shearwater, trawl fisheries

Table A-11: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
2002–03	534	(284 – 984)	789	(348 – 1 670)	11	(2 – 30)	150	(58 – 356)	1 538	(847 – 2 862)
2003–04	181	(93 – 334)	96	(37 – 226)	6	(1 – 18)	49	(18 – 116)	336	(179 – 595)
2004–05	330	(200 – 526)	59	(19 – 143)	22	(3 – 61)	45	(13 – 108)	463	(272 – 732)
2005–06	407	(254 – 674)	189	(97 – 376)	36	(7 – 103)	124	(79 – 217)	798	(535 – 1 191)
2006–07	314	(175 – 553)	143	(48 – 359)	42	(19 – 92)	102	(40 – 227)	620	(365 – 1 040)
2007–08	264	(151 – 475)	43	(15 – 102)	32	(9 – 78)	95	(37 – 216)	455	(273 – 765)
2008–09	210	(135 – 347)	82	(36 – 190)	25	(3 – 74)	164	(74 – 352)	514	(335 – 829)

Table A-12: Capture rate (birds per 100 trawls) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
2002–03	6.5	(3.5 – 12.0)	3.0	(1.3 – 6.2)	0.2	(0.0 – 0.6)	2.0	(0.8 – 4.8)	3.0	(1.6 – 5.5)
2003–04	2.2	(1.1 – 4.0)	0.5	(0.2 – 1.1)	0.2	(0.0 – 0.5)	0.8	(0.3 – 1.9)	0.8	(0.4 – 1.4)
2004–05	3.2	(2.0 – 5.1)	0.4	(0.1 – 1.0)	0.5	(0.1 – 1.3)	0.7	(0.2 – 1.8)	1.2	(0.7 – 1.8)
2005–06	4.9	(3.1 – 8.2)	1.7	(0.9 – 3.4)	0.7	(0.1 – 2.1)	2.1	(1.3 – 3.7)	2.2	(1.5 – 3.3)
2006–07	5.8	(3.2 – 10.2)	1.4	(0.5 – 3.5)	0.8	(0.4 – 1.8)	1.8	(0.7 – 3.9)	1.9	(1.1 – 3.2)
2007–08	6.2	(3.6 – 11.2)	0.5	(0.2 – 1.2)	0.7	(0.2 – 1.6)	1.3	(0.5 – 2.9)	1.4	(0.9 – 2.4)
2008–09	5.4	(3.5 – 9.0)	1.0	(0.4 – 2.3)	0.6	(0.1 – 1.9)	2.3	(1.0 – 4.9)	1.8	(1.2 – 2.9)

Table A-13: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated sooty shearwater captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	35 899	22.1	126	1.6	514	(335 – 829)
Middle-depths	Chatham Rise	2 706	9.1	13	5.3	126	(45 – 306)
Squid	Stewart-Snares	1 805	29.3	43	8.1	112	(66 – 219)
Squid	Auckland Islands	1 925	39.4	31	4.1	80	(50 – 129)
Hoki	Chatham Rise	4 012	14.2	15	2.6	72	(30 – 179)
Middle-depths	Stewart-Snares	1 015	24.7	12	4.8	35	(16 – 87)
Scampi	Auckland Islands	1 457	4.2	0	0	19	(2 – 61)
Squid	Chatham Rise	122	2.5	0	0	18	(0 – 91)
Hake	Chatham Rise	502	12.5	6	9.5	10	(6 – 20)
Hake	Stewart-Snares	274	28.5	0	0	9	(0 – 44)
Hoki	Stewart-Snares	789	35.4	2	0.7	8	(2 – 27)

Table A-14: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		12.4		
Area	4	9.9	2.5	20.1
Annual sine exponent	1	9.4	0.5	4.8
Six month cosine exponent	1	8.4	1.1	11.3

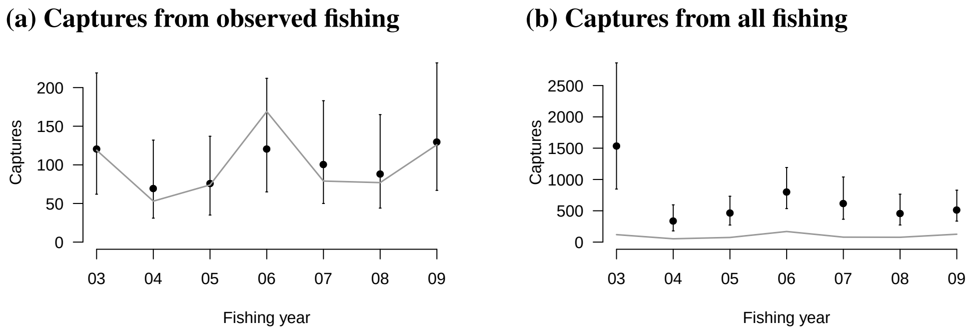

Figure A-3: Estimated captures of sooty shearwater in all trawl fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-15: Summary of the posterior distributions of the model parameters. The base level of Area is Stewart-Snares.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.331	0.356	0.171	0.677
Base rate, $100 \times \lambda_{03-04}$	0.163	0.174	0.063	0.342
Base rate, $100 \times \lambda_{04-05}$	0.185	0.195	0.085	0.354
Base rate, $100 \times \lambda_{05-06}$	0.268	0.282	0.132	0.505
Base rate, $100 \times \lambda_{06-07}$	0.265	0.278	0.139	0.486
Base rate, $100 \times \lambda_{07-08}$	0.262	0.275	0.141	0.492
Base rate, $100 \times \lambda_{08-09}$	0.290	0.305	0.149	0.558
Area, Inner Chatham Rise	1.220	1.265	0.727	2.088
Area, Southern	0.327	0.332	0.223	0.472
Area, Outer Chatham Rise	0.180	0.191	0.090	0.355
Area, Other	0.026	0.029	0.007	0.073
Six month cosine exponent	0.304	0.309	0.214	0.427
Annual sine exponent	3.888	3.955	2.738	5.569
Vessel-year s.d., $\exp(\sigma_\nu)$	3.887	4.004	2.904	5.691
Overdispersion, θ	0.029	0.030	0.022	0.039

A.4 Model summary, other albatrosses, trawl fisheries

Table A-16: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
2002–03	55	(32 – 87)	178	(121 – 251)	42	(22 – 71)	58	(30 – 98)	350	(245 – 487)
2003–04	46	(28 – 71)	114	(67 – 172)	26	(13 – 45)	41	(19 – 70)	258	(172 – 370)
2004–05	108	(74 – 155)	155	(106 – 219)	85	(48 – 138)	73	(40 – 123)	468	(338 – 639)
2005–06	54	(31 – 84)	69	(40 – 106)	53	(28 – 90)	45	(22 – 77)	242	(157 – 351)
2006–07	26	(14 – 43)	46	(25 – 75)	38	(17 – 70)	32	(15 – 57)	163	(98 – 255)
2007–08	24	(13 – 39)	59	(37 – 88)	49	(26 – 80)	53	(28 – 87)	220	(149 – 313)
2008–09	40	(26 – 59)	84	(50 – 131)	68	(42 – 106)	107	(68 – 159)	345	(246 – 467)

Table A-17: Capture rate (birds per 100 trawls) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
2002–03	0.7	(0.4 – 1.1)	0.7	(0.5 – 0.9)	0.9	(0.5 – 1.5)	0.8	(0.4 – 1.3)	0.6	(0.4 – 0.8)
2003–04	0.6	(0.3 – 0.9)	0.5	(0.3 – 0.8)	0.7	(0.4 – 1.2)	0.7	(0.3 – 1.2)	0.5	(0.3 – 0.7)
2004–05	1.1	(0.7 – 1.5)	1.1	(0.8 – 1.6)	1.8	(1.0 – 3.0)	1.2	(0.7 – 2.0)	1.0	(0.7 – 1.3)
2005–06	0.6	(0.4 – 1.0)	0.6	(0.4 – 0.9)	1.1	(0.6 – 1.8)	0.8	(0.4 – 1.3)	0.6	(0.4 – 0.8)
2006–07	0.5	(0.3 – 0.8)	0.5	(0.2 – 0.7)	0.7	(0.3 – 1.4)	0.6	(0.3 – 1.0)	0.4	(0.2 – 0.6)
2007–08	0.6	(0.3 – 0.9)	0.7	(0.4 – 1.0)	1.0	(0.5 – 1.7)	0.7	(0.4 – 1.2)	0.6	(0.4 – 0.8)
2008–09	1.0	(0.7 – 1.5)	1.0	(0.6 – 1.6)	1.7	(1.1 – 2.7)	1.5	(0.9 – 2.2)	1.0	(0.7 – 1.3)

Table A-18: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other albatrosses captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	35 899	22.1	63	0.8	345	(246 – 467)
Middle-depths	Chatham Rise	2 706	9.1	8	3.3	59	(33 – 95)
Hoki	Chatham Rise	4 012	14.2	3	0.5	57	(31 – 94)
Scampi	Chatham Rise	1 306	15.6	14	6.9	49	(29 – 80)
Squid	Stewart-Snares	1 805	29.3	8	1.5	21	(12 – 34)
Middle-depths	Stewart-Snares	1 015	24.7	11	4.4	18	(12 – 26)
Squid	Auckland Islands	1 925	39.4	7	0.9	17	(10 – 27)
Hoki	Cook Strait	1 826	9.2	0	0	15	(5 – 29)
Hake	Chatham Rise	502	12.5	1	1.6	13	(4 – 28)
Middle-depths	Cook Strait	728	0	0		12	(3 – 26)
Scampi	Auckland Islands	1 457	4.2	0	0	12	(3 – 23)

Table A-19: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		1081.4		
Fishery	5	950.0	131.4	12.1
Area	4	886.0	64.0	6.7
Fishing year	6	860.2	25.8	2.9
Six month sine exponent	1	849.0	11.2	1.3
Vessel length	3	834.6	14.4	1.7

