Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2006–07

Edward R. Abraham
Finlay N. Thompson

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www.dragonfly.co.nz

Dragonfly
PO Box 27535
Wellington 6141
New Zealand

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EXECUTIVE SUMMARY

Seabirds are caught during commercial fishing, most frequently either 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 protected species that occur. These observer data provide a consistent basis for estimating total captures.

In this report, generalized linear models were used to estimate total captures of seabirds by trawl and longline methods from observer data. Captures were estimated for the fishing years 2002–03 to 2006–07, by fishing within the New Zealand Exclusive Economic Zone (EEZ). For trawl, bottom longline, and surface longline fisheries, 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 2006–07 fishing year was 3554 (95% c.i.: 2629 to 5270). There were 1328 (95% c.i.: 967 to 2002) estimated seabird captures in offshore trawl fisheries, 1199 (95% c.i. 746 to 2155) captures in surface longline fisheries, and 921 (95% c.i.: 430 to 2330) captures in the bottom longline fisheries for which estimates were made. Due to low observer coverage, trawl fishing targeting inshore fish species, bottom longline fishing from small vessels ($<$ 34 m), was not included in the modelling. Of the five species groups used for the modelling, the other birds and other albatross groups had the highest number of estimated captures during 2006–07 (median estimates of 1204 and 876, respectively). In this year there were also median estimated captures of 721 sooty shearwaters, 274 white-capped albatrosses, and 268 white-chinned petrels.

Across all offshore trawl fisheries, there was a significant decrease in the total number of birds caught between 2002–03 and 2006–07, with the total number of captures falling by 49% between the 2002–03 and 2006–07 fishing years. In surface longline fisheries, there was a small non-significant increase in the number of albatross captures between 2002–03 and 2006–07, but the number of petrels caught per year has decreased markedly falling by 69% between 2002–03 and 2006–07. Although the uncertainties were large, in the modelled bottom longline fisheries there was a 33% decrease in the median estimated captures of seabirds over the five year period. All these decreases were associated with decreases in the fishing effort.

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". In this report, seabird captures were estimated for the 2006–07 fishing year. 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), and estimates for the 2007–08 and 2008–09 years will be presented subsequently.

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 either 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. 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 protected species that occur. These observer data provide a 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 2006–07 fishing year over 30% of trawls targeting hoki (*Macruronus novaezelandiae*) were observed. In contrast, only 0.5% of trawls targeting inshore fish species were observed. The total coverage during 2006–07 was 7.7% of tows for trawl fisheries, 25.7% of hooks for surface longline fisheries, and 6.1% of hooks for bottom longline fisheries, respectively (Abraham & Thompson 2009a). To estimate the total mortality, it is necessary to extrapolate from the captures recorded during observed fishing to all fishing effort. This approach assumes that the observers record all fishing related mortalities. Estimated captures based on observer data will necessarily be an underestimate, as there are some birds that are killed by fishing but are not brought on board. 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 assessed as fatal. Of these, only 2 birds were brought on board the vessel. In the New Zealand observer data, only the birds that are brought on board are generally recorded. 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, MacKenzie & Fletcher (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 scaffold 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 1998–99 to the 2006–07 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). Seabirds are often caught in groups, with many tows or sets without any 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).

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 2006–07. 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. 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 0.5% of tows observed). 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 focussed 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 focussed 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 0.5%, 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 2006–07 were used for estimating captures in longline fisheries, however only a shorter series 2002–03 to 2004–07 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 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 fishery was used of the event by the same vessel that was closest in time (but within a year), and that had a defined fishery. Within trawl fisheries, it was found that the fishery determined from the fisher declared target species and the fishery determined from the observer target species were the same for 98.2% of tows where the effort and observer data could be matched.

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

Table 1: Fishing effort included in the seabird models.

Method	Subset	Years
Trawl	All targets, except inshore species	2002–03 to 2006–07
Bottom longline	Large vessels (> 34 m), all targets	1998–99 to 2006–07
Bottom longline	Northern area, snapper target	2002–03 to 2006–07
Surface longline	All targets	1998–99 to 2006–07

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)
	Deep water	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)

were white-capped albatross (*Thalassarche steadi*), white-chinned petrel (*Procellaria aequinoctialis*) and sooty petrel (*Puffinus griseus*). Separate models were made for each of these three species. In addition models were made for other albatrosses (Diomedeidae), and then for the remaining birds. With few exceptions, the reported captures or 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 2006–07 are summarised by Abraham & Thompson (2009a). 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. 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.

Deck captures (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 deck 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 are 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 are 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 are 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 1995–96 fishing year to the 2006–07 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 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 12 year period from 1 October 1998 to 30 September 2007 (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 trawling (MW), mid-water pair-trawl (MPT), surface longline (SLL), or bottom longline (BLL).
4. All observer non-fish bycatch data that recorded the capture of a seabird, from the *obs_lfs* database.
5. Observer station data from the *obs* 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 2008, necropsy data for seabirds had not been included in the database for the 2006–07 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 were two experiments on bycatch mitigation that required a special permit. The first was conducted on a bottom longliner and studied 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. In the analysis, we excluded all captures from this trip and the trip was treated as unobserved, so bycatch on the trip was estimated.

Similarly, 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 trawls were made without any warp mitigation. These tows were excluded from observations. The captures that occurred on the unmitigated tows were not included and the tows were treated as unobserved.

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

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	32 861	3 192
Events at same time, in summer	1 063	52
Events at same time, adjusted to NZST, and same position, summer	23 618	212
Events at same time, adjusted to NZST, and same position, not summer	44	7
Events at same time, incorrectly adjusted to NZST, same position	16	4
Events at similar time, trip already matched, summer	4 525	
One unmatched event on each dataset on the same day	2 292	
One unmatched event on each dataset, same day, over midnight	463	
Gap of one event between matched events on both datasets	484	
Gap of one event before first matched event at trip start	4	
Gap of one event after last matched event at trip end	38	
Gap of more than one event between matched events on both datasets	563	220
Gap of more than one event before first matched event at trip start	62	9
Gap of more than one event after last matched event at trip end	25	11
Total matched events	66 058	3 707
Effort data made from observer data		12
Unmatched events	1 580	62
Total observed events	67 638	3 781

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 are unable to be matched using these rules, 1580 tows (2.3% of all observed tows) and 62 surface longline sets (1.6% 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

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	515	1 374	10 012
Close match on CELR forms	357	915	6 521
Gap filling between previous matches on CELR forms	266	598	4 758
Match on day and vessel only from CELR forms	1 144	4 082	23 419
Total matched	2 282	6 969	44 710
Unmatched	46	70	201
Percentage matched	98	99	99.6
Total observed	2 328	7 039	44 911

details of individual sets. Since 2004–05, Lining Catch Effort (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 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 3103 observed bird captures in the trawl data, 829 observed bird captures in the surface longline data, and 1704 observed bird captures in the bottom longline data. Of these, 24 captures (0.8%) were on trawls that could not be matched, 7 captures (0.8%) were on surface longline sets that could not be matched, and 19 captures (1.1%) 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. Consequently, there are some differences with the data presented in Abraham & Thompson (2009a).

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 trawls 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 5.9 trawls within each group. The total size of the dataset reduced from 401 264 trawls to 67 525, and the number of observations were reduced from 34 833 to 4154. The seabird capture data were sparse: in the full dataset captures occurred on 1034 trawls, 3% of observed trawls. By grouping the data the density of the captures was increased: after grouping captures occurred on 556 groups, 13.4% 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 Baird & Smith (2008)) and quasi-Poisson methods (used in the analysis of warp strike data by Middleton & Abraham (2007) and Abraham et al. (2008)). 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 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 also has the convenient property that the sum of n samples is drawn from a negative binomial distribution, 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

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

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

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.

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,

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

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_{v_i}. 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 and fishing year of each group of events, v_i. When vessel-year effects were included, the equation for catch on a tow (Equation 1) was modified to be

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

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

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

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_ν. 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):

$$\begin{aligned}
\beta_0 &\sim \text{Normal}(\mu = 0, \sigma = 10), && (7)\\
\beta_j &\sim \text{Normal}(\mu = 0, \sigma = 10), && (8)\\
\log(\lambda_1) &\sim \text{Normal}(\mu = \log(\bar{y}_i), \sigma = 100), && (9)\\
\delta_\lambda &\sim \text{Normal}(\mu = \log(\bar{y}_i), \sigma = 100), && (10)\\
\sigma_\lambda &\sim \text{Half-Cauchy}(\sigma = \sigma_y), && (11)\\
\theta &\sim \text{Uniform-shrinkage}(\mu = \bar{y}_i), && (12)\\
\theta_\nu &\sim \text{Uniform-shrinkage}(\mu = \bar{y}_\nu), && (13)
\end{aligned}$$

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 a further 40 000 updates, with every 20$^{\text{th}}$ 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. In these models, the overdispersion did not depend on the number of events in each observation, and no random year or vessel effects were included, however fishing year was presented to the step analysis as a fixed-effect.

At each stage of the 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, and if the model had converged, then the posterior distributions of each chain were similar. In making this comparison, the key measure of interest, total captures during the 2006–07 fishing year, was inspected.

Given that the MCMC chains had converged, it was necessary to check whether the assumptions underlying the model were met. The captures were estimated on observed groups of fishing events. Randomised quantile residuals (Dunn & Smyth 1996) were used to determine whether the difference between the modelled and the observed captures had the expected distribution. 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.

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

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 3.5% and 97.5% percentiles.

2.8 Prediction

To make predictions of captures, the number of captures that occurred during each group of fishing events were 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 & Thompson (2009a). In many cases, different areas and fisheries were used during the 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 trawl fisheries that had the highest number of captures.
- The number of captures by fishery and area combination. The areas used in this summary are the areas that were used by (Abraham & Thompson 2009a), 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 on all fishing. 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.
- Diagnostic plots of total estimated captures during the 2006–07 fishing year are shown, calculated for each sample from the MCMC chains. The MCMC chains and the density of the posterior distribution are shown for each chain.

- A plot of the randomised quantile residuals, comparing observed captures, with the mean expected captures for each observed fishing event.

2.8.2 Bottom longline hooks observed

Observers on large bottom longline vessels only watched a portion of the haul. On the haul forms they recorded the number of hooks that were observed. From the data that were recorded it was not possible to determine whether birds were caught during the portion of the haul that was observed, or when the observer was elsewhere. During 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.

During modelling, no account was made of the fact that observers only monitor a portion of the haul. As a sensitivity analysis, a set of model runs were made were the mean expected catch from each set (or group of sets) was divided by the proportion of hooks that were observed. Formally, rather than following Equation 5, the number of catches on an event group i was calculated as

$$y_i \sim \mathrm{Poisson}(n_i \nu_{v_i y_i} \mu_i \delta_i / h_i) \quad , \tag{16}$$

where h_i was the fraction of hooks that were observed ($0 < h_i \leq 1$).

Data on the number of hooks observed were double entered from the bottom longline forms, and both the total number of hooks observed and the total number set were calculated on the matched effort data. For each set, or group of sets, in the effort data the ratio, h_i, was calculated. Missing values of the fraction h_i were imputed by randomly selecting values firstly from other observed hauls on the same trip, and then from other observed hauls on the same vessel. On hauls where the observer reported that they observed more hooks than were set, the ratio h_i was set to 1. Across all the observed events, the mean fraction of hooks observed was 0.60 (median 0.54, inter-quartile range 0.45 to 0.78). On vessels over 34 m in length, the mean fraction of hooks observed was 52%, while in the northern snapper fishery the mean fraction of hooks observed was 99%.

3. RESULTS

3.1 Trawl fisheries

3.1.1 Summary of trawl fisheries

Trawl fisheries were diverse and geographically widespread. During the five year period used for the modelling there were over 400 000 tows made by trawlers (Table 5). During the period of the model, the most frequently targeted offshore species were hoki and squid. These fisheries, together with deepwater species, jack mackerel and southern blue whiting, all had over 10% observer coverage. In contrast, while over 38% of tows targeted inshore species (including flatfish) only 0.21% of these tows were observed. Both the highest number of seabird captures, and the highest capture rate (13.4 birds per 100 tows), were in the squid fishery. There were low observed capture rates, of less than 1 bird per 100 tows, in the deepwater, southern blue whiting and jack mackerel fisheries.

Variations in trawl effort over the five year period were summarised by Abraham & Thompson (2009a). The total number of tows fell from 130 177 in 2002–03, to 103 793 in 2006–07. In the model dataset, the number of tows targeting offshore species fell from 60 735 to 40 210. Effort in the squid fishery, which had the highest observed seabird capture rate, increased from 8199 tows in 2002–03 to a peak of 10 241 tows in 2004–05. By 2006–07, the number of tows targeting squid had fallen to 5436.

Table 5: Summary of observations, effort and seabird captures in trawl fisheries for the five years 2002–03 to 2006–07. This is the model dataset, with inshore and flatfish trawl fisheries also being shown.

Fishery	Effort (Tows)	Obs. (Tows)	Coverage (%)	Captures (All birds)	Rate (Birds/100 tows)
Squid	40 402	7 953	19.7	1 069	13.4
Hoki	83 580	10 473	12.5	240	2.3
Middle depths	42 877	2 993	7.0	140	4.7
Scampi	23 125	1 768	7.6	62	3.5
Deepwater	38 737	7 700	19.9	28	0.4
Jack mackerel	13 444	2 539	18.9	13	0.5
S. blue whiting	3 502	1 286	36.7	7	0.5
Inshore	112 881	332	0.3	6	1.8
Flatfish	42 751	0	0.0		
Total	401 299	35 044	8.7	1 565	4.5

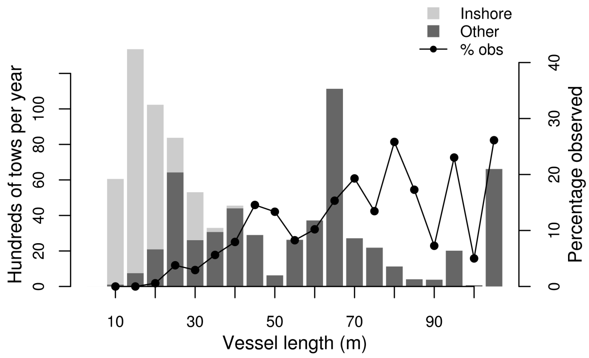


Figure 1: Average number of trawls per year by vessels of different lengths. The vessel length is divided into 5 m length classes. Inshore and other fisheries are shown separately. The percentage of tows observed is is calculated for length classes were there have been a total of more than 100 tows per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

Trawl vessels ranged in length from less than 10 m to over 100 m (Figure 1). The largest trawlers were 104.5 m long, and there were two trawl records where the vessels had a stated length of less 5 m. 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 25% of all tows for vessels over 100 m. The smallest observed vessel was 18.1 m long, and out of a total of over 128 000 trawls made by vessels of 20 m or less, only 224 were observed.

3.1.2 Model covariates

The covariates that were assessed for inclusion in the final models are listed in Table 6. The covariates were either 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 the fishing events (duration, gear type), or characteristics of the vessels (size, processing type). The frequency distributions of the covariates are given for all tows, and for observed tows, in Figure 2. Of the offshore fisheries, middle-depths fisheries had the lowest observer coverage. The larger size classes of vessels were well observed, while observer coverage was low on small vessels. Most effort was carried out by vessels that were recorded as having a

Table 6: Covariates used in estimating seabird captures in trawl fisheries.

Vessel size	Four groups, vessels less 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. The groups are illustrated in Figure 3.
Fishery	Factor variable, based on target species. Includes deepwater species, hoki, jack mackerel, southern blue whiting, scampi, squid, and other middle-depths species. The classification follows that used in Abraham & Thompson (2009a). 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.

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 the majority of 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, with the groupings being illustrated in Figure 3. Contiguous areas where no captures were recorded (the 'Other' area for white-capped albatross, white-chinned petrel, and other birds) were excluded from the modelling. This was equivalent to assuming that the observations in these areas were representative and that there were no captures on the unobserved fishing in those regions. 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 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 regions. Capture rates of other albatrosses were highest on the Chatham Rise, with some captures also being reported from the subantarctic and northern regions. 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 7. 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

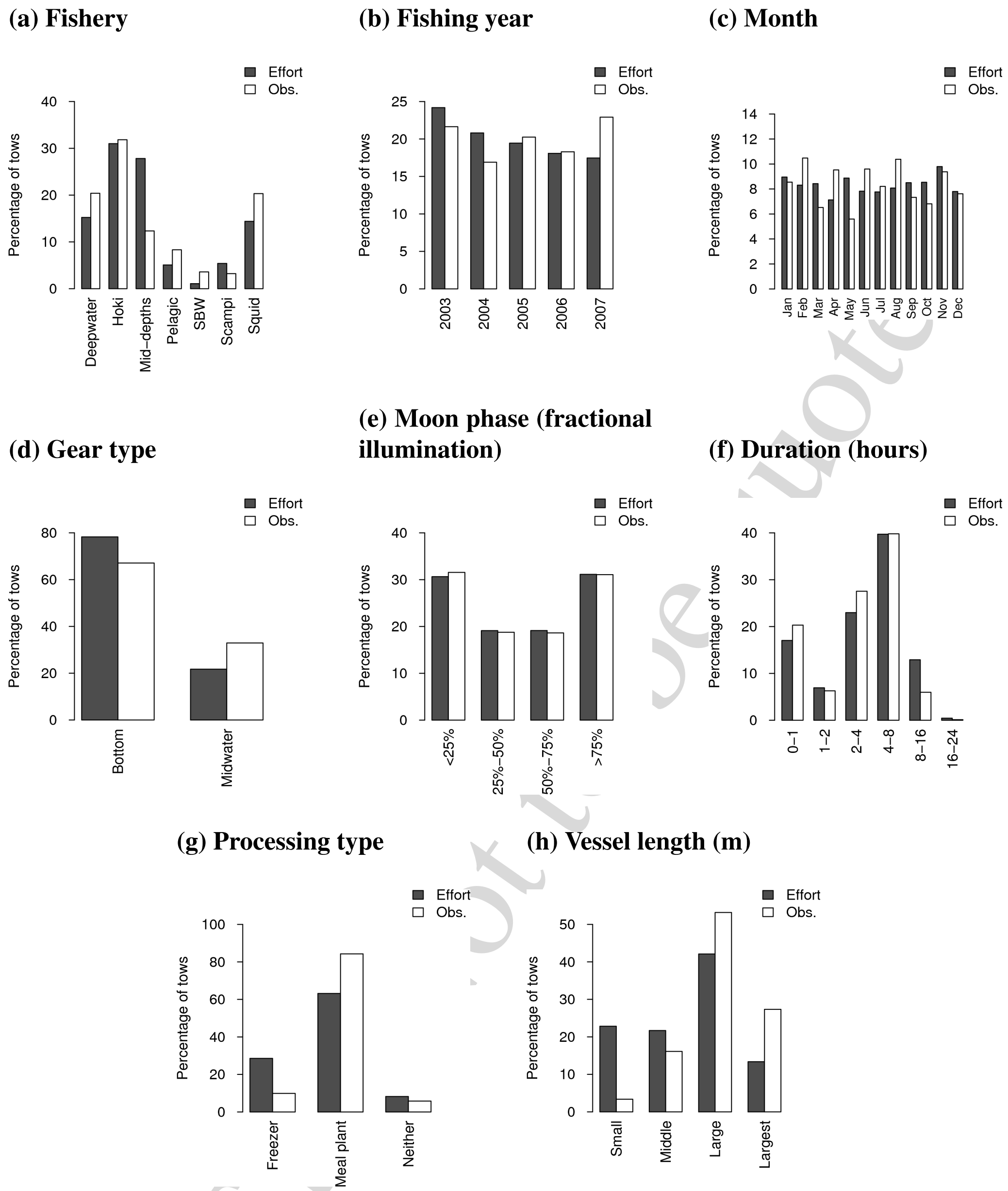


Figure 2: Frequency distributions of covariates for all tows (Effort) and observed tows (Obs.). The data are from all tows from the years 2002–03 to 2006–07 that targeted offshore species.

other albatross models. The only other covariate that was 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 these models, 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.

