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Estimated captures of New Zealand fur seal, New Zealand sea lion, common dolphin, and turtles in New Zealand commercial fisheries, 1995–96 to 2014–15

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Commercial fisheries in New Zealand waters interact with non-target species, with some of these interactions resulting in incidental captures and mortality. Captures of protected species are documented by fisheries observers, providing an independent record of the number and identify of the species captured in New Zealand's Exclusive Economic Zone (EEZ). For species with sufficient numbers of observed captures, the observer records and fishing effort data are used to develop statistical models to estimate the total number of captures across species and fisheries in New Zealand waters. This study presents total capture estimates of marine mammals and sea turtles in trawl and longline fisheries for the period between the 1995–96 and 2014–15 fishing years (a fishing year runs from 1 October to 30 September).

For marine mammals, observer data allowed the estimation of captures of common dolphin, New Zealand fur seal, and New Zealand sea lion in trawl fisheries. In addition, estimates were made of New Zealand fur seal and sea turtles in surface-longline fisheries. Estimates of captures were made with hierarchical Generalised Linear Models (GLMs), fitted using Bayesian methods.

Observed captures of marine mammals during the 2014–15 fishing year included 176 fur seal captures (127 in trawl fisheries, 37 in surface-longline fisheries, and 12 in set-net fisheries), 24 common dolphin captures (21 in trawl fisheries, two in set-net fisheries, and one in surface-longline fisheries); and eight New Zealand sea lion captures in trawl fisheries. In addition, there were observed captures of two dusky dolphin in trawl fisheries, and one bottlenose dolphin in surface-longline fisheries. A green turtle was observed caught during trawl fishing, and a leatherback turtle was observed caught during surface longlining.

For common dolphin, capture estimates were made for the 20-year period between 1995–96 and 2014–15. Separate estimates of common dolphin captures were derived for the large-vessel (90 m length and longer) jack mackerel trawl fishery off North Island's west coast, and for all other trawl fisheries in New Zealand waters. The jack mackerel trawl fishery has been characterised by high numbers of observed common dolphin captures throughout the reporting period. In the 2014–15 fishing year, there were an estimated 21 (95% c.i.: 19 to 28) common dolphin captures in this trawl fishery. Across all trawl fisheries within New Zealand's EEZ, there were an estimated 104 (95% c.i.: 50 to 189) common dolphin captures. Included in these captures were 60 (95% c.i.: 14 to 135) estimated common dolphin captures in flatfish and inshore trawl fisheries in the Taranaki area (which extends from north of Taranaki Peninsula to Farewell Spit, including Tasman Bay). We recommend increased observer coverage of inshore fisheries in the Taranaki area to reduce uncertainty in the estimates.

Estimates of New Zealand fur seal captures were made in trawl and surface-longline fisheries for the period from 2002–03 to 2014–15. Estimated fur seal captures in trawl fisheries peaked in 2004–05 at 1487 (95% c.i.: 964 to 2370) captures, and by 2014–15, estimated captures were reduced to 536 (95% c.i.: 332 to 969) fur seal. Hoki trawl fisheries had the highest captures, especially in the Cook Strait area, where there were an estimated 160 (95% c.i.: 36 to 527) captures during 2014–15. Between 2002–03 and 2014–15, the average observed capture rate on small hoki trawl vessels in the Cook Strait area was 22.33 fur seals per 100 tows. Observer coverage in this fishery has been limited, and to reduce the uncertainty in estimated New Zealand fur seal captures, we recommend increased observer coverage of small hoki trawl vessels operating in the Cook Strait area. In surface-longline fisheries, there were an estimated 116 (95% c.i.: 87 to 151) fur seal captures during 2014–15. Most (94.7%) of the fur seal observed caught in surface-longline fisheries were released alive.

Captures of New Zealand sea lion were estimated for 20 fishing years between 1995–96 and 2014–15. Across all trawl fisheries, there were 12 (95% c.i.: 8 to 17) estimated captures of New Zealand sea lion

during the 2014–15 fishing year. There was high observer coverage in the fisheries that frequently catch sea lion (88.3% observer coverage of squid fishing in the Auckland Islands area, and 100% observer coverage of subantarctic southern blue whiting fishing), so estimated captures were close to the observed captures. In subantarctic squid and southern blue whiting fisheries, sea lion exclusion devices (SLEDs) are used to reduce the number of animals that are caught. There were 81 (95% c.i.: 27 to 281) estimated sea lion interactions, providing an estimate of the number of sea lion that would have been observed caught, if no SLEDs had been used. There is very high uncertainty in the number of interactions. There is little information available to inform the model, as the interaction rate (interactions per tow) may vary from year to year. We recommend that the model structure is simplified, for example, by assuming a constant base interaction rate over all years, or an interaction rate that is proportional to the sea lion population.

Estimates were also made of turtle captures in surface-longline fisheries between 2002–03 and 2014–15. In 2014–15, there were an estimated 13 (95% c.i.: 2 to 35) captures of turtles in surface-longline fisheries, an average capture rate over all New Zealand surface-longline fisheries of 0.005 (95% c.i.: 0.001 to 0.015) turtle captures per 1000 hooks.

1. INTRODUCTION

Interactions with commercial fisheries can lead to the incidental capture of non-target and protected species, including seabirds, marine mammals and turtles. In New Zealand's Exclusive Economic Zone (EEZ), incidental captures of protected species are recorded by government fisheries observers when they are on-board commercial fishing vessels. These independently-collected data provide systematic records of incidental captures across different commercial fisheries.

For fisheries with sufficient observer coverage, observer data can be used to estimate the total number of incidental captures (most recently, Abraham et al. 2016, Abraham & Richard 2017). These estimates are obtained from statistical models that integrate observer records with fishing effort data. The resulting estimates are the number of captures that would have been documented by observers, if they had been on every vessel in the fisheries assessed. These captures are referred to as "observable captures", and do not include mortalities that would not be recorded by observers (for example, animals that are caught but fall out of the fishing gear before being brought on-board the vessel).

Observer records of incidental captures of marine mammals in New Zealand's EEZ include pinnipeds and cetaceans, in trawl, longline and set-net fisheries. These records include both mortalities and animals that were released alive. In this study, we estimated the total number of incidental captures of three marine mammal species: common dolphin (*Delphinus delphis*), New Zealand fur seal (*Arctocephalus forsteri*), and New Zealand sea lion (*Phocarctos hookeri*) in trawl fisheries, and total captures of New Zealand fur seal in surface-longline fisheries. Incidental captures of these three species were observed sufficiently frequently to allow estimations of the total number of individuals that were incidentally captured in commercial fisheries in New Zealand waters. In addition, observer records of incidental captures of turtles (without species identifications) were used to update turtle capture estimates.

Common dolphin are captured in New Zealand trawl fisheries, with captures most frequently recorded by observers on vessels targeting mackerel on the North Island west coast. Previous assessments of incidental common dolphin captures have focused on this fishery, covering different periods between 1995–96 and 2012–13 (Thompson & Abraham 2009, Thompson et al. 2010a, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). In the current study, we also estimated common dolphin captures in other trawl fisheries, providing a complete estimate of common dolphin captures across all New Zealand trawl fisheries. A smaller number of common dolphin captures have also been recorded in set-net and surface-longline fisheries, but estimates of total captures in these fisheries were not made.

Observed captures of New Zealand fur seal are predominantly recorded in trawl fisheries, and recent model-based estimates cover different periods between 2002–03 and 2012–13 (Thompson & Abraham 2010, Thompson et al. 2010b, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). The majority of incidental fur seal captures were in trawl fisheries targeting hoki (*Macruronus novaezelandiae*) and southern blue whiting (*Micromesistius australis*) in different areas of New Zealand's EEZ. Estimates were also made of the total number of captures of New Zealand fur seal in surface-longline fisheries. A smaller number of New Zealand fur seal has also been reported caught in set-net, bottom-longline, and purse-seine fisheries, but these fisheries were not included in the current estimation.

Observer records of New Zealand sea lion were in subantarctic trawl fisheries, particularly the Auckland Islands squid and the Campbell Island southern blue whiting fisheries. The high number of observed sea lion captures in these fisheries led to the introduction of sea lion exclusion devices (SLEDs) in the squid trawl fishery in early 2000, and more recently, in the southern blue whiting fishery in 2014. Previous assessments provide capture estimates of New Zealand sea lion in subantarctic trawl fisheries, spanning different periods between 2002–03 and 2012–13 (Thompson & Abraham 2011, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). A single New Zealand sea lion has been observed caught in surface-longline fisheries, but estimates of total captures in these fisheries were not made.

Incidental captures of protected species also include sea turtles. Most records of observed turtle captures were in surface-longline fisheries, with fewer captures in trawl and bottom-longline fisheries. For sea turtles, the current assessment provides capture estimates for surface-longline fisheries for the period between 2002–03 and 2014–15.

The current study is part of project PRO2013–01, which has the objective to estimate "the nature and extent of incidental captures of seabirds, marine mammals, and turtles in New Zealand commercial fisheries". The analysis updates previous bycatch assessments by including data from the 2013–14 and 2014–15 fishing years (the fishing year in New Zealand spans from 1 October to 30 September the following year). Estimates were made for the period from 1995–96 to 2013–14 for common dolphin and New Zealand sea lion, and from 2002–03 to 2014–15 for New Zealand fur seal. Turtle captures were estimated for the period from 2002–03 to 2015–15. As data were updated and all models were re-run, previous bycatch assessments are superseded. Any comparison across fishing years should be made using the current report. A summary of incidental captures of seabirds is presented elsewhere (Abraham & Richard 2017). Detailed information on all observed and estimated protected species captures is available from the protected species capture website (https://psc.data.dragonfly.co.nz/).

2. METHODS

2.1 General approach

Statistical models were used to estimate total captures from observed captures. The methods used in this study closely followed methods used previously (most recently by Abraham et al. 2016). For the estimation, generalised linear models (GLMs) were fitted to observer data, and then used to estimate the observable captures on unobserved fishing effort. The estimated total captures were the sum of the observed captures on observed fishing, and the model estimated captures on unobserved fishing. The models had varying complexity. For example, for sea lion captures in squid trawl fisheries, the models were relatively complex, with random vessel-year effects and overdispersion. In other cases, such as turtle captures in surface-longline fisheries, there were few covariates and a simple model structure.

The models were coded in the BUGS language (Spiegelhalter et al. 2003), a domain-specific language for describing Bayesian models. Each model was fitted with the software package JAGS (Just Another Gibbs Sampler; Plummer 2005), using Markov chain Monte Carlo (MCMC) methods. Two chains were fitted to each model, with the output including samples of the posterior distribution from each chain. Model convergence was assessed with diagnostics provided by the CODA package for the R statistical system (Plummer et al. 2006), including the criteria developed by Heidelberger and Welch (1983).

Table 1: Models to estimate the total number of incidental captures of marine mammals and turtles in New Zealand commercial fisheries.

Species	Fishing method	Strata	Period
Common dolphin	Trawl	North Island west coast jack mackerel	1995–96 to 2014–15
		All	1995–96 to 2014–15
New Zealand fur seal	Trawl	All, other than flatfish and northern NZ	2002–03 to 2014–15
	Surface longline	All	2002–03 to 2014–15
New Zealand sea lion	Trawl	Auckland Islands squid trawl	1995–96 to 2014–15
	Trawl	Campbell Island southern blue whiting	1995–96 to 2014–15
	Trawl	Other Auckland Islands and Stewart-Snares trawl	1995–96 to 2014–15
Turtles (all species)	Surface longline	All	2002–03 to 2014–15

The assessment used observer data to estimate captures of marine mammals and turtles in trawl and longline fisheries (Table 1). For marine mammals, estimates of the total number of captures were derived for the species and fishing methods where most observed captures have occurred.

For common dolphin, the estimation focused on the large-vessel ($\geq$90 m length) jack mackerel trawl fishery off the west coast of North Island, where common dolphin captures were most frequently observed. In addition, estimates of common dolphin captures were derived for other trawl fisheries including inshore, middle-depth, and flatfish targets. This assessment was the first time an estimate of common dolphin captures across all New Zealand trawl fisheries was made. Capture estimates of common dolphin species were based on data for the 20-year period between 1995–96 and 2014–15.

For New Zealand fur seal, captures were estimated for all trawling except flatfish target fisheries (no fur seal captures have been observed in these target fisheries, and captures in flatfish trawl were assumed to be zero). Fur seal captures were also estimated for surface-longline fisheries. For this species, estimates were derived from 13 years of data between 2002–03 and 2014–15. For New Zealand sea lion, capture estimates were made for trawl fisheries in subantarctic waters, based on 20 years of data from 1995–96 to 2014–15.

Estimates of marine turtle captures were derived for surface-longline fisheries, for 13 fishing years between 2002–03 and 2014–15. The estimation of sea turtle captures did not distinguish between species.

2.2 Data preparation

Fisheries observers record the captures of protected species when they are on-board commercial fishing vessels. The capture events are entered into a database maintained by the National Institute of Water and Atmospheric Research (NIWA) on behalf of Ministry for Primary Industries (MPI). Currently, data are housed in the Centralised Observer Database (COD), and data used in the current analysis included the species identification, the capture method, life status and station details (Table 2). A detailed summary of the data preparation of observed protected species captures is provided by Thompson and Berkenbusch (2016).

Table 2: Protected species bycatch information from the Centralised Observer Database used in the current bycatch estimation.

Data	Description
Species	Species identification as recorded by the observer. This identification may either be at the species level or be a more general classification, depending on how accurately the observer was able to identify the animal.
Capture method	Code indicating how the animal was captured. For example, the capture may have occurred in the net or through entanglement in the line. Additional information from observer comments was also used to identify the capture method.
Life status	Observers record whether the animal was alive, dead, killed by the crew, or decomposed (i.e., dead before capture).
Station details	Trip number, station number, date at beginning of the tow or set, and target species. This information is required for all observed stations, including stations where there was no protected species bycatch.

In addition to the observer data, fishing effort data were used to allow the scaling of observed captures to the total fishing effort. Commercial fishing vessels return a record of all fishing effort on each trip to MPI. Skippers complete either a Trawl Catch Effort Processing Return (TCEPR), Trawl Catch Effort Return (TCER), Tuna Longline Catch Effort Return (TLCER), Catch Effort Landing Return (CELR), Lining Catch Effort Return (LCER), Lining Trip Catch Effort Return (LTCER), or Netting Catch Effort Landing Return (NCELR) form. During the 2007–08 fishing year, inshore trawl fisheries moved from reporting fishing effort on CELR forms to TCER forms. The TCER form requires the recording of the latitude and longitude of fishing effort, instead of only the statistical area. This greater spatial detail in the recording allows a more accurate understanding of where inshore fishing is occurring. Data from these forms are stored in databases administered by MPI (Ministry for Primary Industries 2012).

Each fishing event was allocated to a fishery on the basis of the fishing method, and the fisher-declared target species (Table 3). There were some unusual codes that were targeted in fewer than 100 fishing events (these codes included misspelled codes for common species). The fishery of these events was set to the fishery of the closest fishing event in time, by the same vessel, that had a defined fishery. For the few events that remained without a defined fishery, the fishery was imputed by randomly sampling from fishing events by vessels of the same class in the same statistical area.

Table 3: Definition of target trawl fisheries used in the estimation of protected species captures, with common names and three-letter codes used by Ministry for Primary Industries. Only species and codes that were used on more than 100 fishing events were included. In multi-species target fisheries, species are listed in decreasing order of how frequently they were targeted.

Method	Target fishery	Target species
Trawl	Squid	Squid (SQU)
	Hoki	Hoki (HOK)
	Deepwater	Orange roughy (ORH), oreos (OEO, SSO, BOE), cardinalfish (CDL), Patagonian toothfish (PTO)
	Southern blue whiting	Southern blue whiting (SBW)
	Mackerel	Jack mackerel (JMA), blue mackerel (EMA).
	Scampi	Scampi (SCI).
	Middle depth	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), hāpuku (HPB)
	Flatfish	Flatfish (FLA), lemon sole (LSO), sand flounder (SFL), New Zealand sole (ESO), yellow-belly flounder (YBF), flounder (FLO), greenback flounder (GFL), Turbot (TUR), brill (BRI), black flounder (BFL)

Before carrying out the estimation, the observer data were linked to the fisher-reported effort data. The linking was carried out by searching for fishing events recorded by the fisher from the same vessel at a similar place and time as recorded by the observer, using the same fishing method and targeting the same species. The criteria for matching the records were progressively loosened to allow most of the observed fishing events to be associated with fisher-reported effort. In each of the years used in the estimation, over 97.5% of observed surface-longline sets, and over 98.5% of observed trawl tows were able to be linked to effort reported by the fisher. A small number of captures were during observations that could not be linked to fishing effort, and were not included in the modelling. There were five unlinked sea lion captures on trawlers in the Auckland Islands area between 1995–96 and 2014–15, and one unlinked fur seal capture in surface-longline fishing between 2002–03 and 2014–15. All observed common dolphin captures and all observed turtle captures could be associated with fisher-reported fishing effort.

Non-fishing related captures (such as fur seal that climbed onto the vessel) were excluded from the estimation. Similarly, any animals that were reported by the observer as decomposed were excluded.

2.3 Estimation of common dolphin captures

2.3.1 North Island west coast jack mackerel fishery

The estimation of common dolphin captures in the large-vessel jack mackerel trawl fishery on North Island's west coast followed the same modelling approach used previously (e.g., Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). Around 90% of observed common dolphin captures in trawl fisheries have been in this fishery. The model of common dolphin captures separately estimated the probability of capture events occurring and the number of captures on each capture event. Models of this kind are called hurdle models (Mullahy 1986, Ridout et al. 1998), and are appropriate when different processes are influencing the occurrence of captures and the number of animals caught in each capture event. In the first stage, a logistic GLM estimated the probability of capturing common dolphin on a given tow as a linear function of a number of covariates. Given that there was a capture event, the number of captures was then estimated in the second stage by sampling from a zero-truncated Poisson distribution.

In addition to estimating total captures, the model estimated the relation between covariates and dolphin captures in the jack mackerel fishery. The present study updated the model to include data from the large-vessel mackerel fishery from the 2014–15 fishing year, covering the 20-year period between 1 October 1995 and 30 September 2015. The model methods are as described by Abraham et al. (2016), and are included here for completeness.

Data for modelling and analysis were selected from the North Island west coast and Taranaki areas (Figure 1(a)), as these areas are where most common dolphin captures were observed. For higher spatial resolution, the region was divided into northern and southern sub-areas by a line at latitude 39°18′ S.

The statistical model estimated the probability, π_i, of capturing dolphins on a tow, i. An annual base rate or year effect, λ_y, was estimated for each year, y, allowing for annual variation in the capture event rates (the year effects include the intercept). The contribution of each covariate, x, was governed by a regression coefficient, β_x, that was estimated by the model. The logit transform of the capture event probability was defined as the sum of the year effect, λ_y, and the covariates:

$$\text{logit}(\pi_i) = \lambda_y + \sum_x \beta_x[x_i]. \tag{1}$$

Non-informative normal priors were given to the regression coefficients, β_x, and to the mean of the year effects, λ_y. A half-Cauchy prior, with a scale of 25, was given to the standard deviation of the year effects.

On tows where common dolphin captures occurred, the captures were assumed to follow a zero-truncated Poisson distribution with size μ. The use of a zero-truncated distribution reflected the structure of the hurdle model (if a capture event occurred the number of dolphins caught must have been one or more). The probability that c_i dolphins were captured on tow i was given by

$$\Pr(c_i =) = \begin{cases} (1-\pi_i) & \text{if} \quad c = 0, \\ \pi_i \frac{e^{-\mu}\mu^c}{(1-e^{-\mu})c!} & \text{if} \quad c > 0. \end{cases} \tag{2}$$

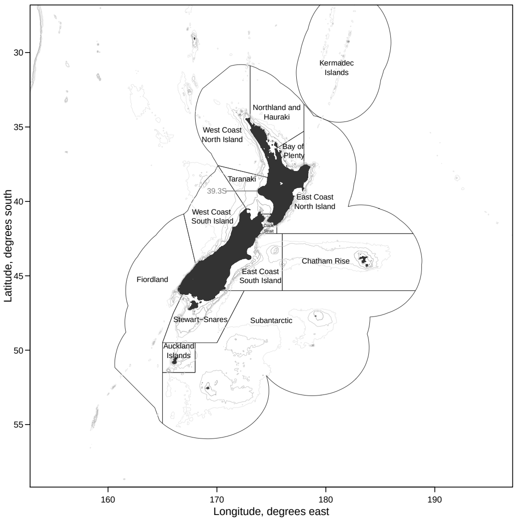
The size, μ, was given a prior that was uniform between 0.5 and 30. It would be possible for the size of the truncated Poisson distribution, μ, to vary with the value of covariates on each tow. Nevertheless, initial exploration suggested that there was no consistent variation of the size μ with any available covariates.

The model structure allowed for the dolphin capture event probability to depend on covariates. The same covariates used previously (see Thompson & Abraham 2009, Thompson et al. 2010a, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016) were used in this assessment, and included trawl duration, headline depth, sub-area, and light condition (see definitions in Table 4).

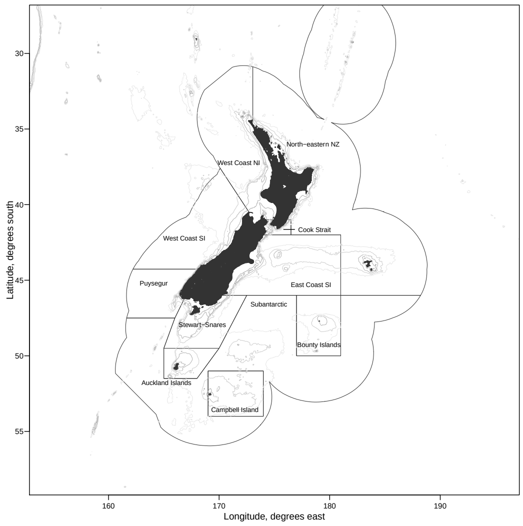
2.3.2 All trawl fisheries

A statistical model was also fitted to observed captures of common dolphin in all observed trawl fisheries between 1995–96 and 2014–15. This model was used to estimate captures on trawl effort not included in the North Island west coast large-vessel mackerel fishery. The all-trawl model followed a similar structure to the jack mackerel model, in that the probability of a capture event occurring, π_i, depended

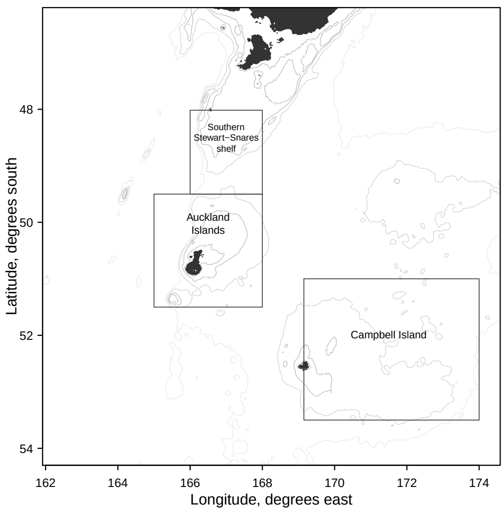
(a) Common dolphin trawl



(b) New Zealand fur seal trawl



(c) New Zealand sea lion trawl



(d) Surface longline

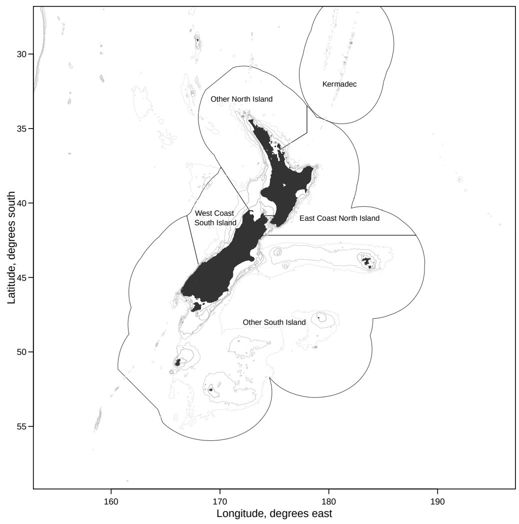


Figure 1: Areas used in the estimation of marine mammal and turtle captures. The areas used for estimating common dolphin captures (a) are also the areas used on the protected species captures website (https://psc.data.dragonfly.co.nz). In (a), the line at 39.3° S divides the jack mackerel fishery into southern and northern sub-areas.

Table 4: Covariates included in the common dolphin capture model.

Covariate	Description
Trawl duration	Duration of trawls in hours from start and end times recorded on Trawl Catch Effort Processing Return (TCEPR) forms.
Headline depth	Depth in metres of the top of the net, derived by subtracting the headline height from the ground line depth (both recorded on TCEPR forms). Indicates the depth of the top of the net.
Sub-area	The North Island west coast and Taranaki region was divided into two sub-areas (north and south of 39°18′ S) that were included as a factor variable.
Light condition	Three-level factor characterising the time of the haul and the phase of the moon: light (net hauled between dawn and dusk, or between dusk and midnight on a moonlit night), dark (net hauled between dusk and midnight on a dark night, or between midnight and dawn on a moonlit night), and black (net hauled between midnight and dawn on a dark night). The illumination of the moon and time of dawn and dusk were calculated using algorithms from Meeus (1991). Night was classified as moonlit if more than 17% of the moon's disc was illuminated. Dawn and dusk were defined as when the centre of the sun's disk was 6° below the horizon (civil dawn and dusk).

on covariates, and the number of animals caught during a capture event was assumed to be drawn from a zero-truncated Poisson distribution (Equation 2). The covariates were simple, however, and the only covariates that were considered were the area of the fishing, the fishery, and the vessel size. There was no year effect, and no covariates related to the time of day. Model exploration was carried out to identify which covariates (vessel size, area, or target fishery) best explained variations in the captures, and the leave-one-out information criterion (LOOIC; Vehtari et al. 2016) was used to choose between models. The selected model had the following structure:

$$\text{logit}(\pi_i) = \beta_s s_i + \beta_a a_i, \tag{3}$$

with the logit probability of captures on a group of fishing events, i, being the sum of vessel size covariates, s_i, and fishery-area covariates, a_i.