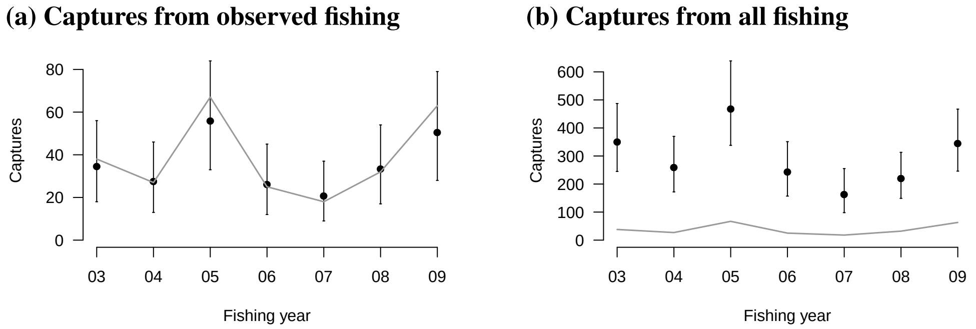

Figure A-4: Estimated captures of other albatrosses in all trawl fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-20: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Chatham Rise (Area) and Hoki (Fishery).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.186	0.190	0.110	0.288
Base rate, $100 \times \lambda_{03-04}$	0.166	0.170	0.094	0.270
Base rate, $100 \times \lambda_{04-05}$	0.305	0.309	0.182	0.465
Base rate, $100 \times \lambda_{05-06}$	0.178	0.182	0.101	0.282
Base rate, $100 \times \lambda_{06-07}$	0.122	0.126	0.066	0.208
Base rate, $100 \times \lambda_{07-08}$	0.171	0.174	0.102	0.263
Base rate, $100 \times \lambda_{08-09}$	0.299	0.305	0.183	0.454
Area, Southern	0.261	0.267	0.173	0.395
Area, Snares	0.340	0.354	0.193	0.594
Area, East	0.503	0.522	0.300	0.843
Area, Other	0.054	0.062	0.011	0.159
Fishery, Mid-depths	1.600	1.631	1.084	2.345
Fishery, Squid	1.589	1.634	1.007	2.485
Fishery, Deepwater	0.097	0.103	0.047	0.190
Fishery, SBW	0.239	0.295	0.034	0.895
Fishery, Mackerel	0.100	0.158	0.004	0.628
Overdispersion, θ	0.018	0.018	0.013	0.026

A.5 Model summary, other birds, trawl fisheries

Table A-21: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
2002–03	37	(16 – 68)	72	(42 – 114)	30	(9 – 73)	13	(3 – 31)	174	(102 – 273)
2003–04	41	(25 – 66)	53	(27 – 89)	26	(7 – 64)	10	(2 – 27)	155	(93 – 246)
2004–05	88	(49 – 143)	70	(38 – 113)	58	(18 – 137)	19	(5 – 42)	313	(202 – 472)
2005–06	45	(23 – 77)	28	(13 – 49)	36	(17 – 73)	11	(4 – 22)	143	(87 – 220)
2006–07	17	(7 – 33)	17	(7 – 31)	19	(5 – 47)	6	(1 – 15)	75	(40 – 129)
2007–08	23	(13 – 38)	19	(9 – 34)	30	(12 – 63)	11	(3 – 23)	106	(69 – 159)
2008–09	65	(48 – 89)	33	(16 – 58)	54	(20 – 120)	24	(12 – 44)	214	(145 – 312)

Table A-22: Capture rate (birds per 100 trawls) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Squid		Hoki		Scampi		Middle depths		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
2002–03	0.4	(0.2 – 0.8)	0.3	(0.2 – 0.4)	0.6	(0.2 – 1.5)	0.2	(0.0 – 0.4)	0.3	(0.2 – 0.4)
2003–04	0.5	(0.3 – 0.8)	0.2	(0.1 – 0.4)	0.7	(0.2 – 1.7)	0.2	(0.0 – 0.5)	0.3	(0.2 – 0.5)
2004–05	0.9	(0.5 – 1.4)	0.5	(0.3 – 0.8)	1.3	(0.4 – 2.9)	0.3	(0.1 – 0.7)	0.6	(0.4 – 1.0)
2005–06	0.5	(0.3 – 0.9)	0.2	(0.1 – 0.4)	0.7	(0.3 – 1.5)	0.2	(0.1 – 0.4)	0.3	(0.2 – 0.5)
2006–07	0.3	(0.1 – 0.6)	0.2	(0.1 – 0.3)	0.4	(0.1 – 0.9)	0.1	(0.0 – 0.3)	0.2	(0.1 – 0.3)
2007–08	0.5	(0.3 – 0.9)	0.2	(0.1 – 0.4)	0.6	(0.2 – 1.3)	0.1	(0.0 – 0.3)	0.3	(0.2 – 0.4)
2008–09	1.7	(1.2 – 2.3)	0.4	(0.2 – 0.7)	1.4	(0.5 – 3.0)	0.3	(0.2 – 0.6)	0.6	(0.4 – 0.9)

Table A-23: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other birds captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	35 899	22.1	60	0.8	214	(145 – 312)
Squid	Stewart-Snares	1 805	29.3	23	4.3	35	(26 – 50)
Scampi	North	804	10.6	2	2.4	30	(6 – 86)
Squid	Auckland Islands	1 925	39.4	14	1.8	28	(17 – 45)
Hoki	Chatham Rise	4 012	14.2	1	0.2	15	(5 – 30)
Scampi	Auckland Islands	1 457	4.2	0	0	12	(2 – 35)
Deepwater	Chatham Rise	2 978	45.8	2	0.1	9	(3 – 19)
Scampi	Chatham Rise	1 306	15.6	2	1	8	(2 – 20)
Middle-depths	Stewart-Snares	1 015	24.7	5	2	7	(5 – 12)
Hoki	West South Island	1 170	42.4	2	0.4	6	(2 – 14)
Middle-depths	Chatham Rise	2 706	9.1	1	0.4	6	(1 – 16)

Table A-24: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		687.7		
Log(fishing duration)	1	637.5	50.2	7.3
Fishing year	6	598.4	39.2	6.1
Area	6	576.9	21.4	3.6
Fishery	6	551.7	25.2	4.4

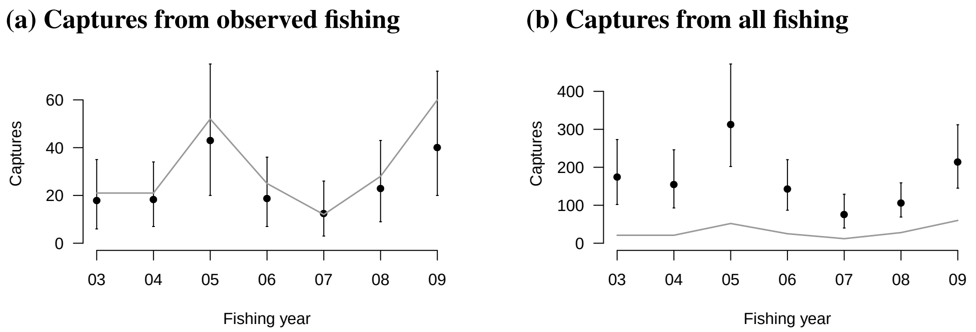

Figure A-5: Estimated captures of other birds in all trawl fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-25: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Stewart-Snares (Area) and Squid (Fishery).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.141	0.145	0.080	0.235
Base rate, $100 \times \lambda_{03-04}$	0.143	0.147	0.081	0.241
Base rate, $100 \times \lambda_{04-05}$	0.287	0.293	0.180	0.447
Base rate, $100 \times \lambda_{05-06}$	0.142	0.147	0.081	0.238
Base rate, $100 \times \lambda_{06-07}$	0.091	0.094	0.046	0.163
Base rate, $100 \times \lambda_{07-08}$	0.142	0.145	0.085	0.225
Base rate, $100 \times \lambda_{08-09}$	0.287	0.294	0.182	0.439
Area, Auckland-Campbell	1.048	1.090	0.624	1.793
Area, West	1.537	1.645	0.747	3.147
Area, Chatham Rise	0.630	0.678	0.300	1.351
Area, East	1.208	1.329	0.540	2.799
Area, Northeast	4.525	5.573	1.333	15.789
Area, Other	0.131	0.161	0.026	0.476
Log(fishing duration)	1.962	1.994	1.456	2.677
Fishery, Hoki	0.543	0.571	0.278	1.066
Fishery, Deepwater	1.791	2.033	0.686	4.728
Fishery, Scampi	0.652	0.739	0.235	1.709
Fishery, Mid-depths	0.273	0.294	0.124	0.577
Fishery, Mackerel	0.270	0.306	0.098	0.715
Fishery, SBW	1.011	1.156	0.358	2.896
Overdispersion, θ	0.007	0.007	0.005	0.011

APPENDIX B: BOTTOM LONGLINE FISHERIES MODELS

B.1 Model summary, white-capped albatross, bottom longline fisheries

Table B-1: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	7	(1 – 16)	0	(0 – 1)	0	(0 – 1)	7	(1 – 16)
1999–00	10	(5 – 18)	0	(0 – 0)	0	(0 – 0)	10	(5 – 18)
2000–01	5	(1 – 11)	0	(0 – 0)	0	(0 – 0)	5	(1 – 11)
2001–02	6	(2 – 13)	0	(0 – 1)	0	(0 – 0)	6	(2 – 13)
2002–03	2	(0 – 5)	0	(0 – 0)	0	(0 – 0)	2	(0 – 5)
2003–04	2	(0 – 7)	0	(0 – 2)	0	(0 – 1)	3	(0 – 8)
2004–05	2	(0 – 7)	0	(0 – 0)	0	(0 – 0)	2	(0 – 7)
2005–06	3	(1 – 6)	0	(0 – 0)	0	(0 – 0)	3	(1 – 6)
2006–07	2	(0 – 5)	0	(0 – 0)	0	(0 – 0)	2	(0 – 5)
2007–08	2	(0 – 6)	0	(0 – 0)	0	(0 – 0)	2	(0 – 6)
2008–09	2	(0 – 5)	0	(0 – 0)	0	(0 – 0)	2	(0 – 5)