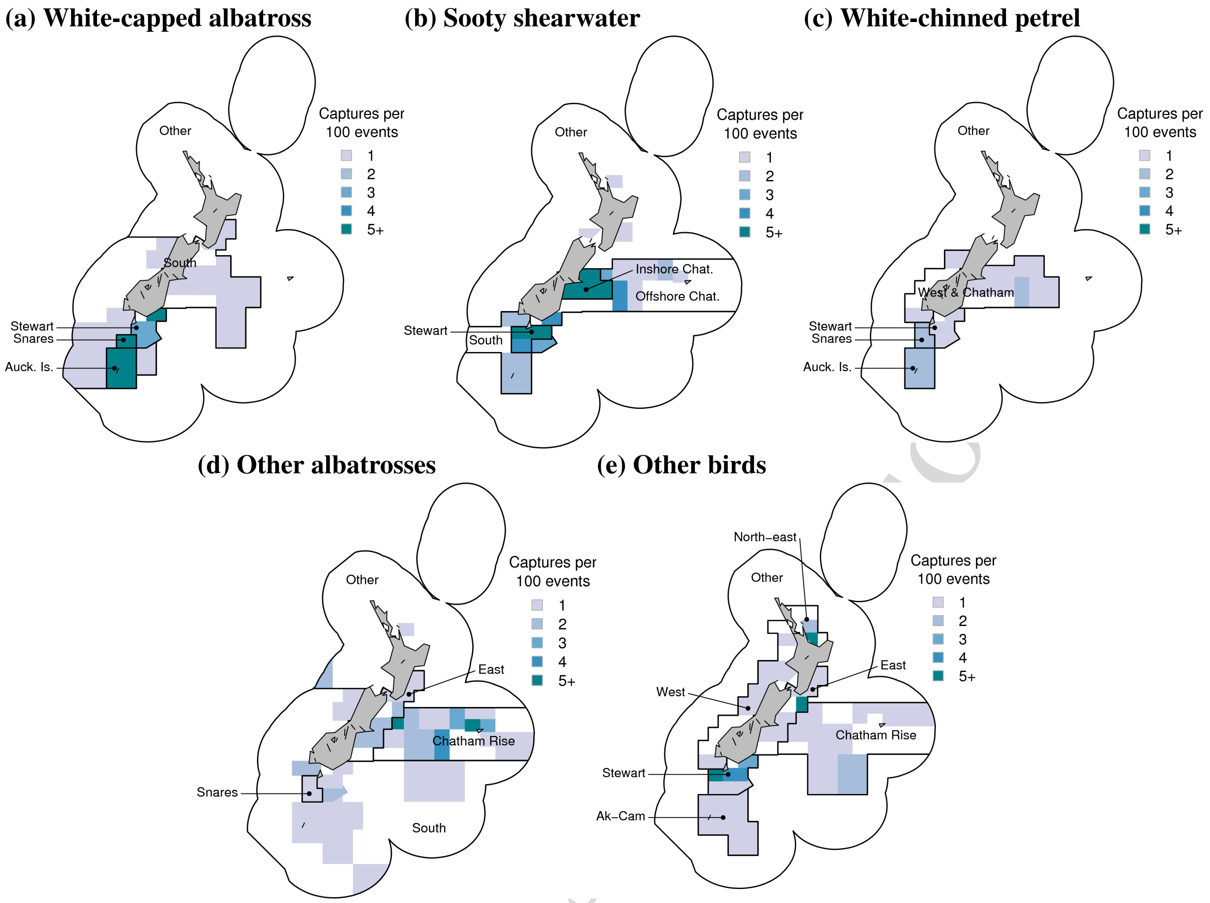


Figure 3: Areas used as covariates in the trawl fisheries models. The colours give the capture rate (birds per 100 tows) for each of the species groups within each statistical area. Capture rates are only shown if there were more than 100 observed tows in a statistical area.

Table 7: 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, cdoy, sdoy2
	White chinned petrel	•	-	•	Area, fishery
	Other albatross	•	-	•	Annual sine, area, fishery
	Other birds	•	-	•	Area, processing type

The model results are summarised in detail in Appendix A, with the estimated captures for the 2006–07 fishing year being given in Table 8. This table gives captures for the three fisheries with the highest total number of seabird captures, and for all other offshore fisheries combined.

During the 2006–07 fishing year, a total of 660 birds (95% c.i.: 468 to 1 021) 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, 354 (95% c.i.: 196 to 698) were of sooty shearwater. The next most frequently caught species was white-capped albatross, with an estimated 155 (95% c.i.: 92 to 246) captures. The fishery with the second highest number of total captures was the hoki fishery, with an estimated total of 241 (95% c.i.: 134 to

Table 8: Summary of results from all models, showing the estimated total seabird captures in offshore trawl fisheries. The median and 95% credible intervals of the posterior distribution of the totals are given.

Group	Squid		Hoki		Middle depths		Other offshore	
	Med.	c.i.	Med.	c.i.	Med.	c.i.	Med.	c.i.
White-capped alb.	155	(92 – 246)	10	(3 – 24)	26	(11 – 54)	27	(11 – 57)
Other albatross	39	(19 – 75)	51	(25 – 90)	26	(12 – 52)	52	(26 – 99)
Total albatross	197	(127 – 298)	61	(34 – 102)	54	(30 – 92)	81	(49 – 134)
Sooty shearwater	354	(196 – 698)	146	(51 – 464)	126	(54 – 325)	48	(20 – 122)
White-chinned petr.	85	(46 – 149)	11	(3 – 23)	6	(1 – 14)	15	(5 – 32)
Other birds	12	(5 – 25)	19	(8 – 38)	9	(3 – 20)	51	(24 – 93)
Total petrel	456	(288 – 801)	178	(79 – 498)	141	(69 – 345)	118	(70 – 197)
Total birds	660	(468 – 1 021)	241	(134 – 561)	198	(116 – 406)	203	(141 – 293)

561) bird captures. In hoki fisheries, sooty shearwater was still the most frequently caught species with 146 (95% c.i. 51 to 464) captures. However, there were more captures of other albatrosses than white-capped albatross. There were similar numbers of bird captures in middle depth fisheries, a total of 198 (95% c.i.: 116 to 406) birds, with sooty shearwater again being the most frequently caught species.

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, known as 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. The relationship between vessel length and the number of hooks set per day by bottom longline vessels is shown in Figure 4. A threshold length of 34 m separates the vessels into two classes. With the exception of a single vessel over 90 m long that only carried out 2 sets, all vessels over 34 m set a median number of more than 20 000 hooks per day. There were a total of 10 larger vessels in the dataset. In contrast, all vessels less than 34 m in length set a median of less than 15 000 hooks per day. Over the 9 year period of the data there were 454 distinct vessel keys for smaller vessels.

The large vessels targeted ling on 98.2% of all sets. In contrast, the small vessels targeted snapper on 62.6% of sets, ling on 10.7% of sets and bluenose on 12.6% 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% were in the northern region (FMA 1).

Seabird captures in bottom longline fisheries are summarised in Table 9. Observer effort was primarily focussed 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 26.0 birds per 100 sets that was observed in the large vessel ling fishery.

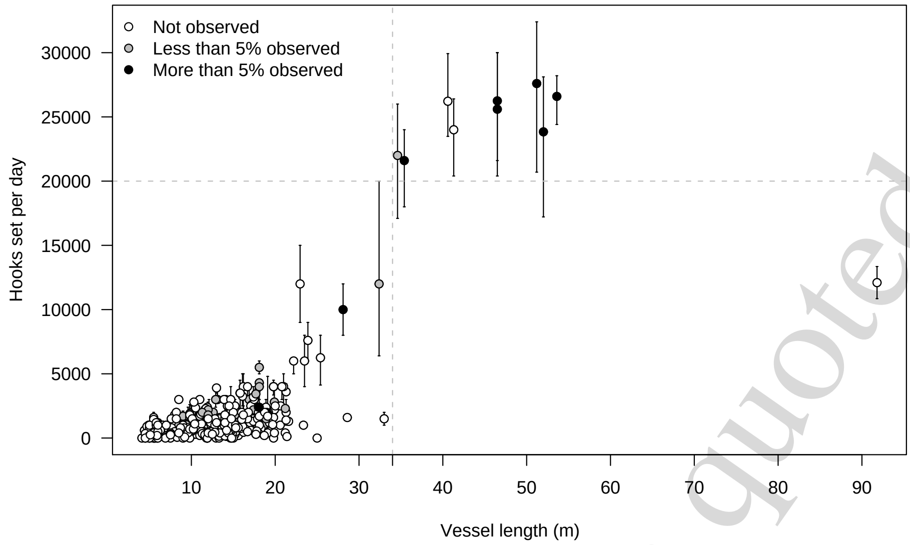


Figure 4: Relationship between vessel length and hooks set per day for bottom longliners. The points mark the median number of hooks set per day of fishing for each vessel, with the bars indicating the upper and lower quartiles. The colour of the points indicates the percentage of sets made by each vessel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

Table 9: Summary of observations, effort and seabird captures in bottom longline fisheries. All data between 1998–99 and 2006–07 are included.

Fishery	Effort (Sets)	Obs. (Sets)	Coverage (%)	Captures (All birds)	Rate (Birds/100 sets)
Ling, large vessel	28 937	5 994	20.7	1 561	26.0
Ling, small vessel	21 220	322	1.5	68	21.1
Snapper, northern	93 308	321	0.3	58	18.1
Bluenose	26 484	88	0.3	5	5.7
Other target species	32 899	39	0.1	0	0.0
Snapper, not northern	3 413	0	0.0		
Total	206 261	6 764	3.3	1 692	25.0

3.3 Model covariates

The potential covariates used in the modelling are given in Table 10. 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 modelling. In particular, a possible effect of time of day on seabird captures was not 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. The areas used in the modelling are shown in 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' region 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 region, where the Solander trough approaches the South Island

Table 10: 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.

(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) that were carried out in 2002 and 2003, integrated weight lines were adopted by some of the large 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 mortality (in particular, the mortality of white-chinned petrels was reduced by over 98%). For each of the 10 large vessels, the Ministry of Fisheries provided a date for when the vessel started using integrated weight line. By the 2006–07 fishing year, four large bottom longline vessels had installed integrated weight lines. Three of these vessels fished during the 2006–07 year, and one large vessel fished without integrated weight lines.

A summary of integrated weight line use in the large vessel fleet is given in Figure 6. Integrated weight lines were first introduced during the 2002–03 fishing year. In the 2006–07 fishing year all observed sets, but only half of all sets, were on vessels that used integrated weight line.

3.3.1 Model results

A summary of the model configuration for the bottom longline models is given in Table 11. Because of the small number of vessels, models that included separate year and vessel-year effects had convergence problems, and the 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

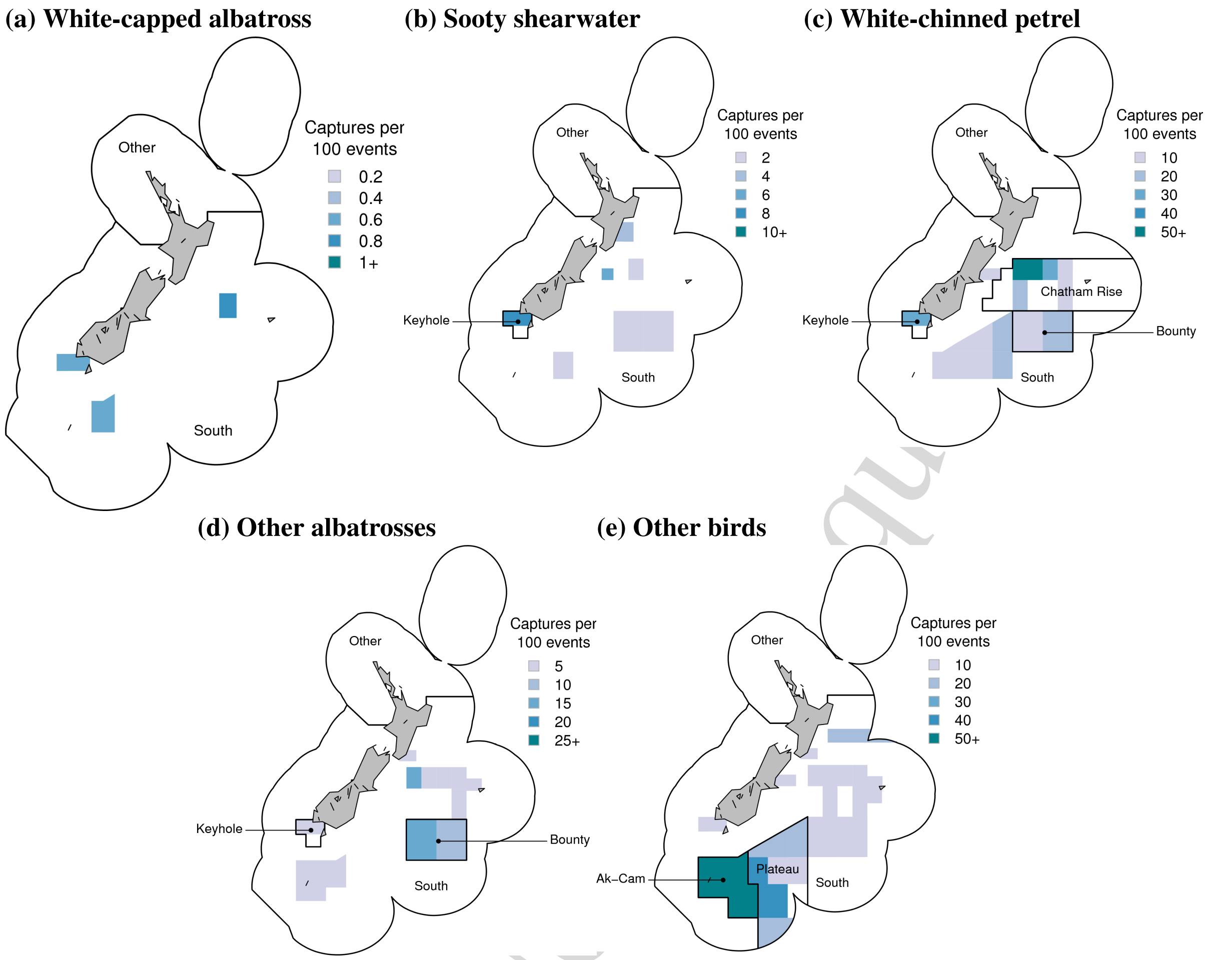


Figure 5: Areas used as covariates in the large vessel bottom longline fisheries models. The colours give the capture rate (birds per 100 tows) for each of the species groups within each statistical area.

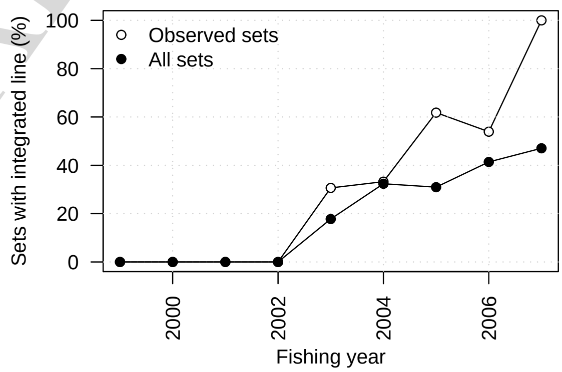


Figure 6: Use of integrated weight line by large bottom longline vessels (longer than 34 m).

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 only a seasonal effect being included.

Table 11: 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)	-	•	•	Season

Model results, model diagnostics, and a summary of the model parameters are given in Appendix B, and a summary of model estimates for the 2006–07 fishing year are given in Table 12. In the large vessel fishery seabird captures were dominated by captures of white-chinned petrel, with a median estimate of 130 white-chinned petrel captures during the year. The uncertainty in the white-chinned petrel captures was high (with the confidence interval corresponding to a c.v. of 160%). In the northern snapper fishery, there were estimated to have been be 457 seabirds caught, all in the other birds group, with a c.v. of 60%. Captures of albatrosses and sooty shearwater were low when compared with the numbers caught 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 0.193 (95% c.i.: 0.031 to 1.439), but again the uncertainty was large and the effect was not significantly different from one. 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 regions, 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 2006–07. 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. However, the effect was only significantly less than one for the white-capped albatross and other albatrosses 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. The only covariate included in the model was the season, with there being few captures during the winter.

Table 12: Summary of results from all models, showing the estimated total seabird captures by fishery and across all bottom longline fishing, during the 2006–07 fishing year. The median and 95% credible intervals of the posterior distribution of the totals are given.

Group	Large vessel		Nth. snapper	
	Med.	c.i.	Med.	c.i.
White-capped alb.	1	(0 – 5)	0	(0 – 0)
Other albatross	28	(10 – 68)	0	(0 – 0)
Total albatross	29	(12 – 70)	0	(0 – 0)
Sooty shearwater	9	(2 – 31)	0	(0 – 0)
White-chinned petr.	130	(14 – 1 180)	0	(0 – 0)
Other birds	25	(2 – 157)	457	(195 – 1 257)
Total petrel	185	(39 – 1 250)	457	(195 – 1 257)
Total birds	218	(65 – 1 282)	457	(195 – 1 257)

3.4 Surface longline fisheries

3.4.1 Summary of surface longline fisheries

Over the period covered by the estimation, 1998–99 to 2006–07, 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 range from 24 to 119, with a median of 66. In contrast, all of the New Zealand domestic fleet were less than 40 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 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 40 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 13. When

Table 13: Summary of effort, observations, and seabird captures in surface longline fisheries, covering the period 1998–99 to 2006–07. 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 long.

Fishery	Effort (Sets)	Obs. (Sets)	Coverage (%)	Captures (All birds)	Rate (Birds/100 sets)
Bluefin, Large vessel	2 992	2 555	85.4	458	17.9
Bigeye	33 635	592	1.8	163	27.5
Albacore	4 179	249	6.0	80	32.1
Swordfish	636	63	9.9	75	119.0
Bluefin, Small vessel	9 378	267	2.8	37	13.9
Other	1 272	41	3.2	8	19.5
Total	52 092	3 767	7.2	821	21.8

Table 14: Development of the surface longline swordfish fishery.

	Before 2004-05	2004–05	2005–06	2006–07
Sets	28	129	224	255
Trips	15	49	81	53
Observed sets		14	4	45
Observed trips		5	1	7
Captured albatross		1	2	60

viewed by numbers of sets, surface long line effort was dominated by the bigeye tuna fishery, which had over 30 000 sets over the 9 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 85% 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 14). 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. All 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 albatross was greater than the number of sets. These three trips were one trip targeting big-eye tuna in 2001–02 and two trips targeting swordfish in 2006–07. During one of these swordfish trips, by an Australian charter vessel in the Kermadec region, there were 12 sets and 51 albatrosses were caught. Although this trip was much shorter than the 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, was a short trip of only three sets that caught nine albatross. 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 large 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 the shallow set depth of the lines. This information was not available from the commercial effort data, and so could not be 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.

Observed captures of seabirds in surface longline fisheries were summarised by Abraham & Thompson (2009a). Most captures in 2006–07 were of other albatrosses in the southern bluefin fishery (mainly Buller's albatrosses) and other albatrosses in the swordfish fishery (mainly unidentified albatrosses and wandering albatross species). Observed captures in the bigeye tuna fishery were mainly of other birds (most frequently flesh-footed shearwater). All white-capped albatrosses where caught in the southern bluefin fishery, with the exception of a single capture on a set targeting swordfish in Area 3. While the captures of white-capped albatross were mainly in the southern area (Area 3), there were also 2 captures of white-capped albatross on southern bluefin sets in Area 1. There were few observed captures of either white-chinned petrel or sooty shearwater in surface longline fisheries.

3.4.2 Model covariates

The covariates that were tested for inclusion in the surface longline models are summarised in Table 15. The set of covariates was relatively simple, 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 the surface longline modelling, the fishing is dispersed within regions to the south-west and north-east of New Zealand. The areas used were focussed on the Area 1 and Area 4 regions, to the north-east of New Zealand, the Area 2 and Area 3 regions, focussed on the south-west of New Zealand. The Kermadec region (FMA 10) was treated separately.

The distribution of selected covariates is shown in Figure 7 for both observed and unobserved data. The marked differences between the observations and the effort that are seen, for example, in target fishery 7(a), area 7(b), and vessel size 7(c), were due to the observations been strongly focussed 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 7(e).