The New Zealand region was divided into fourteen areas (Figure 1(a)), and effort in the North Island west coast area was further divided into effort included in the pelagic model and effort in the other trawl fisheries. The pelagic trawl model selected data based on whole trips, and there was a small number of non-jack-mackerel target tows included in the jack-mackerel model. The area-fisheries effect was included as a random effect:

$$\beta_a \sim \text{Normal}(\beta_0, \sigma_a),$$

with a mean value given by the intercept, β_0, and a standard deviation σ_a. Three vessel size groups were defined, including vessels that were less than 28 m, between 28 and 90 m, and over 90 m length. The large size aligns with the vessel size used in the model of pelagic trawl fisheries. The vessel size effect, β_s, was included as a fixed effect, relative to the base level (vessels over 90 m length).

From the probability, π_i, the number of captures on a group of events, c_i, was estimated by drawing from a binomial distribution:

$$c_i \sim \text{Binomial}(\pi_i, n_i), \tag{4}$$

where n_i is the number of fishing events in the group, i.

In addition to estimating the number of capture events, the model estimated the mean of the Poisson distribution of the number of dolphins captured in a capture event. A separate estimate was derived for pelagic trawl and for all other trawl fisheries.

2.4 Estimation of fur seal captures in trawl fisheries

A Bayesian capture model was developed to predict fur seal captures in commercial trawl fisheries for the 13-year period between 2002–03 and 2014–15. The same model was previously used to estimate the total number of incidental fur seal captures per fishing year for the periods from 2002–03 to 2007–08, 2008–09, 2009–10, 2010–11, and 2012–13, respectively (Thompson & Abraham 2010, Thompson et al. 2010b, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). In this report, the model was re-fitted to new data, and the fitted model was used to update fur seal capture estimates across commercial trawl effort. As previously, captures by vessels targeting flatfish were assumed to be zero, as no fur seal have been observed caught in these fisheries. The model methods were the same as described by Abraham et al. (2016), and are included here for completeness.

As the number of observed tows greatly exceeded the number of tows that could be easily fitted by the model, trawl events were aggregated to reduce the computational load. The grouping was similar to methods used in an earlier fur seal bycatch assessment (Manly et al. 2002). Tow groups were defined as trawls by the same vessel, in the same statistical area, fishing for species in the same target fishery, observed or unobserved, and in the same calendar month. The aggregation of trawl events into groups reduced the accuracy of representation of some covariates, but allowed the simultaneous fitting of all trawl data from New Zealand's EEZ between 2002–03 and 2014–15 by the model using Bayesian methods.

In the model, captures, c_i, in a trawl group, i, were modelled as samples from a negative-binomial distribution:

$$c_i \sim \text{NegativeBinomial}(\text{mean} = \mu_i n_i,\ \text{shape} = \theta n_i), \tag{5}$$

where n_i is the number of tows in a trawl group. The shape parameter, θ, allows for extra dispersion in the number of captures, relative to a Poisson distribution. The shape was assumed to be the same for all trawl groups. The negative-binomial distribution has the property that the mean of n samples from a negative-binomial distribution (NegativeBinomial(μ, θ)) is itself negative-binomially distributed, with mean μn and shape θn. For this reason, while c_i is the number of captures per group, μ_i should be interpreted as the mean capture rate per tow.

The mean capture rate within each group was estimated as the product of a random year effect λ_y, a random vessel-year effect ν_{vy}, and the exponential of a sum over covariates,

$$\begin{aligned}
\mu_i &= \lambda_y \nu_{vy} \exp\left(\sum_x \beta_x x_i\right), && (6)\\
\log(\lambda_y) &\sim \text{Normal}(\mu = \mu_\lambda,\ \sigma = \sigma_\lambda), && (7)\\
\nu_{vy} &\sim \text{Gamma}(\text{shape} = \theta_\nu,\ \text{rate} = \theta_\nu). && (8)
\end{aligned}$$

The random year effect λ_y on each tow was drawn from a log normal distribution with mean μ_λ, and standard deviation σ_λ. The random vessel-year effect ν_{vy} for each observed vessel v and year y was included to account for the variation between vessels, and was drawn from a gamma distribution with shape and rate θ_ν. With this parameterisation, the gamma distribution has unit mean. The coefficient of a covariate x was denoted β_x.

Standard priors were used for the model (hyper-)parameters (e.g., Gelman et al. 2006). Non-informative normal priors were used for the covariate coefficients and for the logarithm of the mean year effect, μ_λ. The shape hyper-parameters were given uniform shrinkage priors, with the size parameter for the overdispersion equal to the mean number of captures, and the size parameter for the vessel-year effect equal to the mean number of captures per vessel:

$$
\begin{aligned}
\log(\mu_\lambda) &\sim \text{Mean}(\mu = \bar{y}, \sigma = 100), & (9)\\
\sigma_\lambda &\sim \text{Half-Cauchy}(25), & (10)\\
\theta &\sim \text{Uniform-shrinkage}(\bar{y}), & (11)\\
\theta_\nu &\sim \text{Uniform-shrinkage}(\bar{y_i}), & (12)\\
\beta &\sim \text{Normal}(\mu = 0, \sigma = 100). & (13)
\end{aligned}
$$

The same covariates used in previous modelling of fur seal captures (Thompson & Abraham 2010, Thompson et al. 2010b, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016) were used in the current report, and included fishing area, target fishery, day of year, and distance from shore (see definitions in Table 5). Fishing area was used to provide higher spatial resolution within New Zealand's entire EEZ. The EEZ was divided into 13 areas, which were the same areas as used in the reporting of protected species captures (Figure 1(b)). Eleven of those areas had observed fur seal captures and were included in the model data set. The areas used in the modelling included the north-eastern New Zealand area, as there were four observed captures of fur seal in this area (Bay of Plenty) between October 2013 and August 2015. Previously, there had been no observed fur seal captures in the north-eastern area, so that fur seal captures were assumed to be zero in this area in the analysis by Thompson and Abraham (2010).

The definitions of target fishery were the same as those applied previously (Thompson & Abraham 2010, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016), with tows targeting hoki, hake and ling combined into one group during the modelling (estimated captures are reported separately for each of these target species). Tows targeting inshore species were included in the model, but flatfish target fishing was excluded. Low observer effort in the past prevented the inclusion of inshore target fisheries in previous assessments of incidental captures. An increase in observer effort in recent years allowed for inshore trawl fisheries to be included in the present estimation.

The covariate distance from shore was correlated with fur seal captures in some areas in previous analyses (Mormede et al. 2008, Smith & Baird 2009), and was included in the model. The New Zealand coastline was obtained from the GSHHS (Global Self-consistent, Hierarchical, High-resolution Geography Database) (Wessel & Smith 1996), and distance from shore was calculated using functions from PostGIS (http://postgis.refractions.net/). Islands with an area of less than 0.25 km^2 were excluded from the calculations of distance from shore. To account for seasonal variation, day of year was included as a covariate in the model.

A single area–target interaction term was included in the model, following Thompson and Abraham (2010), for the subantarctic area and the deepwater target group. The inclusion of this interaction term allowed the model to accurately fit the observed captures within each area and by each target fishery.

2.5 Estimation of sea lion captures and interactions

New Zealand sea lion captures in subantarctic trawl fisheries were estimated using Bayesian generalised linear models, closely following methods applied previously to estimate sea lion captures in the 1995–96 to 2007–08, 2008–09, 2009–10, 2010–11, and 2012–13 fishing years, respectively (Thompson & Abraham 2011, Thompson et al. 2010c, Thompson et al. 2011, Thompson et al. 2013b, Abraham et al. 2016). The previous estimates were updated by including data from the 2014–15 fishing year, presenting capture estimates over the 20-year period between 1 October 1995 and 30 September 2015.

Three separate models were used for estimating sea lion captures in subantarctic trawl fisheries, with a model each for i) the squid fishery near Auckland Islands, ii) the southern blue whiting fishery near Campbell Island, and iii) for other fisheries (including the scampi fishery near Auckland Islands, other fisheries near Auckland Islands, and all trawl fisheries on the southern end of the Stewart-Snares shelf) (Figure 1(c)).

Table 5: Covariates included in the fur seal capture model.

Fishing area	New Zealand's Exclusive Economic Zone was divided into 13 fishing areas. Eleven areas in which fur seal captures had been observed were included in the model data set (see Figure 1(b)).
Target fishery	Defined by individual target species and species groups: hoki, hake, ling; southern blue whiting; squid; jack (and blue) mackerel; scampi; middle-depth species (barracouta, ribaldo, rubyfish, alfonsino, bluenose, frostfish, ghost shark, gemfish, spiny dogfish, sea perch, and warehou); deepwater species (orange roughy, oreos, and cardinalfish); inshore species (tarakihi, snapper, gurnard, red cod, trevally, John dory, giant stargazer, elephantfish, leatherjacket, school shark, blue moki, blue cod, rig, hāpuku).
Day of year	Calculated from the mean day of the year of the tows in a group, and used to account for any seasonal variation. Harmonic functions were used to ensure that the seasonal effects were truly periodic.
Distance from shore	Four-level factor calculated using the distance from shore: coastal ($\leq$ 25 km), near (between 25 km and 90 km), far (between 90 km and 180 km), and ocean ($>$ 180 km)(see map in Thompson & Abraham 2010).

For the Auckland Islands squid fishery, observer and capture data supported the development of a Bayesian GLM, with a simpler model applied to data from the Campbell Island southern blue whiting fishery. The other three strata included fisheries with lower observer coverage and sporadic records of sea lion captures, so that capture estimates for the non-squid Auckland Islands fisheries (scampi, other non-squid targets) and the Stewart-Snares shelf fishery were derived using a simple model with only fishery-area effects, and with no annual variation in the capture rate. A single total estimate was then obtained by combining the output from all strata.

The methods used in the current estimation closely followed methods used previously (most recently by Abraham et al. 2016), and are included here for completeness. There was one model that required minor re-development in the current study: the model of sea lion captures in the southern blue whiting fishery. This re-development was necessary as vessels in this fishery began using sea lion exclusion devices (SLEDs) during the 2013 season. Previously, SLEDs were only used in the Auckland Islands squid trawl fishery.

2.5.1 Sea lion exclusion devices (SLEDs)

Owing to the number of sea lion that have been captured by trawlers targeting squid near Auckland Islands, sea lion exclusion devices (SLEDs) were introduced as a mitigation method for incidental captures, and a fishery-related mortality limit (FRML) (Breen et al. 2003) was applied to manage the impact of the fishery on the sea lion population. To support the management of the squid fishery, sea lion capture estimates for the Auckland Islands squid trawl fishery include terms that do not apply to other subantarctic trawl fisheries (see full terminology in Table 6).

SLEDs were first introduced in 2001, and since 2004–05, the majority of tows in the Auckland Islands squid fishery have used SLEDs that have been audited and approved by Ministry for Primary Industries (and its predecessor). Since their introduction, the design of SLEDs has undergone some modifications, including the narrowing of the bar spacing on the angled grid that guides sea lion to the exit (in 2005–06), and standardisation of the kite material used to hold the SLED hood above the exit open. A detailed audit of SLEDs before the start of the 2006–07 fishing year included alterations to SLEDs that deviated from the standard specifications, ensuring consistency across the squid trawl fishery (Clement & Associates 2007). Since 2013, SLEDs have also been used in the Campbell Island southern blue whiting fishery.

On tows using SLEDs, the exact number of sea lion killed (or injured) is unknown, as some sea lion may escape from the net. Animals that escape may nonetheless drown before reaching the surface, or sustain fatal injuries. Because of the uncertainty in the survival of animals that escape through the SLED opening, the number of sea lion that would have been caught without SLEDs, on both observed and non-observed tows was estimated as the number of interactions. This is an estimate of how many sea lion would have been observed caught, if no SLEDs were used, and if there was an observer on every vessel. Exclusions are calculated as the number of sea lion captures (the sum of observed and estimated captures) subtracted from the number of estimated interactions. The interation rate is defined as the number of estimated sea lion interactions per 100 tows.

2.5.2 Sea lion capture model for the Auckland Islands squid fishery

The current modelling approach followed the modelling used to estimate captures in the Auckland Islands squid fishery during the 2010–11 fishing year (Thompson et al. 2013b).

A split SLED retention model allowed the SLED retention probability to vary before and after a cut-off date, based on the prior knowledge that the SLED design changed sometime in the three years 2004–05, 2005–06, and 2006–07. To allow for this change in SLED design, the model chose the cut-off date from these three fishing years, with early and late sled retention probabilities for the periods up to and including the cut-off year (i.e., 2004–05, 2005–06, or 2006–07) and subsequently. A second model was fitted that had a single SLED retention probability through the whole period. Results from the split and the single SLED retention models were combined with equal weight.

The basic unit of effort used in the models was a single trawl event. Observers recorded the number of sea lion caught per tow. Tows in fishing year y were indexed by vessel key, j, and number, k, and the number of sea lion captured on tow jk in year y was denoted c^y_{jk}. The captures, c^y_{jk}, were assumed to follow a negative-binomial distribution with a mean, μ^y_{jk}, that varied from tow to tow, and with an overdispersion, θ, that was the same for all tows. The negative-binomial distribution was implemented using a Poisson distribution with a gamma-distributed mean, which was achieved by multiplying the mean interaction rate by a value randomly sampled from a gamma distribution with shape θ and unit mean. As $1/\theta$ decreases, the model becomes less dispersed, with the limiting case, when $1/\theta = 0$, being a Poisson model. The model parameter θ was given the uniform shrinkage prior (Natarajan & Kass 2000, Gelman 2006) with mean equal to the mean number of sea lion captures per tow, μ_θ:

$$
\begin{aligned}
c^y_{jk} &\sim \text{Poisson}(\mu^y_{jk} g_\theta), && (14)\\
g_\theta &\sim \text{Gamma}(\theta, \theta), && (15)\\
\theta &\sim \text{Uniform-shrinkage}(\mu_\theta). && (16)
\end{aligned}
$$

The mean interaction rate μ^y_{jk} was composed of three components multiplied together: a random year effect λ_i, a random vessel-year effect ν^y_j, and a linear regression component that depended on the value of covariates x^{yb}_{jk} and the regression coefficients β_b,

$$
\mu^y_{jk} = \lambda^y \nu^y_j \exp\left(\sum_b x^{yb}_{jk}\beta_b\right). \qquad (17)
$$

The random year effects, λ^y, carried the mean interaction rate for each year, and were drawn from a single log-normal distribution with mean μ_λ and standard deviation σ_λ. These hyper-parameters were given fixed prior distributions:

$$
\begin{aligned}
\log \lambda^y &\sim \text{Normal}(\mu_\lambda, \sigma_\lambda), && (18)\\
\mu_\lambda &\sim \text{Normal}(-4, 100), && (19)\\
\sigma_\lambda &\sim \text{Half-Cauchy}(0, 25). && (20)
\end{aligned}
$$

For each vessel and year combination, there was a vessel-year random effect, ν^y_j, that was drawn from a gamma distribution with a mean value of 1. This selection allowed the interaction rate for each vessel in

Table 6: Terminology used in this report for sea lion captures in the Auckland Islands squid fishery.

Term	Definition
Auckland Islands squid fishery	Trawlers targeting squid in the Auckland Islands part of the SQU6T fishing area.
SLED	Sea lion exclusion device, a mitigation method used in the Auckland Islands squid fishery. A SLEDs is a fitted mid-section in the trawl net that allows sea lion inside the net to escape.
Approved SLED	A SLED that has been audited and approved by Ministry for Primary Industries as meeting specifications.
Closed SLED	A trawl net that either does not have a SLED fitted, or that has a SLED fitted with the SLED exit covered so that sea lions are unable to escape.
Open SLED	A trawl net that has a SLED fitted, with the SLED's exit open.
Observed captures	The number of sea lions brought on deck, both dead and alive, during observed tows. Decomposed animals and any sea lions that climb on-board the vessel are excluded.
Captures	An estimate of the total number of sea lion captures, calculated as the sum of observed captures and the estimated captures that would have been recorded on unobserved tows, had observers been present.
Interactions	An estimate of the number of sea lions that would have been captured if no SLEDs were used in the Auckland Islands squid fishery.
Interaction rate	Sea lion interactions per 100 tows.
Strike rate	A management setting used in calculating fishing effort limits in the management of the Auckland Islands squid fishery (SQU6T); the strike rate is meant to approximate a point estimate of interaction rate, but may be set higher than the mean interaction rate estimate, to reflect uncertainty.
FRML (fishery-related mortality limit)	The maximum number of sea lion mortalities permitted in the Auckland Islands squid fishery. This number is converted into a permitted number of tows by dividing by the strike rate.
Discount rate	The discount rate is a management setting–a percentage reduction in the strike rate applied to tows that used approved SLEDs. The discount rate is used when determining the amount of fishing effort permitted in the Auckland Islands squid fishery under the FRML. In the 2014–15 fishing year, the discount rate was 82%.

Table 7: Covariates used in the sea lion capture model of the Auckland Islands squid fishery.

Covariate	Definition
Distance to colony	A continuous variable, the logarithm of distance to nearest sea lion breeding colony.
Tow duration	A continuous variable, the logarithm of tow duration.
Sub-area	A two-level factor variable, indicating in which sub-area the start of the tow was located. The Auckland Islands part of squid fishing area SQU6T was divided into two sub-areas, NW (Northwest, north of $50.45\,^\circ$ S and west of $166.95\,^\circ$ E), and S&E (South and east: the remainder of the Auckland Islands part of SQU6T).
Open SLED	A factor variable, indicating that the net had a sea lion exclusion device (SLED) attached and that the cover net was open. In the model with a split SLED retention probability, the open-SLED factor depended on whether or not the tow was after the cut-off fishing year of 2004–05, 2005–06, or 2006–07.

each year to have a mean value different from the year effect λ^y. The shape of the gamma distribution was defined by the hyper-parameter, θ_ν. The shape parameter was given the uniform shrinkage prior, with a mean value equal to the mean number of sea lions caught per vessel, μ_{vs}. For vessels that were not observed in a given year, a value of the random effect ν_j^y was drawn from the gamma distribution:

$$\nu_j^y \sim \text{Gamma}(\theta_\nu, \theta_\nu), \tag{21}$$

$$\theta_\nu \sim \text{Uniform-shrinkage}(\mu_{vs}). \tag{22}$$

The model was also used to investigate factors that may have contributed to sea lion captures, including distance to colony, tow duration, sub-area and open SLED (i.e., SLED present with the cover net open; see covariate definitions in Table 7). The covariates included in the model were those selected previously by Smith and Baird (2007b), based on earlier research specifically aimed at identifying the factors associated with sea lion captures (Smith & Baird 2005). To improve model convergence, the covariates were normalised before model fitting by subtracting the mean value and dividing by the standard deviation. This normalisation was removed before presenting results from the model. The regression coefficients, β_b, were assumed to be the same for all years. The priors for the regression coefficients of the three covariates, distance to colony, tow duration, and sub-area, were non-informative normal distributions,

$$\beta_b \sim \text{Normal}(0, 100). \tag{23}$$

The presence or absence of a SLED with the cover net open (open SLED) was treated as a covariate. The regression coefficients were $\beta_{\textit{open SLED}_{1,2}}$, where the index 1 or 2 refers to the two periods (up to and including the cut-off year, and after the cut-off year). These coefficients were transformed into the SLED retention probabilities, $\pi_{1,2} = \exp\left(\beta_{\textit{open SLED}_{1,2}}\right)$, and were given uniform priors,

$$\pi_{1,2} \sim \text{Uniform}(0, 1). \tag{24}$$

The choice to allow the SLED retention probability to vary before and after a cut-off date was made to reflect the known changes that have been made to the SLED design. Two models were fitted, including a model with a single SLED retention probability in addition to a split-retention model.

A significant limitation to this modelling approach, however, was that the model data set was greatly unbalanced, as there have been few observed captures in recent years. This imbalance means that recent changes in SLED retention were unable to greatly improve the overall fit of the model, while adding to model complexity.

From the fitted model, posterior distributions were calculated for the captures, interactions, and interaction rate (see definitions in Table 6). For each sample from the MCMC, the estimated number of sea lion interactions i_{jk} was calculated for each tow (here, and in the following, the year index y was assumed). The mean interaction rate was given by the linear predictor, μ_{jk} (Equation 17), but with the net assumed to be closed, irrespective of whether or not a SLED was used. This approach was enforced by setting the open-SLED covariate to the value corresponding with a closed SLED. The number of interactions on a tow can be interpreted as the number of sea lion that would have been caught if a SLED had not been used. They were obtained from the mean interaction rate by sampling from a negative-binomial distribution (following Equations 14, 15 and 16). From the interactions, the captures were then calculated by sampling from a binomial distribution with the probability given by the SLED retention probability and the size given by the number of interactions,

$$c_{jk} \sim \begin{cases} \text{Binomial}(\pi_{1,2},\, i_{jk}) & \text{(open SLED),} \\ i_{jk} & \text{(no SLED or closed SLED).} \end{cases} \tag{25}$$

This procedure simulated the independent random capture of interacting sea lion, with retention probability $\pi_{1,2}$. It ensured that, on any tow, the number of captures was less than or equal to the number of interactions. The number of sea lion exclusions on a tow was calculated as the difference between the interactions and the captures, $e_{jk} = i_{jk} - c_{jk}$.

The estimated quantities were calculated as follows:

$$\text{Captures} \quad C = \sum_u c_{jk} + C_o, \tag{26}$$

$$\text{Interactions} \quad I = \sum_u i_{jk} + \sum_o e_{jk} + C_o, \tag{27}$$

$$\text{Interaction rate} \quad \mu = I/n, \tag{28}$$

where C_o is the number of observed captures in the fishery, $\sum_u$ denotes a sum over unobserved tows, $\sum_o$ denotes a sum over observed tows, $\sum_a$ denotes a sum over all tows, and n denotes the total number of tows in the fishery.

Posterior distributions of these quantities were obtained by calculating them for every sample from the MCMC. The posterior distributions were summarised by the median, mean, and 95% credible interval (calculated from the 2.5% and 97.5% quantiles).

2.5.3 Sea lion captures in the Campbell Island southern blue whiting fishery

A simple Bayesian model was used to estimate sea lion captures in the southern blue whiting fishery east of Campbell Island. Data for this fishery were organised by calendar rather than fishing year as this fishery extends beyond the end of the standard fishing year (30 September). All fishing effort in the Campbell Island southern blue whiting fishery occurs between August and November. This trawl fishery has had observer coverage since 1996, with the first observed sea lion capture in 2002.

The southern blue whiting fishery operates on Pukaki Rise, and to the east of Campbell Island, while all sea lion captures have been observed on the shelf to the east and south of Campbell Island. As a consequence, the data set was restricted to fishing effort near Campbell Island (see Figure 1(c)).

The model used for the southern blue whiting trawl fishery was a variation of the Auckland Islands squid fishery model detailed above, fitted to data from 1996 to 2015. The model used a Poisson error model, and included random year effects, overdispersion, and a SLED effect. No other covariates were included in the model, and no vessel-year effects were included.

The prior of the SLED effect was set to a log-normal distribution, with mean and standard deviation from the posterior distribution of the SLED effect from the Auckland Islands squid model, on the assumption that the SLED is similarly effective in both the squid and the southern blue whiting fishery.

2.5.4 Sea lion captures in other trawl fisheries

A simple Bayesian model was used to estimate sea lion captures in the Auckland Islands scampi fishery, other Auckland Islands non-squid trawl fisheries, and all trawl fisheries at the south end of the Stewart-Snares shelf. The area for the Stewart-Snares trawl fishery was defined as the southern end of the Stewart-Snares shelf, south of $48.02\,^\circ$, north of $49.5\,^\circ$ latitude, west of $168\,^\circ$, and east of $166\,^\circ$ longitude.

The estimates were derived within a simple Poisson GLM, with a single fixed-effect for each stratum, estimated using Bayesian methods. The sea lion capture rate was estimated as a constant rate over all years, from 1995–96 to 2013–14.

2.5.5 Sea lion captures and interactions in combined trawl fisheries

Estimates from the three models were combined to provide an estimate of total sea lion captures (and interactions) in each fishing year. The posterior distribution of estimated captures in each of the five strata was described by a set of 4000 samples, from the MCMC in the relevant Bayesian models. The samples were added to obtain 4000 samples from the combined posterior distribution of total estimated captures in each year. Annual interactions were calculated as the sum of estimated interactions in the Auckland Islands squid fishery, estimated interactions in the southern blue whiting trawl fishery, and estimated captures in other trawl fisheries. The mean and 95% credible intervals (c.i.) were calculated for each year from the samples.