Table B-2: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	0.1	(0.0 – 0.3)	0.3	(0.0 – 4.0)	0.2	(0.0 – 4.2)	0.1	(0.0 – 0.3)
1999–00	0.3	(0.1 – 0.5)	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.0)	0.2	(0.1 – 0.4)
2000–01	0.1	(0.0 – 0.3)	0.0	(0.0 – 0.0)			0.1	(0.0 – 0.3)
2001–02	0.2	(0.1 – 0.3)	0.1	(0.0 – 3.4)			0.2	(0.1 – 0.3)
2002–03	0.1	(0.0 – 0.2)			0.4	(0.0 – 0.0)	0.1	(0.0 – 0.2)
2003–04	0.1	(0.0 – 0.2)	0.2	(0.0 – 1.0)	0.2	(0.0 – 2.2)	0.1	(0.0 – 0.2)
2004–05	0.1	(0.0 – 0.3)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.3)
2005–06	0.1	(0.0 – 0.3)	0.0	(0.0 – 0.0)			0.1	(0.0 – 0.3)
2006–07	0.1	(0.0 – 0.3)					0.1	(0.0 – 0.3)
2007–08	0.1	(0.0 – 0.3)					0.1	(0.0 – 0.3)
2008–09	0.1	(0.0 – 0.3)			0.0	(0.0 – 0.0)	0.1	(0.0 – 0.3)

Table B-3: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-capped albatross captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All large vessels	All areas	1 912	19.1	0	0	2	(0 – 5)
Large vessel, ling	Chatham Rise	1 206	18.3	0	0	2	(0 – 5)
Large vessel, ling	Cook Strait	34	0	0		0	(0 – 0)
Large vessel, ling	East North Island	88	0	0		0	(0 – 0)
Large vessel, ling	Puysegur	27	0	0		0	(0 – 1)
Large vessel, ling	Stewart-Snares	193	0	0		0	(0 – 0)
Large vessel, ling	Subantarctic	312	46.2	0	0	0	(0 – 2)
Large vessel, other	Puysegur	19	0	0		0	(0 – 0)
Large vessel, other	Subantarctic	33	0	0		0	(0 – 0)

Table B-4: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		38.4		
Moon phase	1	32.3	6.1	15.9
Integrated weight line	1	27.4	4.9	15.2

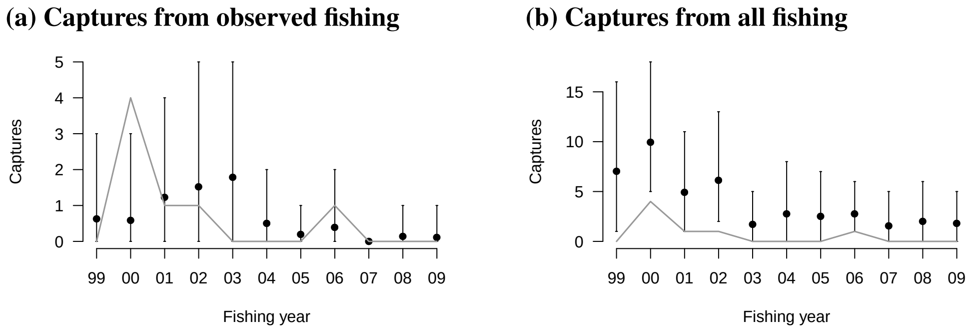

Figure B-1: Estimated captures of white-capped albatross in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-5: Summary of the posterior distributions of the model parameters. The base level of Integrated weight line is False.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.000	0.005	0.000	0.038
Moon phase exponent	0.022	0.058	0.000	0.332
Integrated weight line, True	0.000	0.012	0.000	0.131

B.2 Model summary, white-chinned petrel, bottom longline fisheries

Table B-6: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	989	(96 – 3 920)	0	(0 – 0)	0	(0 – 0)	989	(96 – 3 920)
1999–00	885	(230 – 2 658)	0	(0 – 0)	14	(0 – 79)	900	(234 – 2 681)
2000–01	666	(353 – 1 512)	0	(0 – 0)	0	(0 – 0)	666	(353 – 1 512)
2001–02	1 025	(595 – 2 179)	0	(0 – 0)	0	(0 – 0)	1 025	(595 – 2 179)
2002–03	215	(139 – 431)	0	(0 – 0)	1	(0 – 8)	216	(139 – 432)
2003–04	180	(22 – 896)	38	(0 – 259)	3	(0 – 28)	221	(23 – 1 158)
2004–05	433	(58 – 1 641)	34	(0 – 178)	0	(0 – 0)	467	(61 – 1 747)
2005–06	118	(40 – 307)	0	(0 – 0)	0	(0 – 0)	118	(40 – 307)
2006–07	218	(14 – 1 018)	0	(0 – 0)	0	(0 – 0)	218	(14 – 1 018)
2007–08	204	(18 – 993)	0	(0 – 0)	0	(0 – 0)	204	(18 – 993)
2008–09	369	(34 – 1 366)	0	(0 – 0)	2	(0 – 13)	371	(36 – 1 366)

Table B-7: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	25.1	(2.4 – 99.6)			0.0	(0.0 – 0.0)	25.0	(2.4 – 99.2)
1999–00	31.1	(8.1 – 93.3)			142.3	(0.0 – 790.0)	31.5	(8.2 – 93.8)
2000–01	27.6	(14.7 – 62.8)					27.6	(14.7 – 62.8)
2001–02	37.6	(21.8 – 79.9)					37.6	(21.8 – 79.9)
2002–03	10.9	(7.0 – 21.7)			21.5	(0.0 – 160.0)	10.9	(7.0 – 21.7)
2003–04	8.5	(1.0 – 42.5)	21.3	(0.0 – 145.5)	7.6	(0.0 – 60.9)	9.5	(1.0 – 49.6)
2004–05	28.3	(3.8 – 107.4)	64.0	(0.0 – 335.9)			29.5	(3.9 – 110.5)
2005–06	7.6	(2.6 – 19.9)	0.0	(0.0 – 0.0)			7.5	(2.5 – 19.5)
2006–07	14.9	(1.0 – 69.6)					14.9	(1.0 – 69.6)
2007–08	13.9	(1.2 – 67.8)					13.9	(1.2 – 67.8)
2008–09	27.2	(2.5 – 100.7)			3.3	(0.0 – 25.0)	26.3	(2.6 – 96.9)

Table B-8: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-chinned petrel captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All large vessels	All areas	1 912	19.1	1	0.3	371	(36 – 1 366)
Large vessel, ling	Chatham Rise	1 206	18.3	1	0.5	294	(23 – 1 100)
Large vessel, ling	Subantarctic	312	46.2	0	0	46	(1 – 221)
Large vessel, ling	Puysegur	27	0	0		23	(0 – 159)
Large vessel, ling	Stewart-Snares	193	0	0		5	(0 – 33)
Large vessel, other	Puysegur	19	0	0		1	(0 – 10)
Large vessel, other	Subantarctic	33	0	0		0	(0 – 3)

Table B-9: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		764.9		
Breeding season	1	579.8	185.0	24.2
Area	3	539.9	39.9	6.9
Integrated weight line	1	516.7	23.3	4.3
Moon phase	1	507.2	9.5	1.8

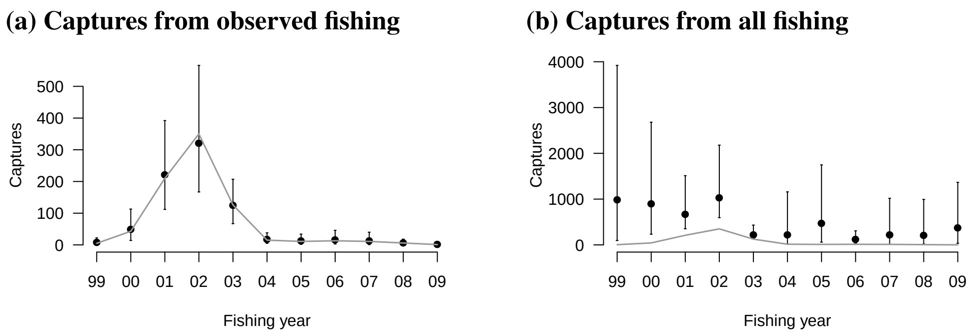

Figure B-2: Estimated captures of white-chinned petrel in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-10: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Breeding (Season), False (Integrated weight line), and Chatham Rise (Area).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	4.082	4.209	2.691	6.499
Season, Shoulder	0.025	0.028	0.009	0.065
Integrated weight line, True	0.128	0.176	0.024	0.594
Moon phase exponent	2.670	2.765	1.560	4.498
Area, Keyhole	3.352	4.463	0.909	14.835
Area, Bounty	0.668	0.887	0.199	2.894
Area, Southern	1.339	1.727	0.371	5.467
Vessel-year s.d., $\exp(\sigma_v)$	4.151	5.186	2.211	14.610
Overdispersion, θ	0.071	0.071	0.056	0.089

B.3 Model summary, sooty shearwater, bottom longline fisheries

Table B-11: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	41	(15 – 89)	0	(0 – 0)	0	(0 – 0)	41	(15 – 89)
1999–00	30	(14 – 58)	0	(0 – 1)	0	(0 – 0)	30	(14 – 58)
2000–01	22	(14 – 35)	1	(1 – 1)	0	(0 – 0)	23	(15 – 36)
2001–02	41	(25 – 67)	0	(0 – 1)	0	(0 – 0)	41	(25 – 67)
2002–03	34	(25 – 54)	0	(0 – 0)	0	(0 – 0)	34	(25 – 54)
2003–04	27	(19 – 42)	1	(0 – 3)	0	(0 – 1)	28	(19 – 43)
2004–05	26	(10 – 56)	0	(0 – 1)	0	(0 – 0)	26	(10 – 56)
2005–06	11	(4 – 24)	0	(0 – 0)	0	(0 – 0)	11	(4 – 24)
2006–07	13	(3 – 34)	0	(0 – 0)	0	(0 – 0)	13	(3 – 34)
2007–08	18	(7 – 42)	0	(0 – 0)	0	(0 – 0)	18	(7 – 42)
2008–09	12	(2 – 30)	0	(0 – 0)	0	(0 – 1)	12	(2 – 30)