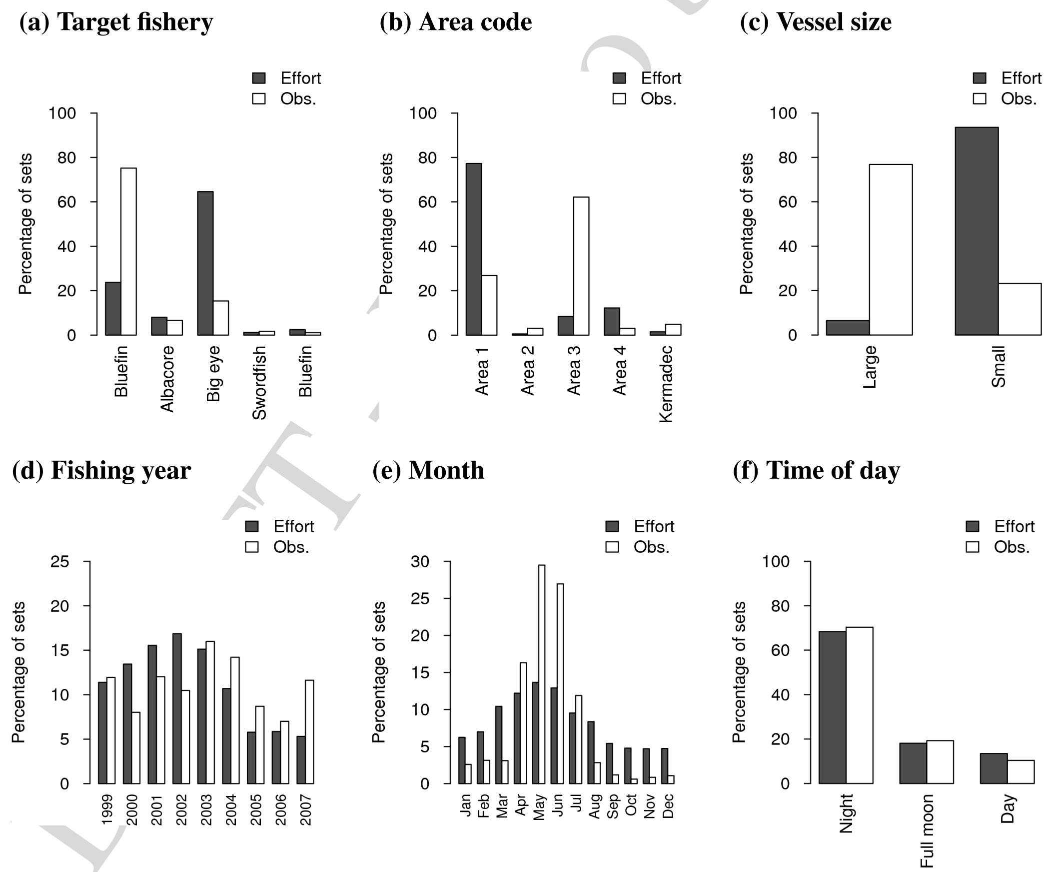


Figure 7: Comparison between the distribution of covariates on all sets (Effort) and observed sets (Obs.).

Table 15: Covariates used in estimating seabird captures in surface longline fisheries

Covariate	Definition
Target species	Southern bluefin tuna, bigeye tuna, albacore and swordfish. There were a number of other species that 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 region, 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 fulls entirely in the night, or is partly in the day. Astronomical algorithms were used to calculate the suns angle relative to the horizon, with night being defined by when the sun was below the horizon at both (Meeus 1991) the start and the end of the set. For night sets, the fractional illumination of the moons 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.

3.4.3 Surface longline model results

A summary of the configuration of the surface longline models is given in Table 16. 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.

Table 16: 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	-	-	-	Annual cosine, set time (day, night, full moon), 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

Table 17: Summary of results from all models, showing the estimated total seabird captures by fishery and across all surface longline fishing. The median and 95% credible intervals of the posterior distribution of the totals are given.

Group	Bluefin		Bigeye		Swordfish		Other		Total	
	Med.	c.i.	Med.	c.i.	Med.	c.i.	Med.	c.i.	Med.	c.i.
White-capped alb.	21	(8 – 46)	0	(0 – 1)	13	(0 – 230)	0	(0 – 0)	38	(13 – 249)
Other albatross	174	(88 – 476)	275	(116 – 680)	179	(75 – 516)	17	(3 – 66)	669	(346 – 1 532)
Total albatross	196	(108 – 500)	275	(116 – 680)	212	(90 – 610)	17	(3 – 66)	730	(389 – 1 675)
Sooty shearwater	3	(0 – 9)	2	(0 – 8)	0	(0 – 1)	0	(0 – 0)	6	(1 – 14)
White-chinned petr.	4	(1 – 10)	9	(2 – 22)	1	(0 – 4)	0	(0 – 1)	16	(6 – 30)
Other birds	43	(20 – 89)	290	(132 – 672)	46	(16 – 189)	12	(2 – 38)	400	(209 – 846)
Total petrel	51	(28 – 97)	304	(143 – 682)	47	(17 – 192)	12	(2 – 38)	424	(229 – 869)
Total birds	251	(158 – 559)	605	(336 – 1 131)	268	(133 – 684)	32	(11 – 84)	1 199	(746 – 2 155)

A summary of captures in the 2006–07 fishing year is given in Table 17. Of the median total estimated captures for 2006–07, 56% were of other albatrosses and 33% were of other birds, with only relatively small numbers of white-capped albatrosses, sooty shearwaters, or white-chinned petrels being caught. Most of the estimated bird captures were in the bigeye tuna fishery, with similar numbers of captures estimated for the southern bluefin tuna and swordfish fisheries, and few captures estimated for other target species. Full summaries of the model fitting are given in Appendix C.

Estimated captures for white-capped albatross in 2006–07 were skewed (Figure C-2), with high upper confidence intervals for the annual cosine and sine exponents, and for the swordfish fishery factor (Table C-5). This resulted in wide confidence intervals for the number of captures, particularly in the swordfish fishery (Table C-1). The number of white-capped albatross in the swordfish fishery had a median of 13 with a 95% confidence interval of 0 to 230. These estimated captures were derived from a single observed capture during May of the 2005–06 fishing year. The low number of observations in the swordfish fishery, and the inclusion of target fishery as a covariate, results in the high uncertainty. In this model, there is no direct area effect. As white-capped albatross have a southern distribution, the upper bound for white-capped albatross captures would be reduced by excluding fishing effort north of East Cape from the model.

Only a restricted number of covariates were included in the full model of other albatross captures (Table C-20). The included covariates were vessel length, set time of day, and an annual sine exponent. Other covariates (nationality, fishery, and area) were selected during maximum likelihood fitting (Table C-17), but if these additional covariates were 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. This is consistent with using a restriction on day setting as a measure to reduce other albatross captures. Estimated captures of other albatrosses increased in 2006–07 to 669 (95% c.i.: 346 to 1532) from 298 (95% c.i.: 134 to 756) in 2005–06. This increase was partly associated with the increase in effort in the swordfish fishery. Across the whole series, from 1998–99 to 2006–07, changes in the number of estimated captures broadly followed changes in the number of observed captures (Figure C-7).

In 2006–07, captures of other birds in surface longline fisheries were estimated at 400 (95% c.i.: 209 to 846). This was significantly fewer captures than the peak of 1903 (95% c.i.: 1068 to 3997) other bird captures that were estimated for 2001–02. From the fitted covariates (Table C-25), capture rates of other birds were low in the southern area, and increased during daylight or full moon. The full moon covariate was significantly higher than 1, and had a mean value that was higher than the daylight covariate.

4. DISCUSSION

4.1 Seabird captures during the 2006-07 fishing year

Estimated seabird captures during the 2006–07 fishing year are summarised in Table 18. The total number of seabirds that were estimated to have been caught was 3 554 (95% c.i.: 2 629 to 5 270). Seabird captures in trawl fisheries targeting inshore species, or in bottom longline fishing from small vessels (< 34 m), were not estimated. Of this total, 32% were albatross species, with the remainder being petrels and shearwaters. In trawl fisheries, sooty shearwater were the most frequently caught species, with an estimated 704 captures (95% c.i.: 405 to 1337). In surface longline fisheries other albatrosses were estimated to have been caught most frequently, with an estimated catch of 669 (95% c.i.: 346 to 1532) birds. Of these, 275 were estimated to have been caught in the bigeye tuna fishery. The high number of captures in the bigeye fishery occurred despite a very small number of observed captures (only 1 other albatross was observed caught in this fishery, with 5% of the sets being observed). In the large-vessel bottom longline fisheries, where 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 660 birds (95% c.i.: 308 to 1647). These captures were mainly in the northern snapper fishery. The most frequently caught species in this fishery was grey petrel (*Procellaria cinerea*), followed by black petrel (*Procellaria parkinsoni*) (Abraham & Thompson 2009a).

4.2 Trends

Changes in the estimated numbers of captures of albatrosses and petrels over the five year period covered by all the models are shown in Figure 8, with the estimates also being given in Table 19. Across all offshore trawl fisheries, there has been a significant decrease in the total number of birds caught, with the total number of captures falling by 49% between the 2002–03 and 2006–07 fishing years. Over this same period, the total number of tows in offshore fisheries fell by 34%, and so part of this decrease may be attributed to the decrease in trawl effort. In the squid fishery, where the most birds were caught, there have been marked changes in effort. Although there was a similar 30% decrease in effort in the squid fishery between 2002–03 and 2006–07, the number of squid tows peaked in 2004–05 rather than steadily decreasing. The decrease in seabird captures over the five-year period occurred for both albatross and petrel species, but was most marked for albatrosses, with the estimated number of captures falling from a peak of 1503 in 2004–05, to 398 in 2006–07. This 74% decrease was greater than the decrease in effort. It coincides with the introduction of compulsory warp-mitigation devices, which were made mandatory

Table 18: Summary of results from all models, showing the estimated total seabird captures. The median and 95% credible 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	
	Med.	c.i.	Med.	c.i.	Med.	c.i.	Med.	c.i.
White-capped alb.	223	(136 – 341)	38	(13 – 249)	1	(0 – 5)	274	(173 – 503)
Other albatross	171	(98 – 278)	669	(346 – 1 532)	28	(10 – 65)	876	(538 – 1 736)
Total albatross	398	(277 – 559)	730	(389 – 1 675)	29	(12 – 67)	1 166	(793 – 2 104)
Sooty shearwater	704	(405 – 1 337)	6	(1 – 14)	9	(2 – 31)	721	(419 – 1 355)
White-chinned petr.	117	(67 – 198)	16	(6 – 30)	126	(15 – 1 121)	268	(124 – 1 271)
Other birds	92	(46 – 160)	400	(209 – 846)	660	(308 – 1 647)	1 204	(739 – 2 231)
Total petrel	917	(600 – 1 576)	424	(229 – 869)	890	(398 – 2 290)	2 314	(1 601 – 3 854)
Total birds	1 328	(967 – 2 002)	1 199	(746 – 2 155)	921	(430 – 2 330)	3 554	(2 629 – 5 270)

before the start of the 2005–06 squid season. Observations of warp-strike have shown that these devices may reduce the rate of interactions between albatrosses and trawl warps. Since their introduction into New Zealand fisheries there has been a decrease in the numbers of albatrosses caught on the trawl warp relative to those caught in the net (Abraham & Thompson 2009b).

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 netsonde cables and this 'third wire' was associated with high capture rates. In the 1991 season, observers recorded the capture of 250 white-capped albatross from 897 tows, a capture rate of 27.9 birds per 100 tows. The capture rate compares with an observed capture rate of 3.2 white-capped albatrosses per 100 tows in the Auckland Islands squid fishery in 2006–07. From the 1991 data, it was estimated that a total of 1212 white-capped albatross were caught from the 4349 tows made during that season. This compares with a catch of 45 (95% c.i.: 23 to 81) from 1318 tows made in the Auckland Islands squid fishery during 2006–07. It appears from these data, that the elimination of the use of a third-wire, the introduction of warp mitigation, and other changes in vessel practice, have reduced the catch rates of white-capped albatross considerably.

In surface longline fisheries, there was a small non-significant increase in the number of albatross captures between 2002–03 and 2006–07, but the number of petrels caught per year has decreased markedly falling by 69% between 2002–03 and 2006–07. Over that same period the number of hooks set in surface longline fisheries fell by 49%.

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 33% decrease in the median estimated captures over the five year period. This was associated with a decline of effort in both the large-vessel fisheries and the northern snapper fishery.

4.3 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

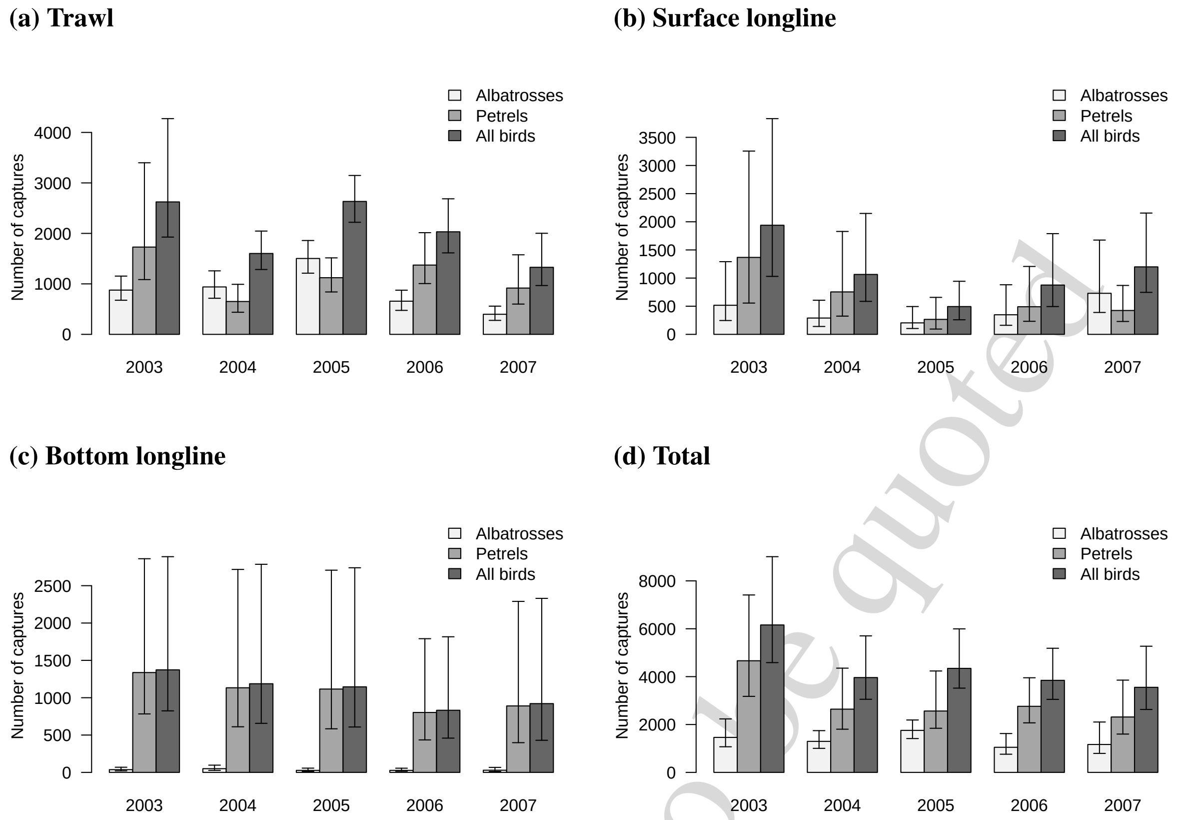


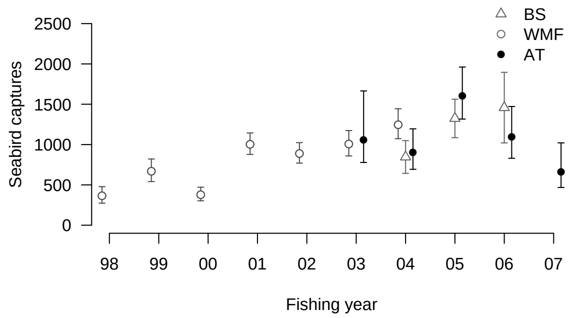
Figure 8: Time series of estimated seabird captures

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 used (season, area, fishing year, vessel size), with separate models being fitted for fishing by vessels over 28 m in length and by vessels less than 28 m in length. The model was used to directly estimate total seabird captures, with additional estimates being made of albatross captures of trawl fisheries.

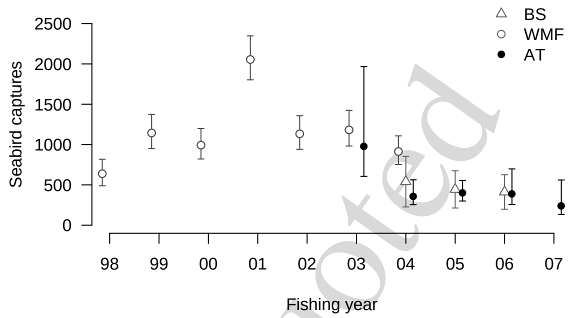
The key difference between the methodology used in this report and the methods used by Waugh et al. (2008) were that we estimated captures for each of five species groups. We also used a different model structure, with a negative binomial model of the captures that included vessel-year random effects where there had been sufficient capture events.

A comparison between the two sets of model estimates is given in Figure 9. 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 9(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.

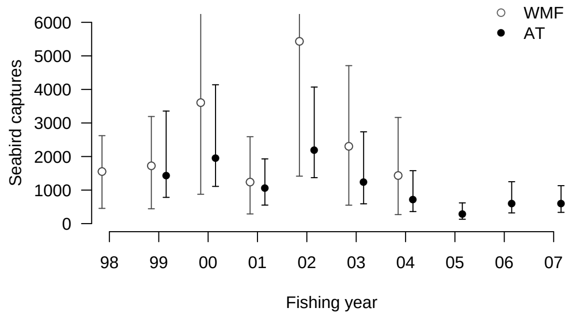
(a) Trawl, squid



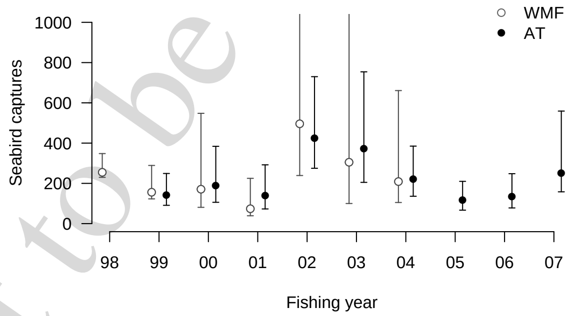
(b) Trawl, hoki



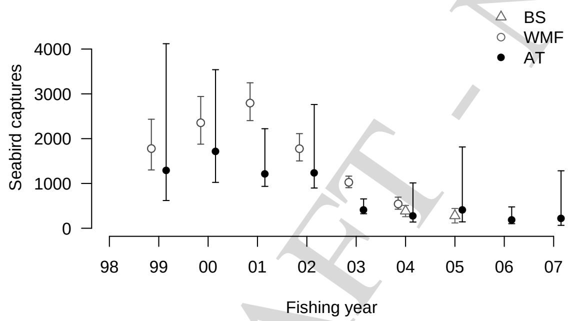
(c) Surface longline, bigeye tuna



(d) Surface longline, southern bluefin tuna



(e) Bottom longline, large vessel



(f) Bottom longline, small vessel snapper

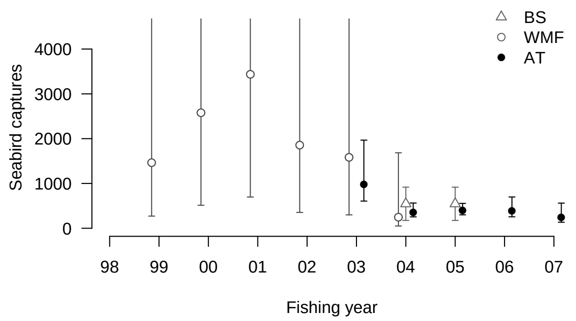


Figure 9: Comparison of selected estimates of total seabird captures made by Waugh et al. (2008) (WMF) and Baird and Smith (2007, 2008)(BS), with estimates presented in this report (AT). The plots give the median and 95% c.i. of the posterior distributions, with some upper confidence intervals from the 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.

Table 19: Summary of results from all models, showing the estimated total seabird captures. The median and 95% credible 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 summaries 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 petrels, sooty shearwater and other birds).