2.6 Estimation of fur seal and turtle captures in surface-longline fisheries

The same modelling approach was used to estimate captures of New Zealand fur seal and of sea turtles in surface-longline fisheries, with data including the period between the 2002–03 and 2014–15 fishing years. Two models were fitted, one to fur seal captures, and one to sea turtle captures (without distinguishing species)(see areas used for the estimation in Figure 1(d)).

Captures in surface-longline fisheries were estimated using a Poisson GLM with random year-effects, and with fixed strata as covariates (Table 8). A model selection process was used to choose the covariates that explained the observed captures, choosing the combination of covariates that minimised the LOOIC (Vehtari et al. 2016).

Fishing effort was grouped into region, fishery and vessel-size strata. The number of captures, c_i on a group of fishing events, i, was estimated as:

$$c_i \sim \text{Poisson}(\mu_i n_i \lambda_y[y_i]), \tag{29}$$

where μ_i is the mean capture rate, n_i is the number of hooks, and $\lambda[y_i]$ is a random-effect (with mean 1) for each fishing year, y_i. The mean capture rate was expressed as a combination of the selected covariates, β_x:

$$\log(\mu_i) = \beta_0 + \sum_x \beta_x[x_i], \tag{30}$$

where β_0 is an intercept, and x_i is the value of the A covariate in the fishery group, i. The year random effect was drawn from a gamma distribution with mean 1, and with shape and scale given by θ:

$$\lambda_y \sim \text{Gamma}(\theta, \theta). \tag{31}$$

The priors for the β parameters were normal distributions with mean 0 and standard deviation 10. The prior for the θ was a uniform-shrinkage prior (Gelman et al. 2006). For the model of fur seal captures, southern bluefin tuna, West Coast South Island, and large vessels were chosen as the base levels of the covariates. For the model of sea turtle captures, bigeye tuna, East Coast North Island, and small vessels were chosen as the base levels of the covariates. The parameters corresponding to these base levels were set to zero.

Table 8: Covariates used in estimating captures in surface-longline fisheries.

Covariate	Definition
Fishery	Target fishery, either southern bluefin tuna; bigeye tuna; or other targets.
Region	Areas from aggregating areas used for estimating protected species captures (Figure 1(d)): Kermadec, "Eastern North Island" (Cook Strait, North Island east coast, and Bay of Plenty areas), "Other North Island" (Northland-Hauraki, Taranaki, and North Island west coast areas), West Coast South Island, and "Other South Island" (Fiordland, Stewart Island, Chatham Rise, South Island east coast, and sub-antarctic areas). West Coast South Island was chosen as the base case.
Vessel size	Either large (over 45 m length) or small, with large vessels chosen as the base case. With some exceptions, vessel size divides the surface-longline fleet into Japanese charter vessels and the domestic fleet.

2.7 Presentation of model estimates and fitted models

The fitted models were used to estimate captures or each fishing event covered by the method, spatial extent, and period of the model. Although a number of models were fitted to aggregated data, estimates were made at the event level. A database was built to hold 4000 samples from the posterior distribution of the estimated captures, for each fishing event.

As the samples are stored at a fishing event level, they may be aggregated as required. Uncertainty of aggregated quantities may be calculated by repeating the aggregation for each sample. The database of estimates may be queried through the protected species capture website (https://data.dragonfly.co.nz/psc/), which allows summaries of captures by area, fishing year, calendar year, and vessel-size strata.

Summaries of the estimates from the protected species capture website are presented in Appendix A. For each taxon, and for selected fisheries or groups of fisheries, this appendix includes summaries of the fishing effort, observed effort and captures, estimated captures, estimated capture rate, and (where relevant) estimated interactions and interaction rate. The monthly distribution of observed captures and fishing effort is also presented, and a map shows observed captures between 1 October 2014 and 30 September 2015. These summaries are presented consistently, independently of the strata used in the underlying model.

For each model, posterior distributions of the parameters are summarised in Appendix B. For each model, this appendix includes a statistical summary of the parameters (mean, median, and 95% credible interval, calculated from the 2.5% and 97.5% quantiles of the posterior distribution). Diagnostic information is also provided for each parameter, including the number of chains that fail half-width and convergence tests (Heidelberger & Welch 1983), and the reduction in the effective number of samples caused by autocorrelation in the chains. Also included is a trace-plot, showing the samples from each chain, which allows visual inspection of the quality of the model fit. In these summaries of the posterior distribution, any covariates associated with discrete strata are exponentiated, so that they can be interpreted as multiplicative effects.

3. RESULTS

3.1 Common dolphin captures

3.1.1 Observed cetacean captures

In the 2014–15 fishing year, there were 27 observed captures of cetaceans in commercial fisheries in New Zealand waters (see Appendix A, Table A-1). Cetacean captures were recorded in trawl, surface-longline and set-net fisheries. Most (23) of the observed captures were in trawl fisheries, including 21

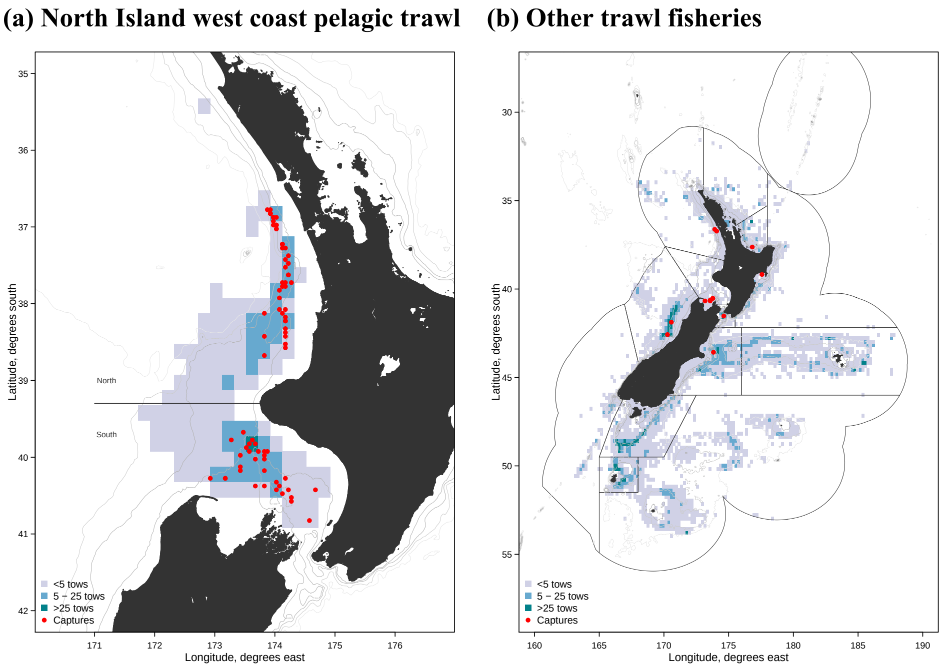


Figure 2: Spatial distribution of observed trawl effort (blue squares) and common dolphin captures (red dots) between 1995–96 and 2014–15, included in the statistical models to estimate total captures of common dolphin in New Zealand's Exclusive Economic Zone. The estimation included (a) pelagic trawl, and (b) other trawl fisheries. Annual average observed fishing effort within 0.2° squares is indicated by blue shades, model areas are indicated by lines.

captures of common dolphin and two captures of dusky dolphin. All of these captures were mortalities. The observed captures of common dolphin in trawl fisheries occurred on 12 separate capture events, with multiple captures of up to three individuals. Nineteen of the observed captures were in trawl fisheries targeting jack mackerel off North Island's west coast and off Taranaki. The remaining two captures were in the barracouta fishery off Taranaki and the tarakihi trawl fishery in the Bay of Plenty area. In recent years, Hector's dolphin and long-finned pilot whale have also been observed caught.

Incidental captures of cetaceans during 2014–15 also occurred in surface-longline and set-net fisheries. There was one common dolphin capture in the surface-longline fishery targeting bigeye tuna in the Bay of Plenty area, and one bottlenose dolphin capture in the southern bluefin tuna fishery in the same region. Both these dolphins were released alive. In addition, there were two observed common dolphin mortalities in set-net fisheries in 2014–15, targeting rig in the East Coast South Island area and common warehou in the Taranaki area, respectively.

Over the period included in the common dolphin model, 1995–96 to 2014–15, there was a total of 206 observed common dolphin captures. Most (186) of these captures were recorded in jack mackerel trawl fisheries. The number of observed captures of common dolphin was highest during 2013–14, when observer coverage of the jack mackerel trawl fishery reached 89.4% (see Appendix A, Table A-3).

Observed common dolphin captures included in the West Coast North Island pelagic trawl model were concentrated in two areas, north and south of the Taranaki peninsula (Figure 2). Common dolphin captures were sporadically observed in other trawl fisheries in North Island and northern South Island areas. No common dolphin captures were observed in the Chatham Rise area or in southern areas.

Table 9: Model selection for the common dolphin all-trawl models, showing the leave-one-out information criterion (LOOIC). The candidate models are ordered by the mean LOOIC (WCNI, west coast North Island). Models with a lower LOOIC were considered to be a better fit to the data, and in each case the candidate with the lowest LOOIC was chosen (s.d., standard deviation).

Candidate	LOOIC	
	Mean	s.d.
Area and WCNI pelagic random effect, and vessel size effect	119	34
Area and WCNI pelagic random effect	125	35
Area by size random effect (size is WCNI pelagic and three vessel sizes)	125	33
Area by fishery random effect (fishery is WCNI pelagic or other)	126	35
Fishery random effect (fishery is WCNI pelagic and four fisheries)	191	76
Size random effect (size is WCNI pelagic and three vessel sizes)	198	78

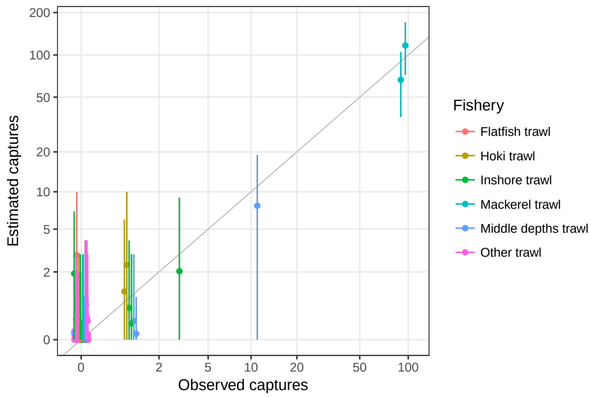


Figure 3: Comparison between observed captures and estimated captures of common dolphin on observed fishing, for target fishery and summary area combinations used on the protected species capture website (https://psc.dragonfly.co.nz/). Captures are totals for the model periods, from 1995–96 to 2014–15. Lines show the 95% credible interval of the estimated captures. Observed captures are offset to reduce overlap.

3.1.2 Common dolphin model fit

For common dolphin captures in all trawl fisheries, a model selection was undertaken, based on the LOOIC (Table 9). For common dolphin, all models that included an area effect performed better than models without an area effect. For the best two models, trawl effort was categorised by area, with fishing effort in the North Island's west coast and Taranaki areas being further divided into effort that was included in the pelagic trawl model, and other fishing effort. In addition, the best model also included a three-level vessel-size effect (vessels under 28 m, 28 to 90 m, and 90 m length and over).

Model chains passed the convergence and half-width tests (Heidelberger & Welch 1983) (see Appendix B for model parameters and model fit for each model). Inspection of the traces showed that samples from the two MCMC chains overlapped, indicating that there were no considerable structural limitations with any of the models. When the models were used to estimate captures on observed fishing effort, the observed captures were within the range of the estimates Figure 3. The models successfully represented variation in observed captures between fisheries and areas.

The covariates in the model of common dolphin captures in large-vessel West Coast North Island mackerel trawl fisheries (Table B-24) were similar to estimated covariates from a fit of the model to data from 1995–96 to 2010–11 (Thompson et al. 2013a). Dolphin captures were more likely when the headline was close to the surface, less likely during the day, less likely in the southern sub-area, and more likely on longer tows.

Table 10: Fisheries and areas with the highest estimated common dolphin captures during the 2014–15 fishing year. Included for each fishery-area are: total fishing effort, observer coverage, observed common dolphin captures and capture rate, and the estimated captures and capture rate (showing the mean and 95% credible interval, c.i.). Capture rates are reported as dolphin per 100 tows.

Target fishery	Area	Tows	Observed			Est. captures		Est. rate	
			%	Caps.	Rate	Mean	c.i.	Mean	c.i.
Flatfish trawl	Taranaki	2 557	0.0	0		31	7–74	1.22	0.27–2.89
Inshore trawl	Taranaki	2 435	1.4	0	0.00	29	6–67	1.18	0.25–2.75
Mackerel trawl	West Coast NI	341	87.7	16	5.35	17	16–22	5.03	4.69–6.45
Inshore trawl	West Coast NI	3 540	20.4	0	0.00	5	0–17	0.14	0.00–0.48
Middle depths trawl	Taranaki	614	56.0	1	0.29	4	1–11	0.67	0.16–1.79

For common dolphin in other trawl fisheries (Table B-25), the Poisson mean was lower in other fisheries (fewer dolphin were estimated caught per capture event) than in the North Island west coast mackerel trawl fishery. Mean capture rates were highest in the Taranaki and North Island west coast areas (in both pelagic and other trawl fisheries), followed by Cook Strait. The mean capture rate was also high in the Kermadec Islands area, but the uncertainty was very high, reflecting the lack of trawl fishing in this area. Relative to other areas, capture rates were lowest in the Auckland Islands, Stewart-Snares shelf, Chatham Rise, and subantarctic areas. Capture rates for small vessels (less than 28 m length) were similar to capture rates in large (over 90 m length) vessels, but capture rates for intermediate-sized vessels (28 to 90 m length) were considerably lower (a mean of 0.07, 95% c.i.: 0.00 to 0.34).

3.1.3 Estimated captures of common dolphin in trawl fisheries

Across all trawl fishing in New Zealand waters in 2014–15, it was estimated that 104 (95% c.i.: 50 to 189) common dolphin were captured (see Appendix A, Section A.1). In the large-vessel mackerel trawl fishery, there were an estimated 21 (95% c.i.: 19 to 28) common dolphin captures in 2014–15, which was within the range of estimated captures over the previous three years. Observer coverage was high, at 86.5%, and so uncertainty in the capture estimates was relatively low. Fishing effort in this fishery has fluctuated over the period included in the estimation, but the effort during 2014–15, 1745 tows, was lower than in any of the other years. The estimated capture rate in this fishery was 1.20 (95% c.i.: 1.09 to 1.60) common dolphins per 100 tows, similar to the estimated capture rate during 2013–14.

During 2014–15, estimated captures of common dolphin in other trawl fisheries were predominantly in inshore species fisheries, 42 (95% c.i.: 14 to 85) captures, and in flatfish target trawl fisheries, 33 (95% c.i.: 8 to 76) captures. The estimates of captures in flatfish target trawl fisheries were derived by applying the area effect to the flatfish trawl effort, and no captures of common dolphin have been observed in flatfish trawl. When grouped by target fishery and area, the highest estimated mean dolphin captures were in flatfish trawl fisheries and inshore trawl fisheries in the Taranaki area (Table 10). Observer coverage has been extremely limited in flatfish trawl fisheries, with only four years when observer coverage was higher than 1%, and with no observer coverage of this fishery during 2014–15.

3.2 New Zealand fur seal captures

3.2.1 Observed fur seal captures

There were 176 observed captures of New Zealand fur seal during the 2014–15 fishing year. During 2014–15, New Zealand fur seal were captured in a variety of fisheries operating within New Zealand's EEZ, with 127 captures in trawl fisheries, 37 captures in surface-longline fisheries, and 12 captures in set-net fisheries (annual observed captures of fur seal, and observed fishing, in selected trawl and surface-longline fisheries are summarised in Appendix A, Section A.2). The majority of fur seal captures in trawl fisheries were mortalities. Most of the observed fur seal captures in trawl fisheries occurred while targeting hoki (42 captures; primarily in the South Island west coast region) or southern blue whiting (41 captures in subantarctic waters), followed by trawl fishing targeting squid (19 captures). All other target fisheries had fewer than 10 observed captures.

The total trawl fishing effort was over 78 000 tows in 2014–15 (see Appendix A, Table A-7). This was the lowest in any of the years included in the model, around 60% of the total trawl effort during 2002–03. Inshore fish species target fisheries contributed the single largest proportion to the total fishing effort, with 30 000 tows fished in 2014–15. Observer coverage in inshore trawl fisheries was less than 7% compared with observer coverage of 17.2% in all trawl fisheries during 2014–15.

In surface-longline fisheries, there were 37 observed fur seal captures in the 2014–15 fishing year (see Appendix A, Table A-18). All observed captures of fur seal during 2014–15 were in southern bluefin tuna target fisheries. In set-net fisheries, observers recorded 12 incidental captures of fur seal in 2014–15, which were largely in school shark target fisheries and most frequently resulted in mortality.

Over the period covered by the estimation, 2002–03 to 2014–15, fur seal were observed caught in a wide range of trawl fisheries (Figure 4). New Zealand fur seal are the most frequently observed caught of any marine mammal species, with 1422 observed captures in trawl fisheries over this period. As with the captures during 2014–15, these captures were predominantly in southern fisheries, with 629 observed captures in hoki trawl fisheries, and 400 observed captures in southern blue whiting trawl fisheries. Within this period, no captures were reported close to Chatham Islands. There have only recently been observed captures in northern or north-eastern New Zealand, with four fur seal captures reported between 2013–14 and 2014–15 in Bay of Plenty.

In surface-longline fisheries, there were 361 observed captures of New Zealand fur seal between 2002–03 and 2014–15. Of these captures, 357 captures were in surface-longline fishing targeting southern bluefin tuna, two captures were observed while targeting bigeye tuna, and two captures were during fishing targeting swordfish. Most (94.7%) of the fur seal observed caught in surface-longline fisheries during the reporting period were released alive. In contrast, most (88.3%) observed fur seal captures in trawl fisheries over the same period were mortalities.

3.2.2 Fur seal model fit

For New Zealand fur sea in surface-longline fisheries, a model selection was undertaken, based on the LOOIC (Table 11). For New Zealand fur seal in surface-longline fisheries, fishery was an important explanatory variable, with all models that included fishery as an effect performing better than the models without it. The best model included both area and fishery effects.

All model chains passed the convergence and half-width tests (Heidelberger & Welch 1983) (see Appendix B for model parameters and model fit for each model). Inspection of the traces showed that samples from the two MCMC chains overlapped, indicating that there were no considerable structural limitations with any of the models. In some of the models, however, there was autocorrelation in the chains that reduced the effective number of samples. For New Zealand fur seal in trawl fisheries, autocorrelation reduced the effective length of the chains of the overdispersion parameter by 94.7%. There was also high autocorrelation in some of the other parameters, indicating indeterminacy in the model. In some areas, fishing was dominated by a single fishery (for example, fishing near the Bounty Islands area mainly targeted southern blue whiting). This aspect made it difficult for the model to distinguish between area and fishery effects, in these cases.

Nevertheless, when the models were used to estimate captures on observed fishing effort, the observed captures were generally within the range of the estimates (Figure 5). The models successfully represented variation in observed captures between fisheries and areas.

In the model of fur seal captures in trawl fisheries (Table B-26), the mean values of the area, target, season, and distance from shore covariates were all within the credible interval of estimates from the

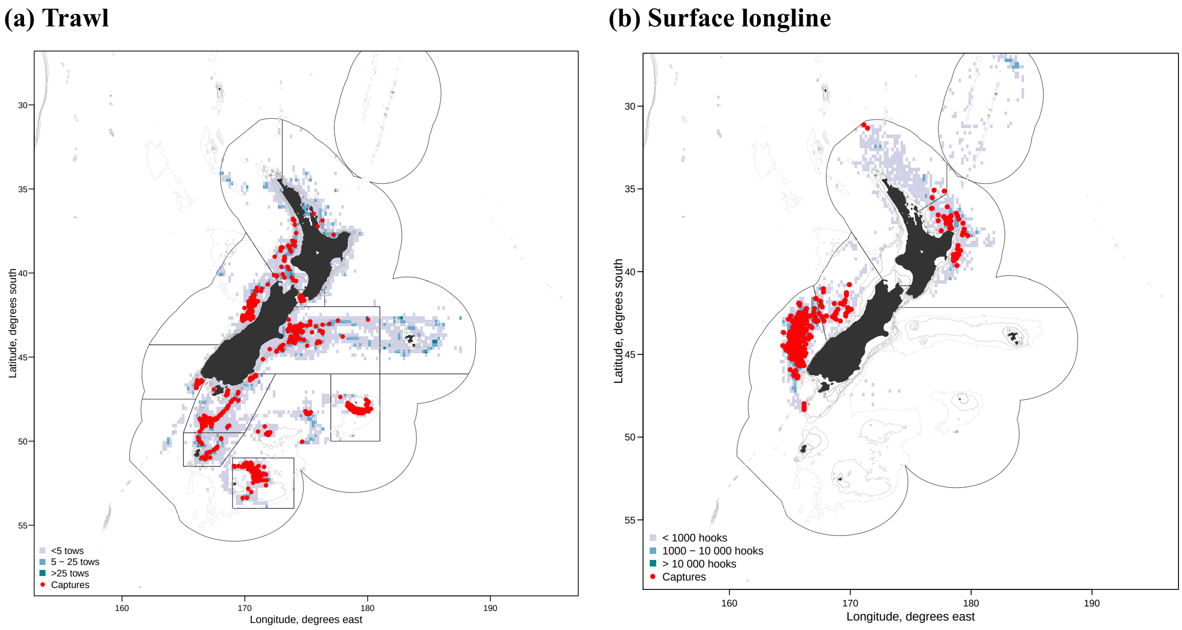


Figure 4: Spatial distribution of fishing effort (blue squares) and New Zealand fur seal captures (red dots) between 2002–03 and 2014–15, included in the statistical models to estimate total captures of fur seal in New Zealand's Exclusive Economic Zone. The estimation included (a) trawl, and (b) surface-longline fisheries. Annual average observed fishing effort within 0.2° squares is indicated by blue shades, model areas are indicated by lines.

Table 11: Model selection for fur seal in surface-longline fisheries, showing the leave-one-out information criterion (LOOIC). The candidate models are ordered by the mean LOOIC. Models with a lower LOOIC were considered to be a better fit to the data, and the candidate with the lowest LOOIC was chosen (s.d., standard deviation).

Candidate	LOOIC	
	Mean	s.d.
Area and fishery effects	371	61
Fishery and vessel size effects	384	58
Area by fishery random effects	411	61
Fishery effect	443	83
Area and vessel size effects	462	73
Area effect	490	84
Vessel size effect	530	80

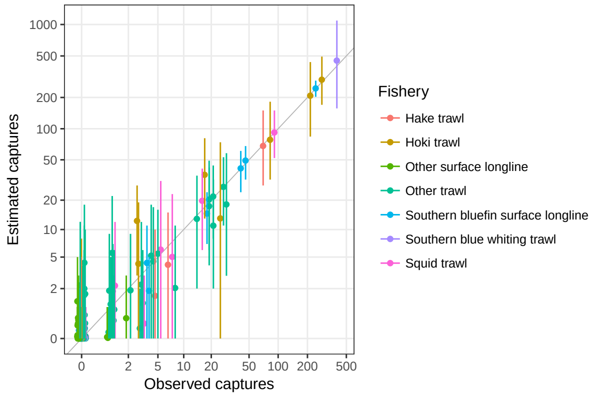


Figure 5: Comparison between observed and estimated captures of New Zealand fur seal on observed fishing, for target fishery and summary area combinations used on the protected species capture website (https://psc.dragonfly.co.nz/). Captures are totals for the model periods, from 2002–03 to 2014–15. Lines show the 95% credible interval of the estimated captures. Observed captures are offset to reduce overlap.

same model fitted to data from 2002–03 to 2012–13 (Abraham et al. 2016). Based on the day of year coefficients, the relative capture rate for fur seal peaked in mid August (and was lowest in February). In addition, fur-seal were more likely to be caught within 25 km of the shore, and less likely to be caught at distances at least 180 km from shore. Capture rates, relative to other areas, were highest in the Bounty Islands and subantarctic areas, and lowest on the North Island west coast and north-eastern New Zealand. Fur seal capture rates, relative to other fisheries, were highest in the squid target fishery, and lowest in the deepwater species target fishery.

For fur seal in surface-longline fisheries (Table B-27), capture rates were lower in the bigeye tuna and other surface-longline target fisheries (relative to southern bluefin tuna). Capture rates were higher in the eastern North Island area, relative to the South Island west coast, and were lowest in the Kermadec Islands area.

3.2.3 Estimated captures of New Zealand fur seal in trawl fisheries

The estimation of fur seal captures in New Zealand trawl fisheries was based on observer and effort data covering the period from 2002–03 to 2014–15 (see summaries in Appendix A, Section A.2; and model details in Appendix B).

During 2014–15 there was a total of 536 (95% c.i.: 332 to 969) estimated fur seal captures across all trawl fisheries, with a corresponding estimated capture rate of 0.68 (95% c.i.: 0.42 to 1.23) fur seal per 100 tows (Table A-7). The 2014–15 capture estimates were the highest since 2008–09.