Table B-12: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	1.1	(0.4 – 2.3)			0.0	(0.0 – 0.0)	1.1	(0.4 – 2.3)
1999–00	1.1	(0.5 – 2.1)	0.3	(0.0 – 3.4)	0.1	(0.0 – 0.0)	1.1	(0.5 – 2.1)
2000–01	1.0	(0.6 – 1.6)	3.3	(3.3 – 3.3)			1.0	(0.7 – 1.6)
2001–02	1.6	(1.0 – 2.6)	0.9	(0.0 – 20.0)			1.6	(1.0 – 2.6)
2002–03	1.9	(1.4 – 3.1)			0.3	(0.0 – 0.0)	1.9	(1.4 – 3.1)
2003–04	1.4	(1.0 – 2.1)	0.3	(0.0 – 1.5)	0.2	(0.0 – 2.2)	1.2	(0.8 – 1.9)
2004–05	1.7	(0.7 – 3.7)	0.3	(0.0 – 1.9)	0.3	(0.0 – 0.0)	1.7	(0.6 – 3.6)
2005–06	0.7	(0.3 – 1.6)	0.0	(0.0 – 0.0)			0.7	(0.3 – 1.6)
2006–07	0.9	(0.2 – 2.3)					0.9	(0.2 – 2.3)
2007–08	1.3	(0.5 – 3.0)					1.3	(0.5 – 3.0)
2008–09	0.9	(0.1 – 2.2)			0.1	(0.0 – 1.9)	0.8	(0.1 – 2.1)

Table B-13: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated sooty shearwater captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All large vessels	All areas	1 912	19.1	0	0	12	(2 – 30)
Large vessel, ling	Stewart-Snares	193	0	0		6	(0 – 21)
Large vessel, ling	Puysegur	27	0	0		3	(0 – 13)
Large vessel, ling	Chatham Rise	1 206	18.3	0	0	2	(0 – 8)
Large vessel, ling	Cook Strait	34	0	0		0	(0 – 1)
Large vessel, ling	East North Island	88	0	0		0	(0 – 1)
Large vessel, ling	Subantarctic	312	46.2	0	0	0	(0 – 2)
Large vessel, other	Puysegur	19	0	0		0	(0 – 0)
Large vessel, other	Subantarctic	33	0	0		0	(0 – 1)

Table B-14: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		335.5		
Area	1	212.0	123.5	36.8
Breeding season	1	205.6	6.4	3.0
Moon phase	1	202.0	3.6	1.7
Integrated weight line	1	199.3	2.7	1.3

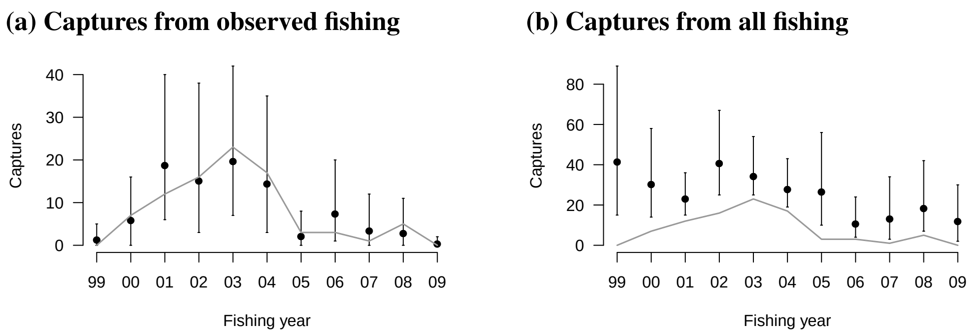

Figure B-3: Estimated captures of sooty shearwater in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-15: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Keyhole (Area), Shoulder (Season), and False (Integrated weight line).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.495	0.510	0.256	0.864
Area, Southern	0.037	0.041	0.013	0.089
Season, Breeding	0.436	0.461	0.219	0.853
Integrated weight line, True	0.445	0.525	0.156	1.377
Moon phase exponent	0.407	0.454	0.161	1.021
Vessel-year s.d., $\exp(\sigma_v)$	1.478	1.561	1.099	2.564
Overdispersion, θ	0.065	0.068	0.034	0.121

B.4 Model summary, other albatrosses, bottom longline fisheries

Table B-16: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	68	(17 – 136)	0	(0 – 1)	0	(0 – 0)	68	(17 – 137)
1999–00	87	(52 – 136)	0	(0 – 2)	0	(0 – 3)	88	(52 – 136)
2000–01	143	(102 – 199)	0	(0 – 0)	0	(0 – 0)	143	(102 – 199)
2001–02	73	(30 – 132)	0	(0 – 1)	0	(0 – 0)	73	(30 – 133)
2002–03	26	(11 – 50)	0	(0 – 0)	0	(0 – 1)	26	(11 – 51)
2003–04	30	(12 – 60)	2	(0 – 11)	1	(0 – 6)	33	(13 – 66)
2004–05	16	(3 – 40)	0	(0 – 4)	0	(0 – 0)	16	(3 – 40)
2005–06	17	(7 – 36)	0	(0 – 0)	0	(0 – 0)	17	(7 – 36)
2006–07	15	(2 – 39)	0	(0 – 0)	0	(0 – 0)	15	(2 – 39)
2007–08	15	(4 – 37)	0	(0 – 0)	0	(0 – 0)	15	(4 – 37)
2008–09	17	(4 – 42)	0	(0 – 0)	0	(0 – 1)	17	(4 – 42)

Table B-17: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	1.4	(0.3 – 2.7)	0.3	(0.0 – 4.0)	0.1	(0.0 – 0.0)	1.4	(0.3 – 2.7)
1999–00	2.2	(1.3 – 3.4)	0.5	(0.0 – 6.9)	2.2	(0.0 – 30.0)	2.2	(1.3 – 3.4)
2000–01	4.1	(2.9 – 5.7)	0.0	(0.0 – 0.0)			4.0	(2.9 – 5.6)
2001–02	1.9	(0.8 – 3.4)	0.4	(0.0 – 3.4)			1.9	(0.8 – 3.4)
2002–03	0.9	(0.4 – 1.8)			1.5	(0.0 – 20.0)	0.9	(0.4 – 1.9)
2003–04	1.0	(0.4 – 2.0)	1.1	(0.0 – 5.3)	1.8	(0.0 – 13.0)	1.0	(0.4 – 2.1)
2004–05	0.7	(0.1 – 1.8)	0.8	(0.0 – 7.5)	0.6	(0.0 – 0.0)	0.7	(0.1 – 1.7)
2005–06	0.8	(0.3 – 1.7)	0.0	(0.0 – 0.0)			0.8	(0.3 – 1.6)
2006–07	0.7	(0.1 – 2.0)					0.7	(0.1 – 2.0)
2007–08	0.7	(0.2 – 1.8)					0.7	(0.2 – 1.8)
2008–09	0.9	(0.2 – 2.3)			0.2	(0.0 – 1.9)	0.9	(0.2 – 2.2)

Table B-18: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other albatrosses captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All large vessels	All areas	1 912	19.1	2	0.5	17	(4 – 42)
Large vessel, ling	Chatham Rise	1 206	18.3	2	0.9	14	(3 – 36)
Large vessel, ling	Subantarctic	312	46.2	0	0	2	(0 – 10)
Large vessel, ling	Cook Strait	34	0	0		0	(0 – 0)
Large vessel, ling	East North Island	88	0	0		0	(0 – 1)
Large vessel, ling	Puysegur	27	0	0		0	(0 – 3)
Large vessel, ling	Stewart-Snares	193	0	0		0	(0 – 2)
Large vessel, other	Puysegur	19	0	0		0	(0 – 1)
Large vessel, other	Subantarctic	33	0	0		0	(0 – 1)

Table B-19: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		369.9		
Summer	1	286.6	83.3	22.5
Integrated weight line	1	268.1	18.5	6.5
Area	2	255.9	12.2	4.6
Moon phase	1	252.7	3.2	1.3

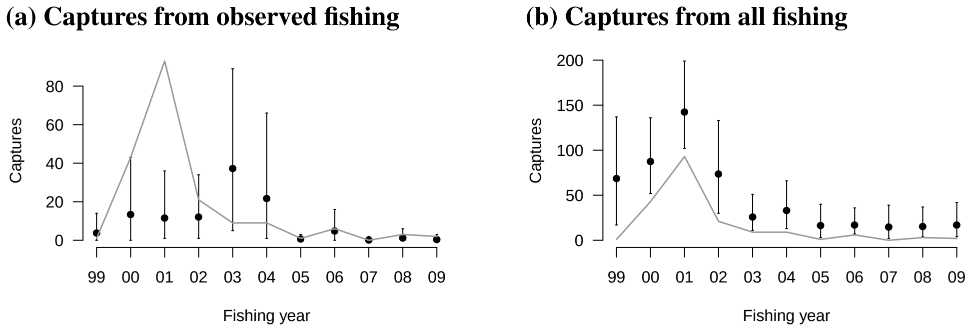

Figure B-4: Estimated captures of other albatrosses in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-20: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Summer (Season), False (Integrated weight line), and Bounty (Area).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.368	0.377	0.121	0.701
Season, Winter	0.192	0.216	0.072	0.498
Integrated weight line, True	0.089	0.106	0.019	0.286
Area, Southern	0.323	0.362	0.131	0.831
Area, Keyhole	0.235	0.254	0.107	0.504
Moon phase exponent	1.833	2.040	0.790	4.439
Overdispersion, θ	0.008	0.008	0.002	0.016

B.5 Model summary, other birds, bottom longline fisheries

Table B-21: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	486	(244 – 985)	2	(0 – 7)	2	(2 – 5)	490	(247 – 987)
1999–00	838	(436 – 1 608)	1	(0 – 7)	0	(0 – 2)	840	(437 – 1 613)
2000–01	426	(314 – 633)	2	(2 – 2)	0	(0 – 0)	428	(316 – 635)
2001–02	173	(96 – 359)	1	(0 – 4)	0	(0 – 0)	173	(97 – 359)
2002–03	151	(102 – 263)	0	(0 – 0)	0	(0 – 1)	151	(102 – 263)
2003–04	77	(18 – 186)	7	(0 – 32)	1	(0 – 5)	84	(20 – 214)
2004–05	46	(8 – 167)	0	(0 – 2)	0	(0 – 1)	46	(8 – 168)
2005–06	34	(11 – 85)	2	(1 – 8)	0	(0 – 0)	36	(12 – 89)
2006–07	38	(2 – 156)	0	(0 – 0)	0	(0 – 0)	38	(2 – 156)
2007–08	75	(28 – 162)	0	(0 – 0)	0	(0 – 0)	75	(28 – 162)
2008–09	13	(3 – 46)	0	(0 – 0)	1	(0 – 3)	14	(3 – 47)