Birds	Year	Trawl		SLL		BLL		All	
		Med.	c.i.	Med.	c.i.	Med.	c.i.	Med.	c.i.
Alb.	2003	876	(676 – 1 154)	517	(246 – 1 291)	37	(21 – 69)	1 462	(1 071 – 2 234)
	2004	940	(715 – 1 258)	290	(140 – 606)	50	(27 – 97)	1 296	(1 004 – 1 744)
	2005	1 503	(1 212 – 1 859)	204	(104 – 494)	27	(13 – 57)	1 755	(1 414 – 2 189)
	2006	657	(475 – 875)	348	(161 – 881)	27	(15 – 56)	1 048	(759 – 1 623)
	2007	398	(277 – 559)	730	(389 – 1 675)	29	(12 – 67)	1 166	(793 – 2 104)
Petr.	2003	1 729	(1 085 – 3 399)	1 367	(556 – 3 256)	1 337	(783 – 2 861)	4 664	(3 176 – 7 411)
	2004	651	(438 – 991)	754	(324 – 1 828)	1 133	(611 – 2 718)	2 642	(1 804 – 4 354)
	2005	1 122	(840 – 1 515)	266	(94 – 657)	1 116	(584 – 2 708)	2 564	(1 843 – 4 236)
	2006	1 372	(1 006 – 2 014)	490	(232 – 1 207)	802	(435 – 1 790)	2 760	(2 070 – 3 953)
	2007	917	(600 – 1 576)	424	(229 – 869)	890	(398 – 2 290)	2 314	(1 601 – 3 854)
All birds	2003	2 624	(1 927 – 4 273)	1 938	(1 030 – 3 832)	1 373	(824 – 2 888)	6 159	(4 586 – 9 011)
	2004	1 602	(1 285 – 2 046)	1 064	(586 – 2 148)	1 187	(657 – 2 787)	3 962	(3 054 – 5 702)
	2005	2 633	(2 220 – 3 147)	494	(259 – 943)	1 146	(608 – 2 740)	4 345	(3 520 – 5 995)
	2006	2 032	(1 614 – 2 685)	876	(494 – 1 789)	832	(459 – 1 816)	3 845	(3 050 – 5 185)
	2007	1 328	(967 – 2 002)	1 199	(746 – 2 155)	921	(430 – 2 330)	3 554	(2 629 – 5 270)

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.

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 included 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 9(a, b), with the estimates of captures in the 2004–05 squid fishery being just outside each-others 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 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 9(e, f). The estimates agree with 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. 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.

4.4 Summary

In this report, estimates have been made of seabird captures in a consistent portion of New Zealand's commercial fisheries. The estimated total captures of 3 856 (95% c.i.: 2 866 to 5 607) birds in 2006–07, was obtained across all offshore trawl fisheries, all surface longline fisheries, large vessel (longer than 34 m) bottom longline fisheries, and the northern snapper bottom longline fishery. Observer coverage on smaller vessels was consistently low. Because of this low coverage a complete model-based estimate of seabird captures in trawl and longline fisheries is not yet possible.

The estimates 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. When the model of white-chinned petrel captures in the large-vessel bottom longline was rerun, accounting for the fact that only 52% of hooks in these fisheries were observed, the number of estimated captures approximately doubled (from 130 (95% c.i.: 14 – 1 180) to 289 (95% c.i.: 23 – 3 631)). In this sense, the estimates quoted in this report must be treated as conservative. 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 addition, genuinely cryptic mortalities may be occurring. These are mortalities that are difficult to detect because no carcase is 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. During the time that these interactions were recorded, only 2 birds were brought on board the vessel. The other 28 interactions would not have been recorded by an observer during normal operations. No attempt has been made to adjust the estimates for under-reporting or for the cryptic mortalities.

The primary aim of this research was to obtain estimates of seabird captures for the period 2002–03 to 2006–07. More detailed information is available from these models, for example on where captures are occurring, and how capture rates are affected by the covariates that were included in the models. We have focussed on the total captures, but have included sets of tables in Appendix A, B, and C that give more detailed information on each model. These tables include summaries of captures in the fisheries where most of the captures occur (e.g., Table A-1), summaries of the capture rates (birds caught per 100 tows or sets) (e.g., Table A-2), a breakdown of the captures by area (e.g., Table A-3), a summary of the covariate selection process (e.g., Table A-4)

Within this research, there was no attempt to consider the effect of the captures on the seabird populations. Research is currently being undertaken to determine the population status of white-capped albatross and white-chinned petrel, two of the species for which separate bycatch estimates were made. There have also been projects that take a risk assessment approach, these compare estimated mortality with estimates of demographic parameters to determine whether the fishing may be having population impacts (Waugh et al. 2009). These risk assessments require bycatch estimates for a broad range of species, including those that are only caught infrequently. We have extended the modelling to include the most frequently caught species (white-capped albatross, sooty shearwater, and white-chinned petrel), but the challenge remains to obtain bycatch estimates for a wider range of species.

5. ACKNOWLEDGEMENTS

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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 median 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.
2006–07	155	(92 – 246)	10	(3 – 24)	12	(2 – 37)	26	(11 – 54)	208	(127 – 321)
2005–06	267	(166 – 420)	17	(7 – 35)	15	(3 – 49)	35	(16 – 64)	342	(221 – 513)
2004–05	756	(568 – 1 006)	35	(16 – 67)	30	(7 – 103)	55	(26 – 104)	885	(673 – 1 177)
2003–04	518	(365 – 773)	49	(24 – 93)	18	(5 – 57)	38	(18 – 81)	631	(450 – 905)
2002–03	355	(239 – 540)	67	(31 – 123)	21	(6 – 59)	49	(24 – 95)	500	(349 – 731)

Table A-2: Capture rate (birds per 100 trawls) by year and fishery, giving the median 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.
2006–07	2.9	(1.7 – 4.6)	0.1	(0.0 – 0.3)	0.3	(0.1 – 1.0)	0.7	(0.3 – 1.4)	1.0	(0.6 – 1.5)
2005–06	3.3	(2.0 – 5.1)	0.2	(0.1 – 0.4)	0.5	(0.1 – 1.5)	1.0	(0.5 – 1.9)	1.4	(0.9 – 2.1)
2004–05	7.5	(5.6 – 9.9)	0.3	(0.1 – 0.5)	1.0	(0.2 – 3.5)	1.5	(0.7 – 2.9)	3.1	(2.3 – 4.1)
2003–04	6.6	(4.6 – 9.8)	0.3	(0.1 – 0.5)	0.7	(0.2 – 2.1)	1.1	(0.5 – 2.4)	1.9	(1.4 – 2.8)
2002–03	4.6	(3.1 – 6.9)	0.3	(0.1 – 0.5)	0.5	(0.2 – 1.5)	1.1	(0.6 – 2.2)	1.3	(0.9 – 1.9)

Table A-3: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	26 566	13.7	49	1.4	208	(127 – 321)
Squid	Stewart-Snares	2 926	24.1	24	3.4	101	(58 – 169)
Squid	Auckland Islands	1 318	40.7	17	3.2	45	(23 – 81)
Middle-depths	Stewart-Snares	1 174	12.1	2	1.4	16	(5 – 36)
Scampi	Auckland Islands	1 328	7.2	2	2.1	8	(1 – 29)
Squid	Chatham Rise	1 038	3.6	0	0	7	(1 – 19)
Middle-depths	Chatham Rise	1 926	5	1	1	4	(0 – 12)
Hoki	Chatham Rise	4 970	16.1	0	0	3	(0 – 10)
Hoki	Stewart-Snares	1 202	17.1	0	0	3	(0 – 10)
Scampi	Chatham Rise	2 297	6.6	0	0	3	(0 – 10)
Middle-depths	West South Island	855	2.3	0	0	2	(0 – 7)

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. (%)
		1291.8		
Fishery	4	829.0	462.8	35.8
Area	3	792.2	36.8	4.4
Fishing year	4	768.2	24.1	3.0
Annual sine exponent	1	758.4	9.7	1.3

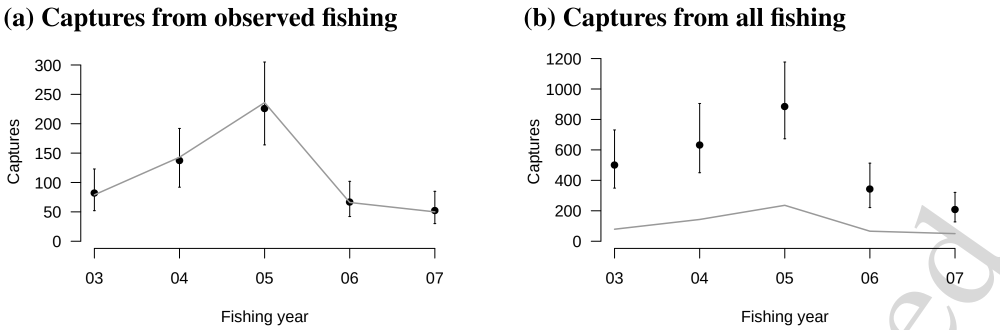

Figure A-1: Estimated captures of white-capped albatross in all trawl fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda_{02-03}$	0.747	0.763	0.467	1.190
Base rate, $100 \times \lambda_{03-04}$	0.760	0.784	0.493	1.204
Base rate, $100 \times \lambda_{04-05}$	0.902	0.921	0.590	1.384
Base rate, $100 \times \lambda_{05-06}$	0.493	0.509	0.295	0.801
Base rate, $100 \times \lambda_{06-07}$	0.396	0.410	0.220	0.683
Area, Snares	0.946	0.955	0.699	1.282
Area, Southern	0.211	0.220	0.117	0.364
Area, Stewart-Snares	0.665	0.690	0.374	1.163
Fishery, Mid-depths	0.748	0.780	0.415	1.336
Fishery, Hoki	0.206	0.221	0.099	0.416
Fishery, Scampi	0.261	0.300	0.088	0.719
Fishery, Deepwater	0.059	0.092	0.002	0.348
Annual sine exponent	1.714	1.743	1.178	2.516
Vessel-year s.d., $\exp(\sigma_v)$	2.352	2.382	1.948	3.025
Overdispersion, θ	0.082	0.084	0.057	0.124

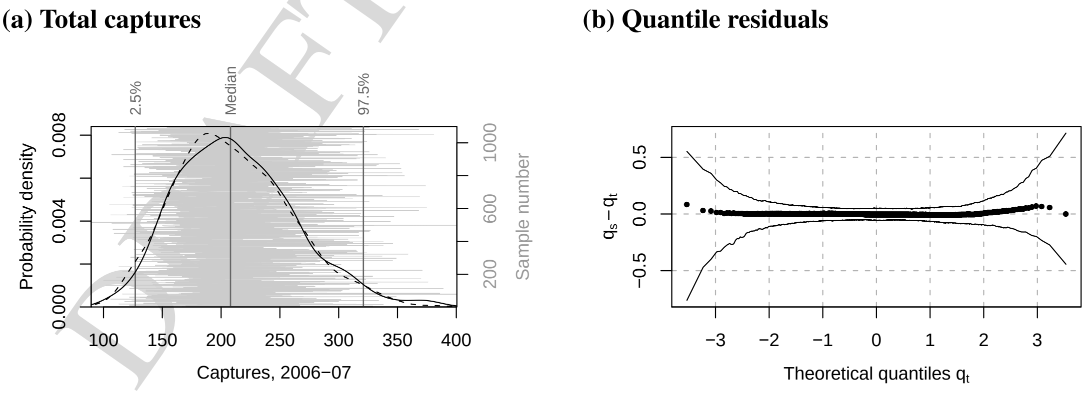

Figure A-2: Diagnostic plots for captures of white-capped albatross by year in all trawl fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

Table A-6: Captures by year and fishery, giving the median 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.
2006–07	85	(46 – 149)	11	(3 – 23)	9	(2 – 20)	6	(1 – 14)	112	(64 – 189)
2005–06	273	(168 – 435)	22	(9 – 42)	16	(6 – 34)	11	(4 – 24)	325	(208 – 501)
2004–05	185	(122 – 273)	15	(6 – 30)	9	(2 – 20)	5	(1 – 13)	215	(144 – 315)
2003–04	69	(34 – 120)	11	(3 – 24)	4	(0 – 10)	2	(0 – 7)	86	(45 – 147)
2002–03	65	(30 – 126)	17	(6 – 36)	5	(1 – 13)	4	(0 – 10)	91	(43 – 170)

Table A-7: Capture rate (birds per 100 trawls) by year and fishery, giving the median 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.
2006–07	1.6	(0.8 – 2.7)	0.1	(0.0 – 0.2)	0.2	(0.0 – 0.4)	0.1	(0.0 – 0.2)	0.4	(0.2 – 0.7)
2005–06	3.3	(2.0 – 5.3)	0.2	(0.1 – 0.4)	0.3	(0.1 – 0.7)	0.2	(0.1 – 0.4)	1.1	(0.7 – 1.7)
2004–05	1.8	(1.2 – 2.7)	0.1	(0.0 – 0.2)	0.2	(0.0 – 0.4)	0.1	(0.0 – 0.2)	0.6	(0.4 – 0.9)
2003–04	0.8	(0.4 – 1.5)	0.1	(0.0 – 0.1)	0.1	(0.0 – 0.3)	0.0	(0.0 – 0.1)	0.2	(0.1 – 0.4)
2002–03	0.8	(0.4 – 1.5)	0.1	(0.0 – 0.1)	0.1	(0.0 – 0.3)	0.1	(0.0 – 0.1)	0.2	(0.1 – 0.4)

Table A-8: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	26 566	13.7	30	0.8	112	(64 – 189)
Squid	Stewart-Snares	2 926	24.1	9	1.3	44	(21 – 82)
Squid	Auckland Islands	1 318	40.7	17	3.2	34	(15 – 65)
Squid	Chatham Rise	1 038	3.6	0	0	7	(1 – 20)
Scampi	Auckland Islands	1 328	7.2	0	0	6	(1 – 16)
Hoki	Chatham Rise	4 970	16.1	1	0.1	5	(1 – 13)
Hoki	Stewart-Snares	1 202	17.1	1	0.5	3	(0 – 10)
Middle-depths	Stewart-Snares	1 174	12.1	2	1.4	3	(0 – 9)
Scampi	Chatham Rise	2 297	6.6	0	0	2	(0 – 7)
Hoki	West South Island	1 981	21	0	0	1	(0 – 5)
Middle-depths	Chatham Rise	1 926	5	0	0	1	(0 – 5)

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. (%)
		598.7		
Fishery	1	429.4	169.3	28.3
Area	4	402.4	27.0	6.3
Fishing year	4	377.4	25.0	6.2
Annual cosine exponent	1	368.1	9.3	2.5
Six month cosine exponent	1	362.4	5.7	1.6
Fishing duration	1	355.7	6.7	1.9
Vessel length	3	340.4	15.3	4.3

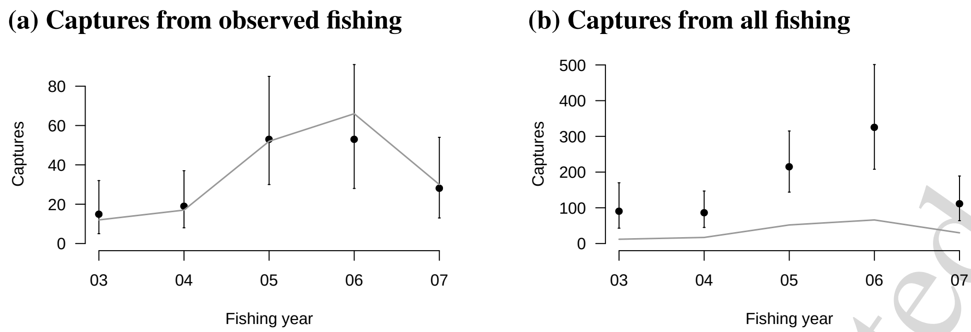

Figure A-3: Estimated captures of white-chinned petrel in all trawl fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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	0.094	0.037	0.184
Base rate, $100 \times \lambda_{03-04}$	0.072	0.077	0.032	0.147
Base rate, $100 \times \lambda_{04-05}$	0.163	0.169	0.077	0.295
Base rate, $100 \times \lambda_{05-06}$	0.295	0.303	0.141	0.515
Base rate, $100 \times \lambda_{06-07}$	0.151	0.157	0.070	0.285
Fishery, Mid-depths	0.180	0.190	0.091	0.347
Area, Snares	0.599	0.617	0.379	0.936
Area, Chatham Rise	0.254	0.275	0.110	0.568
Area, Stewart-Snares	0.508	0.559	0.202	1.225
Area, Other	0.048	0.061	0.007	0.187
Overdispersion, θ	0.023	0.024	0.015	0.037

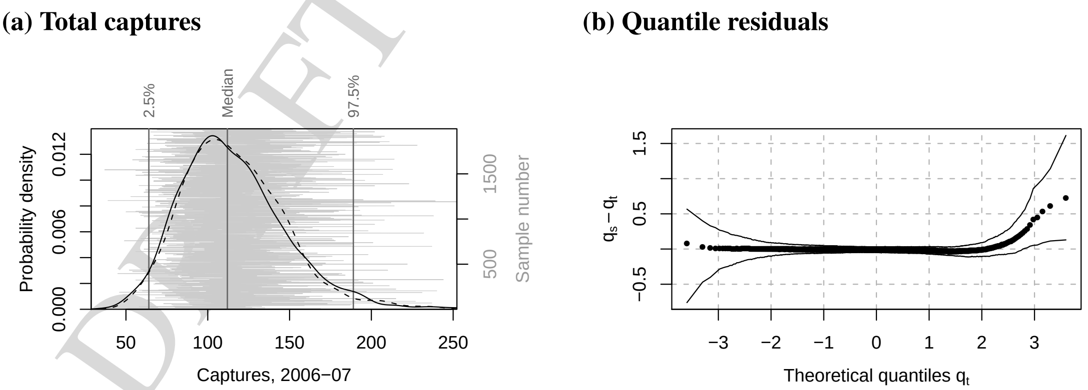

Figure A-4: Diagnostic plots for captures of white-chinned petrel by year in all trawl fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

A.3 Model summary, sooty shearwater, trawl fisheries

Table A-11: Captures by year and fishery, giving the median 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.
2006–07	355	(198 – 696)	148	(52 – 463)	30	(8 – 89)	127	(55 – 315)	689	(402 – 1 294)
2005–06	403	(229 – 737)	225	(104 – 538)	29	(6 – 95)	105	(48 – 238)	787	(486 – 1 372)
2004–05	368	(207 – 654)	78	(30 – 205)	18	(4 – 59)	56	(21 – 153)	533	(309 – 935)
2003–04	203	(102 – 391)	92	(31 – 280)	6	(1 – 23)	49	(16 – 148)	366	(184 – 708)
2002–03	519	(278 – 1 110)	640	(289 – 1 580)	11	(2 – 33)	168	(70 – 461)	1 368	(749 – 2 915)

Table A-12: Capture rate (birds per 100 trawls) by year and fishery, giving the median 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.
2006–07	6.5	(3.6 – 12.8)	1.5	(0.5 – 4.6)	0.6	(0.2 – 1.7)	2.2	(0.9 – 5.4)	2.6	(1.5 – 4.9)
2005–06	4.9	(2.8 – 8.9)	2.0	(0.9 – 4.8)	0.6	(0.1 – 2.0)	1.8	(0.8 – 4.0)	2.6	(1.6 – 4.5)
2004–05	3.6	(2.0 – 6.4)	0.6	(0.2 – 1.5)	0.4	(0.1 – 1.3)	0.9	(0.3 – 2.5)	1.5	(0.9 – 2.7)
2003–04	2.5	(1.2 – 4.7)	0.4	(0.1 – 1.3)	0.2	(0.0 – 0.6)	0.8	(0.3 – 2.5)	0.9	(0.5 – 1.8)
2002–03	6.3	(3.4 – 13.5)	2.4	(1.1 – 5.9)	0.2	(0.0 – 0.7)	2.3	(0.9 – 6.2)	2.9	(1.6 – 6.2)