In hoki trawl fisheries, there were an estimated 313 (95% c.i.: 145 to 724) fur seal captures in 2014–15, with a corresponding capture rate of 2.30 (95% c.i.: 1.07 to 5.33) fur seal captures per 100 tows. Fishing effort in this target fishery was consistently high, with at least 10 000 tows annually in recent years. In southern blue whiting fisheries, the number of estimated captures was 41 (95% c.i.: 41 to 42) fur seal, and the capture rate was 6.09 (95% c.i.: 6.09 to 6.24) fur seal per 100 tows. This fishery was characterised by low fishing effort, with 674 tows in 2014–15, while observer coverage has recently been high, with over 99% observer coverage in each of the three most recent fishing years.

Other target fisheries with relatively high capture estimates during 2014–15 were middle-depth trawl fisheries, with 70 (95% c.i.: 29 to 156) estimated captures; inshore trawl with an estimated 48 (95% c.i.: 12 to 130) fur seal captures; and squid trawl fisheries with an estimated 22 (95% c.i.: 19 to 33) fur seal captures.

The fishery-area with the highest number of estimated captures was hoki trawl in the Cook Strait area

Table 12: Fisheries and areas with the highest estimated New Zealand fur seal captures during the 2014–15 fishing year. Included for each fishery-area are: total fishing effort, observer coverage, observed fur seal captures and capture rate, and estimated captures and capture rate (showing the mean and 95% credible interval, c.i.). Effort is reported in tows for trawl fisheries and hooks for surface-longline fisheries; capture rates are reported as fur seal per 100 tows for trawl fisheries, and fur seal per 1000 hooks for surface-longline fisheries.

Target fishery	Area	Effort	Observed			Est. captures		Est. rate	
			%	Caps.	Rate	Mean	c.i.	Mean	c.i.
Hoki trawl	Cook Strait	1948	20.7	6	1.49	160	36–527	8.22	1.85–27.05
Hoki trawl	West Coast SI	4712	43.0	34	1.68	112	53–247	2.38	1.12–5.24
Southern bluefin SLL	East Coast NI	304534	11.9	14	0.39	43	29–60	0.14	0.10–0.20
Southern blue whiting trawl	Subantarctic	666	100.0	41	6.16	41	41–41	6.16	6.16–6.16
Southern bluefin SLL	West Coast SI	564975	35.7	5	0.02	29	17–43	0.05	0.03–0.08

(Table 12). There were six observed fur seal captures in this fishery and area during 2014–15, based on 20.7% observer coverage (403 observed tows), however the model estimated 160 (95% c.i. 36 to 527 captures. Fur seal captures are strongly seasonal, with highest capture rates during August and September (Thompson & Abraham 2010), however most (304) observed tows in the 2014–15 Cook Strait hoki fishery were in March through May. There were only 21 observed tows during August and September, with 4 observed captures, corresponding to a fur seal capture rate of 19.0 per 100 tows during these two months. In the West Coast South Island hoki trawl fishery there were 112 (95% c.i.: 53 to 247) estimated captures. In this case, the observed capture rate was within the range of the estimated capture rate. All tows in the subantarctic southern blue whiting trawl fishery were observed, with 41 fur seal captures being reported by observers.

3.2.4 Estimated captures of New Zealand fur seal in surface-longline fisheries

In 2014–15, there were an estimated 116 (95% c.i.: 87 to 151) fur seal captures in surface-longline fisheries, with an estimated capture rate 0.048 (95% c.i.: 0.036 to 0.063) fur seals per 1000 hooks. Over the 13-year reporting period, capture estimates in surface-longline fisheries showed some variation, with an increase in the number of estimated captures from 2011–12. There was no year effect in the model of fur seal captures in surface-longline fisheries, so this variation reflects changes in fishing effort.

During 2014–15, fur seal captures in surface-longline fisheries were highest in the East Coast North Island southern bluefin tuna fishery, with 43 (95% 29 to 60) estimated captures.

3.3 New Zealand sea lion captures and interactions

3.3.1 Observed sea lion captures

There were eight observed captures of New Zealand sea lion during 2014–15 (annual observed captures of sea lion, and observed fishing, in selected trawl fisheries are summarised in Appendix A, Section A.3). All of the sea lion captures were in trawl fisheries, with six observed captures in the Campbell Island southern blue whiting trawl and two captures in Auckland Islands squid trawl fisheries. All of the New Zealand sea lion captures were recorded as mortalities. Over the model period, sea lion were mainly observed caught in squid fisheries. Fishing effort in the squid trawl fishery fluctuates between years, and there were 633 squid target tows during 2014–15, the lowest effort since 2000–01. Observer coverage of squid fisheries was 88.3% in 2014–15, similar to observer coverage in the two previous years.

At the beginning of the reporting period (until 2007–08), the Auckland Island squid trawl fishery was characterised by the highest number of observed sea lion captures across all trawl fisheries. In recent years, however, the number of observed sea lion captures in this fishery has markedly decreased, corres-

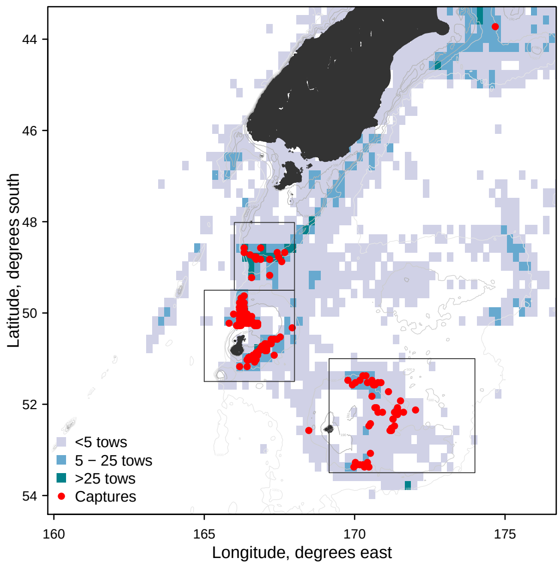


Figure 6: Spatial distribution of trawl fishing effort (blue squares) and New Zealand sea lion captures (red dots) between 1995–96 and 2014–15, included in the statistical models to estimate total captures of sea lion in New Zealand's Exclusive Economic Zone. Annual average observed fishing effort within 0.2° squares is indicated by blue shades, model areas are indicated by lines.

ponding with a decrease in fishing effort, an increase in the use of SLEDs, and changes in SLED design. In contrast, the number of observed sea lion captures in the Campbell Island southern blue whiting fishery was relatively low until 2006, but has increased since then; there were 21 observed captures of sea lion in 2013, prompting the use of SLEDs in this fishery from August 2013.

Over the period covered by the estimation, 1995–96 to 2014–15, observed sea lion captures in trawl fisheries were mainly in the Auckland Islands area (Figure 6), with 232 observed captures. Over the same period there were 61 observed captures in the Campbell Island area, and 18 captures on the Stewart-Snares shelf. There were two observed captures, one on a southern blue whiting trawl west of Campbell Island in 2001, and one during hoki fishing on the eastern South Island in 1996, that were outside the model areas and were not included in the estimation. Annual observed captures of sea lion, and observed fishing, in selected trawl fisheries are summarised in Appendix A (Section A.3).

3.3.2 Sea lion model fit

With a single exception, model chains passed the convergence and half-width tests (Heidelberger & Welch 1983) (see Appendix B for model parameters and model fit for each model). Inspection of the traces showed that samples from the two MCMC chains overlapped, indicating that there were no considerable structural limitations with any of the models. In some of the models, however, there was autocorrelation in the chains that reduced the effective number of samples. This reduction was largest for the overdispersion parameter in the two models of sea lion captures in the Auckland Islands squid trawl fishery. In both of these models, there was a reduction in the effective number of samples of the overdispersion parameter of 99.4%. The reduction in the length of the chain was less than 50% for all other parameters.

When the models were used to estimate captures on observed fishing effort, the observed captures were generally within the range of the estimates (Figure 7). The models successfully represented variation in observed captures between fisheries and areas.

In the two models of sea lion captures in the Auckland Islands squid fishery (Table B-28, Table B-29), the

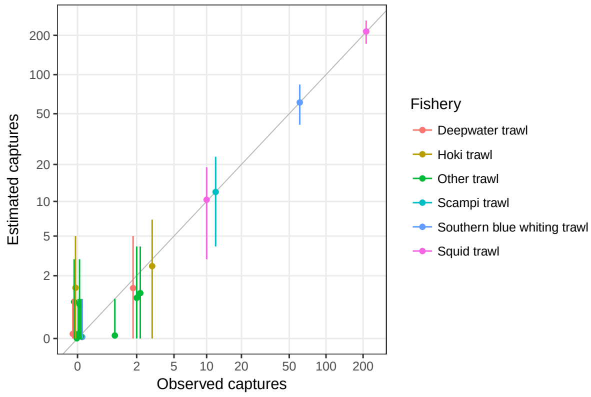


Figure 7: Comparison between observed captures and estimated captures of New Zealand sea lion on observed fishing, for target fishery and summary area combinations used on the protected species capture website (https://psc.dragonfly.co.nz/). Captures are totals for the model period, from 1995–96 to 2014–15. Lines show the 95% credible interval of the estimated captures. Observed captures are offset to reduce overlap.

values of the covariates were all close to the values from previous modelling (Abraham et al. 2016). Sea lion capture rates increased at a less than linear way with tow duration; they decreased with increasing distance from the colonies; and they were lower in the south-east area, relative to the north-west.

The model of sea lion captures in the Campbell Island southern blue whiting fishery (Table B-30) only had year effects (and a SLED retention probability that was based on the SLED retention probability from the Auckland Islands squid fishery). In the model of sea lion captures in other trawl fisheries (Table B-31), the highest capture rates were in the Auckland Islands scampi trawls, with the effect for other trawl fisheries in the Auckland Islands area overlapping with the effect for all trawling on the southern Stewart-Snares shelf.

3.3.3 Estimated captures of New Zealand sea lion in trawl fisheries

Sea lion captures in subantarctic trawl fisheries were estimated using four separate models: the Auckland Islands squid fishery (which had two separate models, representing the change in efficacy of SLEDs differently), the Campbell Island southern blue whiting fishery; and other target fisheries in the Auckland Islands and southern Stewart-Snares areas. There were assumed to be no sea lion captures in trawl fisheries outside these areas. Across all trawl fisheries, there were 12 (95% c.i.: 8 to 17) estimated captures during 2014–15 (see Appendix A, Section A.3, for summaries of estimated sea lion captures and interactions by fishery). In Auckland Islands squid trawl fisheries, there was 1 (95% c.i.: 1 to 3) estimated capture during 2014–15. This estimate was the lowest number of estimated captures across the entire model period. The estimated capture rate was 0.22 (95% c.i.: 0.16 to 0.47) sea lion captures per 100 tows, which was also the lowest capture rate across the period. During 2014–15, the Auckland Islands squid trawl fishery was 88.3% observed (558 observed tows of a total 633 tows). On the observed tows there was one recorded capture; on the 74 unobserved tows there were 0 (95% c.i.: 0 to 2) estimated captures. The subantarctic southern blue whiting fishery was 100% observed, with six reported sea lion captures. In Auckland Islands scampi trawl fisheries, there were an estimated 3 (95% c.i.: 0 to 8) sea lion captures.

Estimated sea lion captures in Auckland Islands squid trawl fisheries peaked at 140 (95% c.i.: 92 to 208) estimated captures during the 1996–97 fishing year. The decrease in the number of captures since then is partly due to a decline in fishing effort (with squid trawl fishing decreasing from 3721 tows in 1996–97 to 633 tows in 2014–15), and also due to the introduction of SLEDs.

Management of squid fisheries takes account of the interaction rate, representing the number of captures

Table 13: Sea lion interaction rate (interactions per 100 tows), calculated from all tows in the Auckland Island squid trawl fishery.

Description	Fishing years	Mean	95% c.i.
Before widespread use of SLEDs	1995–96 to 2004–05	4.78	3.64–6.34
With widespread use of SLEDs	2005–06 to 2014–15	7.58	2.14–29.57
Most recent year	2014–15	6.91	0.47–37.28
All years	1995–96 to 2014–15	5.89	3.43–14.70

Table 14: Interactions and captures of sea lion in the Auckland Islands squid trawl fishery, during 2014–15.

	Mean	2.5%	50%	97.5%
Interactions	43.7	3	21	236
Captures	1.4	1	1	3

that would have occurred per 100 tows, if all of the Auckland Islands squid fishery had been observed, and no vessels had used SLEDs. Before the widespread use of SLEDs, the interaction rate was relatively constrained with a mean of 4.78 interactions per 100 tows (95% c.i.: 3.64 to 6.34) (Table 13). When more recent data were included, however, the uncertainty in the interaction rate increased, as the use of SLEDs meant that no information was available to estimate the interaction rate, other than by comparison with past years. In 2014–15, there was an estimated mean of 1.4 (95% c.i.: 1 to 3) sea lion captures in the Auckland Islands squid trawl fishery (Table 14).

The model estimated that the SLED retention probability was 0.148 (95% c.i.: 0.087 to 0.243) in the version of the model without a change in SLED retention probability (Appendix B, Table B-28). In the model with a change in SLED retention probability, the mean retention probability decreased from 0.174 (95% c.i.: 0.091 to 0.293) before the year of the change, to 0.106 (0.008 to 0.492) in recent years (see Appendix B, Table B-29). The year of the change was allowed to be one of the three years 2004–05, 2005–06, or 2006–07, and the mean year of the change was estimated by the model as a mean of 2005–06. In the model with a change in the SLED retention probability, the uncertainty in the SLED retention probability in recent years was higher, leading to increased uncertainty in the estimated interaction rate.

3.4 Turtle captures

3.4.1 Observed turtle captures

Observed incidental captures of sea turtles in 2014–15 were of two individuals in two separate incidents (see Appendix A, Table A-1; annual observed captures of sea turtle, and observed fishing, in surface-longline fisheries are summarised in Appendix A, Section A.4). In one incident, a green turtle (*Chelonia mydas*) was captured during trawl fishing for trevally in the North Island west coast region (northern Northland). The second capture incident was of a leatherback turtle during surface longlining for bigeye tuna in the Northland and Hauraki Gulf region. Both turtles were released alive.

In recent years, leatherback turtle have also been reported caught. Over the period 2002–03 to 2014–15 there were a total of 16 observed turtle captures in surface-longline fisheries, with two turtle captures in trawl fisheries, and one capture in bottom-longline fisheries (Table 15). Turtle captures in surface-longline fisheries were in northern New Zealand, with no captures observed in South Island surface-longline fisheries (Figure 8).

Table 15: Observed captures of turtles in New Zealand commercial fisheries, 2002–03 to 2014–15. Shown are the number of each species caught in each target fishery. All turtles were recorded as released alive.

Method	Target fishery	Species	Number
Surface longline	Bigeye	Leatherback turtle	8
	Bigeye	Unidentified turtle	3
	Southern bluefin	Leatherback turtle	2
	Swordfish	Leatherback turtle	2
	Southern bluefin	Green turtle	1
Trawl	Inshore species	Green turtle	2
Bottom longline	Snapper	Green turtle	1

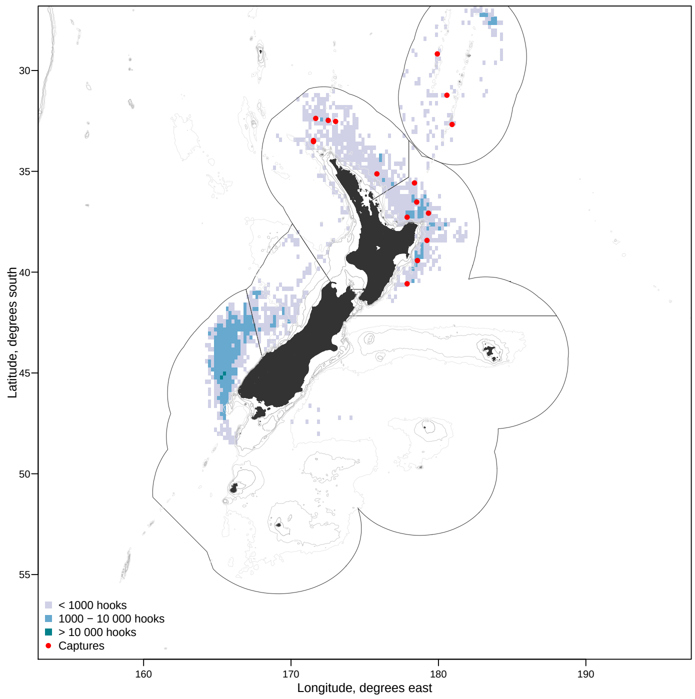


Figure 8: Spatial distribution of surface-longline fishing effort (blue squares) and sea turtle captures (red dots) between 2002–03 and 2014–15, included in the statistical model to estimate total captures of sea turtles in New Zealand's Exclusive Economic Zone. Annual average observed fishing effort within 0.2° squares is indicated by blue shades, model areas are indicated by lines.

Table 16: **Model selection for turtle captures in surface-longline fisheries, showing the leave-one-out information criterion (LOOIC). The candidate models are ordered by the mean LOOIC. Models with a lower LOOIC were considered to be a better fit to the data, and the candidate with the lowest LOOIC was chosen (s.d., standard deviation).**

Candidate	LOOIC	
	Mean	s.d.
Area and vessel size effects	93	21
Area effect	95	19
Area and fishery effects	96	26
Fishery and vessel size effects	97	27
Vessel size effect	97	21
Fishery effect	109	37
Area by fishery random effects	411	61

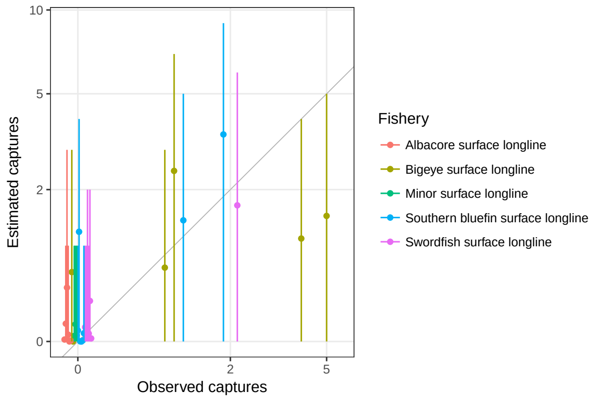


Figure 9: Comparison between observed captures and estimated captures of turtles on observed fishing, for target fishery and summary area combinations used on the protected species capture website (https://psc.dragonfly.co.nz/). Captures are totals for the model period, from 2002–03 to 2014–15. Lines show the 95% credible interval of the estimated captures. Observed captures are offset to reduce overlap.

3.4.2 Turtle model fit

For turtle captures in surface-longline fisheries, a model selection was undertaken, based on the LOOIC (Table 16). For turtle captures in surface-longline fisheries, area was an important explanatory effect, with the second best model only having an area effect. This model was further improved by also including vessel size, which distinguished between vessels shorter or longer than 45 m length.

Model chains passed the convergence and half-width tests (Heidelberger & Welch 1983) (see Appendix B for model parameters and model fit for each model). Inspection of the traces showed that samples from the two MCMC chains overlapped, indicating that there were no considerable structural limitations with any of the models. When the models were used to estimate captures on observed fishing effort, the observed captures were generally within the range of the estimates (Figure 9). The models successfully represented variation in observed captures between fisheries and areas.

In the model of turtle captures in surface-longline fisheries (Table B-32), the highest mean relative capture rates were in the Kermadec Islands area, followed by the other North Island area. Capture rates were lowest in the South Island west coast area. Capture rates were lower in large vessels (45 m length or more) than on small vessels.

3.4.3 Estimated captures of turtles in surface-longline fisheries

There were an estimated 13 (95% c.i.: 2 to 35) sea turtle captures in New Zealand surface-longline fisheries in 2014–15, corresponding to a capture rate of 0.005 (95% c.i.: 0.001 to 0.015) capture per thousand hooks (see Appendix A, Section A.4). Estimated captures during 2014–15 were considerably fewer than the estimated 57 (95% c.i.: 0 to 176) captures during 2002–03. There was no year effect included in the model, and the change reflected a decrease in fishing effort, from a total of over 10 million hooks set in surface-longline fisheries in 2002–03, to 2.4 million hooks set in 2014–15.

4. DISCUSSION

4.1 Estimation of marine mammal captures

In this study, we estimated captures of selected marine mammal species in trawl and surface-longline fisheries. The focus was on estimating the total observable captures, i.e., the number of captures that would have been observed, if every vessel had carried an observer. No account was made of fatalities that would not be recorded by observers, other than estimating sea lion interactions in fisheries that use SLEDs. The estimated captures may be aggregated to compare captures between area, vessel size class, or fishing year, allowing for monitoring of captures through time, or understanding which fisheries are associated with the highest mortalities. We did not consider the impact of the captures on the populations, although the estimates may be used as inputs into demographic models that investigate the impacts of these direct mortalities (e.g., Hamilton & Baker 2014, Meyer et al. 2015, Roberts & Doonan 2016).

The method used here for estimating total captures was only suitable for species that had sufficient numbers of observed captures. Other approaches, such as the Spatially Explicit Fisheries Risk Assessment (Sharp 2017), may be used for species that are seldom observed caught. This kind of risk assessment relies on assumptions about the distribution of the species and the resulting overlap with fisheries to estimate total captures, and has been successfully used to estimate captures of seabirds (e.g., Richard & Abraham 2015). It has been recently applied to New Zealand marine mammals to estimate direct impacts of fisheries for species that are less frequently observed caught (Abraham et al. 2017). In the application of this risk assessment, estimated captures were compared to estimates of population productivity to determine the impact of fishery captures on the associated population of New Zealand marine mammals.

4.2 Common dolphin captures

Common dolphin have been most frequently observed caught in the large-vessel (90 m length and over) jack mackerel fishery that operates off North Island's west coast (see detailed description of the model of common dolphin captures by Thompson et al. 2013a). Here, the model was updated with observer data to the end of the 2014–15 fishing year. Estimated common dolphin captures in the mackerel trawl fishery peaked during the 2002–03 fishing year, at 128 (95% c.i.: 54 to 243) captures. Dolphin captures have since reduced, and mean estimated captures have been 30 dolphin or less since 2011–12.

In this study, we also estimated common dolphin captures in all trawl fisheries. Although there have been fewer observed captures of common dolphin in other trawl fisheries, estimated captures of common dolphin in fisheries targeting inshore species and flatfish species were higher than in the jack mackerel fishery. Across all trawl fisheries, there were estimated to be 104 (95% c.i.: 50 to 189) captures during 2014–15. There has been no demographic modelling of the impact of fisheries mortalities on New Zealand common dolphin populations. The marine mammal risk assessment allows comparison between estimated fatalities and an estimate of population productivity.

Estimated common dolphin captures during 2014–15 were concentrated in the Taranaki area, which extends from north of Taranaki Peninsula to Farewell Spit, including Tasman and Golden bays. There were 60 (95% c.i.: 14 to 135) dolphin captures estimated in inshore species and flatfish trawl fisheries in this area. The uncertainty in the estimate reflects low observer effort. To reduce uncertainty in the capture estimates of this species, we recommend increased observer coverage of trawl vessels targeting inshore and flatfish species within the Taranaki area.

4.3 Fur seal captures

New Zealand fur seal had the highest estimated captures in trawl fisheries (see detailed description of the model of fur seal captures by Thompson & Abraham 2010). Estimated fur seal captures peaked in 2004–05 at 1487 (95% c.i.: 964 to 2370) captures, and by 2014–15 estimated captures had reduced to 536 (95% c.i.: 332 to 969) fur seal. The total size of the New Zealand fur seal population is poorly known, with no nationwide estimate since the 1970s (Wilson 1981). There has been no demographic modelling of the impact of fisheries mortalities on New Zealand fur seal populations.

New Zealand fur seal were estimated to be most frequently caught in hoki trawl fisheries, especially in the Cook Strait area. There were large hoki trawl vessels (28 m length or over) that operated in this area. In 2012–13 and 2014–15, the observed fur seal capture rate on these vessels was fewer than one fur seal per 100 tows. There were also small hoki trawl vessels that fished in the Cook Strait area. Between 2002–03 and 2014–15, the average observed capture rate on these vessels was 22.33 fur seal per 100 tows. Observer coverage in this fishery has been limited; for example, during 2013–14, no tows were observed, and in 2014–15, only four tows were observed (1.0% observer coverage). If the uncertainty in New Zealand fur seal captures is to be reduced, we recommend increased observer coverage of small hoki trawl vessels operating in the Cook Strait area.

The model provides no insight into the operational reasons for high estimated fur seal capture rates on the small trawl vessels targeting hoki. It is possible that reasons relate to the time of year the small vessels were fishing (the fur seal capture rate appeared to be strongly seasonal), or they could be related to specific factors associated with the way those vessels fish. The modelling approach used here was primarily aimed at estimating total captures across all New Zealand trawl fisheries. To provide greater understanding of the underlying reasons for the high capture rates, a model focused on the hoki fishery, with the aim of exploring the factors associated with captures, may provide insight.

4.4 Sea lion captures and interactions

The model used for estimating sea lion captures in the Auckland Island squid fishery traces back to research by Smith and Baird (2007a). Estimated captures of sea lion peaked at 151 (95% c.i.: 102 to 220) in 1996–97, before the introduction of SLEDs in the Auckland Islands squid fishery. Across all trawl fisheries, there were 12 (95% c.i.: 8 to 17) estimated captures of New Zealand sea lion in the Auckland Islands area during 2014–15.