Table B-22: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Large ling		Large bluenose		Large other		All large vessels	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	9.8	(4.9 – 19.9)	7.4	(0.0 – 28.0)	9.8	(8.3 – 20.8)	9.8	(4.9 – 19.7)
1999–00	21.1	(11.0 – 40.6)	4.7	(0.0 – 24.1)	2.8	(0.0 – 20.0)	21.0	(10.9 – 40.3)
2000–01	12.2	(9.0 – 18.1)	6.7	(6.7 – 6.7)			12.1	(9.0 – 18.0)
2001–02	4.4	(2.4 – 9.1)	2.7	(0.0 – 13.8)			4.4	(2.5 – 9.1)
2002–03	5.5	(3.7 – 9.6)			1.9	(0.0 – 20.0)	5.5	(3.7 – 9.6)
2003–04	2.6	(0.6 – 6.3)	3.3	(0.0 – 15.5)	2.0	(0.0 – 10.9)	2.6	(0.6 – 6.7)
2004–05	2.1	(0.4 – 7.4)	0.6	(0.0 – 3.8)	4.3	(0.0 – 33.3)	2.0	(0.3 – 7.3)
2005–06	1.6	(0.5 – 4.0)	3.1	(1.4 – 11.1)			1.6	(0.5 – 4.0)
2006–07	1.9	(0.1 – 7.9)					1.9	(0.1 – 7.9)
2007–08	3.7	(1.4 – 7.9)					3.7	(1.4 – 7.9)
2008–09	0.7	(0.2 – 2.5)			1.0	(0.0 – 5.8)	0.7	(0.2 – 2.5)

Table B-23: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other birds captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All large vessels	All areas	1 912	19.1	2	0.5	14	(3 – 47)
Large vessel, ling	Chatham Rise	1 206	18.3	0	0	8	(0 – 33)
Large vessel, ling	Subantarctic	312	46.2	2	1.4	4	(2 – 12)
Large vessel, ling	Puysegur	27	0	0		1	(0 – 4)
Large vessel, ling	Cook Strait	34	0	0		0	(0 – 1)
Large vessel, ling	East North Island	88	0	0		0	(0 – 2)
Large vessel, ling	Stewart-Snares	193	0	0		0	(0 – 2)
Large vessel, other	Puysegur	19	0	0		0	(0 – 2)
Large vessel, other	Subantarctic	33	0	0		0	(0 – 2)

Table B-24: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		1141.1		
Area	2	699.4	441.7	38.7
Summer	1	687.5	11.9	1.7
Log(hooks observed)	1	674.4	13.1	1.9
Log(hook number)	1	654.3	20.1	3.0

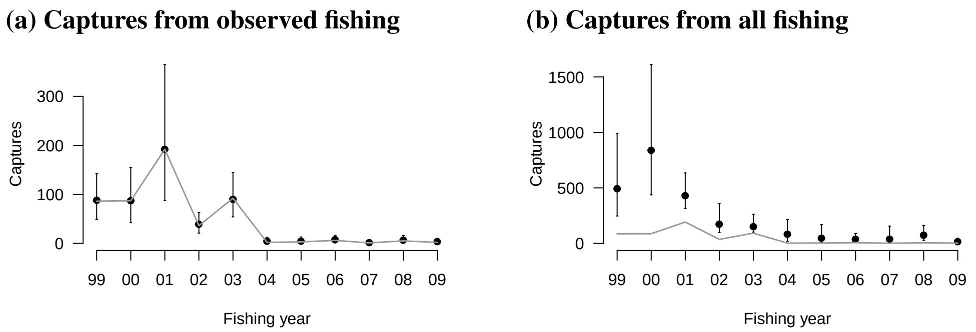

Figure B-5: Estimated captures of other birds in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-25: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are Auckland-Campbell (Area), Winter (Season), and False (Integrated weight line).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	3.254	3.292	2.535	4.311
Area, Campbell plateau	0.455	0.499	0.189	1.057
Area, Southern	0.114	0.123	0.046	0.261
Season, Summer	0.442	0.458	0.261	0.744
Integrated weight line, True	0.606	0.671	0.272	1.421
Vessel-year s.d., $\exp(\sigma_v)$	3.130	3.410	2.065	6.438
Overdispersion, θ	0.120	0.123	0.088	0.168

B.6 Model summary, other birds, northern snapper, bottom longline fisheries

Table B-26: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Small snapper	
	Caps.	95% c.i.
2002–03	1 148	(554 – 2 242)
2003–04	964	(479 – 1 764)
2004–05	776	(409 – 1 401)
2005–06	789	(400 – 1 459)
2006–07	688	(306 – 1 353)
2007–08	644	(293 – 1 253)
2008–09	673	(375 – 1 173)

Table B-27: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Small snapper	
	Rate	95% c.i.
2002–03	11.6	(5.6 – 22.6)
2003–04	11.4	(5.7 – 20.9)
2004–05	10.2	(5.4 – 18.5)
2005–06	12.1	(6.2 – 22.5)
2006–07	11.1	(5.0 – 21.9)
2007–08	11.5	(5.2 – 22.4)
2008–09	11.7	(6.5 – 20.4)

Table B-28: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other birds, northern snapper captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
Small vessel, snapper	North	5 755	3	21	12	673	(375 – 1 173)

Table B-29: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
	104.3		

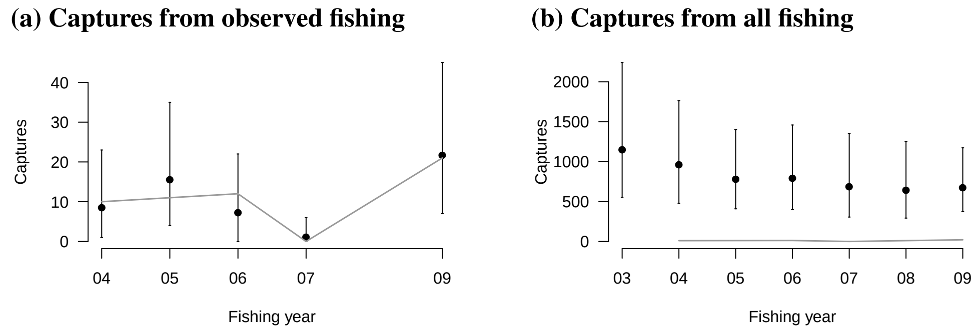

Figure B-6: Estimated captures of other birds, northern snapper in all bottom longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-30: Summary of the posterior distributions of the model parameters.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	10.873	11.237	6.889	17.652
Vessel-year s.d., $\exp(\sigma_v)$	3.162	3.745	1.681	8.939
Overdispersion, θ	0.184	0.206	0.056	0.481

APPENDIX C: SURFACE LONGLINE FISHERIES MODELS

C.1 Model summary, white-capped albatross, surface longline fisheries

Table C-1: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	12	(8 – 23)	0	(0 – 4)	0	(0 – 2)	3	(0 – 20)	17	(8 – 46)
1999–00	31	(9 – 91)	0	(0 – 4)	0	(0 – 2)	0	(0 – 3)	34	(10 – 95)
2000–01	40	(7 – 141)	0	(0 – 4)	0	(0 – 2)	0	(0 – 1)	41	(7 – 141)
2001–02	77	(22 – 223)	0	(0 – 3)	1	(0 – 3)	0	(0 – 0)	81	(22 – 231)
2002–03	72	(10 – 227)	0	(0 – 4)	1	(0 – 3)	0	(0 – 1)	75	(11 – 232)
2003–04	49	(20 – 134)	0	(0 – 3)	0	(0 – 1)	0	(0 – 0)	49	(20 – 134)
2004–05	9	(3 – 26)	0	(0 – 1)	0	(0 – 0)	5	(0 – 24)	14	(4 – 44)
2005–06	5	(1 – 16)	0	(0 – 2)	0	(0 – 0)	14	(1 – 73)	19	(3 – 79)
2006–07	30	(24 – 41)	0	(0 – 2)	0	(0 – 0)	11	(0 – 54)	41	(25 – 90)
2007–08	8	(3 – 17)	0	(0 – 1)	0	(0 – 0)	5	(0 – 27)	13	(4 – 36)
2008–09	8	(3 – 23)	0	(0 – 1)	0	(0 – 0)	2	(0 – 14)	10	(3 – 29)

Table C-2: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	1.3	(0.9 – 2.4)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.4)	15.1	(0.0 – 100.0)	0.3	(0.1 – 0.8)
1999–00	3.1	(0.9 – 9.2)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.3)	9.7	(0.0 – 75.0)	0.5	(0.1 – 1.4)
2000–01	3.3	(0.6 – 11.8)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.4)	9.3	(0.0 – 50.0)	0.5	(0.1 – 1.8)
2001–02	4.1	(1.2 – 11.7)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.4)			0.9	(0.3 – 2.7)
2002–03	3.1	(0.4 – 9.7)	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.3)	5.1	(0.0 – 50.0)	1.0	(0.1 – 3.0)
2003–04	2.5	(1.0 – 6.9)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.3)			0.9	(0.4 – 2.4)
2004–05	0.9	(0.3 – 2.4)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	3.5	(0.0 – 18.6)	0.5	(0.1 – 1.5)
2005–06	0.5	(0.1 – 1.6)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	8.2	(0.6 – 42.9)	0.6	(0.1 – 2.7)
2006–07	3.1	(2.5 – 4.3)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	6.6	(0.0 – 33.5)	1.5	(1.0 – 3.4)
2007–08	1.1	(0.4 – 2.3)	0.0	(0.0 – 0.1)	0.2	(0.0 – 0.0)	4.7	(0.0 – 23.5)	0.7	(0.2 – 1.9)
2008–09	0.9	(0.3 – 2.5)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	5.7	(0.0 – 35.9)	0.4	(0.1 – 1.1)