Table A-13: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	26 566	13.7	74	2	689	(402 – 1 294)
Squid	Stewart-Snares	2 926	24.1	42	6	239	(122 – 490)
Hoki	Chatham Rise	4 970	16.1	7	0.9	134	(41 – 443)
Squid	Chatham Rise	1 038	3.6	2	5.4	61	(17 – 198)
Middle-depths	Chatham Rise	1 926	5	0	0	58	(19 – 195)
Middle-depths	Stewart-Snares	1 174	12.1	3	2.1	58	(19 – 172)
Squid	Auckland Islands	1 318	40.7	4	0.7	43	(17 – 103)
Scampi	Auckland Islands	1 328	7.2	13	13.7	17	(3 – 68)
Hoki	Stewart-Snares	1 202	17.1	2	1	10	(2 – 35)
Scampi	Chatham Rise	2 297	6.6	0	0	8	(1 – 35)
Middle-depths	Puysegur	150	20	0	0	1	(0 – 10)

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. (%)
		1197.6		
Area	4	791.0	406.6	34.0
Six month cosine exponent	1	660.8	130.2	16.5
Annual sine exponent	1	617.8	43.0	6.5
Six month sine exponent	1	596.1	21.7	3.5
Annual cosine exponent	1	585.8	10.2	1.7
Fishing year	4	572.6	13.2	2.3
Vessel length	3	566.6	6.0	1.1
Processing type	2	551.2	15.4	2.7

(a) Captures from observed fishing **(b) Captures from all fishing**

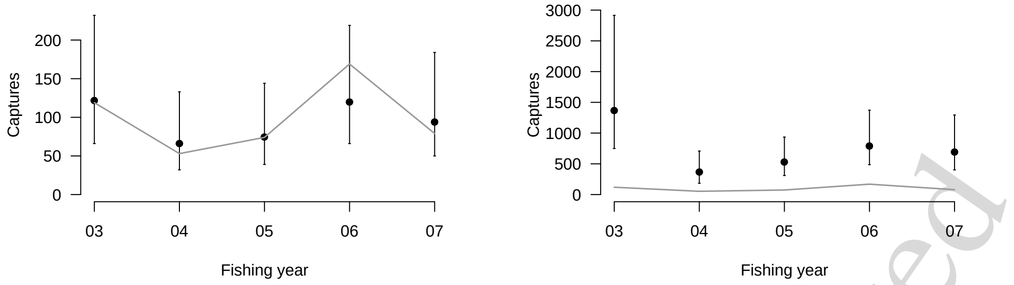

Figure A-5: Estimated captures of sooty shearwater in all trawl fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda_{02-03}$	0.154	0.167	0.061	0.356
Base rate, $100 \times \lambda_{03-04}$	0.083	0.091	0.026	0.203
Base rate, $100 \times \lambda_{04-05}$	0.104	0.112	0.037	0.231
Base rate, $100 \times \lambda_{05-06}$	0.140	0.150	0.054	0.306
Base rate, $100 \times \lambda_{06-07}$	0.139	0.150	0.054	0.313
Area, Inner Chatham Rise	1.637	1.746	0.863	3.162
Area, Southern	0.324	0.332	0.208	0.501
Area, Outer Chatham Rise	0.137	0.150	0.056	0.326
Area, Other	0.029	0.037	0.004	0.115
Six month cosine exponent	0.174	0.179	0.104	0.278
Annual sine exponent	4.844	4.989	2.981	8.029
Six month sine exponent	0.395	0.410	0.238	0.660
Annual cosine exponent	3.852	4.228	1.778	9.046
Vessel-year s.d., $\exp(\sigma_v)$	3.451	3.606	2.507	5.538
Overdispersion, θ	0.036	0.036	0.026	0.050

(a) Total captures **(b) Quantile residuals**

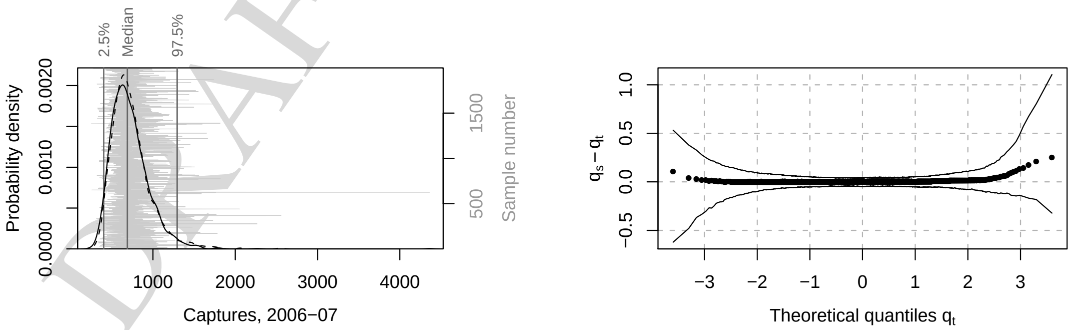

Figure A-6: Diagnostic plots for captures of sooty shearwater by year in all trawl fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

A.4 Model summary, other albatross, trawl fisheries

Table A-16: Captures by year and fishery, giving the median 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.
2006–07	39	(19 – 76)	50	(26 – 90)	33	(14 – 64)	26	(12 – 52)	151	(86 – 251)
2005–06	92	(49 – 161)	84	(48 – 138)	45	(23 – 84)	40	(20 – 74)	265	(165 – 408)
2004–05	195	(120 – 302)	184	(117 – 281)	76	(40 – 136)	68	(37 – 126)	528	(370 – 751)
2003–04	67	(36 – 112)	128	(75 – 204)	27	(12 – 51)	36	(18 – 68)	261	(166 – 394)
2002–03	78	(43 – 134)	168	(108 – 253)	43	(21 – 79)	47	(24 – 87)	341	(231 – 493)

Table A-17: Capture rate (birds per 100 trawls) by year and fishery, giving the median 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.
2006–07	0.7	(0.3 – 1.4)	0.5	(0.3 – 0.9)	0.6	(0.3 – 1.2)	0.4	(0.2 – 0.9)	0.6	(0.3 – 0.9)
2005–06	1.1	(0.6 – 1.9)	0.7	(0.4 – 1.2)	0.9	(0.5 – 1.7)	0.7	(0.3 – 1.2)	0.9	(0.5 – 1.3)
2004–05	1.9	(1.2 – 3.0)	1.3	(0.8 – 2.0)	1.6	(0.9 – 2.9)	1.1	(0.6 – 2.1)	1.5	(1.1 – 2.1)
2003–04	0.8	(0.4 – 1.4)	0.6	(0.4 – 1.0)	0.7	(0.3 – 1.4)	0.6	(0.3 – 1.1)	0.7	(0.4 – 1.0)
2002–03	1.0	(0.5 – 1.6)	0.6	(0.4 – 0.9)	0.9	(0.4 – 1.7)	0.6	(0.3 – 1.2)	0.7	(0.5 – 1.0)

Table A-18: Captures by fishery and area, for the 2006–07 fishing year, giving the median and 95% c.i. of estimated other 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	26 566	13.7	15	0.4	151	(86 – 251)
Hoki	Chatham Rise	4 970	16.1	5	0.6	35	(17 – 64)
Scampi	Chatham Rise	2 297	6.6	1	0.7	25	(10 – 52)
Squid	Stewart-Snares	2 926	24.1	2	0.3	19	(8 – 39)
Middle-depths	Chatham Rise	1 926	5	1	1	16	(6 – 34)
Squid	Chatham Rise	1 038	3.6	3	8.1	15	(5 – 36)
Hoki	Cook Strait	1 754	9.4	0	0	8	(2 – 19)
Scampi	East North Island	694	4.3	0	0	4	(0 – 11)
Squid	Auckland Islands	1 318	40.7	1	0.2	4	(1 – 10)
Hoki	West South Island	1 981	21	1	0.2	3	(0 – 9)
Middle-depths	East North Island	731	0.3	0	0	3	(0 – 9)

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. (%)
		658.3		
Fishery	3	611.9	46.4	7.1
Area	4	553.7	58.2	9.5
Annual sine exponent	1	541.6	12.1	2.2
Fishing year	4	524.6	17.0	3.1
Fishing duration	1	515.7	9.0	1.7
Six month sine exponent	1	509.3	6.4	1.2

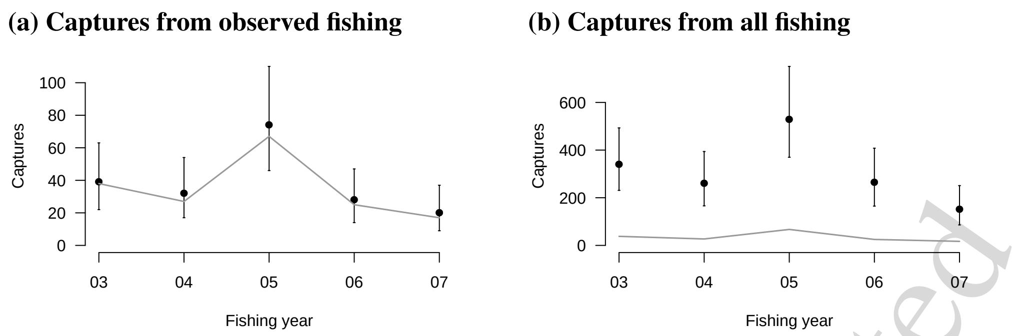

Figure A-7: Estimated captures of other albatross in all trawl fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda_{02-03}$	0.272	0.278	0.176	0.417
Base rate, $100 \times \lambda_{03-04}$	0.261	0.265	0.164	0.394
Base rate, $100 \times \lambda_{04-05}$	0.538	0.544	0.368	0.763
Base rate, $100 \times \lambda_{05-06}$	0.299	0.305	0.186	0.457
Base rate, $100 \times \lambda_{06-07}$	0.196	0.200	0.111	0.317
Area, Southern	0.143	0.147	0.087	0.233
Area, Snares	0.319	0.331	0.181	0.548
Area, East	0.512	0.537	0.278	0.930
Area, Other	0.088	0.096	0.037	0.201
Fishery, Squid	3.946	4.157	2.122	7.503
Fishery, Mid-depths	1.182	1.222	0.713	1.938
Fishery, Deepwater	0.111	0.117	0.041	0.234
Annual sine exponent	0.553	0.563	0.400	0.776
Overdispersion, θ	0.036	0.038	0.022	0.061

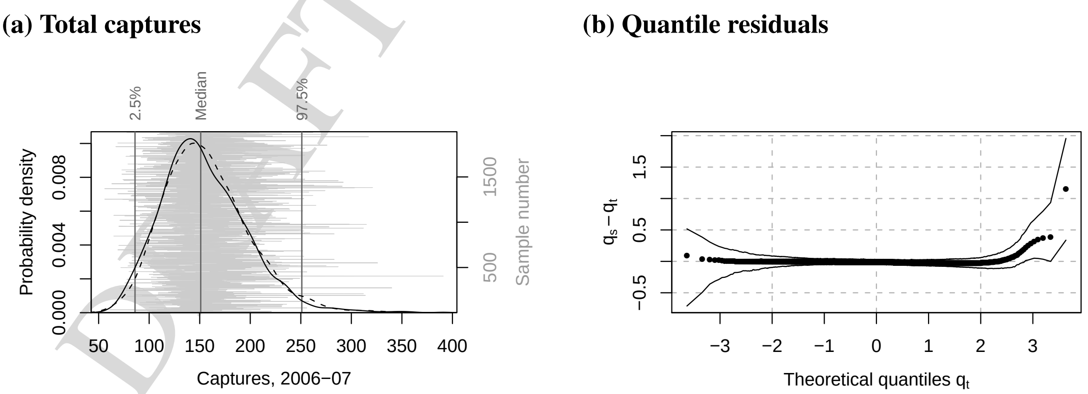

Figure A-8: Diagnostic plots for captures of other albatross by year in all trawl fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

A.5 Model summary, other birds, trawl fisheries

Table A-21: Captures by year and fishery, giving the median 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.
2006–07	12	(4 – 25)	19	(8 – 37)	30	(13 – 61)	9	(3 – 19)	72	(37 – 127)
2005–06	34	(18 – 57)	35	(18 – 57)	51	(27 – 92)	10	(3 – 21)	133	(82 – 199)
2004–05	80	(50 – 120)	81	(52 – 118)	97	(53 – 180)	19	(9 – 37)	280	(192 – 408)
2003–04	33	(17 – 56)	67	(39 – 106)	41	(19 – 82)	10	(3 – 22)	154	(93 – 235)
2002–03	31	(17 – 52)	81	(48 – 128)	38	(19 – 71)	13	(5 – 26)	166	(101 – 256)

Table A-22: Capture rate (birds per 100 trawls) by year and fishery, giving the median 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.
2006–07	0.2	(0.1 – 0.5)	0.2	(0.1 – 0.4)	0.6	(0.3 – 1.2)	0.2	(0.1 – 0.4)	0.3	(0.1 – 0.5)
2005–06	0.4	(0.2 – 0.7)	0.3	(0.2 – 0.5)	1.1	(0.6 – 1.9)	0.2	(0.1 – 0.4)	0.5	(0.3 – 0.7)
2004–05	0.8	(0.5 – 1.2)	0.6	(0.4 – 0.9)	2.1	(1.1 – 3.9)	0.4	(0.2 – 0.7)	0.8	(0.6 – 1.2)
2003–04	0.4	(0.2 – 0.7)	0.3	(0.2 – 0.5)	1.1	(0.5 – 2.2)	0.2	(0.1 – 0.4)	0.4	(0.2 – 0.6)
2002–03	0.4	(0.2 – 0.7)	0.3	(0.2 – 0.5)	0.8	(0.4 – 1.5)	0.2	(0.1 – 0.4)	0.4	(0.2 – 0.6)

Table A-23: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	26 566	13.7	13	0.4	72	(37 – 127)
Scampi	North	815	11.9	6	6.2	15	(4 – 39)
Hoki	Chatham Rise	4 970	16.1	0	0	10	(3 – 21)
Squid	Stewart-Snares	2 926	24.1	1	0.1	6	(1 – 14)
Scampi	Chatham Rise	2 297	6.6	0	0	5	(1 – 14)
Scampi	Auckland Islands	1 328	7.2	1	1.1	5	(1 – 12)
Hoki	West South Island	1 981	21	3	0.7	4	(1 – 11)
Scampi	East North Island	694	4.3	0	0	4	(0 – 11)
Squid	Auckland Islands	1 318	40.7	1	0.2	4	(0 – 10)
Middle-depths	Chatham Rise	1 926	5	0	0	3	(0 – 9)
Middle-depths	Stewart-Snares	1 174	12.1	0	0	2	(0 – 7)

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. (%)
		397.2		
Fishing year	4	380.1	17.1	4.3
Processing type	2	370.5	9.6	2.5
Area	5	355.9	14.5	3.9

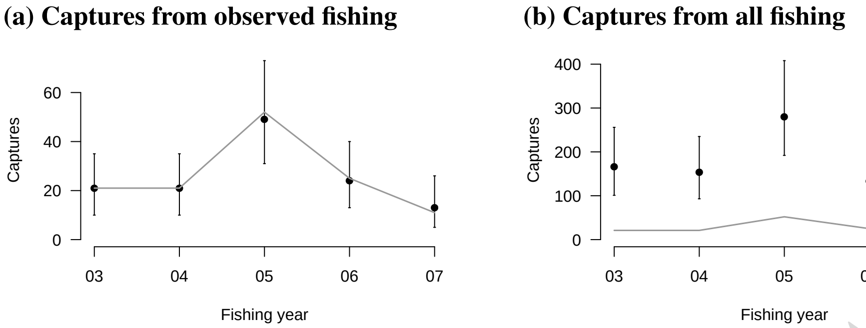

Figure A-9: Estimated captures of other birds in all trawl fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table A-25: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are West (Area) and Fresher (Processor).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda_{02-03}$	0.281	0.287	0.175	0.429
Base rate, $100 \times \lambda_{03-04}$	0.302	0.306	0.188	0.448
Base rate, $100 \times \lambda_{04-05}$	0.556	0.562	0.385	0.772
Base rate, $100 \times \lambda_{05-06}$	0.293	0.299	0.187	0.440
Base rate, $100 \times \lambda_{06-07}$	0.178	0.182	0.091	0.300
Area, Auckland-Campbell	1.156	1.192	0.684	1.907
Area, Chatham Rise	0.754	0.782	0.428	1.294
Area, Stewart-Snares	0.778	0.807	0.438	1.345
Area, East	1.684	1.768	0.823	3.183
Area, Northeast	5.919	6.594	2.315	14.506
Processor, Meal-plant	7.123	12.694	2.053	60.257
Processor, Freezer	11.840	21.393	3.362	96.321
Overdispersion, θ	0.135	0.149	0.070	0.319

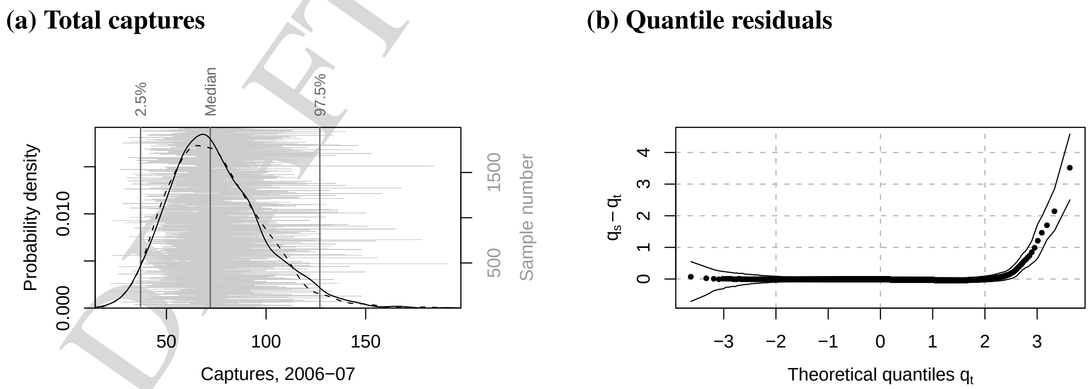

Figure A-10: Diagnostic plots for captures of other birds by year in all trawl fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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 median and 95% c.i. of the estimated captures.