It is apparent that the current modelling approach is no longer providing useful new information to inform the management of interactions between sea lion and fisheries. Since the near universal adoption of SLEDs in the Auckland Islands squid fishery, estimation of the interaction rate has become confounded with the SLED retention rate, such that estimated interaction rates were only weakly bounded (see Table 13), even though captures were well estimated due to high observer coverage (Table 14). Because of the poorly-constrained estimation of the interactions, attributed captures (e.g., Abraham et al. 2016) were not calculated. In this context, a different modelling and management approach, where cryptic mortality rates are estimated separately and used to estimate total mortalities as a function of observed captures, may be more useful.

4.5 Spatial modelling

All the models relied on a representation of spatial variation in the capture rate. For sea lion in the Auckland Islands squid fishery, there was both a distance-from-colony effect, and a spatial-area effect. For fur seal, the capture rate varied across a mosaic of fixed areas, and the model also included a distance-from-shore effect. Instead of imposing these spatial structures on the models, the modelling would be improved if they could be learned during the model fitting. One approach would be to use a conditional autoregressive (CAR) model (Jin et al. 2005). In this approach, the model would learn the typical spatial autocorrelation length scale. It would then be possible to estimate spatial variation in the capture rate without arbitrarily dividing the region into areas. In the current study, the Bayesian models were fitted using the BUGS modelling language (Plummer 2016). This language is not well-suited for fitting CAR models, but they can be fitted using the similar language, Stan (Carpenter et al. 2015).

Using CAR models is likely to be only suitable where there have been sufficient captures. It may not be suitable, for example, to use CAR models for estimating common dolphin captures in other trawl fisheries, or turtle captures in surface-longline fisheries.

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6. REFERENCES

Abraham, E. R.; Neubauer, P.; Berkenbusch, K.; Richard, Y. (2017). Assessment of the risk to New Zealand marine mammals from commercial fisheries. *Draft New Zealand Aquatic Environment and Biodiversity Report*. 123 p.

Abraham, E. R.; Richard, Y. (2017). Estimated capture of seabirds in New Zealand trawl and longline fisheries, 2002–03 to 2014–15. *Draft New Zealand Aquatic Environment and Biodiversity Report*.

Abraham, E. R.; Richard, Y.; Berkenbusch, K.; Thompson, F. (2016). Summary of the capture of seabirds, marine mammals, and turtles in New Zealand commercial fisheries, 2002–03 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report No. 169*. 205 p. Retrieved from http://mpi.govt.nz/document-vault/12180

Breen, P. A.; Hilborn, R.; Maunder, M. N.; Kim, S. W. (2003). Effects of alternative control rules on the conflict between a fishery and a threatened sea lion (*Phocarctos hookeri*). *Canadian Journal of Fisheries and Aquatic Sciences*, *60*, 527–541.

Carpenter, B.; Gelman, A.; Hoffman, M.; Lee, D.; Goodrich, B.; Betancourt, M.; Brubaker, M. A.; Guo, J.; Li, P.; Riddell, A. (2015). Stan: A probabilistic programming language. *Journal of Statistical Software*. Retrieved May 18, 2016, from http://www.demonish.com/cracker/1431548798_9226234ebe/stan-resubmit-jss1293.pdf

Clement & Associates (2007). *Squid trawl fleet sea lion escape device audit*. Unpublished report prepared for the Department of Conservation. Retrieved from http://tinyurl.com/sled-audit

Gelman, A. (2006). Prior distributions for variance parameters in hierarchical models. *Bayesian Analysis*, *1*, 515–534.

Gelman, A.; Hill, J.; Michael, R. (2006). *Data analysis using regression and multilevel/hierarchical models*. 648 p. Cambridge: Cambridge University Press.

Hamilton, S.; Baker, G. B. (2014). Current bycatch levels in Auckland Islands trawl fisheries unlikely to be driving New Zealand sea lion (*Phocarctos hookeri*) population decline. *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Heidelberger, P.; Welch, P. D. (1983). Simulation run length control in the presence of an initial transient. *Operations Research*, *31*, 1109–1144.

Jin, X.; Carlin, B. P.; Banerjee, S. (2005). Generalized hierarchical multivariate CAR models for areal data. *Biometrics*, *61*(4), 950–961.

Manly, B. F. J.; Seyb, A.; Fletcher, D. J. (2002). Bycatch of fur seals (*Arctocephalus forsteri*) in New Zealand fisheries, 1990/91–1995/96, and observer coverage. *DOC Science Internal Series*, *41*. 40 p.

Meeus, J. H. (1991). *Astronomical algorithms*. 389 p. Richmond, Virginia: Willmann-Bell.

Meyer, S.; Robertson, B. C.; Chilvers, B. L.; Krkošek, M. (2015). Population dynamics reveal conservation priorities of the threatened New Zealand sea lion *Phocarctos hookeri*. *Marine Biology*, *162*, 1587–1596.

Ministry for Primary Industries (2012). *Research database documentation*. Retrieved from http://tinyurl.com/fdbdoc

Mormede, S.; Baird, S. J.; Smith, M. H. (2008). Factors that may influence the probability of fur seal capture in selected New Zealand fisheries. *New Zealand Aquatic Environment and Biodiversity Report No. 19*. 42 p.

Mullahy, J. (1986). Specification and testing of some modified count data models. *Journal of Econometrics*, *33*(3), 341–365.

Natarajan, R.; Kass, R. E. (2000). Reference Bayesian methods for generalized linear mixed models. *Journal of the American Statistical Association*, *95*, 227–237.

Plummer, M. (2005). *JAGS: Just another Gibbs sampler. Version 1.0.3*. Retrieved from http://www-fis.iarc.fr/~martyn/software/jags

Plummer, M. (2016). *JAGS: Just another Gibbs sampler. Version 4.2.0*. Retrieved from http://mcmc-jags.sourceforge.net

Plummer, M.; Best, N.; Cowles, K.; Vines, K. (2006). CODA: Convergence diagnosis and output analysis for MCMC. *R News*, *6*, 7–11.

Richard, Y.; Abraham, E. R. (2015). Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2012–13. *New Zealand Aquatic Environment and Biodiversity Report No. 162*. 85 p. Retrieved from https://mpi.govt.nz/document-vault/10523

Ridout, M.; Demetrio, C. G. B.; Hinde, J. (1998). *Models for count data with many zeros*. In: *Proceedings of the XIXth International Biometric Conference*. International Biometric Society, Washington. Pp 179–192.

Roberts, J.; Doonan, I. (2016). Quantitative risk assessment of threats to New Zealand sea lions. *New Zealand Aquatic Environment and Biodiversity Report No. 166*. 117 p. Retrieved from http://fs.fish.govt.nz/Page.aspx?pk=113&dk=24028

Sharp, B. R. (2017). Spatially Explicit Fisheries Risk Assessment (SEFRA): A framework for quantifying and managing incidental commercial fisheries impacts on non-target species and habitats. Chapter 3. In: *Aquatic Environment and Biodiversity Annual Review 2016*. Compiled by the Fisheries Management Science Team, Ministry for Primary Industries, Wellington, New Zealand. 38 p.

Smith, M. H.; Baird, S. J. (2005). Factors that may influence the level of mortality of New Zealand sea lions (*Phocarctos hookeri*) in the squid (*Nototodarus* spp.) trawl fishery in SQU 6T. *New Zealand Fisheries Assessment Report 2005/20*. 35 p.

Smith, M. H.; Baird, S. J. (2007a). Estimation of the incidental captures of New Zealand sea lions (*Phocarctos hookeri*) in New Zealand fisheries in 2003–04, with particular reference to the SQU 6T squid (*Nototodarus* spp.) trawl fishery. *New Zealand Fisheries Assessment Report 2007/7*. 32 p.

Smith, M. H.; Baird, S. J. (2007b). Estimation of the incidental captures of New Zealand sea lions (*Phocarctos hookeri*) in New Zealand fisheries in 2004–05, with particular reference to the SQU 6T squid (*Nototodarus* spp.) trawl fishery. *New Zealand Aquatic Environment and Biodiversity Report No. 12*. 31 p.

Smith, M. H.; Baird, S. J. (2009). Model-based estimation of New Zealand fur seal (*Arctocephalus forsteri*) incidental captures and strike rates for trawl fishing in New Zealand waters for the years 1994–95 to 2005–06. *New Zealand Aquatic Environment and Biodiversity Report No. 40*. 91 p.

Spiegelhalter, D. J.; Thomas, A.; Best, N.; Lunn, D. (2003). *WinBUGS version 1.4 user manual*. 60 p. Cambridge: MRC Biostatistics Unit.

Thompson, F. N.; Abraham, E. R. (2009). Dolphin bycatch in New Zealand trawl fisheries, 1995–96 to 2006–07. *New Zealand Aquatic Environment and Biodiversity Report No. 36*. 24 p. Retrieved from http://fs.fish.govt.nz/Doc/22002/AEBR_36.pdf.ashx

Thompson, F. N.; Abraham, E. R. (2010). Estimation of fur seal (*Arctocephalus forsteri*) bycatch in New Zealand trawl fisheries, 2002–03 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report No. 61*. 37 p. Retrieved from http://fs.fish.govt.nz/Doc/22390/AEBR_61.pdf.ashx

Thompson, F. N.; Abraham, E. R. (2011). Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report No. 66*. 25 p. Retrieved from http://fs.fish.govt.nz/Doc/22903/AEBR_66.pdf.ashx

Thompson, F. N.; Abraham, E. R.; Berkenbusch, K. (2010a). Common dolphin (*Delphinus delphis*) bycatch in New Zealand mackerel trawl fisheries, 1995–96 to 2008–09. *New Zealand Aquatic Environment and Biodiversity Report No. 63*. 20 p. Retrieved from http://fs.fish.govt.nz/Doc/22392/AEBR_63%20common%20dolphin.pdf.ashx

Thompson, F. N.; Abraham, E. R.; Berkenbusch, K. (2011). *Marine mammal bycatch in New Zealand trawl fisheries, 1995–96 to 2009–10*. Final Research Report for research project PRO2010-01. (Unpublished report held by Ministry for Primary Industries, Wellington). Retrieved from http://fs.fish.govt.nz/Doc/22390/AEBR_61.pdf.ashx

Thompson, F. N.; Abraham, E. R.; Berkenbusch, K. (2013a). Common dolphin (*Delphinus delphis*) bycatch in New Zealand commercial trawl fisheries. *PLoS ONE*, *8*, e64438. doi:10.1371/journal.pone.0064438

Thompson, F. N.; Abraham, E. R.; Oliver, M. D. (2010b). Estimation of fur seal bycatch in New Zealand trawl fisheries, 2002–03 to 2007-08. *New Zealand Aquatic Environment and Biodiversity Report No. 56*. 29 p. Retrieved from http://fs.fish.govt.nz/Doc/22314/AEBR_56%20Fur%20lion%20estimation%200708.pdf.ashx

Thompson, F. N.; Berkenbusch, K. (2016). *Preparation of data on observed protected species captures, 2002–03 to 2014–15*. Draft New Zealand Aquatic Environment and Biodiversity Report, Wellington, New Zealand.

Thompson, F. N.; Berkenbusch, K.; Abraham, E. R. (2013b). Marine mammal bycatch in New Zealand trawl fisheries, 1995–96 to 2010–11. *New Zealand Aquatic Environment and Biodiversity Report No. 105*. Retrieved from https://www.mpi.govt.nz/document-vault/4241

Thompson, F. N.; Oliver, M. D.; Abraham, E. R. (2010c). Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report No. 52*. 25 p. Retrieved from http://fs.fish.govt.nz/Doc/22271/AEBR_52.pdf.ashx

Vehtari, A.; Gelman, A.; Gabry, J. (2016). *Loo: Efficient leave-one-out cross-validation and WAIC for bayesian models*. R package version 0.1.6. Retrieved from https://github.com/jgabry/loo

Wessel, P.; Smith, W. H. F. (1996). A global self-consistent, hierarchical, high-resolution shoreline database. *Journal of Geophysical Research B*, *101*, 8741–8743.

Wilson, G. J. (1981). Distribution and abundance of the New Zealand fur seal, *Arctocephalus forsteri*. *Fisheries Research Division Occasional Publication No. 20*. 39 p.

APPENDIX A: SUMMARIES OF CAPTURES BY SPECIES AND FISHERY

Table A-1: Observed marine mammal and turtle captures during the five fishing years between 2010–11 and 2014–15. Shown are the number of capture events, the number of captures, and the status (alive or dead) of captured animals in different commercial fisheries in New Zealand waters.

Fishing year	Species	Scientific name	Method	Events	Captures	Status	
						Alive	Dead
2010–11	Common dolphin	*Delphinus delphis*	Trawl	8	9		9
	Dusky dolphin	*Lagenorhynchus obscurus*	Set net	2	2		2
	Green turtle	*Chelonia mydas*	Surface longline	1	1	1	
	Leatherback turtle	*Dermochelys coriacea*	Surface longline	3	3	3	
	New Zealand fur seal	*Arctocephalus forsteri*	Trawl	53	73	4	69
			Surface longline	16	17	15	2
			Set net	1	1		1
	New Zealand sea lion	*Phocarctos hookeri*	Trawl	5	6	1	5
2011–12	Common dolphin	*Delphinus delphis*	Trawl	4	5		5
	New Zealand fur seal	*Arctocephalus forsteri*	Trawl	70	83	8	75
			Surface longline	30	40	38	2
	New Zealand sea lion	*Phocarctos hookeri*	Trawl	1	1	1	
2012–13	Common dolphin	*Delphinus delphis*	Trawl	9	17	2	15
			Set net	2	2		2
	Dusky dolphin	*Lagenorhynchus obscurus*	Trawl	1	1		1
			Set net	1	1		1
	Hector’s dolphin	*Cephalorhynchus hectori*	Set net	1	1	1	
	New Zealand fur seal	*Arctocephalus forsteri*	Trawl	94	121	21	100
			Surface longline	18	21	18	3
			Set net	10	11	2	9
	New Zealand sea lion	*Phocarctos hookeri*	Trawl	16	25	5	20
	Pilot whale long-finned	*Globicephala melas*	Trawl	2	5		5
	Turtle	*Chelonioidea*	Surface longline	2	2	2	
2013–14	Common dolphin	*Delphinus delphis*	Trawl	8	30		30
			Set net	2	2		2
	Hector’s dolphin	*Cephalorhynchus hectori*	Set net	1	1		1
	New Zealand fur seal	*Arctocephalus forsteri*	Trawl	113	159	3	156
			Surface longline	49	57	56	1
			Set net	4	4		4
	New Zealand sea lion	*Phocarctos hookeri*	Trawl	4	4		4
2014–15	Bottlenose dolphin	*Tursiops truncatus*	Surface longline	1	1	1	
	Common dolphin	*Delphinus delphis*	Trawl	12	21		21
			Set net	2	2		2
			Surface longline	1	1	1	
	Dusky dolphin	*Lagenorhynchus obscurus*	Trawl	2	2		2
	Green turtle	*Chelonia mydas*	Trawl	1	1	1	
	Leatherback turtle	*Dermochelys coriacea*	Surface longline	1	1	1	
	New Zealand fur seal	*Arctocephalus forsteri*	Trawl	100	127	14	113
			Surface longline	29	37	33	4
			Set net	11	12	1	11
	New Zealand sea lion	*Phocarctos hookeri*	Trawl	8	8		8

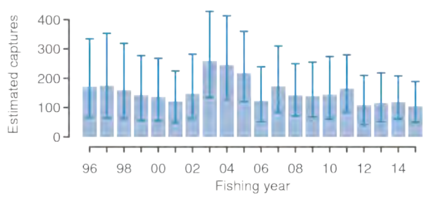
A.1 Common dolphin

A.1.1 Common dolphin captures in all trawl fisheries

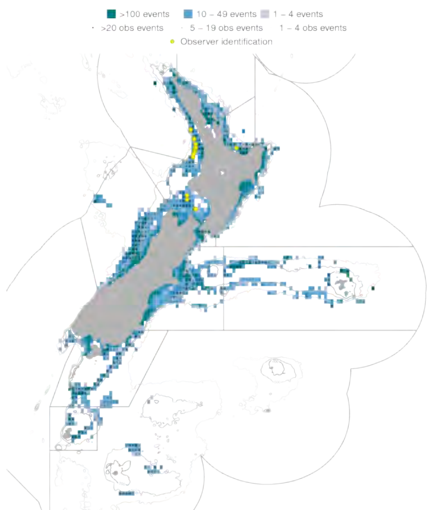
Table A-2: Annual fishing effort (tows), and observer coverage (%) in all trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of common dolphin; estimated captures and capture rate of common dolphin (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	150 437	2.9	2	0.05	171	68–334	0.11	0.05–0.22
1996–97	161 023	3.0	0	0.00	175	64–353	0.11	0.04–0.22
1997–98	158 839	4.3	0	0.00	159	61–319	0.10	0.04–0.20
1998–99	153 617	4.7	0	0.00	142	56–277	0.09	0.04–0.18
1999–00	139 034	5.5	1	0.01	136	55–268	0.10	0.04–0.19
2000–01	134 190	6.8	1	0.01	121	49–225	0.09	0.04–0.17
2001–02	127 759	6.0	1	0.01	147	61–282	0.12	0.05–0.22
2002–03	130 139	5.3	21	0.31	258	135–428	0.20	0.10–0.33
2003–04	120 853	5.4	17	0.26	245	129–413	0.20	0.11–0.34
2004–05	120 448	6.4	22	0.29	218	120–360	0.18	0.10–0.30
2005–06	109 944	6.0	4	0.06	123	52–239	0.11	0.05–0.22
2006–07	103 300	7.7	11	0.14	172	84–310	0.17	0.08–0.30
2007–08	89 529	10.1	20	0.22	141	71–250	0.16	0.08–0.28
2008–09	87 548	11.4	20	0.20	139	68–255	0.16	0.08–0.29
2009–10	92 888	10.3	4	0.04	144	61–274	0.16	0.07–0.29
2010–11	86 085	8.8	9	0.12	165	84–280	0.19	0.10–0.33
2011–12	84 422	11.1	5	0.05	108	42–210	0.13	0.05–0.25
2012–13	83 842	14.8	17	0.14	116	52–218	0.14	0.06–0.26
2013–14	85 114	15.5	30	0.23	118	62–208	0.14	0.07–0.24
2014–15	78 696	17.3	21	0.15	104	50–189	0.13	0.06–0.24

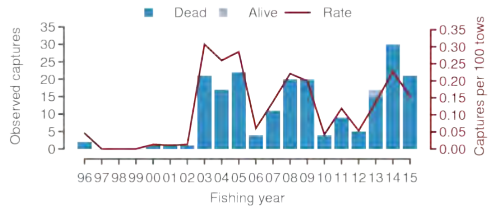
(a) Estimated captures



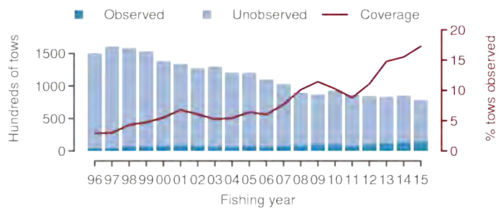
(b) October 2014 to September 2015



(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

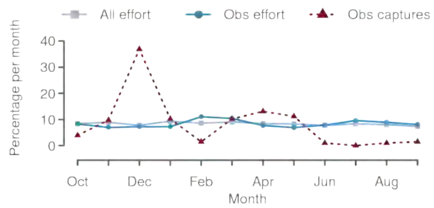


Figure A-1: Common dolphin captures in all trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.1.2 Common dolphin captures in jack mackerel trawl fisheries

Table A-3: Annual fishing effort (tows), and observer coverage (%) in jack mackerel trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of common dolphin; estimated captures and capture rate of common dolphin (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	2 759	10.8	2	0.67	5	2–16	0.18	0.07–0.58
1996–97	2 686	13.1	0	0.00	1	0–5	0.04	0.00–0.19
1997–98	4 164	13.1	0	0.00	2	0–11	0.05	0.00–0.26
1998–99	3 866	16.2	0	0.00	4	0–16	0.10	0.00–0.41
1999–00	2 290	22.5	1	0.19	7	1–27	0.31	0.04–1.18
2000–01	1 941	20.8	1	0.25	11	1–34	0.57	0.05–1.75
2001–02	3 002	11.7	1	0.28	26	2–82	0.87	0.07–2.73
2002–03	3 067	11.3	21	6.07	128	54–243	4.17	1.76–7.92
2003–04	2 383	6.4	17	11.18	105	46–196	4.41	1.93–8.22
2004–05	2 510	22.3	21	3.76	82	43–135	3.27	1.71–5.38
2005–06	2 808	25.2	2	0.28	10	2–29	0.36	0.07–1.03
2006–07	2 711	29.6	11	1.37	50	20–94	1.84	0.74–3.47
2007–08	2 651	30.8	20	2.45	41	23–68	1.55	0.87–2.57
2008–09	2 169	37.5	11	1.35	26	13–49	1.20	0.60–2.26
2009–10	2 406	32.7	4	0.51	23	6–55	0.96	0.25–2.29
2010–11	1 880	31.5	7	1.18	63	24–120	3.35	1.28–6.38
2011–12	2 031	76.2	5	0.32	7	5–14	0.34	0.25–0.69
2012–13	2 210	87.6	15	0.77	16	15–20	0.72	0.68–0.90
2013–14	2 448	89.4	28	1.28	30	28–36	1.23	1.14–1.47
2014–15	1 745	86.5	19	1.26	21	19–28	1.20	1.09–1.60

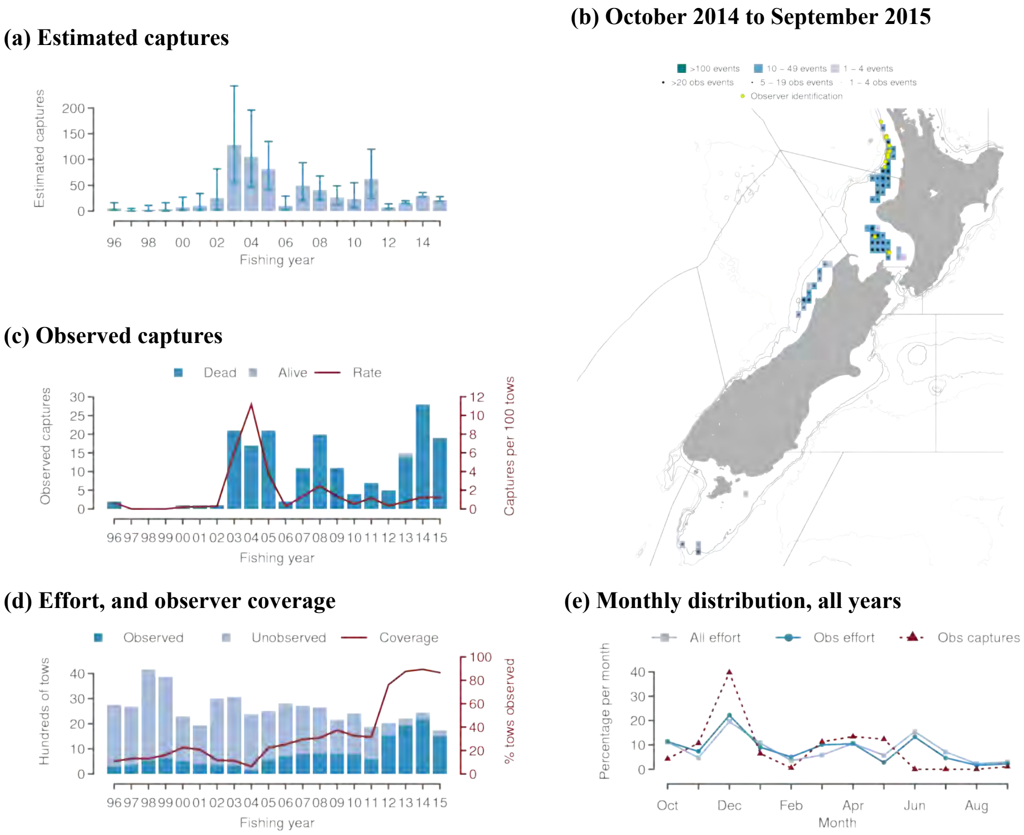


Figure A-2: Common dolphin captures in jack mackerel trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.1.3 Common dolphin captures in middle depths species trawl fisheries

Table A-4: Annual fishing effort (tows), and observer coverage (%) in middle depths species trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of common dolphin; estimated captures and capture rate of common dolphin (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	13 258	0.5	0	0.00	20	5–43	0.15	0.04–0.32
1996–97	13 330	0.6	0	0.00	19	5–42	0.14	0.04–0.32
1997–98	9 718	1.1	0	0.00	9	1–22	0.09	0.01–0.23
1998–99	11 020	1.7	0	0.00	14	3–31	0.13	0.03–0.28
1999–00	12 476	1.6	0	0.00	18	4–40	0.14	0.03–0.32
2000–01	12 255	1.9	0	0.00	17	4–39	0.14	0.03–0.32
2001–02	11 214	2.3	0	0.00	17	4–40	0.15	0.04–0.36
2002–03	11 178	3.1	0	0.00	17	3–40	0.15	0.03–0.36
2003–04	9 169	2.1	0	0.00	20	4–46	0.22	0.04–0.50
2004–05	9 180	2.4	1	0.45	20	5–44	0.22	0.05–0.48
2005–06	8 405	5.8	0	0.00	9	1–23	0.11	0.01–0.27
2006–07	8 193	4.8	0	0.00	8	1–21	0.10	0.01–0.26
2007–08	7 420	6.1	0	0.00	11	1–26	0.15	0.01–0.35
2008–09	7 230	10.7	9	1.16	18	10–30	0.25	0.14–0.41
2009–10	7 220	13.9	0	0.00	7	0–17	0.10	0.00–0.24
2010–11	7 256	8.5	1	0.16	8	2–19	0.11	0.03–0.26
2011–12	6 548	11.7	0	0.00	7	0–18	0.11	0.00–0.27
2012–13	6 448	19.3	1	0.08	8	1–18	0.12	0.02–0.28
2013–14	6 409	21.8	0	0.00	7	0–17	0.11	0.00–0.27
2014–15	6 438	27.5	1	0.06	6	1–14	0.09	0.02–0.22