Table C-3: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-capped albatross captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	2 623	14.4	3	0.8	10	(3 – 29)
Southern bluefin	South-west	368	59.5	3	1.4	5	(3 – 15)
Southern bluefin	North-east	546	13	0	0	3	(0 – 10)
Swordfish	North-east	18	16.7	0	0	1	(0 – 8)
Swordfish	South-west	9	0	0		1	(0 – 7)
Swordfish	North-west	12	8.3	0	0	0	(0 – 1)

Table C-4: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		485.2		
Vessel length	1	460.5	24.7	5.1
Annual sine exponent	1	389.7	70.8	15.4
Fishery	3	371.7	18.0	4.6
Annual cosine exponent	1	356.2	15.5	4.2
Set day, night, dusk	2	343.5	12.7	3.6
Area	1	339.0	4.6	1.3
Nationality	3	331.8	7.2	2.1

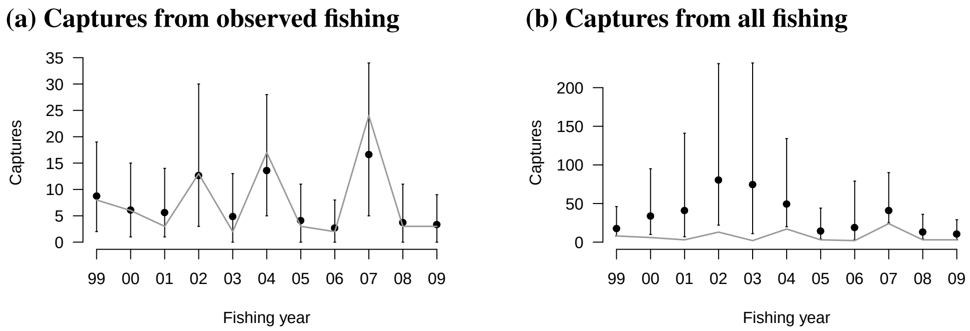

Figure C-1: Estimated captures of white-capped albatross in all surface longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-5: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are >= 40m (Vessel length), Bluefin (Fishery), and Night (Set time).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.018	0.048	0.000	0.300
Vessel length, < 40m	0.870	1.129	0.146	3.610
Annual sine exponent	5.557	8.656	1.363	34.993
Annual cosine exponent	6.953	8.716	1.745	26.334
Fishery, Swordfish	0.279	0.959	0.007	4.554
Fishery, Albacore	0.000	0.009	0.000	0.035
Fishery, Bigeye	0.000	0.001	0.000	0.012
Set time, Full moon	2.680	2.764	1.514	4.599
Set time, Daylight	1.264	1.810	0.145	7.282
Vessel-year s.d., $\exp(\sigma_v)$	2.310	2.416	1.599	3.871
Overdispersion, θ	0.218	0.234	0.079	0.482

C.2 Model summary, white-chinned petrel, surface longline fisheries

Table C-6: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	2	(0 – 7)	14	(1 – 40)	2	(0 – 6)	0	(0 – 1)	19	(2 – 51)
1999–00	15	(8 – 28)	54	(14 – 136)	6	(1 – 18)	0	(0 – 1)	76	(26 – 180)
2000–01	5	(1 – 13)	28	(6 – 65)	3	(0 – 8)	0	(0 – 0)	37	(9 – 84)
2001–02	17	(7 – 36)	47	(15 – 107)	7	(1 – 18)	0	(0 – 0)	73	(27 – 162)
2002–03	12	(3 – 27)	20	(3 – 50)	5	(1 – 12)	0	(0 – 0)	38	(10 – 86)
2003–04	8	(2 – 19)	13	(2 – 33)	2	(0 – 6)	0	(0 – 0)	23	(5 – 54)
2004–05	7	(2 – 16)	10	(2 – 25)	1	(0 – 3)	1	(0 – 3)	19	(6 – 44)
2005–06	5	(1 – 12)	8	(1 – 22)	0	(0 – 2)	1	(0 – 3)	14	(3 – 36)
2006–07	8	(4 – 16)	10	(2 – 24)	0	(0 – 1)	3	(2 – 6)	22	(9 – 43)
2007–08	10	(5 – 19)	9	(1 – 25)	0	(0 – 0)	1	(0 – 4)	20	(8 – 46)
2008–09	6	(2 – 12)	10	(2 – 24)	0	(0 – 1)	0	(0 – 1)	16	(5 – 35)

Table C-7: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	0.2	(0.0 – 0.7)	0.3	(0.0 – 0.9)	0.3	(0.0 – 1.1)	0.3	(0.0 – 5.0)	0.3	(0.0 – 0.9)
1999–00	1.5	(0.8 – 2.8)	1.0	(0.3 – 2.6)	1.0	(0.2 – 2.9)	0.9	(0.0 – 25.0)	1.1	(0.4 – 2.6)
2000–01	0.5	(0.1 – 1.1)	0.5	(0.1 – 1.1)	0.5	(0.0 – 1.5)	0.5	(0.0 – 0.0)	0.5	(0.1 – 1.1)
2001–02	0.9	(0.4 – 1.9)	0.8	(0.3 – 1.9)	0.8	(0.1 – 2.1)			0.8	(0.3 – 1.9)
2002–03	0.5	(0.1 – 1.2)	0.5	(0.1 – 1.2)	0.5	(0.1 – 1.3)	0.5	(0.0 – 0.0)	0.5	(0.1 – 1.1)
2003–04	0.4	(0.1 – 1.0)	0.4	(0.1 – 1.1)	0.4	(0.0 – 1.5)			0.4	(0.1 – 1.0)
2004–05	0.6	(0.2 – 1.5)	0.7	(0.1 – 1.6)	0.6	(0.0 – 2.3)	0.5	(0.0 – 2.3)	0.6	(0.2 – 1.5)
2005–06	0.5	(0.1 – 1.2)	0.5	(0.1 – 1.3)	0.5	(0.0 – 3.1)	0.5	(0.0 – 1.8)	0.5	(0.1 – 1.2)
2006–07	0.9	(0.4 – 1.7)	0.7	(0.1 – 1.7)	0.7	(0.0 – 5.9)	1.9	(1.2 – 3.7)	0.8	(0.3 – 1.6)
2007–08	1.3	(0.7 – 2.6)	0.9	(0.1 – 2.4)	0.9	(0.0 – 0.0)	0.8	(0.0 – 3.5)	1.0	(0.4 – 2.4)
2008–09	0.6	(0.2 – 1.3)	0.6	(0.1 – 1.5)	0.5	(0.0 – 9.1)	0.5	(0.0 – 2.6)	0.6	(0.2 – 1.3)

Table C-8: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated white-chinned petrel captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	2 623	14.4	3	0.8	16	(5 – 35)
Bigeye	North-east	1 338	3.4	1	2.2	8	(2 – 20)
Southern bluefin	North-east	546	13	0	0	3	(0 – 8)
Southern bluefin	South-west	368	59.5	2	0.9	3	(2 – 6)
Bigeye	North-west	274	12.8	0	0	1	(0 – 5)
Albacore	North-east	11	18.2	0	0	0	(0 – 1)
Bigeye	South-west	8	0	0		0	(0 – 1)
Other	North-east	20	0	0		0	(0 – 1)
Swordfish	North-east	18	16.7	0	0	0	(0 – 1)
Swordfish	South-west	9	0	0		0	(0 – 1)
Swordfish	North-west	12	8.3	0	0	0	(0 – 1)

Table C-9: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		155.9		
Vessel length	1	155.2	0.7	0.5

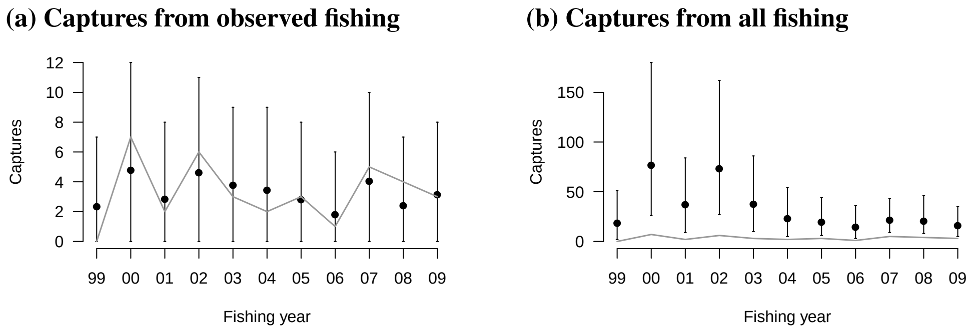

Figure C-2: Estimated captures of white-chinned petrel in all surface longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-10: Summary of the posterior distributions of the model parameters. The base level of Vessel length is >= 40m.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{98-99}$	0.440	0.471	0.075	1.032
Base rate, $100 \times \lambda_{99-00}$	1.346	1.467	0.620	2.998
Base rate, $100 \times \lambda_{00-01}$	0.637	0.661	0.207	1.262
Base rate, $100 \times \lambda_{01-02}$	1.079	1.160	0.534	2.269
Base rate, $100 \times \lambda_{02-03}$	0.650	0.674	0.231	1.255
Base rate, $100 \times \lambda_{03-04}$	0.555	0.582	0.181	1.132
Base rate, $100 \times \lambda_{04-05}$	0.824	0.882	0.318	1.822
Base rate, $100 \times \lambda_{05-06}$	0.650	0.681	0.172	1.408
Base rate, $100 \times \lambda_{06-07}$	0.963	1.032	0.459	1.999
Base rate, $100 \times \lambda_{07-08}$	1.152	1.330	0.506	3.069
Base rate, $100 \times \lambda_{08-09}$	0.774	0.822	0.307	1.645
Vessel length, < 40m	0.580	0.626	0.225	1.275