Year	Large vessel	
	Caps.	95% c.i.
2006–07	1	(0 – 5)
2005–06	3	(1 – 6)
2004–05	2	(0 – 7)
2003–04	2	(0 – 7)
2002–03	2	(0 – 5)
2001–02	6	(2 – 14)
2000–01	5	(1 – 11)
1999–00	10	(5 – 19)
1998–99	7	(1 – 16)

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

Year	Large vessel	
	Rate	95% c.i.
2006–07	0.1	(0.0 – 0.3)
2005–06	0.1	(0.0 – 0.3)
2004–05	0.1	(0.0 – 0.3)
2003–04	0.1	(0.0 – 0.2)
2002–03	0.1	(0.0 – 0.2)
2001–02	0.2	(0.1 – 0.4)
2000–01	0.1	(0.0 – 0.3)
1999–00	0.3	(0.1 – 0.5)
1998–99	0.1	(0.0 – 0.3)

Table B-3: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	1 972	12.3	0	0	1	(0 – 5)
Large vessel	Chatham Rise	1 235	2.6	0	0	1	(0 – 5)
Large vessel	Cook Strait	162	48.1	0	0	0	(0 – 0)
Large vessel	East North Island	59	30.5	0	0	0	(0 – 0)
Large vessel	Puysegur	133	66.2	0	0	0	(0 – 0)
Large vessel	Stewart-Snares	206	12.6	0	0	0	(0 – 0)
Large vessel	Subantarctic	177	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. (%)
		37.4		
Moon phase	1	31.2	6.2	16.6
Integrated weight line	1	27.4	3.8	12.2

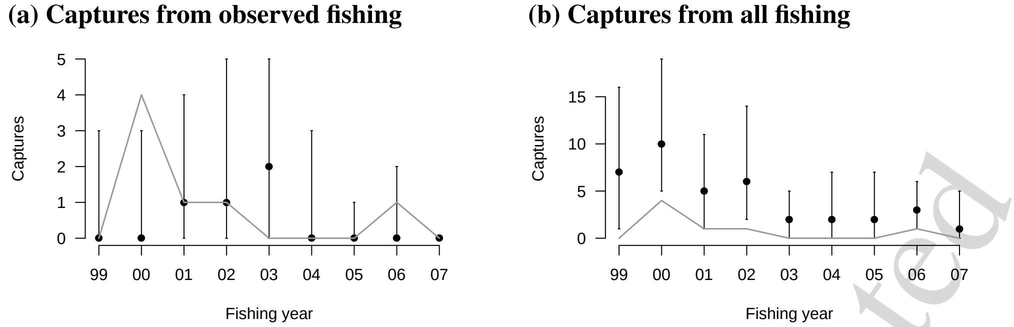

Figure B-1: Estimated captures of white-capped albatross in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda$	0.001	0.007	0.000	0.054
Moon phase exponent	0.021	0.058	0.000	0.324
Integrated weight line, True	0.000	0.019	0.000	0.245

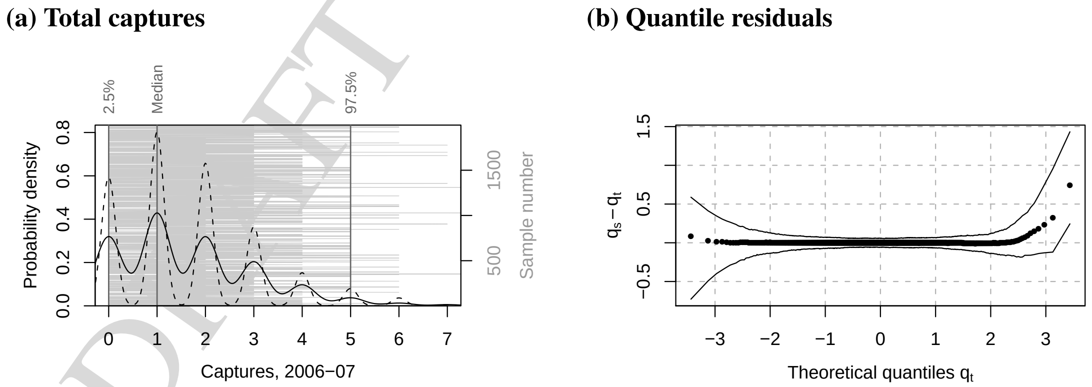

Figure B-2: Diagnostic plots for captures of white-capped albatross by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

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

Year	Large vessel	
	Caps.	95% c.i.
2006–07	130	(14 – 1 180)
2005–06	107	(42 – 404)
2004–05	301	(62 – 1 714)
2003–04	105	(23 – 858)
2002–03	189	(138 – 403)
2001–02	888	(597 – 2 408)
2000–01	567	(350 – 1 575)
1999–00	700	(236 – 2 389)
1998–99	612	(103 – 3 406)

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

Year	Large vessel	
	Rate	95% c.i.
2006–07	8.9	(1.0 – 80.7)
2005–06	6.9	(2.7 – 26.2)
2004–05	19.7	(4.1 – 112.3)
2003–04	5.0	(1.1 – 40.8)
2002–03	9.6	(7.0 – 20.4)
2001–02	32.6	(21.9 – 88.2)
2000–01	23.5	(14.5 – 65.4)
1999–00	24.6	(8.3 – 83.9)
1998–99	15.5	(2.6 – 86.6)

Table B-8: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	1 972	12.3	11	4.5	130	(14 – 1 180)
Large vessel	Chatham Rise	1 235	2.6	0	0	61	(0 – 1 076)
Large vessel	Stewart-Snares	206	12.6	0	0	13	(0 – 223)
Large vessel	Puysegur	133	66.2	11	12.5	12	(11 – 51)
Large vessel	Subantarctic	177	0	0		2	(0 – 51)
Large vessel	Cook Strait	162	48.1	0	0	1	(0 – 23)
Large vessel	East North Island	59	30.5	0	0	0	(0 – 11)

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. (%)
		693.8		
Breeding season	1	535.0	158.8	22.9
Area	3	502.3	32.6	6.1
Moon phase	1	490.7	11.6	2.3
Integrated weight line	1	483.9	6.8	1.4

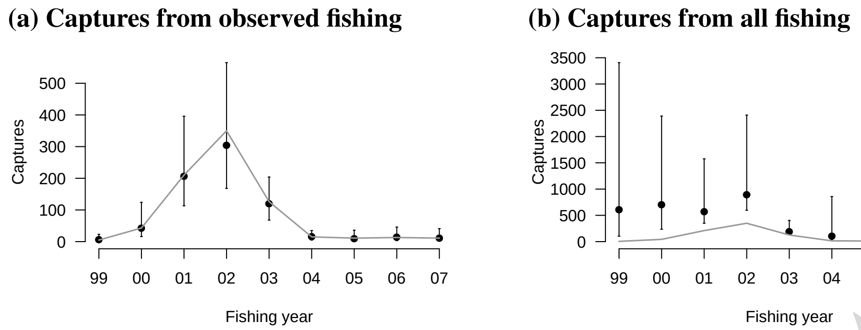

Figure B-3: Estimated captures of white-chinned petrel in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda$	5.744	5.987	3.725	9.566
Season, Shoulder	0.023	0.026	0.008	0.065
Integrated weight line, True	0.193	0.333	0.031	1.439
Moon phase exponent	2.603	2.731	1.567	4.605
Area, Keyhole	3.386	4.590	0.865	16.350
Area, Bounty	0.695	0.899	0.185	2.808
Area, Southern	1.354	1.789	0.397	5.677
Vessel-year s.d., $\exp(\sigma_\nu)$	4.510	5.853	2.181	17.742
Overdispersion, θ	0.074	0.074	0.059	0.092

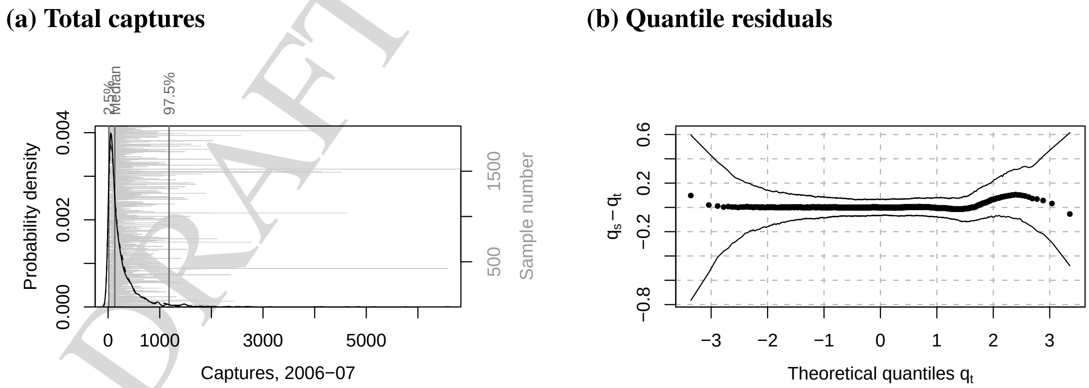

Figure B-4: Diagnostic plots for captures of white-chinned petrel by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

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

Year	Large vessel	
	Caps.	95% c.i.
2006–07	9	(2 – 31)
2005–06	8	(3 – 24)
2004–05	22	(9 – 54)
2003–04	25	(19 – 40)
2002–03	33	(25 – 54)
2001–02	38	(25 – 64)
2000–01	21	(14 – 34)
1999–00	28	(14 – 56)
1998–99	38	(14 – 84)

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

Year	Large vessel	
	Rate	95% c.i.
2006–07	0.6	(0.1 – 2.1)
2005–06	0.5	(0.2 – 1.6)
2004–05	1.5	(0.6 – 3.6)
2003–04	1.3	(1.0 – 2.0)
2002–03	1.9	(1.4 – 3.1)
2001–02	1.5	(1.0 – 2.5)
2000–01	0.9	(0.6 – 1.5)
1999–00	1.0	(0.5 – 2.0)
1998–99	1.0	(0.4 – 2.2)

Table B-13: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	1 972	12.3	1	0.4	9	(2 – 31)
Large vessel	Stewart-Snares	206	12.6	0	0	4	(0 – 20)
Large vessel	Chatham Rise	1 235	2.6	0	0	2	(0 – 8)
Large vessel	Puysegur	133	66.2	1	1.1	2	(1 – 10)
Large vessel	Cook Strait	162	48.1	0	0	0	(0 – 1)
Large vessel	East North Island	59	30.5	0	0	0	(0 – 1)
Large vessel	Subantarctic	177	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. (%)
		317.6		
Area	1	206.2	111.5	35.1
Breeding season	1	200.5	5.6	2.7
Integrated weight line	1	196.6	3.9	1.9
Moon phase	1	193.9	2.7	1.4

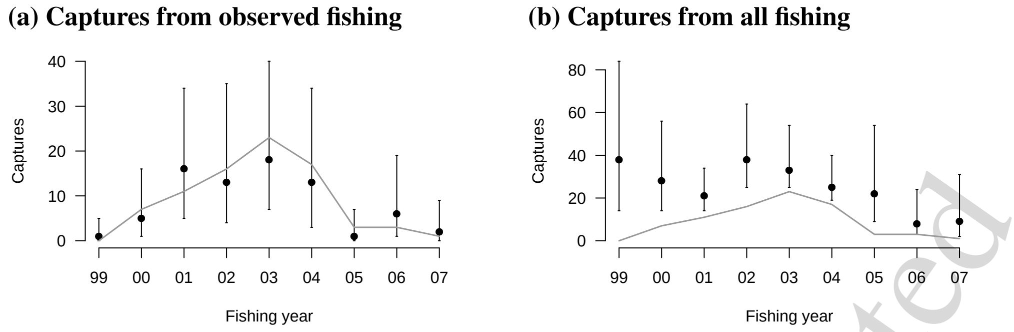

Figure B-5: Estimated captures of sooty shearwater in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda$	0.541	0.558	0.271	0.939
Area, Southern	0.040	0.044	0.013	0.101
Season, Breeding	0.474	0.498	0.244	0.901
Integrated weight line, True	0.345	0.435	0.078	1.320
Moon phase exponent	0.480	0.539	0.198	1.200
Vessel-year s.d., $\exp(\sigma_v)$	1.500	1.584	1.115	2.563
Overdispersion, θ	0.079	0.085	0.044	0.162

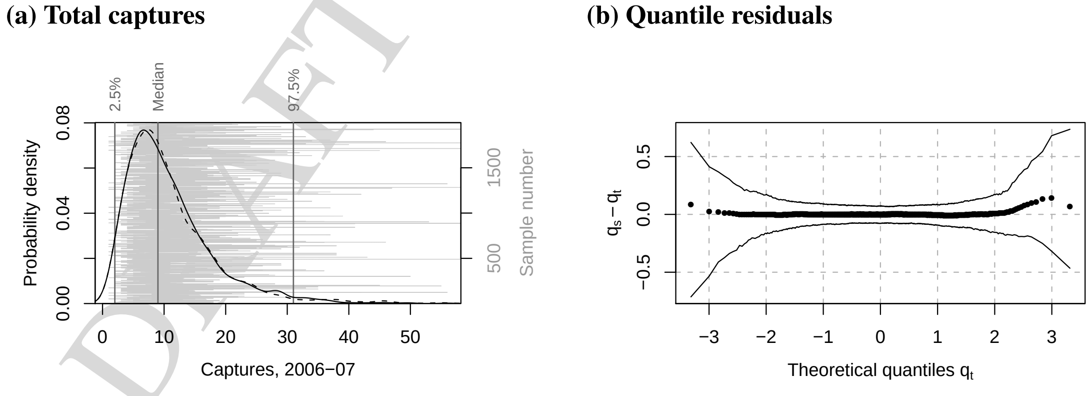

Figure B-6: Diagnostic plots for captures of sooty shearwater by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

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

Year	Large vessel	
	Caps.	95% c.i.
2006–07	28	(10 – 68)
2005–06	24	(12 – 52)
2004–05	25	(10 – 55)
2003–04	47	(25 – 94)
2002–03	35	(20 – 68)
2001–02	111	(69 – 193)
2000–01	180	(137 – 267)
1999–00	115	(81 – 180)
1998–99	115	(64 – 208)

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

Year	Large vessel	
	Rate	95% c.i.
2006–07	1.4	(0.5 – 3.4)
2005–06	1.1	(0.6 – 2.4)
2004–05	1.1	(0.4 – 2.5)
2003–04	1.6	(0.8 – 3.2)
2002–03	1.3	(0.7 – 2.5)
2001–02	2.8	(1.8 – 4.9)
2000–01	5.1	(3.9 – 7.6)
1999–00	2.9	(2.0 – 4.5)
1998–99	2.3	(1.3 – 4.2)

Table B-18: Captures by fishery and area, for the 2006–07 fishing year, giving the median and 95% c.i. of estimated other 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	1 972	12.3	0	0	28	(10 – 68)
Large vessel	Chatham Rise	1 235	2.6	0	0	20	(6 – 53)
Large vessel	Subantarctic	177	0	0		4	(0 – 27)
Large vessel	Stewart-Snares	206	12.6	0	0	1	(0 – 7)
Large vessel	Cook Strait	162	48.1	0	0	0	(0 – 1)
Large vessel	East North Island	59	30.5	0	0	0	(0 – 1)
Large vessel	Puysegur	133	66.2	0	0	0	(0 – 2)

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. (%)
		339.9		
Summer	1	263.0	76.9	22.6
Area	2	247.0	16.0	6.1
Moon phase	1	240.2	6.8	2.8
Integrated weight line	1	235.2	5.0	2.1

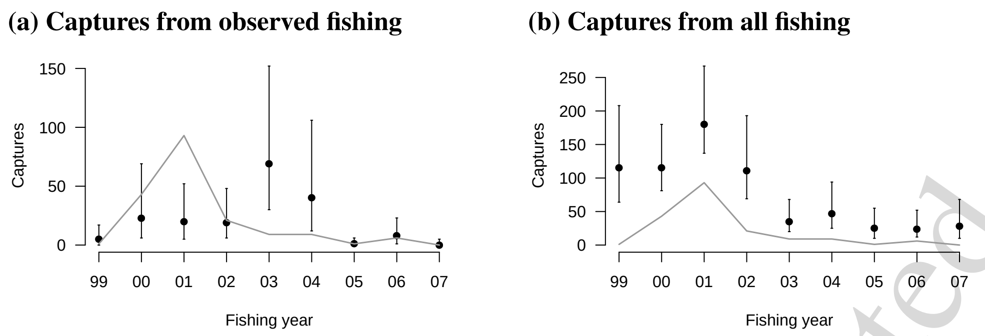

Figure B-7: Estimated captures of other albatross in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda$	0.940	0.957	0.548	1.454
Season, Winter	0.152	0.172	0.054	0.415
Integrated weight line, True	0.236	0.298	0.041	0.921
Area, Keyhole	0.226	0.244	0.106	0.494
Area, Southern	0.270	0.306	0.111	0.690
Moon phase exponent	2.520	2.780	1.085	6.259
Overdispersion, θ	0.017	0.017	0.012	0.025

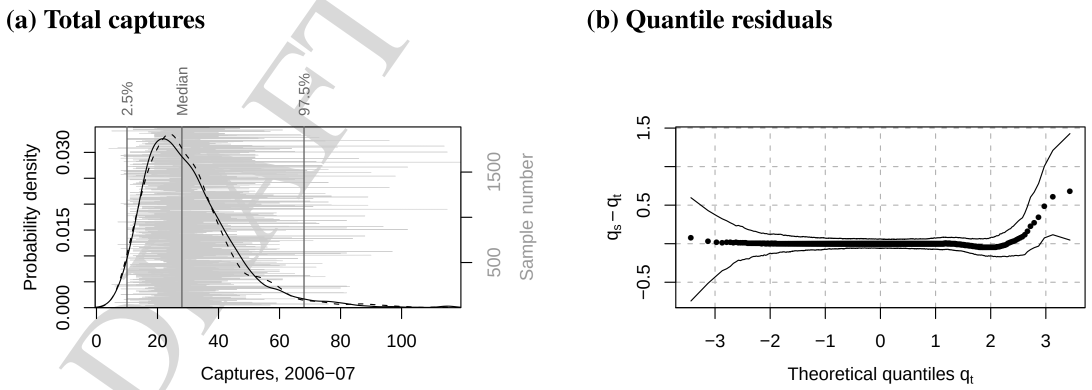

Figure B-8: Diagnostic plots for captures of other albatross by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

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

Year	Large vessel	
	Caps.	95% c.i.
2006–07	25	(2 – 157)
2005–06	31	(11 – 86)
2004–05	35	(9 – 157)
2003–04	73	(20 – 201)
2002–03	139	(102 – 266)
2001–02	158	(98 – 364)
2000–01	414	(315 – 635)
1999–00	768	(433 – 1 534)
1998–99	452	(246 – 1 051)

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

Year	Large vessel	
	Rate	95% c.i.
2006–07	1.3	(0.1 – 8.0)
2005–06	1.5	(0.5 – 4.0)
2004–05	1.6	(0.4 – 7.0)
2003–04	2.5	(0.7 – 6.8)
2002–03	5.1	(3.7 – 9.7)
2001–02	4.0	(2.5 – 9.3)
2000–01	11.8	(9.0 – 18.2)
1999–00	19.4	(10.9 – 38.7)
1998–99	9.1	(5.0 – 21.2)

Table B-23: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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	1 972	12.3	1	0.4	25	(2 – 157)
Large vessel	Chatham Rise	1 235	2.6	0	0	21	(0 – 153)
Large vessel	Puysegur	133	66.2	1	1.1	1	(1 – 2)
Large vessel	Stewart-Snares	206	12.6	0	0	1	(0 – 6)
Large vessel	Cook Strait	162	48.1	0	0	0	(0 – 3)
Large vessel	East North Island	59	30.5	0	0	0	(0 – 2)
Large vessel	Subantarctic	177	0	0		0	(0 – 4)

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. (%)
		1061.5		
Area	2	641.0	420.5	39.6
Summer	1	625.9	15.1	2.4

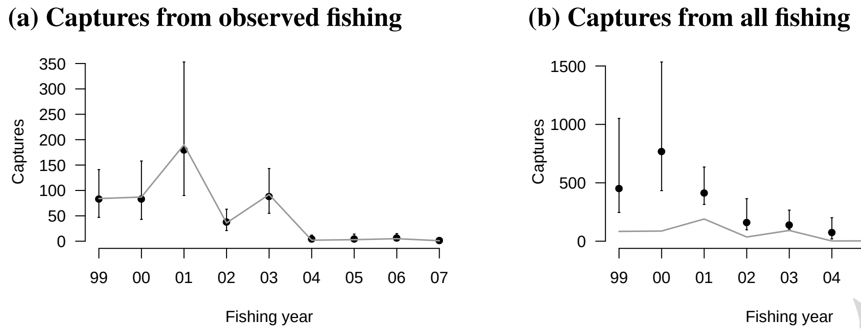

Figure B-9: Estimated captures of other birds in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	3.643	3.694	2.803	4.909
Area, Campbell plateau	0.468	0.512	0.199	1.084
Area, Southern	0.111	0.123	0.045	0.272
Integrated weight line, True	0.741	0.835	0.312	1.907
Season, Summer	0.482	0.499	0.286	0.817
Vessel-year s.d., $\exp(\sigma_v)$	3.030	3.379	1.966	6.909
Overdispersion, θ	0.127	0.129	0.094	0.174

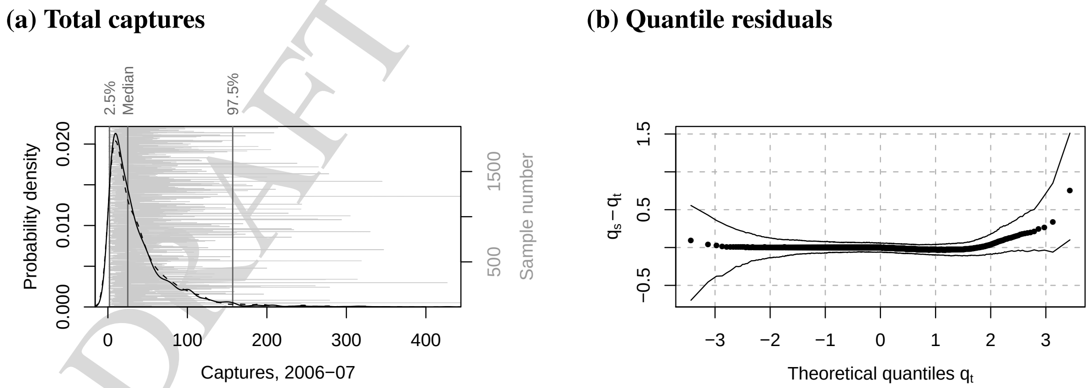

Figure B-10: Diagnostic plots for captures of other birds by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

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

Year	Snapper	
	Caps.	95% c.i.
2006–07	457	(195 – 1 257)
2005–06	469	(222 – 1 234)
2004–05	501	(245 – 1 233)
2003–04	644	(301 – 1 585)
2002–03	739	(332 – 1 997)

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

Year	Snapper	
	Rate	95% c.i.
2006–07	7.4	(3.2 – 20.4)
2005–06	7.2	(3.4 – 19.0)
2004–05	6.6	(3.2 – 16.3)
2003–04	7.6	(3.6 – 18.8)
2002–03	7.4	(3.3 – 20.1)

Table B-28: Captures by fishery and area, for the 2006–07 fishing year, giving the median and 95% c.i. of estimated other birds, snapper captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
Snapper	North	6 174	0.2	0	0	457	(195 – 1 257)

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. (%)
		56.8		
Summer	1	52.0	4.7	8.3

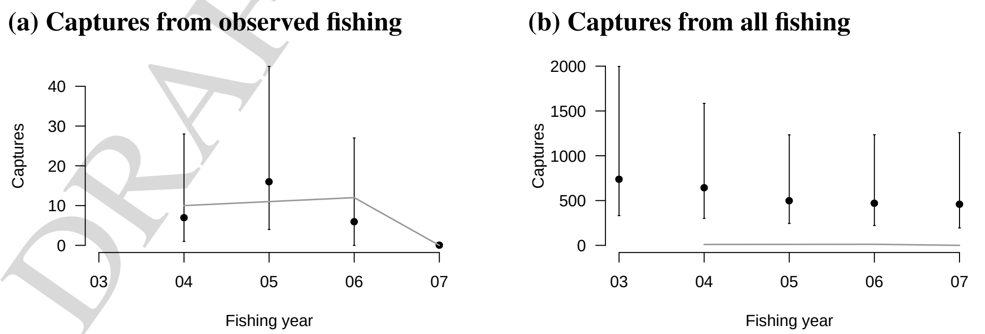

Figure B-11: Estimated captures of other birds, snapper in all bottom longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table B-30: Summary of the posterior distributions of the model parameters. The base level of Season is Summer.