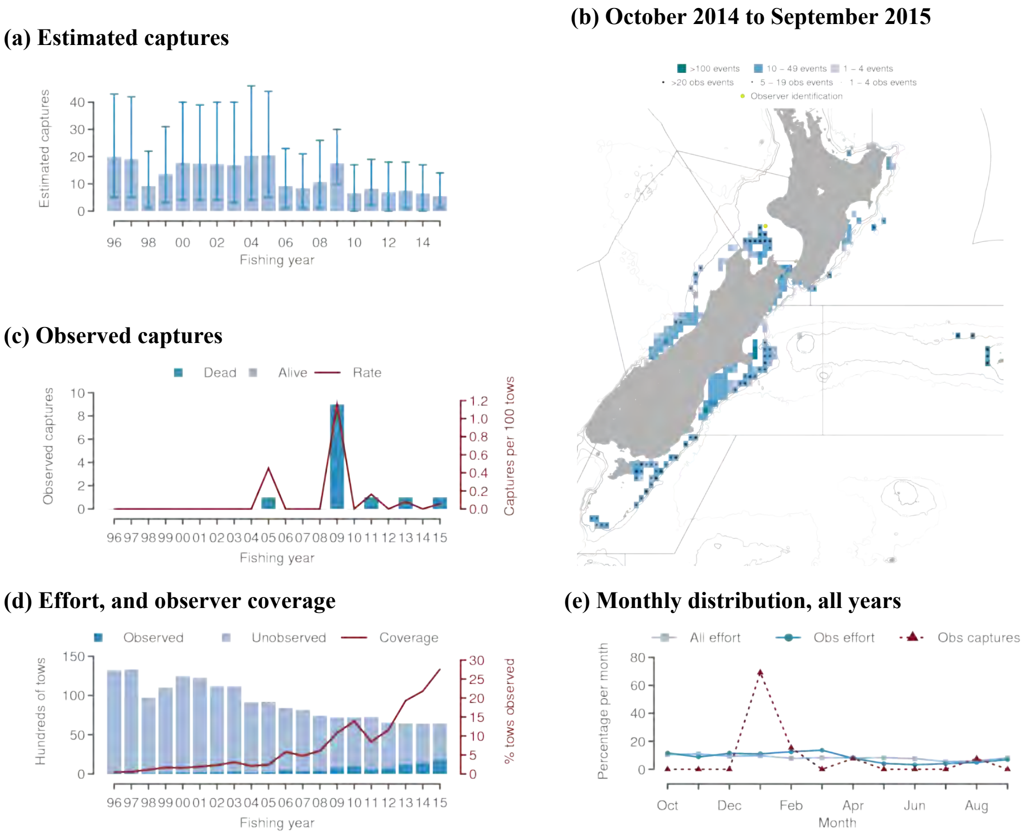


Figure A-3: Common dolphin captures in middle depths species trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.1.4 Common dolphin captures in inshore species trawl fisheries

Table A-5: Annual fishing effort (tows), and observer coverage (%) in inshore species trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of common dolphin; estimated captures and capture rate of common dolphin (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	41 259	0.0	0		45	16–90	0.11	0.04–0.22
1996–97	42 017	0.0	0	0.00	45	16–89	0.11	0.04–0.21
1997–98	43 468	0.0	0	0.00	41	14–81	0.09	0.03–0.19
1998–99	42 485	0.0	0	0.00	53	18–103	0.12	0.04–0.24
1999–00	39 769	0.1	0	0.00	49	17–98	0.12	0.04–0.25
2000–01	38 997	0.1	0	0.00	44	15–86	0.11	0.04–0.22
2001–02	37 390	0.1	0	0.00	42	14–83	0.11	0.04–0.22
2002–03	36 541	0.0	0	0.00	46	16–92	0.13	0.04–0.25
2003–04	37 413	0.0	0	0.00	42	14–85	0.11	0.04–0.23
2004–05	40 838	0.0	0	0.00	38	13–76	0.09	0.03–0.19
2005–06	39 154	0.3	2	1.94	41	15–80	0.10	0.04–0.20
2006–07	35 817	0.8	0	0.00	40	13–80	0.11	0.04–0.22
2007–08	31 414	0.4	0	0.00	38	13–77	0.12	0.04–0.25
2008–09	33 098	3.9	0	0.00	40	13–81	0.12	0.04–0.24
2009–10	35 973	2.3	0	0.00	51	17–104	0.14	0.05–0.29
2010–11	34 985	1.5	1	0.19	52	18–104	0.15	0.05–0.30
2011–12	32 770	0.6	0	0.00	52	18–104	0.16	0.05–0.32
2012–13	33 262	0.5	0	0.00	52	18–104	0.16	0.05–0.31
2013–14	34 216	4.7	1	0.06	48	17–96	0.14	0.05–0.28
2014–15	30 404	6.9	1	0.05	42	14–85	0.14	0.05–0.28

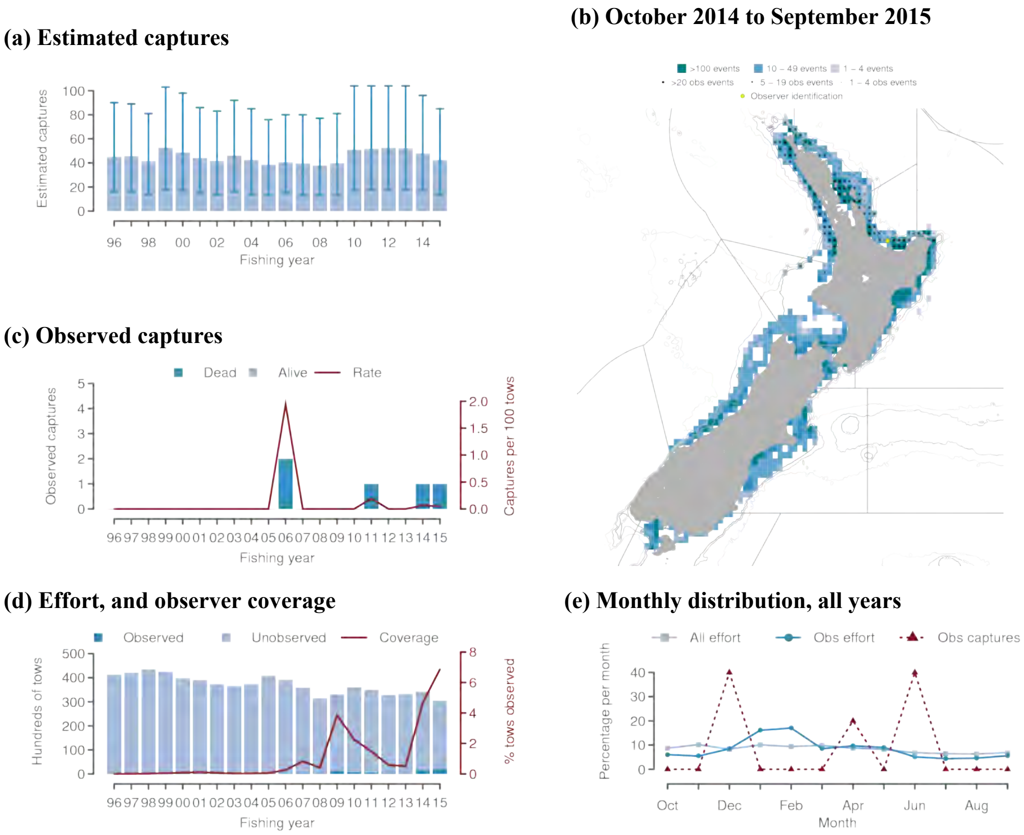


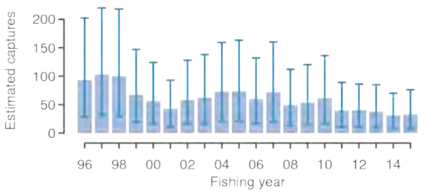
Figure A-4: Common dolphin captures in inshore species trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.1.5 Common dolphin captures in flatfish trawl fisheries

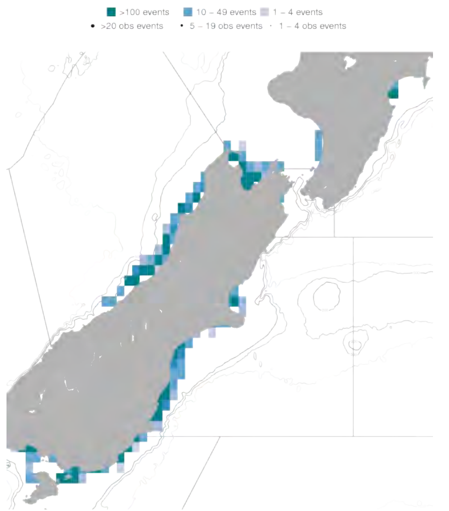
Table A-6: Annual fishing effort (tows), and observer coverage (%) in flatfish trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of common dolphin; estimated captures and capture rate of common dolphin (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	35 706	0.0	0		93	28–202	0.26	0.08–0.57
1996–97	40 012	0.0	0		103	31–220	0.26	0.08–0.55
1997–98	37 038	0.0	0		100	30–218	0.27	0.08–0.59
1998–99	35 120	0.0	0		67	20–147	0.19	0.06–0.42
1999–00	26 665	0.0	0		56	16–124	0.21	0.06–0.47
2000–01	25 131	0.0	0	0.00	43	11–93	0.17	0.04–0.37
2001–02	23 908	0.0	0	0.00	58	16–128	0.24	0.07–0.54
2002–03	26 934	0.0	0		62	17–138	0.23	0.06–0.51
2003–04	26 320	0.0	0		73	21–159	0.28	0.08–0.60
2004–05	26 417	0.0	0		74	21–163	0.28	0.08–0.62
2005–06	22 873	0.0	0		60	17–132	0.26	0.07–0.58
2006–07	23 660	0.0	0		72	20–160	0.30	0.08–0.68
2007–08	18 891	0.1	0	0.00	50	13–112	0.26	0.07–0.59
2008–09	18 523	3.3	0	0.00	54	14–120	0.29	0.08–0.65
2009–10	20 148	1.8	0	0.00	61	16–136	0.30	0.08–0.68
2010–11	15 577	2.3	0	0.00	40	10–89	0.26	0.06–0.57
2011–12	17 527	1.8	0	0.00	40	10–86	0.23	0.06–0.49
2012–13	17 282	0.3	0	0.00	38	9–85	0.22	0.05–0.49
2013–14	16 283	0.4	0	0.00	31	8–70	0.19	0.05–0.43
2014–15	13 584	0.0	0		33	8–76	0.24	0.06–0.56

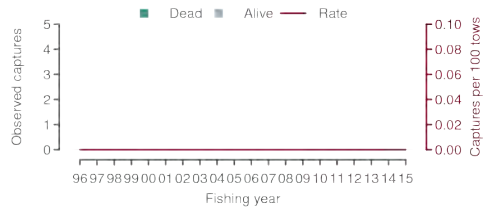
(a) Estimated captures



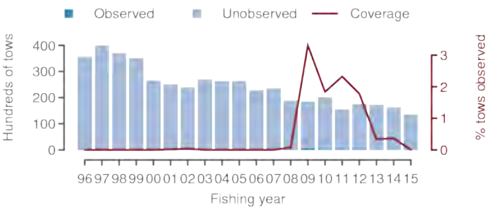
(b) October 2014 to September 2015



(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

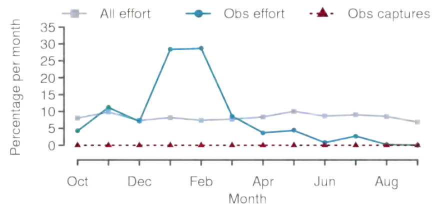


Figure A-5: Common dolphin captures in flatfish trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2 New Zealand fur seal

A.2.1 New Zealand fur seal captures in all trawl fisheries

Table A-7: Annual fishing effort (tows), and observer coverage (%) in all trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	130 156	5.3	68	0.99	924	562–1 504	0.71	0.43–1.16
2003–04	120 837	5.4	90	1.37	1 120	684–1 839	0.93	0.57–1.52
2004–05	120 431	6.4	199	2.58	1 487	964–2 370	1.23	0.80–1.97
2005–06	109 944	6.0	143	2.16	949	597–1 534	0.86	0.54–1.40
2006–07	103 297	7.7	74	0.93	570	360–898	0.55	0.35–0.87
2007–08	89 527	10.1	141	1.56	795	493–1 406	0.89	0.55–1.57
2008–09	87 550	11.4	72	0.72	564	320–1 026	0.64	0.37–1.17
2009–10	92 889	10.3	72	0.76	495	286–911	0.53	0.31–0.98
2010–11	86 086	8.8	73	0.96	443	262–800	0.51	0.30–0.93
2011–12	84 421	11.1	83	0.89	451	267–804	0.53	0.32–0.95
2012–13	83 842	14.8	121	0.98	438	270–760	0.52	0.32–0.91
2013–14	85 114	15.5	159	1.20	416	291–630	0.49	0.34–0.74
2014–15	78 696	17.3	127	0.93	536	332–969	0.68	0.42–1.23

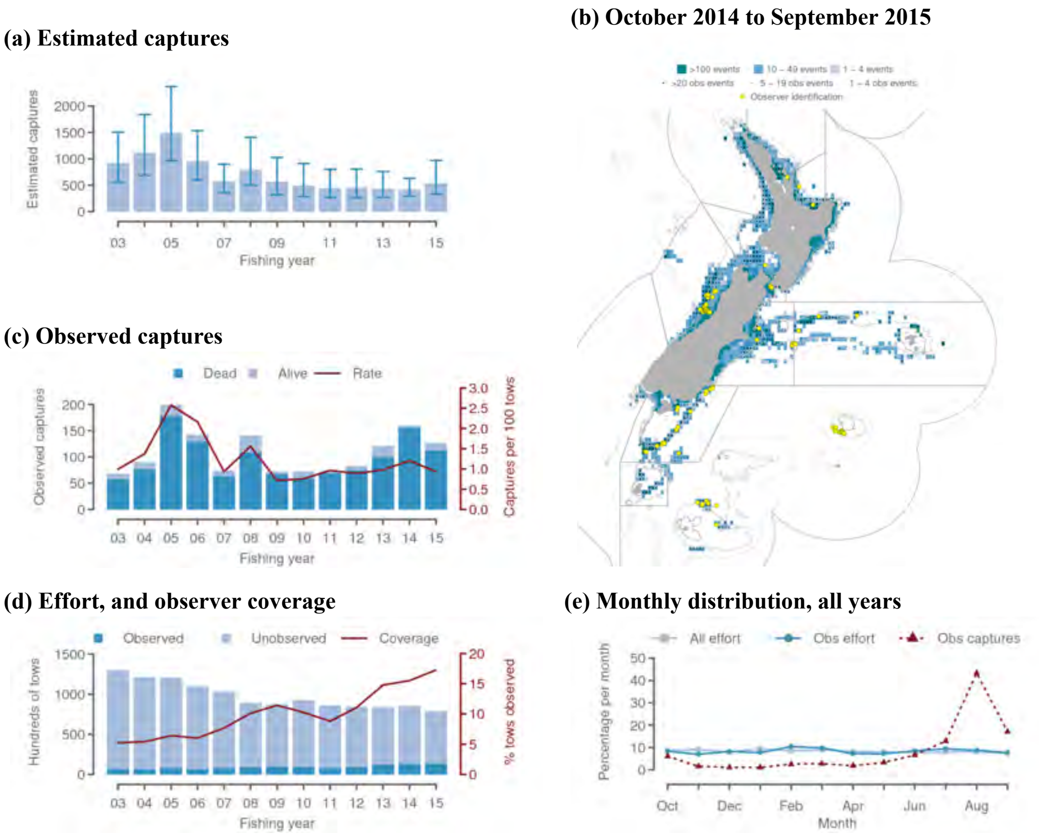


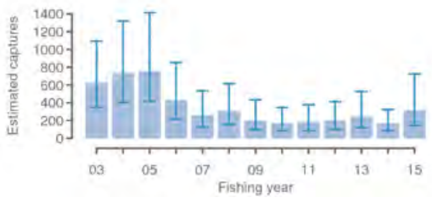
Figure A-6: New Zealand fur seal captures in all trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.2 New Zealand fur seal captures in hoki trawl fisheries

Table A-8: Annual fishing effort (tows), and observer coverage (%) in hoki trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

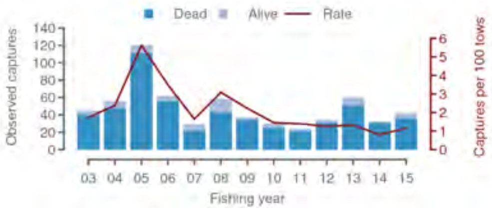
Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	27 786	9.3	45	1.74	622	346–1 094	2.24	1.25–3.94
2003–04	22 522	10.4	56	2.39	735	402–1 320	3.26	1.78–5.86
2004–05	14 540	14.7	120	5.63	755	419–1 414	5.19	2.88–9.72
2005–06	11 589	15.3	62	3.49	432	216–853	3.73	1.86–7.36
2006–07	10 604	16.6	29	1.65	260	125–534	2.45	1.18–5.04
2007–08	8 784	21.4	58	3.09	310	154–616	3.53	1.75–7.01
2008–09	8 175	20.3	37	2.23	200	96–432	2.45	1.17–5.28
2009–10	9 967	20.7	30	1.45	171	87–346	1.72	0.87–3.47
2010–11	10 401	16.6	24	1.39	181	84–379	1.74	0.81–3.64
2011–12	11 334	23.8	34	1.26	201	100–412	1.77	0.88–3.64
2012–13	11 681	38.7	60	1.33	246	119–526	2.11	1.02–4.50
2013–14	12 944	30.7	32	0.81	168	87–324	1.30	0.67–2.50
2014–15	13 589	26.6	42	1.16	313	145–724	2.30	1.07–5.33

(a) Estimated captures

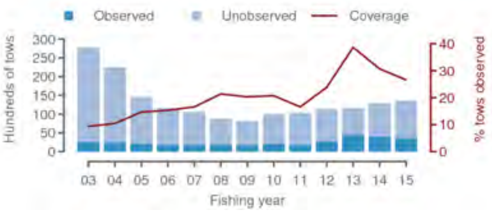


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

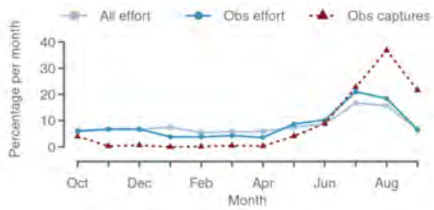


Figure A-7: New Zealand fur seal captures in hoki trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.3 New Zealand fur seal captures in southern blue whiting trawl fisheries

Table A-9: Annual fishing effort (tows), and observer coverage (%) in southern blue whiting trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	638	43.1	8	2.91	22	8–78	3.45	1.25–12.23
2003–04	740	32.6	13	5.39	36	13–122	4.86	1.76–16.49
2004–05	870	38.5	33	9.85	103	35–472	11.84	4.02–54.25
2005–06	624	34.8	52	23.96	67	52–122	10.74	8.33–19.55
2006–07	630	35.6	13	5.80	25	13–76	3.97	2.06–12.06
2007–08	817	40.5	24	7.25	110	25–600	13.46	3.06–73.44
2008–09	1 188	25.3	17	5.67	129	25–488	10.86	2.10–41.08
2009–10	1 113	35.6	16	4.04	114	20–460	10.24	1.80–41.33
2010–11	1 171	37.0	36	8.31	76	38–251	6.49	3.25–21.43
2011–12	951	70.3	25	3.74	69	25–289	7.26	2.63–30.39
2012–13	790	100.0	27	3.42	27	27–27	3.42	3.42–3.42
2013–14	804	99.9	95	11.83	97	95–116	12.06	11.82–14.43
2014–15	673	99.1	41	6.15	41	41–42	6.09	6.09–6.24

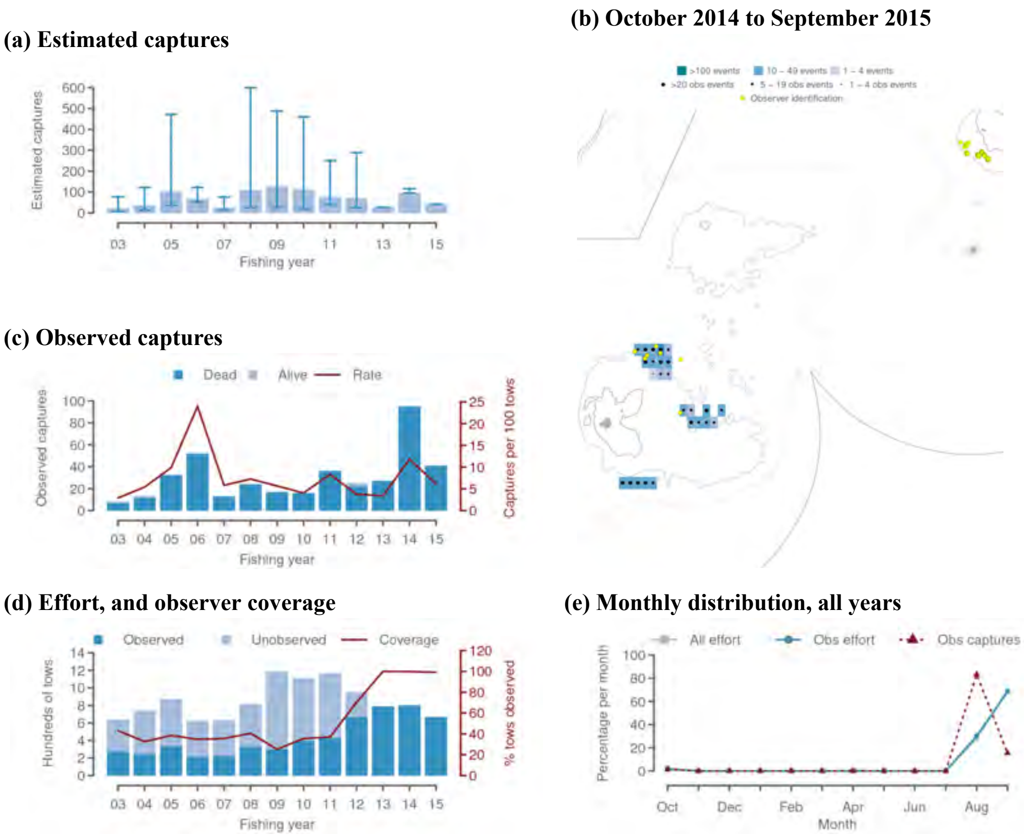


Figure A-8: New Zealand fur seal captures in southern blue whiting trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.4 New Zealand fur seal captures in squid trawl fisheries

Table A-10: Annual fishing effort (tows), and observer coverage (%) in squid trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 411	15.6	8	0.61	71	34–135	0.84	0.40–1.61
2003–04	8 336	21.2	16	0.90	106	54–203	1.27	0.65–2.44
2004–05	10 489	23.9	15	0.60	176	89–327	1.68	0.85–3.12
2005–06	8 576	12.9	4	0.36	111	50–219	1.29	0.58–2.55
2006–07	5 906	21.8	9	0.70	54	26–105	0.91	0.44–1.78
2007–08	4 236	34.4	6	0.41	40	17–83	0.94	0.40–1.96
2008–09	3 868	33.6	1	0.08	21	6–46	0.54	0.16–1.19
2009–10	3 789	28.3	8	0.75	37	18–76	0.98	0.48–2.01
2010–11	4 212	30.0	8	0.63	26	13–48	0.62	0.31–1.14
2011–12	3 506	39.4	8	0.58	26	12–56	0.74	0.34–1.60
2012–13	2 646	85.9	7	0.31	10	7–22	0.38	0.26–0.83
2013–14	2 051	87.1	10	0.56	11	10–16	0.54	0.49–0.78
2014–15	1 950	86.9	19	1.12	22	19–33	1.13	0.97–1.69