C.3 Model summary, sooty shearwater, surface longline fisheries

Table C-11: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	1	(1 – 3)	20	(3 – 48)	1	(0 – 3)	0	(0 – 1)	24	(5 – 55)
1999–00	1	(0 – 4)	22	(3 – 54)	2	(0 – 8)	0	(0 – 0)	26	(5 – 62)
2000–01	1	(0 – 3)	19	(4 – 45)	2	(0 – 6)	0	(0 – 0)	24	(6 – 55)
2001–02	7	(1 – 19)	26	(4 – 65)	2	(0 – 7)	0	(0 – 0)	37	(10 – 84)
2002–03	0	(0 – 2)	18	(2 – 45)	11	(10 – 13)	0	(0 – 0)	29	(13 – 58)
2003–04	3	(3 – 4)	8	(1 – 22)	0	(0 – 2)	0	(0 – 0)	12	(4 – 27)
2004–05	0	(0 – 0)	4	(0 – 11)	0	(0 – 0)	0	(0 – 0)	4	(0 – 11)
2005–06	0	(0 – 0)	2	(0 – 6)	0	(0 – 1)	0	(0 – 1)	2	(0 – 7)
2006–07	3	(1 – 7)	2	(0 – 8)	0	(0 – 0)	1	(1 – 2)	6	(2 – 13)
2007–08	0	(0 – 2)	2	(0 – 7)	0	(0 – 0)	0	(0 – 1)	3	(0 – 8)
2008–09	0	(0 – 1)	2	(0 – 7)	0	(0 – 0)	0	(0 – 0)	2	(0 – 7)

Table C-12: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	0.1	(0.1 – 0.3)	0.5	(0.1 – 1.1)	0.2	(0.0 – 0.6)	0.8	(0.0 – 5.0)	0.4	(0.1 – 0.9)
1999–00	0.1	(0.0 – 0.4)	0.4	(0.1 – 1.0)	0.4	(0.0 – 1.3)	0.3	(0.0 – 0.0)	0.4	(0.1 – 0.9)
2000–01	0.1	(0.0 – 0.3)	0.3	(0.1 – 0.8)	0.3	(0.0 – 1.1)	0.5	(0.0 – 0.0)	0.3	(0.1 – 0.7)
2001–02	0.4	(0.1 – 1.0)	0.5	(0.1 – 1.1)	0.3	(0.0 – 0.8)			0.4	(0.1 – 1.0)
2002–03	0.0	(0.0 – 0.1)	0.4	(0.0 – 1.1)	1.2	(1.1 – 1.4)	0.0	(0.0 – 0.0)	0.4	(0.2 – 0.8)
2003–04	0.2	(0.2 – 0.2)	0.3	(0.0 – 0.7)	0.1	(0.0 – 0.5)			0.2	(0.1 – 0.5)
2004–05	0.0	(0.0 – 0.0)	0.2	(0.0 – 0.7)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.4)
2005–06	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.4)	0.1	(0.0 – 1.5)	0.0	(0.0 – 0.6)	0.1	(0.0 – 0.2)
2006–07	0.3	(0.1 – 0.7)	0.2	(0.0 – 0.6)	0.0	(0.0 – 0.0)	0.6	(0.6 – 1.2)	0.2	(0.1 – 0.5)
2007–08	0.1	(0.0 – 0.3)	0.2	(0.0 – 0.7)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.9)	0.1	(0.0 – 0.4)
2008–09	0.0	(0.0 – 0.1)	0.1	(0.0 – 0.4)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.3)

Table C-13: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated sooty shearwater captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	2 623	14.4	0	0	2	(0 – 7)
Bigeye	North-east	1 338	3.4	0	0	2	(0 – 7)
Bigeye	North-west	274	12.8	0	0	0	(0 – 1)
Other	North-east	20	0	0		0	(0 – 0)
Southern bluefin	South-west	368	59.5	0	0	0	(0 – 1)
Swordfish	North-east	18	16.7	0	0	0	(0 – 0)

Table C-14: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		166.5		
Vessel length	1	164.4	2.1	1.2
Start time sine exponent	1	119.3	45.1	27.4
Annual cosine exponent	1	84.4	34.9	29.3
Area	1	78.9	5.5	6.6

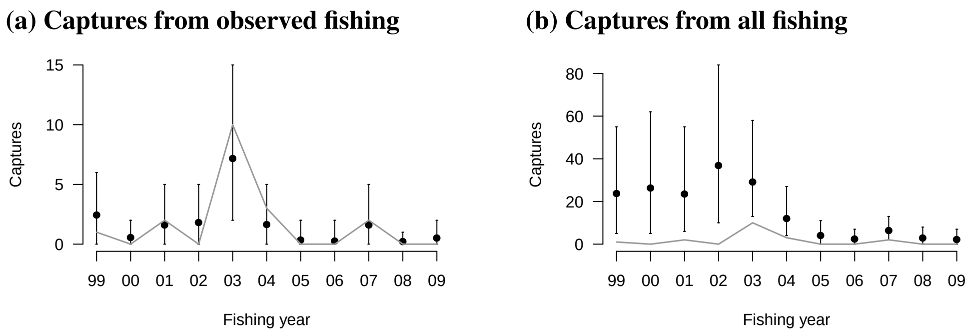

Figure C-3: Estimated captures of sooty shearwater in all surface longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-15: Summary of the posterior distributions of the model parameters. The base level of Vessel length is >= 40m.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.028	0.034	0.006	0.097
Vessel length, < 40m	0.001	0.003	0.000	0.016
Start time sine exponent	24.479	27.963	9.993	67.331
Annual cosine exponent	80.425	119.608	14.836	451.388

C.4 Model summary, other albatrosses, surface longline fisheries

Table C-16: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	76	(60 – 110)	318	(117 – 725)	34	(10 – 92)	2	(0 – 8)	445	(197 – 951)
1999–00	91	(45 – 196)	352	(114 – 757)	39	(9 – 104)	1	(0 – 4)	492	(185 – 1 020)
2000–01	39	(20 – 78)	129	(47 – 289)	15	(3 – 35)	0	(0 – 1)	191	(78 – 408)
2001–02	226	(132 – 408)	475	(220 – 919)	85	(31 – 184)	0	(0 – 0)	810	(417 – 1 529)
2002–03	166	(79 – 356)	246	(84 – 544)	90	(51 – 172)	0	(0 – 1)	513	(226 – 1 061)
2003–04	105	(64 – 181)	133	(44 – 290)	23	(6 – 58)	0	(0 – 0)	274	(123 – 549)
2004–05	67	(40 – 116)	99	(35 – 215)	11	(2 – 29)	11	(2 – 31)	200	(94 – 392)
2005–06	73	(39 – 131)	196	(77 – 406)	7	(0 – 26)	28	(7 – 69)	310	(139 – 605)
2006–07	187	(100 – 391)	284	(113 – 584)	5	(0 – 22)	225	(106 – 441)	715	(371 – 1 372)
2007–08	71	(37 – 133)	99	(38 – 226)	0	(0 – 3)	11	(2 – 30)	187	(89 – 360)
2008–09	87	(60 – 133)	163	(68 – 330)	1	(0 – 3)	3	(0 – 11)	256	(135 – 467)

Table C-17: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	8.1	(6.4 – 11.7)	7.4	(2.7 – 17.0)	6.3	(1.9 – 17.2)	7.9	(0.0 – 40.0)	7.5	(3.3 – 16.1)
1999–00	9.2	(4.5 – 19.8)	6.7	(2.2 – 14.4)	6.3	(1.5 – 16.8)	15.4	(0.0 – 100.0)	7.0	(2.6 – 14.6)
2000–01	3.3	(1.7 – 6.5)	2.1	(0.8 – 4.8)	2.7	(0.6 – 6.5)	1.8	(0.0 – 50.0)	2.4	(1.0 – 5.0)
2001–02	11.8	(6.9 – 21.4)	8.2	(3.8 – 15.8)	10.2	(3.7 – 21.9)			9.2	(4.7 – 17.4)
2002–03	7.1	(3.4 – 15.2)	5.6	(1.9 – 12.5)	8.7	(4.9 – 16.6)	6.3	(0.0 – 50.0)	6.5	(2.9 – 13.5)
2003–04	5.4	(3.3 – 9.3)	4.3	(1.4 – 9.5)	5.8	(1.5 – 14.7)			4.9	(2.2 – 9.9)
2004–05	6.1	(3.6 – 10.5)	6.4	(2.3 – 13.9)	8.5	(1.6 – 22.5)	8.7	(1.6 – 24.0)	6.6	(3.1 – 13.0)
2005–06	7.3	(3.9 – 13.2)	11.3	(4.4 – 23.4)	10.7	(0.0 – 40.0)	12.5	(3.1 – 30.8)	10.1	(4.5 – 19.8)
2006–07	19.7	(10.5 – 41.0)	18.9	(7.5 – 39.0)	27.9	(0.0 – 129.4)	88.1	(41.6 – 172.9)	25.8	(13.4 – 49.6)
2007–08	9.8	(5.1 – 18.3)	9.5	(3.6 – 21.5)	13.5	(0.0 – 150.0)	8.8	(1.6 – 23.3)	9.6	(4.6 – 18.5)
2008–09	9.5	(6.6 – 14.6)	10.0	(4.2 – 20.2)	4.7	(0.0 – 27.3)	7.8	(0.0 – 25.0)	9.8	(5.1 – 17.8)

Table C-18: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other albatrosses captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	2 623	14.4	49	13	256	(135 – 467)
Bigeye	North-east	1 338	3.4	4	8.7	148	(61 – 309)
Southern bluefin	South-west	368	59.5	38	17.4	47	(39 – 62)
Southern bluefin	North-east	546	13	7	9.9	39	(17 – 77)
Bigeye	North-west	274	12.8	0	0	14	(3 – 35)
Other	North-east	20	0	0		3	(0 – 11)
Swordfish	North-east	18	16.7	0	0	2	(0 – 9)

Table C-19: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		1508.5		
Vessel length	1	1469.0	39.5	2.6
Set day, night, dusk	2	1396.5	72.5	4.9
Fishing year	10	1335.0	61.6	4.4
Annual sine exponent	1	1293.0	42.0	3.1
Nationality	3	1276.3	16.8	1.3