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	1.032	2.454	0.004	11.730
Season, Winter	0.000	0.014	0.000	0.101
Vessel-year s.d., $\exp(\sigma_v)$	3.006	4.086	1.436	11.884
Overdispersion, θ	0.137	0.159	0.050	0.382

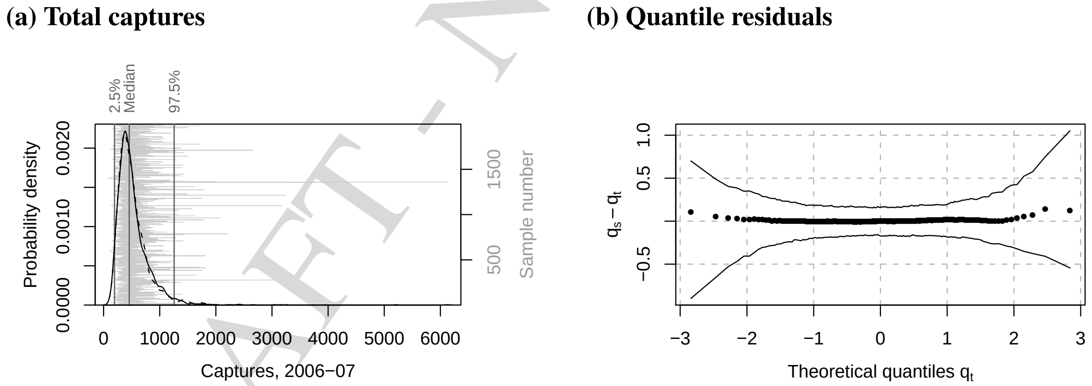

Figure B-12: Diagnostic plots for captures of other birds, snapper by year in all bottom longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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 median 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.
2006–07	22	(8 – 46)	0	(0 – 1)	0	(0 – 0)	13	(0 – 230)	38	(13 – 250)
2005–06	5	(0 – 19)	0	(0 – 1)	0	(0 – 0)	16	(0 – 244)	23	(3 – 248)
2004–05	8	(1 – 30)	0	(0 – 1)	0	(0 – 0)	6	(0 – 97)	17	(3 – 112)
2003–04	34	(11 – 124)	0	(0 – 2)	0	(0 – 1)			34	(11 – 124)
2002–03	50	(8 – 261)	0	(0 – 3)	0	(0 – 3)	0	(0 – 3)	51	(8 – 261)
2001–02	51	(14 – 212)	0	(0 – 3)	0	(0 – 3)			52	(14 – 212)
2000–01	30	(7 – 147)	0	(0 – 3)	0	(0 – 2)	0	(0 – 4)	31	(7 – 148)
1999–00	24	(6 – 104)	0	(0 – 3)	0	(0 – 2)	0	(0 – 15)	26	(7 – 111)
1998–99	11	(3 – 30)	0	(0 – 3)	0	(0 – 2)	2	(0 – 92)	16	(5 – 112)

Table C-2: Capture rate (birds per 100 sets) by year and fishery, giving the median 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.
2006–07	2.3	(0.8 – 4.8)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	8.1	(0.0 – 142.9)	1.5	(0.5 – 9.7)
2005–06	0.5	(0.0 – 1.9)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	9.4	(0.0 – 143.5)	0.8	(0.1 – 8.4)
2004–05	0.7	(0.1 – 2.7)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.0)	4.7	(0.0 – 75.2)	0.6	(0.1 – 3.9)
2003–04	1.7	(0.6 – 6.4)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.3)			0.6	(0.2 – 2.3)
2002–03	2.1	(0.3 – 11.1)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.3)	0.0	(0.0 – 150.0)	0.7	(0.1 – 3.5)
2001–02	2.7	(0.7 – 11.1)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.4)			0.6	(0.2 – 2.5)
2000–01	2.5	(0.6 – 12.3)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.4)	0.0	(0.0 – 200.0)	0.4	(0.1 – 1.9)
1999–00	2.4	(0.6 – 10.5)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.3)	0.0	(0.0 – 375.0)	0.4	(0.1 – 1.6)
1998–99	1.2	(0.3 – 3.2)	0.0	(0.0 – 0.1)	0.0	(0.0 – 0.4)	10.0	(0.0 – 460.1)	0.3	(0.1 – 1.9)

Table C-3: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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.
Swordfish	North-west	26	0	0		0	(0 – 12)
All fisheries	All areas	2 723	16	24	5.5	38	(13 – 250)
Southern bluefin	South-west	323	57.6	23	12.4	19	(7 – 43)
Swordfish	North-east	134	13.4	0	0	12	(0 – 217)
Southern bluefin	North-east	630	20	1	0.8	2	(0 – 10)
Swordfish	South-west	1	0	0		0	(0 – 4)

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. (%)
		470.8		
Vessel length	1	449.8	21.0	4.5
Annual sine exponent	1	373.6	76.2	16.9
Fishing year	8	338.0	35.6	9.5
Set day, night, dusk	2	325.5	12.4	3.7
Fishery	3	314.0	11.5	3.5
Annual cosine exponent	1	307.7	6.3	2.0

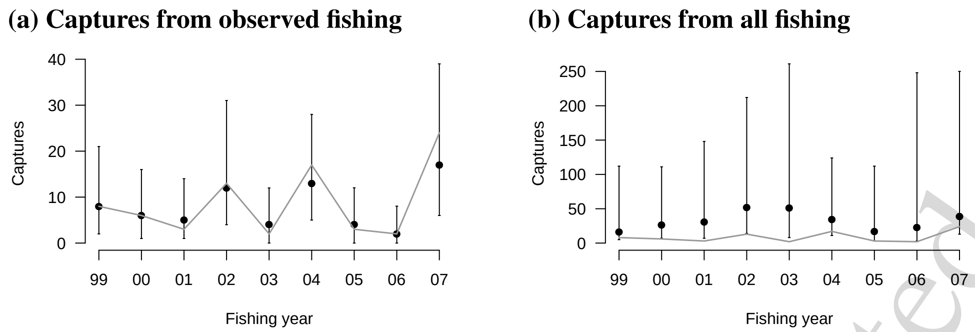

Figure C-1: Estimated captures of white-capped albatross in all surface longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.005	0.034	0.000	0.241
Vessel length, < 40m	0.706	1.023	0.068	3.850
Annual sine exponent	5.539	9.510	1.149	42.572
Set time, Full moon	2.780	2.892	1.572	4.809
Set time, Daylight	0.356	0.671	0.010	3.311
Fishery, Swordfish	1.045	3.800	0.024	24.105
Fishery, Albacore	0.000	0.009	0.000	0.046
Fishery, Bigeye	0.000	0.002	0.000	0.011
Annual cosine exponent	8.472	10.876	1.896	34.718
Vessel-year s.d., $\exp(\sigma_v)$	2.386	2.499	1.618	4.140
Overdispersion, θ	0.245	0.277	0.114	0.631

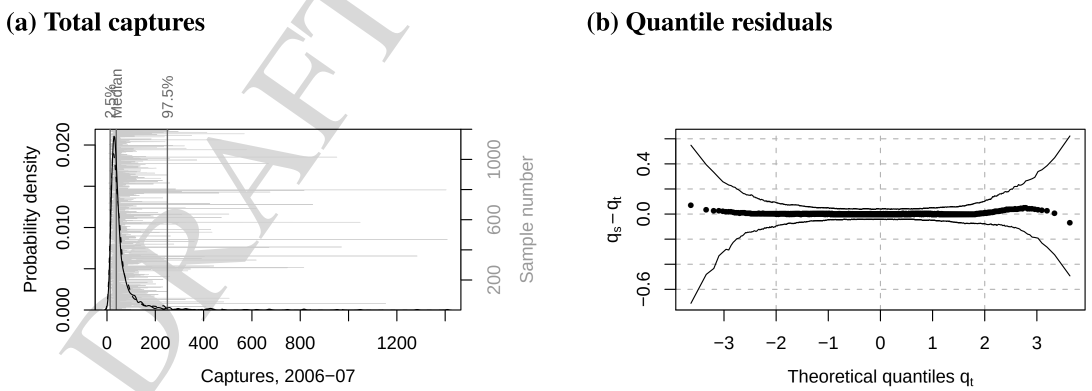

Figure C-2: Diagnostic plots for captures of white-capped albatross by year in all surface longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

Table C-6: Captures by year and fishery, giving the median 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.
2006–07	4	(1 – 10)	9	(2 – 22)	0	(0 – 0)	1	(0 – 4)	15	(6 – 30)
2005–06	1	(0 – 3)	9	(2 – 22)	0	(0 – 2)	1	(0 – 4)	12	(3 – 27)
2004–05	1	(0 – 4)	7	(1 – 16)	0	(0 – 1)	0	(0 – 1)	8	(2 – 19)
2003–04	4	(1 – 9)	18	(5 – 40)	1	(0 – 4)			23	(9 – 47)
2002–03	3	(0 – 8)	28	(9 – 61)	4	(0 – 10)	0	(0 – 0)	36	(14 – 73)
2001–02	5	(1 – 11)	41	(14 – 87)	4	(0 – 10)			50	(19 – 102)
2000–01	4	(0 – 9)	41	(15 – 83)	3	(0 – 8)	0	(0 – 0)	48	(20 – 93)
1999–00	3	(0 – 8)	35	(12 – 76)	5	(1 – 13)	0	(0 – 1)	44	(17 – 91)
1998–99	4	(1 – 10)	33	(12 – 70)	2	(0 – 7)	0	(0 – 2)	40	(17 – 80)

Table C-7: Capture rate (birds per 100 sets) by year and fishery, giving the median 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.
2006–07	0.4	(0.1 – 1.0)	0.6	(0.1 – 1.5)	0.0	(0.0 – 0.0)	0.6	(0.0 – 2.5)	0.6	(0.2 – 1.2)
2005–06	0.1	(0.0 – 0.3)	0.5	(0.1 – 1.3)	0.0	(0.0 – 3.1)	0.6	(0.0 – 2.4)	0.4	(0.1 – 0.9)
2004–05	0.1	(0.0 – 0.4)	0.5	(0.1 – 1.0)	0.0	(0.0 – 0.8)	0.0	(0.0 – 0.8)	0.3	(0.1 – 0.7)
2003–04	0.2	(0.1 – 0.5)	0.6	(0.2 – 1.3)	0.3	(0.0 – 1.0)			0.4	(0.2 – 0.9)
2002–03	0.1	(0.0 – 0.3)	0.7	(0.2 – 1.4)	0.4	(0.0 – 1.1)	0.0	(0.0 – 0.0)	0.5	(0.2 – 1.0)
2001–02	0.3	(0.1 – 0.6)	0.7	(0.2 – 1.5)	0.5	(0.0 – 1.2)			0.6	(0.2 – 1.2)
2000–01	0.3	(0.0 – 0.8)	0.7	(0.3 – 1.4)	0.6	(0.0 – 1.5)	0.0	(0.0 – 0.0)	0.6	(0.3 – 1.2)
1999–00	0.3	(0.0 – 0.8)	0.7	(0.2 – 1.5)	0.8	(0.2 – 2.1)	0.0	(0.0 – 25.0)	0.6	(0.2 – 1.3)
1998–99	0.4	(0.1 – 1.1)	0.8	(0.3 – 1.6)	0.4	(0.0 – 1.3)	0.0	(0.0 – 10.0)	0.7	(0.3 – 1.4)

Table C-8: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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.
Swordfish	North-west	26	0	0		0	(0 – 1)
All fisheries	All areas	2 723	16	5	1.1	15	(6 – 30)
Bigeye	North-east	1 283	4.9	0	0	9	(2 – 21)
Southern bluefin	South-west	323	57.6	3	1.6	4	(1 – 10)
Swordfish	North-east	134	13.4	2	11.1	1	(0 – 4)
Albacore	North-east	17	0	0		0	(0 – 0)
Bigeye	South-west	4	0	0		0	(0 – 0)
Bigeye	North-west	166	8.4	0	0	0	(0 – 2)
Southern bluefin	North-east	630	20	0	0	0	(0 – 1)
Southern bluefin	North-west	1	0	0		0	(0 – 0)
Swordfish	South-west	1	0	0		0	(0 – 0)

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. (%)
		130.2		
Vessel length	1	129.3	0.9	0.7
Set day, night, dusk	2	120.3	9.0	6.9

(a) Captures from observed fishing **(b) Captures from all fishing**

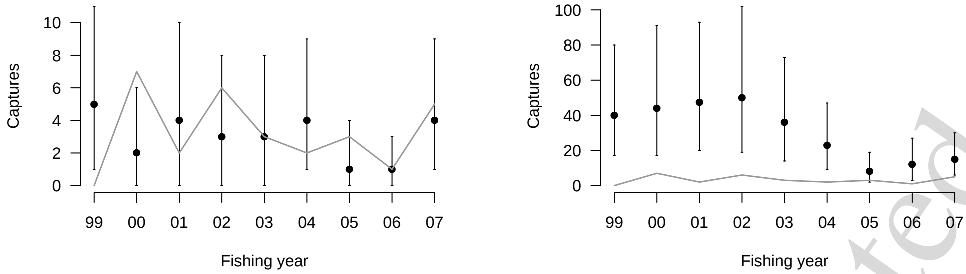

Figure C-3: Estimated captures of white-chinned petrel in all surface longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

Table C-10: Summary of the posterior distributions of the model parameters. Base levels of the factor covariates are >= 40m (Vessel length) and Night (Set time).

Parameter	Statistic			
	Median	Mean	2.5%	97.5%
Base rate, $100 \times \lambda$	0.218	0.231	0.097	0.434
Vessel length, < 40m	0.014	0.020	0.003	0.073
Annual cosine exponent	39.421	47.828	12.411	129.300
Set time, Full moon	3.509	3.812	1.637	7.726
Set time, Daylight	1.591	1.907	0.358	5.220

(a) Total captures **(b) Quantile residuals**

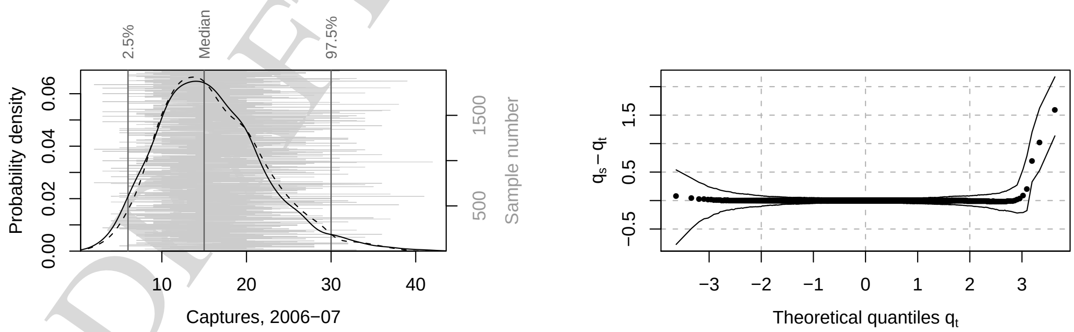

Figure C-4: Diagnostic plots for captures of white-chinned petrel by year in all surface longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

Table C-11: Captures by year and fishery, giving the median 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.
2006–07	3	(0 – 9)	2	(0 – 8)	0	(0 – 0)	0	(0 – 1)	6	(1 – 13)
2005–06	0	(0 – 2)	2	(0 – 6)	0	(0 – 1)	0	(0 – 1)	2	(0 – 7)
2004–05	0	(0 – 2)	3	(0 – 11)	0	(0 – 0)	0	(0 – 0)	4	(0 – 12)
2003–04	1	(0 – 5)	8	(1 – 23)	0	(0 – 2)			10	(2 – 26)
2002–03	1	(0 – 3)	16	(3 – 46)	7	(2 – 15)	0	(0 – 0)	25	(9 – 57)
2001–02	7	(1 – 20)	25	(5 – 69)	2	(0 – 7)			35	(10 – 85)
2000–01	1	(0 – 4)	17	(3 – 47)	2	(0 – 7)	0	(0 – 0)	20	(4 – 54)
1999–00	1	(0 – 5)	21	(4 – 58)	2	(0 – 8)	0	(0 – 0)	25	(6 – 66)
1998–99	2	(0 – 6)	19	(4 – 53)	1	(0 – 4)	0	(0 – 1)	22	(6 – 58)

Table C-12: Capture rate (birds per 100 sets) by year and fishery, giving the median 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.
2006–07	0.3	(0.0 – 0.9)	0.1	(0.0 – 0.6)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.6)	0.2	(0.0 – 0.5)
2005–06	0.0	(0.0 – 0.2)	0.1	(0.0 – 0.4)	0.0	(0.0 – 1.5)	0.0	(0.0 – 0.6)	0.1	(0.0 – 0.2)
2004–05	0.0	(0.0 – 0.2)	0.2	(0.0 – 0.7)	0.0	(0.0 – 0.0)	0.0	(0.0 – 0.0)	0.1	(0.0 – 0.4)
2003–04	0.1	(0.0 – 0.3)	0.3	(0.0 – 0.8)	0.0	(0.0 – 0.5)			0.2	(0.0 – 0.5)
2002–03	0.0	(0.0 – 0.1)	0.4	(0.1 – 1.1)	0.8	(0.2 – 1.6)	0.0	(0.0 – 0.0)	0.3	(0.1 – 0.8)
2001–02	0.4	(0.1 – 1.0)	0.4	(0.1 – 1.2)	0.2	(0.0 – 0.8)			0.4	(0.1 – 1.0)
2000–01	0.1	(0.0 – 0.3)	0.3	(0.1 – 0.8)	0.4	(0.0 – 1.3)	0.0	(0.0 – 0.0)	0.3	(0.1 – 0.7)
1999–00	0.1	(0.0 – 0.5)	0.4	(0.1 – 1.1)	0.3	(0.0 – 1.3)	0.0	(0.0 – 0.0)	0.4	(0.1 – 1.0)
1998–99	0.2	(0.0 – 0.6)	0.4	(0.1 – 1.2)	0.2	(0.0 – 0.7)	0.0	(0.0 – 5.0)	0.4	(0.1 – 1.0)