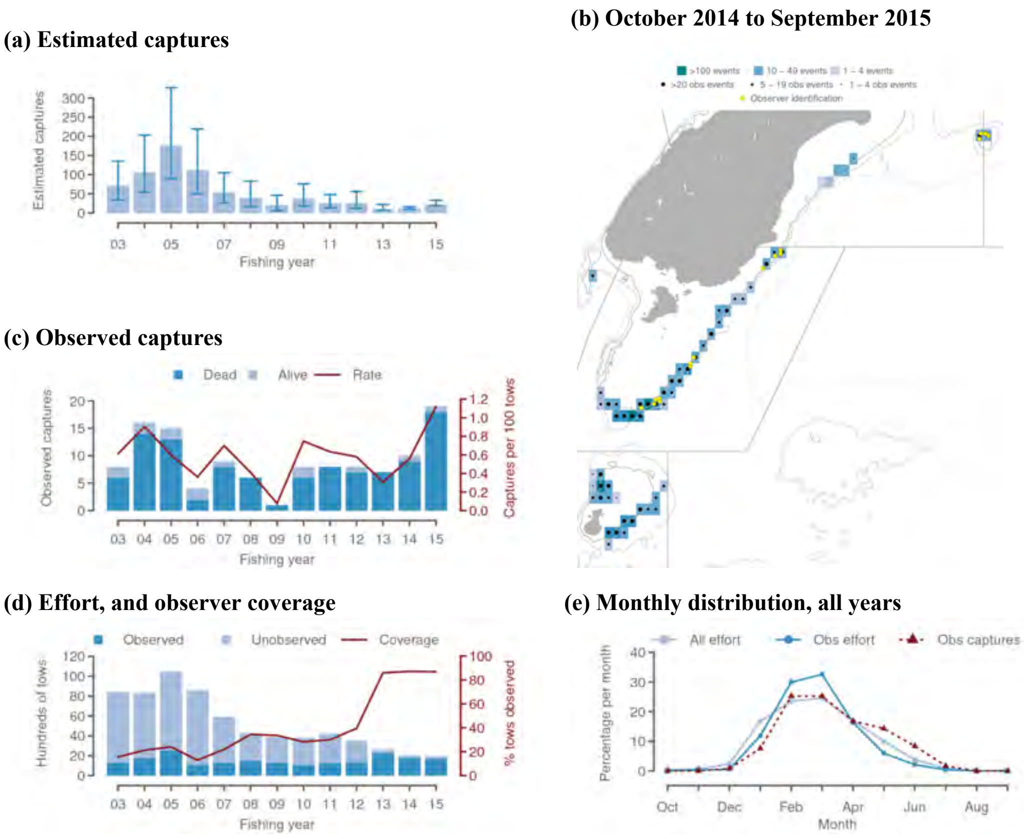


Figure A-9: New Zealand fur seal captures in squid trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.5 New Zealand fur seal captures in inshore species trawl fisheries

Table A-11: Annual fishing effort (tows), and observer coverage (%) in inshore species trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	36 550	0.0	0	0.00	51	9–143	0.14	0.02–0.39
2003–04	37 413	0.0	0	0.00	60	12–174	0.16	0.03–0.47
2004–05	40 825	0.0	0	0.00	114	25–325	0.28	0.06–0.80
2005–06	39 160	0.3	0	0.00	78	17–230	0.20	0.04–0.59
2006–07	35 822	0.8	0	0.00	47	10–134	0.13	0.03–0.37
2007–08	31 417	0.4	0	0.00	60	12–169	0.19	0.04–0.54
2008–09	33 099	3.9	1	0.08	41	10–112	0.12	0.03–0.34
2009–10	35 970	2.3	0	0.00	41	8–116	0.11	0.02–0.32
2010–11	34 984	1.5	0	0.00	41	8–113	0.12	0.02–0.32
2011–12	32 770	0.6	0	0.00	41	8–109	0.13	0.02–0.33
2012–13	33 248	0.5	1	0.59	40	10–110	0.12	0.03–0.33
2013–14	34 204	4.7	2	0.12	42	10–113	0.12	0.03–0.33
2014–15	30 407	6.9	2	0.10	48	12–130	0.16	0.04–0.43

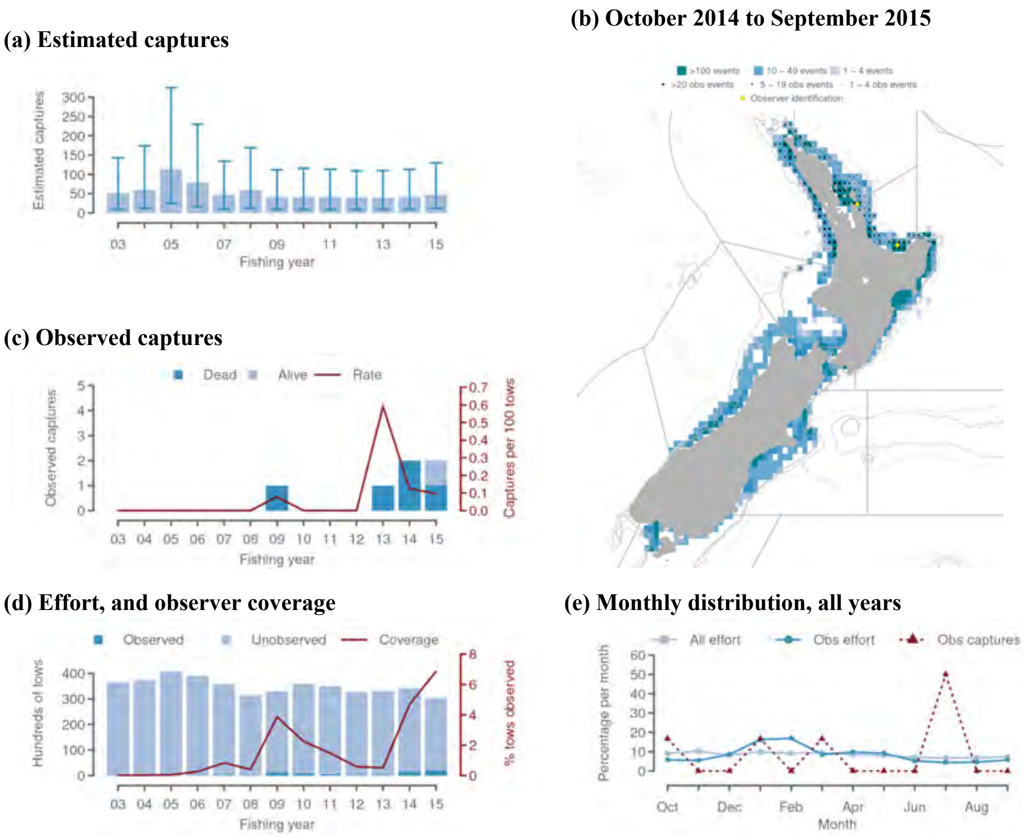


Figure A-10: New Zealand fur seal captures in inshore species trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.6 New Zealand fur seal captures in jack mackerel trawl fisheries

Table A-12: Annual fishing effort (tows), and observer coverage (%) in jack mackerel trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	3 067	11.3	1	0.29	18	5–42	0.59	0.16–1.37
2003–04	2 383	6.4	2	1.32	18	6–43	0.76	0.25–1.80
2004–05	2 509	22.2	5	0.90	29	10–68	1.16	0.40–2.71
2005–06	2 808	25.2	6	0.85	27	11–62	0.96	0.39–2.21
2006–07	2 711	29.6	2	0.25	13	4–35	0.48	0.15–1.29
2007–08	2 652	30.8	7	0.86	29	11–83	1.09	0.41–3.13
2008–09	2 169	37.5	8	0.98	16	9–33	0.74	0.41–1.52
2009–10	2 406	32.7	2	0.25	6	2–13	0.25	0.08–0.54
2010–11	1 881	31.5	0	0.00	3	0–10	0.16	0.00–0.53
2011–12	2 033	76.2	5	0.32	8	5–17	0.39	0.25–0.84
2012–13	2 210	87.6	4	0.21	4	3–9	0.18	0.14–0.41
2013–14	2 448	89.4	10	0.46	11	10–15	0.45	0.41–0.61
2014–15	1 750	86.6	5	0.33	6	5–11	0.34	0.29–0.63

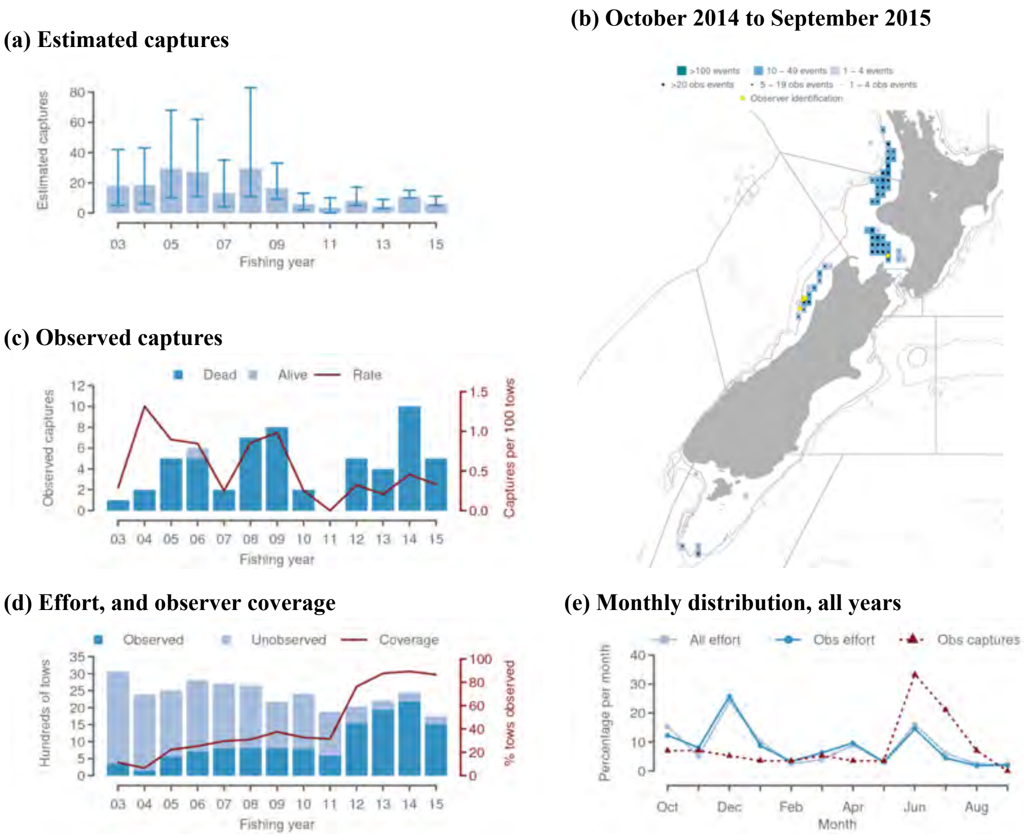


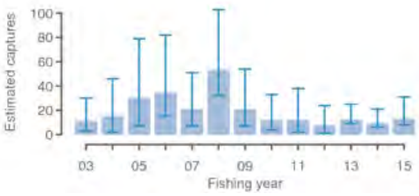
Figure A-11: New Zealand fur seal captures in jack mackerel trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.7 New Zealand fur seal captures in hake trawl fisheries

Table A-13: Annual fishing effort (tows), and observer coverage (%) in hake trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

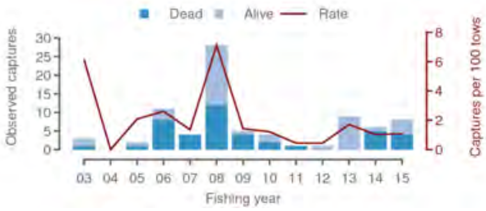
Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	945	5.2	3	6.12	11	3–30	1.16	0.32–3.17
2003–04	1 651	8.5	0	0.00	15	2–46	0.91	0.12–2.79
2004–05	1 556	6.2	2	2.08	30	7–79	1.93	0.45–5.08
2005–06	1 359	31.0	11	2.61	35	15–82	2.58	1.10–6.03
2006–07	1 606	18.4	4	1.35	21	7–51	1.31	0.44–3.18
2007–08	1 545	25.5	28	7.11	53	32–103	3.43	2.07–6.67
2008–09	1 779	19.7	5	1.42	21	7–54	1.18	0.39–3.04
2009–10	822	40.1	4	1.21	12	4–33	1.46	0.49–4.01
2010–11	870	26.1	1	0.44	12	2–38	1.38	0.23–4.37
2011–12	644	35.1	1	0.44	8	1–24	1.24	0.16–3.73
2012–13	708	74.6	9	1.70	12	9–25	1.69	1.27–3.53
2013–14	799	73.0	6	1.03	9	6–21	1.13	0.75–2.63
2014–15	973	76.6	8	1.07	13	8–31	1.34	0.82–3.19

(a) Estimated captures

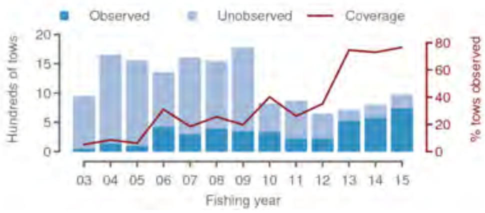


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

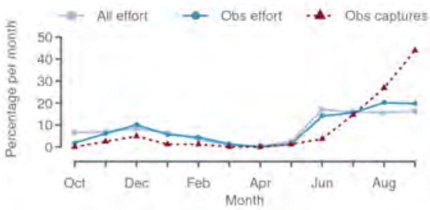


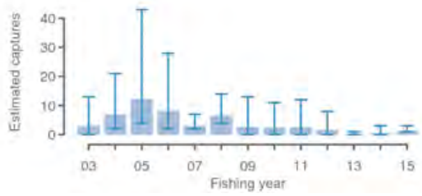
Figure A-12: New Zealand fur seal captures in hake trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.8 New Zealand fur seal captures in deepwater trawl fisheries

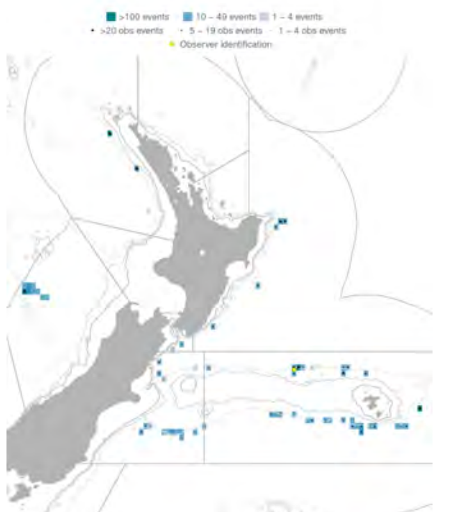
Table A-14: Annual fishing effort (tows), and observer coverage (%) in deepwater trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	8 869	15.6	0	0.00	3	0–13	0.03	0.00–0.15
2003–04	8 006	15.8	2	0.16	7	2–21	0.09	0.02–0.26
2004–05	8 420	19.2	4	0.25	12	4–43	0.14	0.05–0.51
2005–06	8 291	16.4	2	0.15	8	2–28	0.10	0.02–0.34
2006–07	7 368	31.6	2	0.09	3	2–7	0.04	0.03–0.10
2007–08	6 730	41.8	4	0.14	6	4–14	0.09	0.06–0.21
2008–09	6 132	38.7	0	0.00	3	0–13	0.05	0.00–0.21
2009–10	6 015	35.6	0	0.00	2	0–11	0.03	0.00–0.18
2010–11	4 178	28.8	0	0.00	3	0–12	0.07	0.00–0.29
2011–12	3 654	25.2	0	0.00	2	0–8	0.05	0.00–0.22
2012–13	3 098	11.2	0	0.00	0	0–1	0.00	0.00–0.03
2013–14	3 606	12.0	0	0.00	0	0–3	0.00	0.00–0.08
2014–15	3 782	25.9	1	0.10	1	1–3	0.03	0.03–0.08

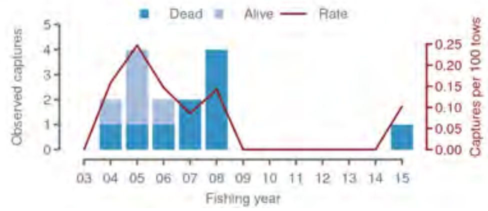
(a) Estimated captures



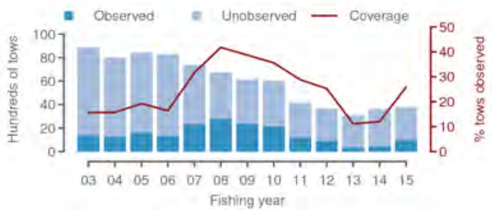
(b) October 2014 to September 2015



(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

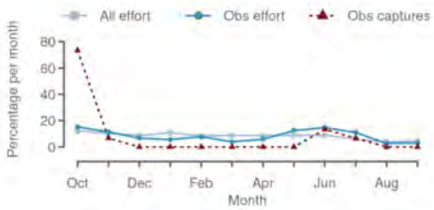


Figure A-13: New Zealand fur seal captures in deepwater trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.9 New Zealand fur seal captures in ling trawl fisheries

Table A-15: Annual fishing effort (tows), and observer coverage (%) in ling trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	632	2.5	0	0.00	8	0–31	1.27	0.00–4.91
2003–04	561	3.9	0	0.00	12	0–54	2.14	0.00–9.63
2004–05	988	7.7	10	13.16	43	15–128	4.35	1.52–12.96
2005–06	1 395	8.1	2	1.77	32	9–86	2.29	0.65–6.16
2006–07	1 661	9.5	12	7.64	35	17–78	2.11	1.02–4.70
2007–08	2 229	10.8	4	1.66	37	13–88	1.66	0.58–3.95
2008–09	1 410	10.3	0	0.00	23	5–60	1.63	0.35–4.26
2009–10	1 193	18.0	6	2.79	23	9–72	1.93	0.75–6.04
2010–11	1 103	9.4	2	1.92	18	5–50	1.63	0.45–4.53
2011–12	947	16.8	1	0.63	15	3–49	1.58	0.32–5.17
2012–13	1 149	23.3	4	1.49	15	5–39	1.31	0.44–3.39
2013–14	1 129	10.5	0	0.00	12	1–38	1.06	0.09–3.37
2014–15	1 128	16.1	1	0.55	15	3–45	1.33	0.27–3.99

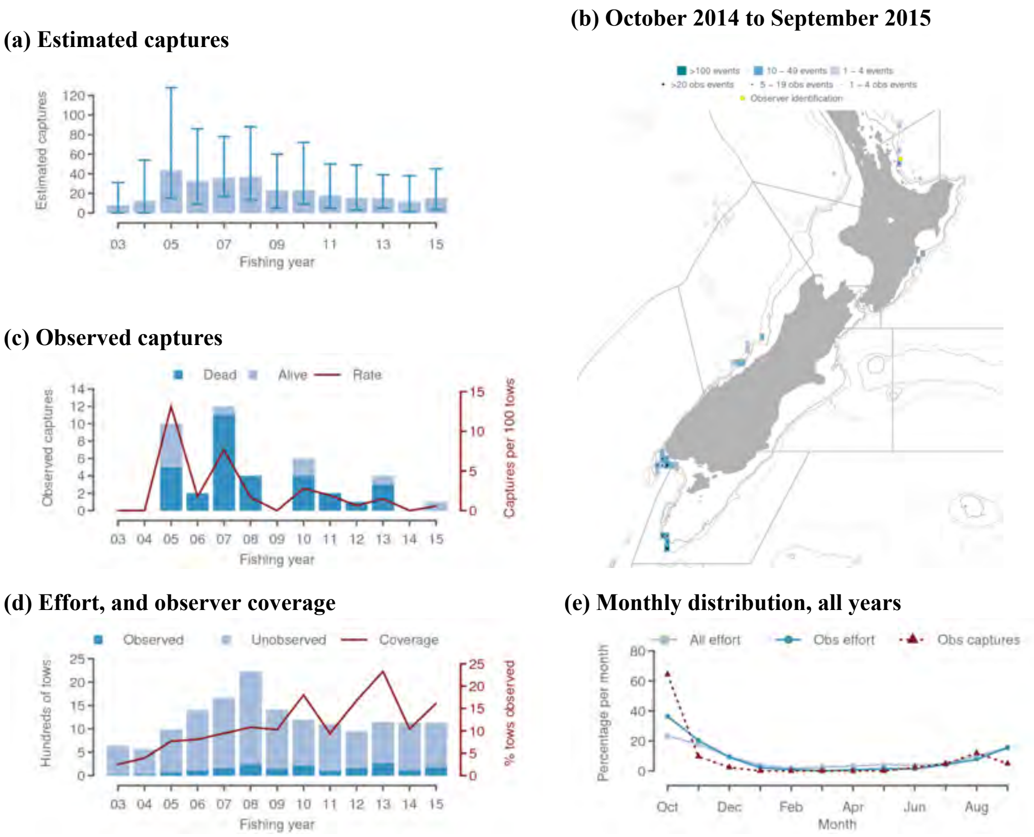


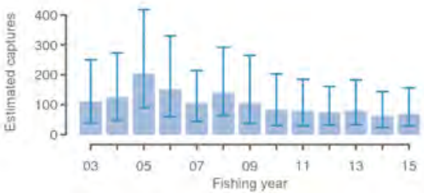
Figure A-14: New Zealand fur seal captures in ling trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.10 New Zealand fur seal captures in middle depths species trawl fisheries

Table A-16: Annual fishing effort (tows), and observer coverage (%) in middle depths species trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

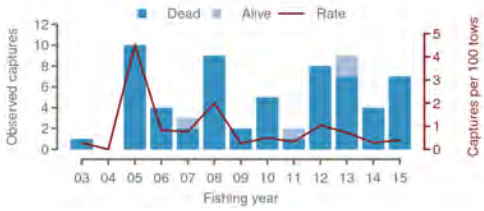
Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	11 176	3.1	1	0.29	111	40–250	0.99	0.36–2.24
2003–04	9 164	2.1	0	0.00	125	48–273	1.36	0.52–2.98
2004–05	9 183	2.4	10	4.50	204	91–418	2.22	0.99–4.55
2005–06	8 403	5.8	4	0.82	150	60–330	1.79	0.71–3.93
2006–07	8 197	4.8	3	0.76	105	44–214	1.28	0.54–2.61
2007–08	7 418	6.1	9	2.00	141	65–292	1.90	0.88–3.94
2008–09	7 233	10.7	2	0.26	105	37–265	1.45	0.51–3.66
2009–10	7 213	13.9	5	0.50	83	31–203	1.15	0.43–2.81
2010–11	7 254	8.5	2	0.32	80	30–185	1.10	0.41–2.55
2011–12	6 553	11.7	8	1.05	75	32–161	1.14	0.49–2.46
2012–13	6 467	19.3	9	0.72	80	33–183	1.24	0.51–2.83
2013–14	6 416	21.8	4	0.29	62	24–144	0.97	0.37–2.24
2014–15	6 439	27.5	7	0.40	70	29–156	1.09	0.45–2.42

(a) Estimated captures

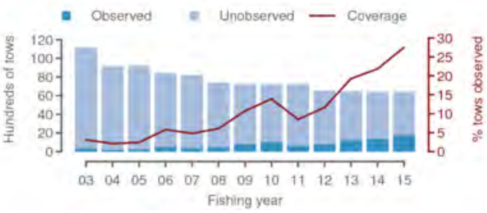


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

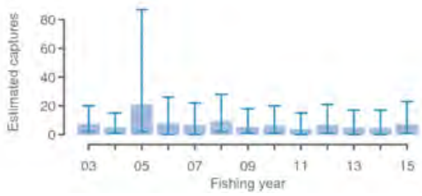
Figure A-15: New Zealand fur seal captures in middle depths species trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.11 New Zealand fur seal captures in scampi trawl fisheries

Table A-17: Annual fishing effort (tows), and observer coverage (%) in scampi trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

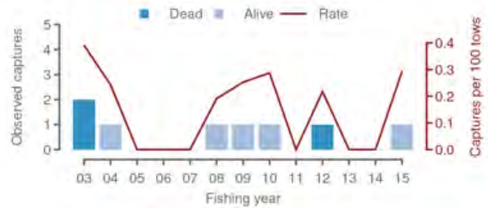
Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	5 130	10.0	2	0.39	7	2–20	0.14	0.04–0.39
2003–04	3 753	11.0	1	0.24	5	1–15	0.13	0.03–0.40
2004–05	4 648	3.1	0	0.00	21	2–87	0.45	0.04–1.87
2005–06	4 867	6.8	0	0.00	8	0–26	0.16	0.00–0.53
2006–07	5 135	7.6	0	0.00	7	0–22	0.14	0.00–0.43
2007–08	4 804	10.9	1	0.19	9	2–28	0.19	0.04–0.58
2008–09	3 975	10.0	1	0.25	5	1–18	0.13	0.03–0.45
2009–10	4 248	8.2	1	0.29	6	1–20	0.14	0.02–0.47
2010–11	4 447	12.1	0	0.00	4	0–15	0.09	0.00–0.34
2011–12	4 509	10.2	1	0.22	7	1–21	0.16	0.02–0.47
2012–13	4 566	5.9	0	0.00	5	0–17	0.11	0.00–0.37
2013–14	4 421	5.7	0	0.00	5	0–17	0.11	0.00–0.38
2014–15	4 423	7.7	1	0.29	7	1–23	0.16	0.02–0.52

(a) Estimated captures

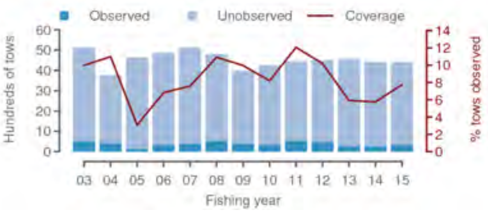


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

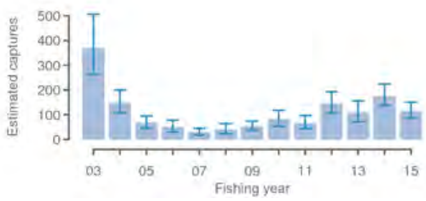
Figure A-16: New Zealand fur seal captures in scampi trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.2.12 New Zealand fur seal captures in surface-longline fisheries

Table A-18: Annual fishing effort (hooks), and observer coverage (%) in surface-longline fisheries; number of observed captures and observed capture rate (captures per thousand hooks) of New Zealand fur seal; estimated captures and capture rate of New Zealand fur seal (mean and 95% credible interval).