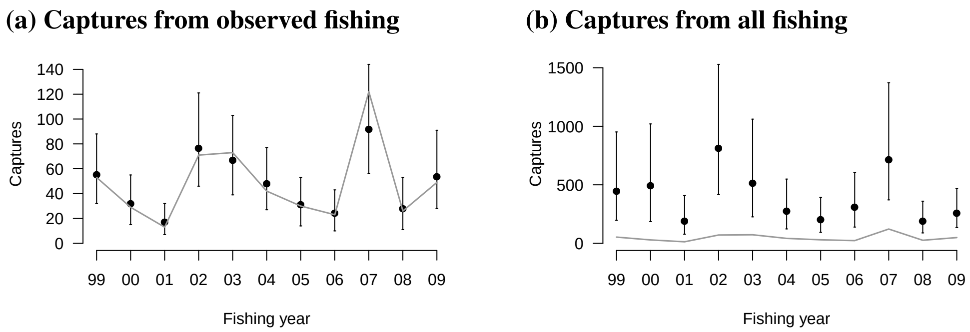

Figure C-4: Estimated captures of other albatrosses in all surface longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-20: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are >= 40m (Vessel length) and Night (Set time).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{98-99}$	8.378	9.015	4.240	17.243
Base rate, $100 \times \lambda_{99-00}$	8.936	9.695	4.162	19.738
Base rate, $100 \times \lambda_{00-01}$	3.402	3.671	1.426	7.534
Base rate, $100 \times \lambda_{01-02}$	11.899	12.484	7.050	21.470
Base rate, $100 \times \lambda_{02-03}$	7.275	7.820	3.708	15.687
Base rate, $100 \times \lambda_{03-04}$	6.126	6.498	2.873	12.331
Base rate, $100 \times \lambda_{04-05}$	9.207	10.020	4.374	20.808
Base rate, $100 \times \lambda_{05-06}$	13.588	15.014	5.996	31.125
Base rate, $100 \times \lambda_{06-07}$	28.945	31.674	12.602	63.139
Base rate, $100 \times \lambda_{07-08}$	12.195	13.260	5.870	26.535
Base rate, $100 \times \lambda_{08-09}$	11.681	12.479	6.259	22.764
Vessel length, < 40m	0.503	0.524	0.274	0.971
Set time, Full moon	3.028	3.048	2.346	3.922
Set time, Daylight	3.968	4.172	2.095	7.358
Annual sine exponent	2.538	2.583	1.845	3.544
Vessel-year s.d., $\exp(\sigma_v)$	2.821	2.945	2.119	4.748
Overdispersion, θ	0.281	0.282	0.203	0.370

C.5 Model summary, other birds, surface longline fisheries

Table C-21: Captures by year and fishery, giving the mean and 95% c.i. of the estimated captures.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.	Caps.	95% c.i.
1998–99	53	(23 – 129)	1 098	(401 – 2 586)	118	(32 – 357)	9	(0 – 53)	1 334	(507 – 3 281)
1999–00	66	(18 – 210)	1 570	(741 – 3 390)	187	(54 – 514)	1	(0 – 6)	1 867	(878 – 3 956)
2000–01	57	(18 – 133)	850	(403 – 1 572)	72	(24 – 171)	0	(0 – 2)	1 033	(485 – 1 876)
2001–02	116	(49 – 271)	1 691	(871 – 3 302)	145	(59 – 337)	0	(0 – 0)	2 016	(1 032 – 3 917)
2002–03	139	(42 – 367)	930	(286 – 2 023)	155	(61 – 346)	0	(0 – 2)	1 251	(426 – 2 636)
2003–04	72	(28 – 148)	579	(189 – 1 208)	42	(10 – 109)	0	(0 – 0)	727	(256 – 1 523)
2004–05	35	(11 – 78)	176	(41 – 428)	6	(0 – 20)	7	(1 – 22)	243	(66 – 572)
2005–06	55	(24 – 121)	401	(165 – 924)	5	(0 – 22)	32	(7 – 101)	508	(221 – 1 083)
2006–07	46	(27 – 79)	303	(122 – 665)	1	(0 – 8)	57	(20 – 180)	421	(205 – 843)
2007–08	15	(4 – 35)	171	(41 – 532)	1	(0 – 4)	8	(1 – 27)	202	(57 – 589)
2008–09	27	(12 – 58)	270	(100 – 627)	1	(0 – 6)	4	(0 – 14)	307	(120 – 693)

Table C-22: Capture rate (birds per 100 sets) by year and fishery, giving the mean and 95% c.i. of the estimated capture rate.

Year	Southern bluefin		Bigeye		Albacore		Swordfish		All fisheries	
	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.	Rate	95% c.i.
1998–99	5.7	(2.4 – 13.7)	25.7	(9.4 – 60.5)	22.1	(6.0 – 66.9)	47.1	(0.0 – 265.0)	22.5	(8.6 – 55.4)
1999–00	6.6	(1.8 – 21.2)	29.8	(14.1 – 64.4)	30.1	(8.7 – 82.9)	25.4	(0.0 – 150.0)	26.7	(12.5 – 56.5)
2000–01	4.8	(1.5 – 11.1)	14.0	(6.6 – 25.9)	13.3	(4.4 – 31.7)	9.4	(0.0 – 100.0)	12.8	(6.0 – 23.2)
2001–02	6.1	(2.6 – 14.2)	29.1	(15.0 – 56.8)	17.3	(7.0 – 40.1)			23.0	(11.8 – 44.6)
2002–03	6.0	(1.8 – 15.7)	21.4	(6.6 – 46.5)	15.0	(5.9 – 33.3)	9.7	(0.0 – 100.0)	15.9	(5.4 – 33.5)
2003–04	3.7	(1.4 – 7.6)	18.9	(6.2 – 39.5)	10.6	(2.5 – 27.7)			13.1	(4.6 – 27.4)
2004–05	3.2	(1.0 – 7.1)	11.3	(2.6 – 27.6)	4.9	(0.0 – 15.5)	5.8	(0.8 – 17.1)	8.1	(2.2 – 19.0)
2005–06	5.5	(2.4 – 12.2)	23.1	(9.5 – 53.2)	7.5	(0.0 – 33.8)	14.4	(3.1 – 45.1)	16.6	(7.2 – 35.5)
2006–07	4.8	(2.8 – 8.3)	20.3	(8.1 – 44.4)	8.6	(0.0 – 47.1)	22.5	(7.8 – 70.6)	15.2	(7.4 – 30.5)
2007–08	2.0	(0.6 – 4.8)	16.3	(3.9 – 50.7)	26.6	(0.0 – 200.0)	6.4	(0.8 – 20.9)	10.4	(2.9 – 30.3)
2008–09	2.9	(1.3 – 6.3)	16.5	(6.1 – 38.4)	7.6	(0.0 – 54.5)	9.6	(0.0 – 31.8)	11.7	(4.6 – 26.4)

Table C-23: Captures by fishery and area, for the 2008–09 fishing year, giving the mean and 95% c.i. of estimated other birds captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
All fisheries	All areas	2 623	14.4	10	2.7	307	(120 – 693)
Bigeye	North-east	1 338	3.4	3	6.5	240	(87 – 566)
Bigeye	North-west	274	12.8	0	0	30	(5 – 83)
Southern bluefin	North-east	546	13	6	8.5	26	(11 – 56)
Other	North-east	20	0	0		5	(0 – 19)
Swordfish	North-east	18	16.7	0	0	3	(0 – 13)
Southern bluefin	South-west	368	59.5	1	0.5	1	(1 – 3)

Table C-24: ANOVA table summarising the maximum-likelihood model selection, giving the deviance explained by the sequential addition of covariates to the model. Only covariates that explained more than 1% of the residual deviance are included in the table.

	Deg. of freedom	Resid. dev.	Dev. expl.	Dev. expl. (%)
		1081.8		
Vessel length	1	874.3	207.5	19.2
Area	2	716.7	157.6	18.0
Annual cosine exponent	1	619.5	97.2	13.6
Fishing year	10	575.1	44.4	7.2
Set day, night, dusk	2	555.8	19.3	3.4
Fishery	3	543.3	12.5	2.2
Nationality	3	533.9	9.4	1.7

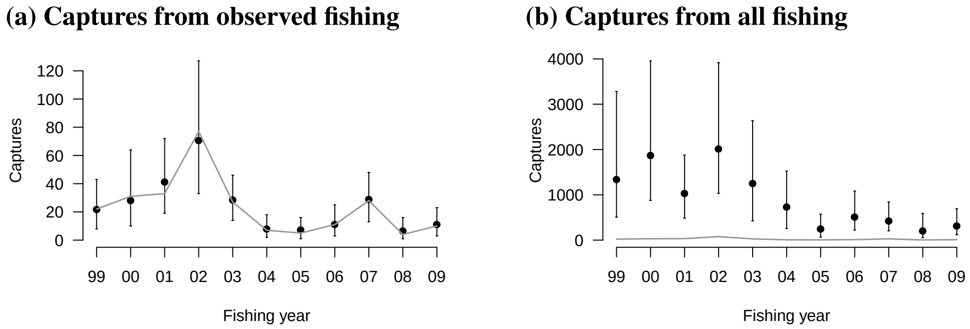

Figure C-5: Estimated captures of other birds in all surface longline fisheries, showing the mean and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-25: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are < 40m (Vessel length), Area1 (Area), and Night (Set time).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{98-99}$	1.087	1.236	0.492	2.843
Base rate, $100 \times \lambda_{99-00}$	1.197	1.411	0.561	3.554
Base rate, $100 \times \lambda_{00-01}$	0.745	0.788	0.259	1.510
Base rate, $100 \times \lambda_{01-02}$	1.194	1.328	0.567	3.077
Base rate, $100 \times \lambda_{02-03}$	0.904	0.972	0.348	2.001
Base rate, $100 \times \lambda_{03-04}$	0.892	0.966	0.397	1.960
Base rate, $100 \times \lambda_{04-05}$	0.758	0.783	0.220	1.595
Base rate, $100 \times \lambda_{05-06}$	1.055	1.173	0.453	2.717
Base rate, $100 \times \lambda_{06-07}$	1.009	1.083	0.494	2.101
Base rate, $100 \times \lambda_{07-08}$	0.756	0.800	0.211	1.602
Base rate, $100 \times \lambda_{08-09}$	0.863	0.910	0.348	1.732
Vessel length, >= 40m	1.950	2.198	0.701	5.106
Area, Kermadec	0.812	0.869	0.403	1.656
Area, Southern	0.022	0.025	0.009	0.052
Annual cosine exponent	3.259	3.364	1.915	5.287
Set time, Full moon	2.681	2.753	1.735	4.259
Set time, Daylight	1.386	1.455	0.734	2.613
Vessel-year s.d., $\exp(\sigma_v)$	3.905	4.150	2.661	7.000
Overdispersion, θ	0.633	0.655	0.362	1.085