Table C-13: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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.
Swordfish	North-east	134	13.4	1	5.6	0	(0 – 1)
All fisheries	All areas	2 723	16	2	0.5	6	(1 – 13)
Southern bluefin	South-west	323	57.6	1	0.5	3	(0 – 9)
Bigeye	North-east	1 283	4.9	0	0	2	(0 – 8)
Bigeye	North-west	166	8.4	0	0	0	(0 – 1)
Southern bluefin	North-east	630	20	0	0	0	(0 – 1)

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. (%)
		161.3		
Vessel length	1	160.0	1.3	0.8
Start time sine exponent	1	116.3	43.6	27.3
Annual cosine exponent	1	83.3	33.0	28.4
Area	1	78.4	4.9	5.9

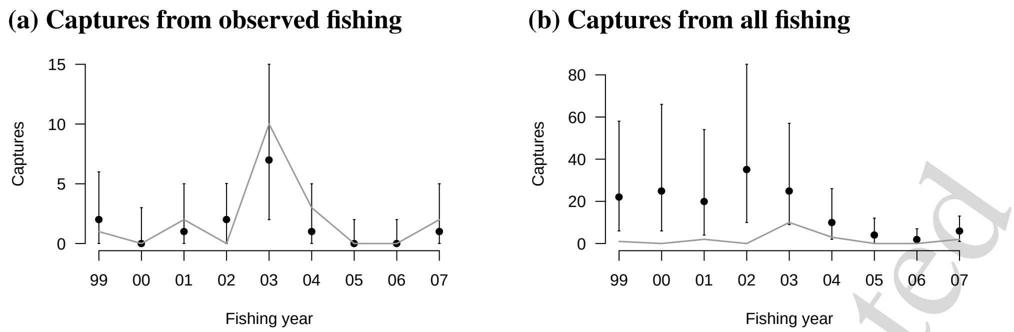

Figure C-5: Estimated captures of sooty shearwater in all surface longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda$	0.041	0.048	0.009	0.133
Vessel length, < 40m	0.001	0.003	0.000	0.018
Start time sine exponent	23.751	26.905	9.474	63.556
Annual cosine exponent	70.212	106.917	14.437	405.467

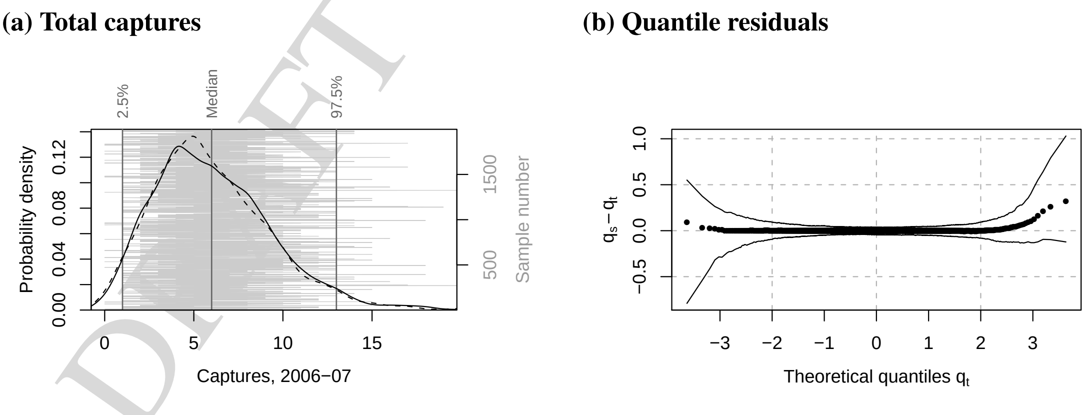

Figure C-6: Diagnostic plots for captures of sooty shearwater by year in all surface longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

Table C-16: Captures by year and fishery, giving the median 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.
2006–07	174	(88 – 476)	275	(116 – 680)	3	(0 – 22)	179	(75 – 516)	656	(340 – 1 500)
2005–06	71	(34 – 154)	192	(77 – 519)	6	(0 – 29)	26	(6 – 86)	298	(134 – 756)
2004–05	63	(32 – 132)	87	(31 – 256)	8	(1 – 28)	9	(2 – 33)	168	(79 – 422)
2003–04	98	(50 – 196)	115	(41 – 307)	19	(4 – 60)			233	(106 – 533)
2002–03	143	(66 – 367)	210	(75 – 628)	76	(37 – 187)	0	(0 – 1)	431	(191 – 1 170)
2001–02	218	(125 – 416)	427	(188 – 1 006)	73	(26 – 188)			722	(365 – 1 562)
2000–01	35	(14 – 90)	108	(36 – 307)	11	(2 – 39)	0	(0 – 0)	156	(59 – 418)
1999–00	83	(39 – 208)	310	(107 – 800)	31	(8 – 110)	0	(0 – 2)	432	(168 – 1 105)
1998–99	73	(43 – 125)	281	(89 – 837)	27	(6 – 93)	1	(0 – 8)	388	(153 – 1 014)

Table C-17: Capture rate (birds per 100 sets) by year and fishery, giving the median 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.
2006–07	18.2	(9.2 – 49.9)	18.4	(7.7 – 45.4)	17.6	(0.0 – 129.6)	70.2	(29.4 – 202.4)	24.1	(12.5 – 55.1)
2005–06	7.2	(3.4 – 15.5)	11.1	(4.4 – 29.9)	9.2	(0.0 – 44.6)	11.6	(2.7 – 38.4)	9.9	(4.4 – 25.1)
2004–05	5.7	(2.9 – 12.0)	5.6	(2.0 – 16.5)	6.2	(0.8 – 21.7)	7.0	(1.6 – 25.6)	5.8	(2.7 – 14.5)
2003–04	5.0	(2.6 – 10.1)	3.8	(1.3 – 10.1)	4.8	(1.0 – 15.2)			4.3	(2.0 – 9.9)
2002–03	6.1	(2.8 – 15.7)	4.8	(1.7 – 14.4)	7.3	(3.6 – 18.0)	0.0	(0.0 – 50.0)	5.6	(2.5 – 15.1)
2001–02	11.4	(6.6 – 21.8)	7.3	(3.2 – 17.3)	8.7	(3.1 – 22.4)			8.4	(4.3 – 18.2)
2000–01	2.9	(1.2 – 7.5)	1.8	(0.6 – 5.1)	2.0	(0.4 – 7.2)	0.0	(0.0 – 0.0)	2.0	(0.8 – 5.3)
1999–00	8.4	(3.9 – 21.0)	5.9	(2.0 – 15.2)	5.0	(1.3 – 17.7)	0.0	(0.0 – 50.0)	6.3	(2.4 – 16.1)
1998–99	7.8	(4.6 – 13.3)	6.6	(2.1 – 19.6)	5.1	(1.1 – 17.4)	5.0	(0.0 – 40.0)	6.7	(2.7 – 17.6)

Table C-18: Captures by fishery and area, for the 2006–07 fishing year, giving the median and 95% c.i. of estimated other albatross captures. Fishery-areas are listed in decreasing order of estimated captures.

Fishery	Area	Observed				Estimated	
		Effort	Obs.(%)	Cap.	Rate	Cap.	95% c.i.
Swordfish	Kermadec	94	28.7	2	7.4	74	(25 – 238)
All fisheries	All areas	2 723	16	122	28	656	(340 – 1 500)
Bigeye	North-east	1 283	4.9	1	1.6	233	(95 – 614)
Southern bluefin	South-west	323	57.6	53	28.5	101	(44 – 355)
Swordfish	North-east	134	13.4	58	322.2	94	(34 – 302)
Southern bluefin	North-east	630	20	8	6.3	67	(29 – 156)
Bigeye	North-west	166	8.4	0	0	21	(4 – 79)

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. (%)
		1334.4		
Vessel length	1	1303.9	30.5	2.3
Set day, night, dusk	2	1231.1	72.9	5.6
Fishing year	8	1173.8	57.3	4.7
Annual sine exponent	1	1136.5	37.3	3.2
Nationality	3	1118.7	17.8	1.6
Fishery	3	1095.3	23.4	2.1
Area	1	1078.7	16.6	1.5

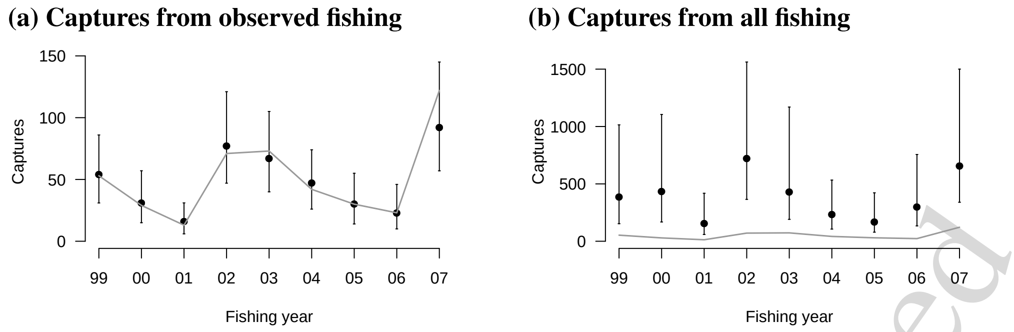

Figure C-7: Estimated captures of other albatross in all surface longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda_{98-99}$	8.438	9.200	4.117	18.941
Base rate, $100 \times \lambda_{99-00}$	9.104	10.191	4.121	22.766
Base rate, $100 \times \lambda_{00-01}$	3.247	3.607	1.371	8.002
Base rate, $100 \times \lambda_{01-02}$	12.052	12.830	6.514	24.227
Base rate, $100 \times \lambda_{02-03}$	7.230	8.032	3.423	16.821
Base rate, $100 \times \lambda_{03-04}$	6.025	6.506	2.919	12.714
Base rate, $100 \times \lambda_{04-05}$	9.459	10.667	4.282	23.878
Base rate, $100 \times \lambda_{05-06}$	15.132	17.583	6.546	43.000
Base rate, $100 \times \lambda_{06-07}$	32.077	36.969	14.568	86.410
Vessel length, < 40m	0.476	0.505	0.216	0.957
Set time, Full moon	3.247	3.276	2.451	4.310
Set time, Daylight	4.621	4.946	2.301	9.434
Annual sine exponent	2.630	2.680	1.842	3.792
Vessel-year s.d., $\exp(\sigma_v)$	3.128	3.341	2.196	5.778
Overdispersion, θ	0.307	0.312	0.231	0.423

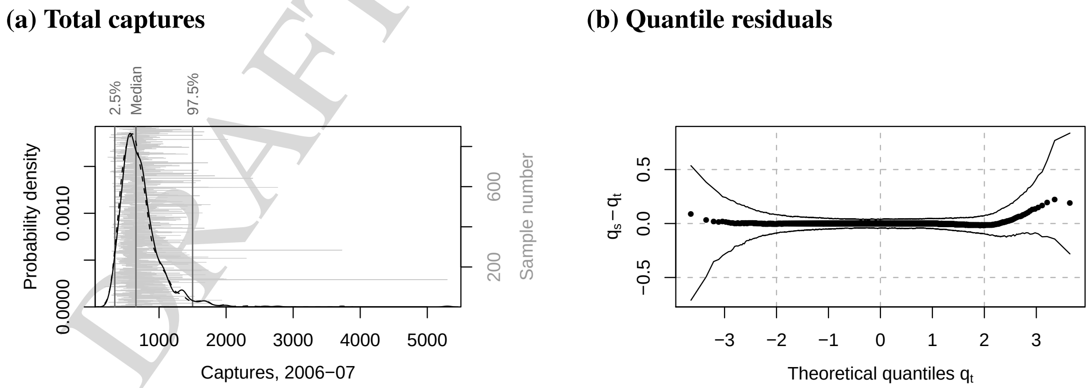

Figure C-8: Diagnostic plots for captures of other albatross by year in all surface longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.

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

Table C-21: Captures by year and fishery, giving the median 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.
2006–07	43	(20 – 88)	290	(131 – 681)	1	(0 – 9)	45	(16 – 189)	388	(198 – 821)
2005–06	52	(21 – 135)	370	(159 – 995)	4	(0 – 24)	29	(7 – 102)	465	(210 – 1 166)
2004–05	37	(12 – 103)	179	(51 – 488)	6	(0 – 23)	6	(1 – 22)	231	(73 – 591)
2003–04	72	(28 – 176)	561	(224 – 1 416)	41	(11 – 133)			678	(283 – 1 676)
2002–03	143	(49 – 419)	954	(346 – 2 468)	157	(68 – 419)	0	(0 – 2)	1 274	(496 – 3 179)
2001–02	118	(51 – 310)	1 634	(914 – 3 476)	143	(62 – 365)			1 903	(1 068 – 3 997)
2000–01	58	(19 – 150)	868	(409 – 1 755)	71	(24 – 189)	0	(0 – 2)	1 003	(467 – 2 067)
1999–00	62	(21 – 186)	1 544	(789 – 3 602)	166	(52 – 553)	0	(0 – 8)	1 783	(921 – 4 246)
1998–99	44	(16 – 140)	1 027	(481 – 2 991)	98	(32 – 378)	4	(0 – 53)	1 199	(573 – 3 404)

Table C-22: Capture rate (birds per 100 sets) by year and fishery, giving the median 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.
2006–07	4.5	(2.1 – 9.2)	19.4	(8.8 – 45.5)	5.9	(0.0 – 52.9)	17.6	(6.3 – 74.1)	14.2	(7.3 – 30.2)
2005–06	5.2	(2.1 – 13.6)	21.3	(9.2 – 57.3)	6.2	(0.0 – 36.9)	12.9	(3.1 – 45.5)	15.4	(7.0 – 38.6)
2004–05	3.4	(1.1 – 9.3)	11.6	(3.3 – 31.5)	4.7	(0.0 – 17.8)	4.7	(0.8 – 17.1)	7.9	(2.5 – 20.3)
2003–04	3.7	(1.4 – 9.1)	18.4	(7.3 – 46.3)	10.4	(2.8 – 33.8)			12.6	(5.2 – 31.1)
2002–03	6.1	(2.1 – 17.9)	21.9	(7.9 – 56.7)	15.1	(6.5 – 40.3)	0.0	(0.0 – 100.0)	16.5	(6.4 – 41.1)
2001–02	6.2	(2.7 – 16.3)	28.1	(15.7 – 59.7)	17.0	(7.4 – 43.5)			22.2	(12.5 – 46.7)
2000–01	4.8	(1.6 – 12.5)	14.3	(6.7 – 28.9)	13.1	(4.4 – 35.0)	0.0	(0.0 – 100.0)	12.8	(6.0 – 26.4)
1999–00	6.3	(2.1 – 18.8)	29.3	(15.0 – 68.4)	26.9	(8.4 – 89.2)	0.0	(0.0 – 200.0)	25.9	(13.4 – 61.7)
1998–99	4.7	(1.7 – 14.9)	24.0	(11.3 – 70.0)	18.4	(6.0 – 70.8)	20.0	(0.0 – 265.0)	20.8	(9.9 – 59.0)

Table C-23: Captures by fishery and area, for the 2006–07 fishing year, giving the median 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.
Swordfish	Kermadec	94	28.7	3	11.1	13	(2 – 67)
All fisheries	All areas	2 723	16	28	6.4	388	(198 – 821)
Bigeye	North-east	1 283	4.9	2	3.2	268	(117 – 633)
Southern bluefin	North-east	630	20	18	14.3	41	(19 – 87)
Swordfish	North-east	134	13.4	5	27.8	30	(10 – 110)
Bigeye	North-west	166	8.4	0	0	15	(4 – 43)
Bigeye	Kermadec	44	4.5	0	0	5	(0 – 18)

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. (%)
		995.8		
Vessel length	1	768.0	227.7	22.9
Area	2	624.0	144.0	18.8
Annual cosine exponent	1	554.3	69.7	11.2
Fishing year	8	517.5	36.8	6.6
Set day, night, dusk	2	504.5	13.1	2.5
Fishery	3	493.1	11.4	2.3
Nationality	3	483.1	9.9	2.0
Start time sine exponent	1	477.8	5.3	1.1

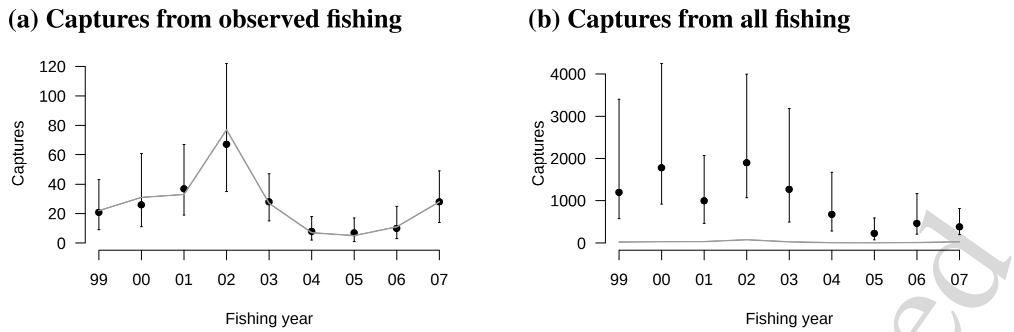

Figure C-9: Estimated captures of other birds in all surface longline fisheries, showing the median and 95% c.i. of the captures estimated on (a) observed effort, and (b) all effort. The grey line shows observed captures.

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, $100 \times \lambda_{98-99}$	1.080	1.217	0.498	2.823
Base rate, $100 \times \lambda_{99-00}$	1.160	1.333	0.515	3.203
Base rate, $100 \times \lambda_{00-01}$	0.711	0.763	0.246	1.521
Base rate, $100 \times \lambda_{01-02}$	1.123	1.244	0.496	2.698
Base rate, $100 \times \lambda_{02-03}$	0.914	0.991	0.358	2.073
Base rate, $100 \times \lambda_{03-04}$	0.877	0.942	0.342	1.937
Base rate, $100 \times \lambda_{04-05}$	0.720	0.774	0.210	1.651
Base rate, $100 \times \lambda_{05-06}$	0.992	1.103	0.403	2.482
Base rate, $100 \times \lambda_{06-07}$	0.949	1.026	0.421	2.080
Vessel length, >= 40m	1.587	1.889	0.582	4.900
Area, Kermadec	0.812	0.862	0.404	1.611
Area, Southern	0.022	0.024	0.007	0.055
Annual cosine exponent	3.096	3.229	1.834	5.343
Set time, Full moon	2.314	2.388	1.475	3.682
Set time, Daylight	1.267	1.341	0.655	2.506
Vessel-year s.d., $\exp(\sigma_v)$	3.906	4.200	2.600	7.446
Overdispersion, θ	0.678	0.714	0.413	1.191

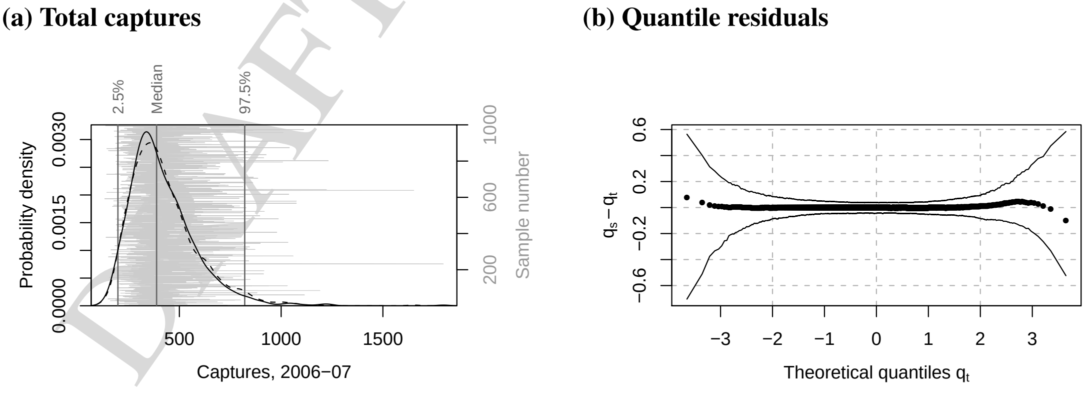

Figure C-10: Diagnostic plots for captures of other birds by year in all surface longline fisheries (a) Posterior distribution of total captures during the 2006–07 fishing year. (b) Randomised quantile residuals, showing the difference between the sample quantiles, q_s and the theoretical quantiles, q_t. The lines give the 95% c.i. of the difference.