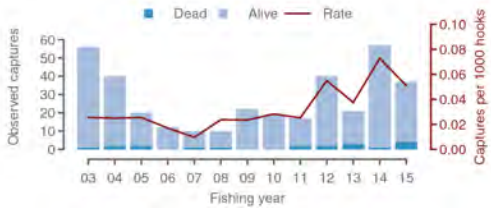
Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	10 770 038	20.4	56	0.026	369	262–507	0.034	0.024–0.047
2003–04	7 386 159	21.8	40	0.025	148	108–200	0.020	0.015–0.027
2004–05	3 679 965	21.3	20	0.026	68	46–95	0.018	0.013–0.026
2005–06	3 691 249	19.1	12	0.017	51	30–78	0.014	0.008–0.021
2006–07	3 739 962	27.8	10	0.010	29	18–45	0.008	0.005–0.012
2007–08	2 246 139	18.8	10	0.024	41	23–64	0.018	0.010–0.028
2008–09	3 115 633	30.1	22	0.023	54	38–74	0.017	0.012–0.024
2009–10	2 995 264	22.5	19	0.028	83	53–118	0.028	0.018–0.039
2010–11	3 188 179	21.2	17	0.025	67	43–97	0.021	0.013–0.030
2011–12	3 100 277	23.5	40	0.055	146	106–193	0.047	0.034–0.062
2012–13	2 876 932	19.5	21	0.037	109	71–156	0.038	0.025–0.054
2013–14	2 549 764	30.7	57	0.073	176	137–224	0.069	0.054–0.088
2014–15	2 407 236	30.1	37	0.051	116	87–151	0.048	0.036–0.063

(a) Estimated captures

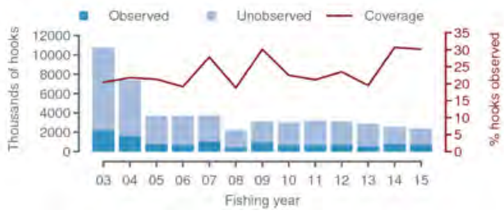


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

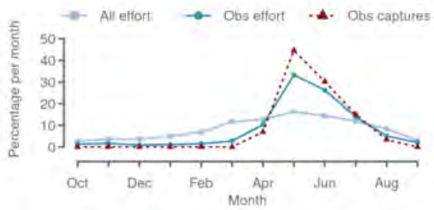


Figure A-17: New Zealand fur seal captures in surface-longline fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.3 New Zealand sea lion

A.3.1 New Zealand sea lion captures in all trawl fisheries

Table A-19: Annual fishing effort (tows), and observer coverage (%) in all trawl fisheries; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand sea lion; estimated captures and capture rate of New Zealand sea lion (mean and 95% credible interval); estimated interactions and interaction rate of New Zealand sea lion (mean and 95% credible intervals).

Fishing year	Effort	Observed			Est. captures		Est. capture rate		Est. interactions		Est. interaction rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i
1995–96	150 437	2.9	17	0.39	145	83–239	0.10	0.06–0.16	144	83–237	0.10	0.06–0.16
1996–97	161 023	3.0	29	0.61	151	102–220	0.09	0.06–0.14	151	101–222	0.09	0.06–0.14
1997–98	158 839	4.3	16	0.23	73	45–115	0.05	0.03–0.07	73	44–117	0.05	0.03–0.07
1998–99	153 617	4.7	6	0.08	30	18–46	0.02	0.01–0.03	30	18–46	0.02	0.01–0.03
1999–00	139 034	5.5	28	0.37	86	60–123	0.06	0.04–0.09	86	58–126	0.06	0.04–0.09
2000–01	134 190	6.8	47	0.52	59	51–69	0.04	0.04–0.05	81	60–106	0.06	0.04–0.08
2001–02	127 759	6.0	23	0.30	61	44–84	0.05	0.03–0.07	92	61–134	0.07	0.05–0.10
2002–03	130 139	5.3	12	0.18	31	21–44	0.02	0.02–0.03	59	36–93	0.05	0.03–0.07
2003–04	120 853	5.4	21	0.32	58	41–79	0.05	0.03–0.07	225	122–402	0.19	0.10–0.33
2004–05	120 448	6.4	14	0.18	50	33–72	0.04	0.03–0.06	187	95–344	0.16	0.08–0.29
2005–06	109 944	6.0	15	0.23	49	33–70	0.04	0.03–0.06	175	87–328	0.16	0.08–0.30
2006–07	103 300	7.7	12	0.15	42	27–60	0.04	0.03–0.06	119	57–245	0.12	0.06–0.24
2007–08	89 529	10.1	11	0.12	30	19–43	0.03	0.02–0.05	178	40–823	0.20	0.04–0.92
2008–09	87 548	11.4	3	0.03	19	10–32	0.02	0.01–0.04	146	25–686	0.17	0.03–0.78
2009–10	92 888	10.3	15	0.16	44	30–63	0.05	0.03–0.07	197	52–847	0.21	0.06–0.91
2010–11	86 085	8.8	6	0.08	27	16–40	0.03	0.02–0.05	113	27–519	0.13	0.03–0.60
2011–12	84 422	11.1	1	0.01	12	5–20	0.01	0.01–0.02	70	12–326	0.08	0.01–0.39
2012–13	83 842	14.8	25	0.20	32	27–39	0.04	0.03–0.05	120	51–437	0.14	0.06–0.52
2013–14	85 114	15.5	4	0.03	10	6–17	0.01	0.01–0.02	69	18–255	0.08	0.02–0.30
2014–15	78 696	17.3	8	0.06	12	8–17	0.02	0.01–0.02	81	27–281	0.10	0.03–0.36

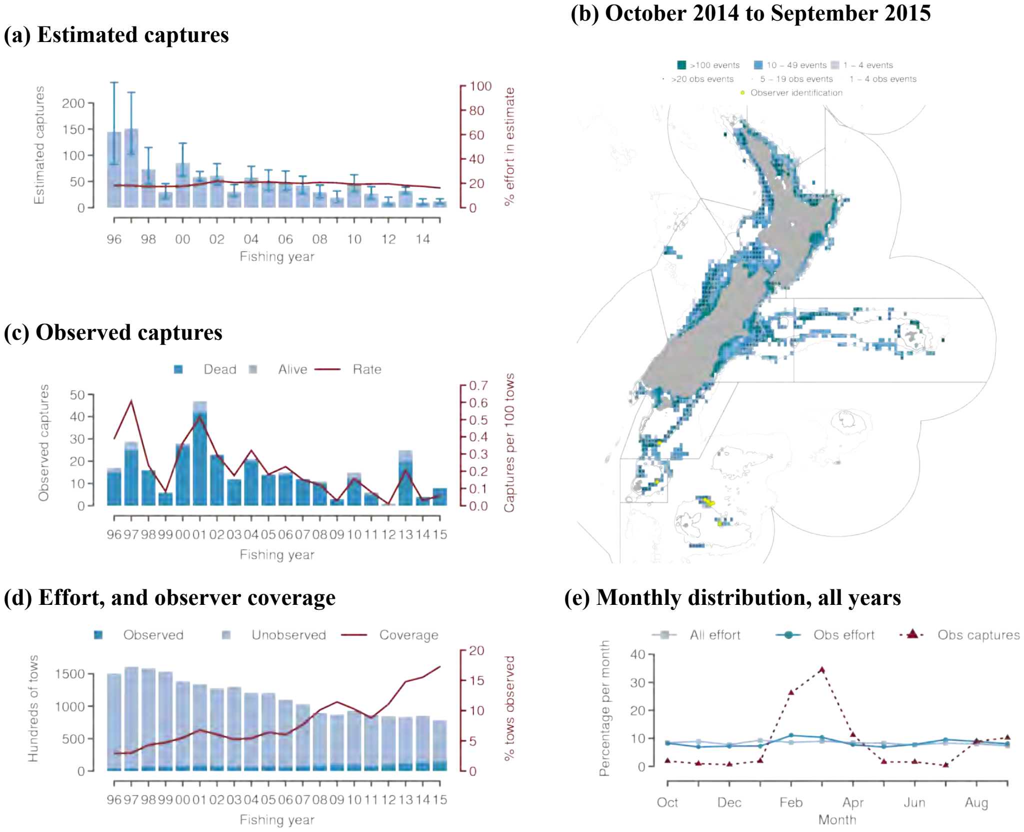


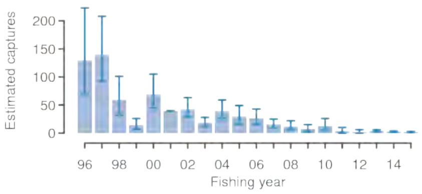
Figure A-18: New Zealand sea lion captures in all trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.3.2 New Zealand sea lion captures in squid trawl fisheries

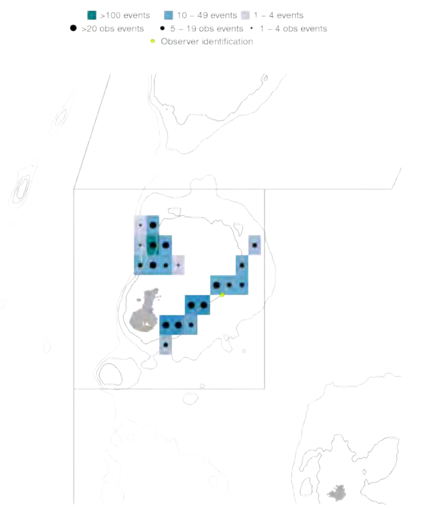
Table A-20: Annual fishing effort (tows), and observer coverage (%) in squid trawl fisheries in the Auckland Islands area; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand sea lion; estimated captures and capture rate of New Zealand sea lion (mean and 95% credible interval); estimated interactions and interaction rate of New Zealand sea lion (mean and 95% credible intervals).

Fishing year	Effort	Observed			Est. captures		Est. capture rate		Est. interactions		Est. interaction rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i
1995–96	4 468	12.5	13	2.33	130	69–223	2.90	1.54–4.99	129	69–223	2.89	1.54–4.99
1996–97	3 721	19.8	28	3.81	140	92–208	3.76	2.47–5.59	140	90–211	3.75	2.42–5.67
1997–98	1 442	23.2	15	4.48	59	32–101	4.11	2.22–7.00	59	31–102	4.10	2.15–7.07
1998–99	403	38.7	5	3.21	14	7–26	3.46	1.74–6.45	14	5–27	3.45	1.24–6.70
1999–00	1 206	36.3	25	5.71	69	45–105	5.70	3.73–8.71	69	44–107	5.72	3.65–8.87
2000–01	583	99.1	39	6.75	39	39–40	6.71	6.69–6.86	62	41–85	10.56	7.03–14.58
2001–02	1 647	34.2	21	3.73	42	29–63	2.58	1.76–3.83	73	44–114	4.44	2.67–6.92
2002–03	1 466	28.4	11	2.64	18	12–28	1.25	0.82–1.91	47	25–79	3.21	1.71–5.39
2003–04	2 594	30.6	16	2.02	39	26–59	1.51	1.00–2.27	206	104–383	7.96	4.01–14.76
2004–05	2 693	29.9	9	1.12	30	16–49	1.10	0.59–1.82	167	76–323	6.19	2.82–11.99
2005–06	2 459	22.4	10	1.82	26	15–43	1.07	0.61–1.75	153	65–306	6.22	2.64–12.44
2006–07	1 317	40.7	7	1.31	15	9–25	1.17	0.68–1.90	93	33–216	7.03	2.51–16.40
2007–08	1 265	46.7	5	0.85	12	6–22	0.92	0.47–1.74	160	24–804	12.64	1.90–63.56
2008–09	1 925	39.6	2	0.26	7	2–15	0.37	0.10–0.78	134	14–672	6.95	0.73–34.91
2009–10	1 188	25.5	3	0.99	12	5–26	1.03	0.42–2.19	165	22–818	13.87	1.85–68.86
2010–11	1 583	34.6	0	0.00	3	0–10	0.22	0.00–0.63	90	5–501	5.65	0.32–31.65
2011–12	1 281	44.6	0	0.00	2	0–6	0.14	0.00–0.47	60	3–319	4.68	0.23–24.90
2012–13	1 027	86.2	3	0.34	4	3–6	0.35	0.29–0.58	73	8–384	7.07	0.78–37.39
2013–14	737	84.4	2	0.32	2	2–4	0.32	0.27–0.54	47	5–231	6.35	0.68–31.34
2014–15	633	88.3	1	0.18	1	1–3	0.22	0.16–0.47	44	3–236	6.91	0.47–37.28

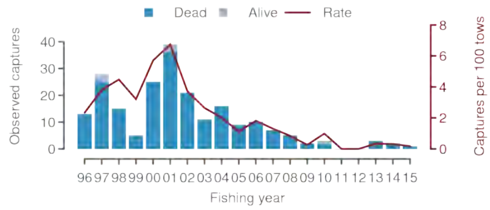
(a) Estimated captures



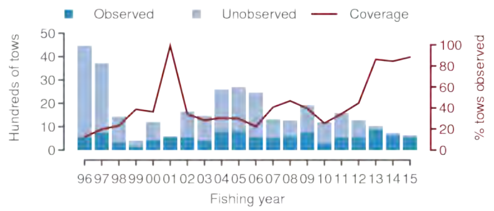
(b) October 2014 to September 2015



(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

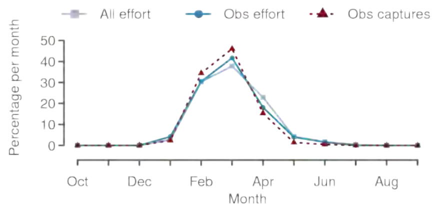


Figure A-19: New Zealand sea lion captures in squid trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.3.3 New Zealand sea lion captures in scampi and other trawl fisheries

Table A-21: Annual fishing effort (tows), and observer coverage (%) in scampi and other trawl fisheries in the Auckland Islands area; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand sea lion; estimated captures and capture rate of New Zealand sea lion (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
1995–96	1 718	5.4	3	3.26	12	6–20	0.70	0.35–1.16
1996–97	1 520	14.0	1	0.47	7	2–14	0.46	0.13–0.92
1997–98	1 797	14.2	1	0.39	9	3–17	0.50	0.17–0.95
1998–99	1 780	4.4	1	1.28	10	4–19	0.56	0.22–1.07
1999–00	2 134	8.1	0	0.00	10	3–19	0.47	0.14–0.89
2000–01	1 996	6.4	4	3.15	14	7–23	0.70	0.35–1.15
2001–02	2 192	8.1	0	0.00	11	3–20	0.50	0.14–0.91
2002–03	1 894	11.6	1	0.45	9	3–17	0.48	0.16–0.90
2003–04	1 652	13.2	3	1.38	11	5–19	0.67	0.30–1.15
2004–05	1 445	0.8	0	0.00	8	2–17	0.55	0.14–1.18
2005–06	1 370	9.1	1	0.81	9	3–16	0.66	0.22–1.17
2006–07	1 366	7.5	1	0.97	9	3–16	0.66	0.22–1.17
2007–08	1 474	10.8	0	0.00	8	2–16	0.54	0.14–1.09
2008–09	1 578	7.7	1	0.83	10	4–18	0.63	0.25–1.14
2009–10	1 017	14.2	0	0.00	5	1–11	0.49	0.10–1.08
2010–11	1 532	16.7	0	0.00	7	2–15	0.46	0.13–0.98
2011–12	1 304	10.4	0	0.00	7	2–14	0.54	0.15–1.07
2012–13	1 153	14.1	0	0.00	6	1–12	0.52	0.09–1.04
2013–14	1 053	9.4	0	0.00	5	1–11	0.47	0.09–1.04
2014–15	772	8.9	0	0.00	4	0–9	0.52	0.00–1.17

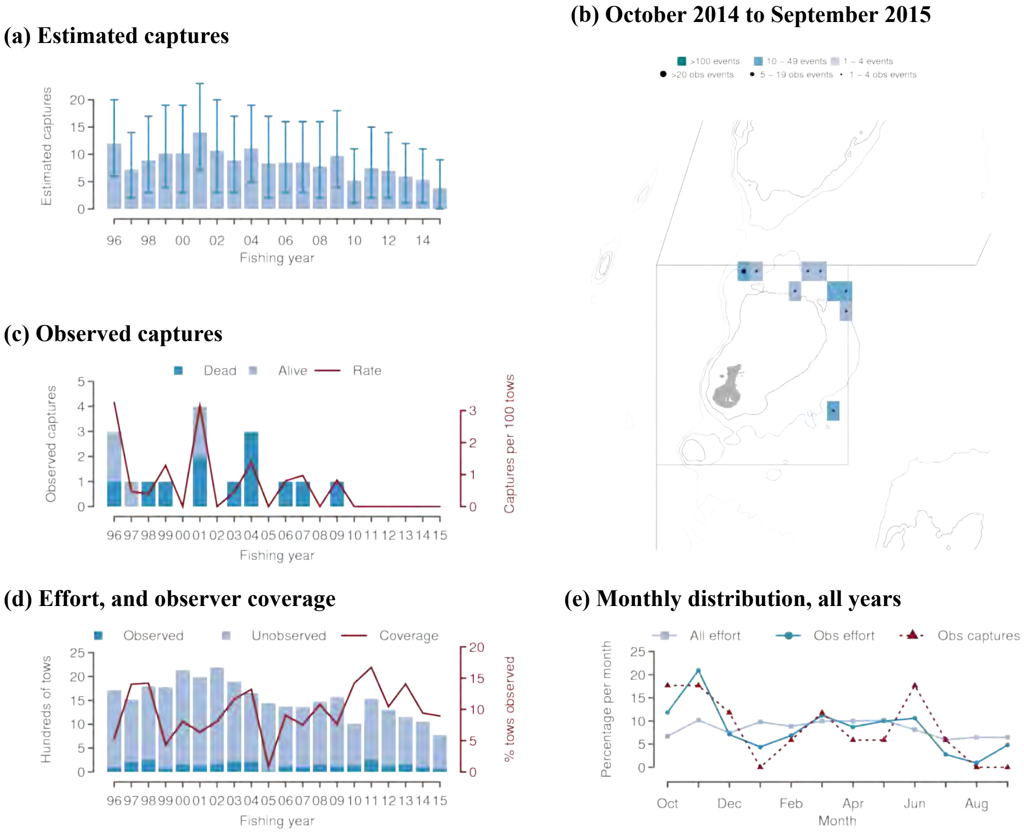


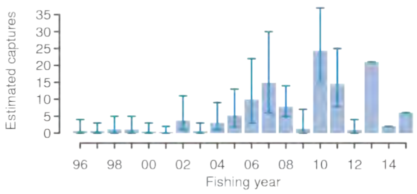
Figure A-20: New Zealand sea lion captures in scampi and other trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.3.4 New Zealand sea lion captures in southern blue whiting trawl fisheries

Table A-22: Annual fishing effort (tows), and observer coverage (%) in southern blue whiting trawl fisheries in the subantarctic area; number of observed captures and observed capture rate (captures per hundred tows) of New Zealand sea lion; estimated captures and capture rate of New Zealand sea lion (mean and 95% credible interval); estimated interactions and interaction rate of New Zealand sea lion (mean and 95% credible intervals).

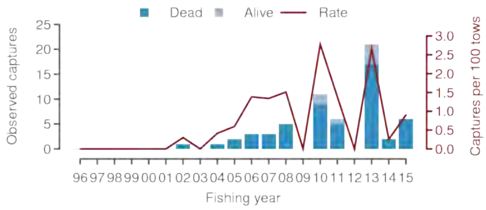
Fishing year	Effort	Observed			Est. captures		Est. capture rate		Est. interactions		Est. interaction rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i
1995–96	577	25.0	0	0.00	1	0–4	0.17	0.00–0.69	1	0–4	0.17	0.00–0.69
1996–97	625	39.8	0	0.00	1	0–3	0.16	0.00–0.48	1	0–3	0.16	0.00–0.48
1997–98	1 175	35.2	0	0.00	1	0–5	0.09	0.00–0.43	1	0–5	0.09	0.00–0.43
1998–99	1 236	27.3	0	0.00	1	0–5	0.08	0.00–0.40	1	0–5	0.08	0.00–0.40
1999–00	693	45.3	0	0.00	0	0–3	0.00	0.00–0.43	0	0–3	0.00	0.00–0.43
2000–01	663	58.4	0	0.00	0	0–2	0.00	0.00–0.30	0	0–2	0.00	0.00–0.30
2001–02	1 138	29.3	1	0.30	4	1–11	0.35	0.09–0.97	4	1–11	0.35	0.09–0.97
2002–03	638	43.1	0	0.00	1	0–3	0.16	0.00–0.47	1	0–3	0.16	0.00–0.47
2003–04	740	32.6	1	0.41	3	1–9	0.41	0.14–1.22	3	1–9	0.41	0.14–1.22
2004–05	870	38.5	2	0.60	5	2–13	0.57	0.23–1.49	5	2–13	0.57	0.23–1.49
2005–06	624	34.8	3	1.38	10	3–22	1.60	0.48–3.53	10	3–22	1.60	0.48–3.53
2006–07	630	35.6	3	1.34	15	6–30	2.38	0.95–4.76	15	6–30	2.38	0.95–4.76
2007–08	816	40.6	5	1.51	8	5–14	0.98	0.61–1.72	8	5–14	0.98	0.61–1.72
2008–09	1 185	25.1	0	0.00	1	0–7	0.08	0.00–0.59	1	0–7	0.08	0.00–0.59
2009–10	1 111	35.6	11	2.78	24	15–37	2.16	1.35–3.33	24	15–37	2.16	1.35–3.33
2010–11	1 171	37.0	6	1.39	15	8–25	1.28	0.68–2.13	15	8–25	1.28	0.68–2.13
2011–12	951	70.3	0	0.00	1	0–4	0.11	0.00–0.42	1	0–4	0.11	0.00–0.42
2012–13	790	100.0	21	2.66	21	21–21	2.66	2.66–2.66	40	28–54	5.06	3.54–6.84
2013–14	785	99.9	2	0.26	2	2–2	0.25	0.25–0.25	16	2–57	2.04	0.25–7.26
2014–15	666	100.2	6	0.90	6	6–6	0.90	0.90–0.90	32	11–72	4.80	1.65–10.81

(a) Estimated captures

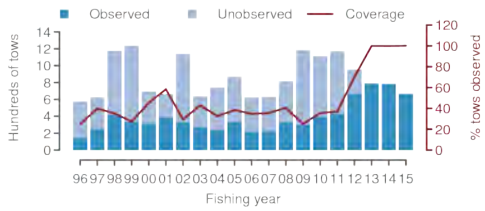


(b) October 2014 to September 2015

(c) Observed captures



(d) Effort, and observer coverage



(e) Monthly distribution, all years

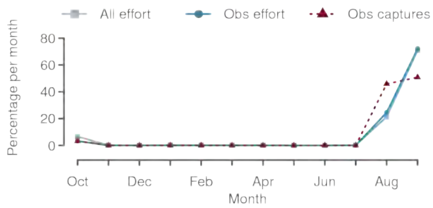


Figure A-21: New Zealand sea lion captures in southern blue whiting trawl fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

A.4 Turtles

A.4.1 Turtle captures in surface-longline fisheries

Table A-23: Annual fishing effort (hooks), and observer coverage (%) in surface-longline fisheries; number of observed captures and observed capture rate (captures per thousand hooks) of turtles; estimated captures and capture rate of turtles (mean and 95% credible interval).

Fishing year	Effort	Observed			Est. captures		Est. capture rate	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	10 770 038	20.4	0	0.000	57	0–176	0.005	0.000–0.016
2003–04	7 386 159	21.8	1	0.001	43	7–106	0.006	0.001–0.014
2004–05	3 679 965	21.3	2	0.003	34	9–83	0.009	0.002–0.023
2005–06	3 691 249	19.1	1	0.001	29	5–72	0.008	0.001–0.020
2006–07	3 739 962	27.8	2	0.002	20	5–43	0.005	0.001–0.011
2007–08	2 246 139	18.8	1	0.002	12	2–30	0.005	0.001–0.013
2008–09	3 115 633	30.1	2	0.002	24	7–54	0.008	0.002–0.017
2009–10	2 995 264	22.5	0	0.000	13	0–35	0.004	0.000–0.012
2010–11	3 188 179	21.2	4	0.006	41	15–92	0.013	0.005–0.029
2011–12	3 100 277	23.5	0	0.000	12	0–35	0.004	0.000–0.011
2012–13	2 876 932	19.5	2	0.004	26	7–69	0.009	0.002–0.024
2013–14	2 549 764	30.7	0	0.000	10	0–29	0.004	0.000–0.011
2014–15	2 407 236	30.1	1	0.001	13	2–35	0.005	0.001–0.015

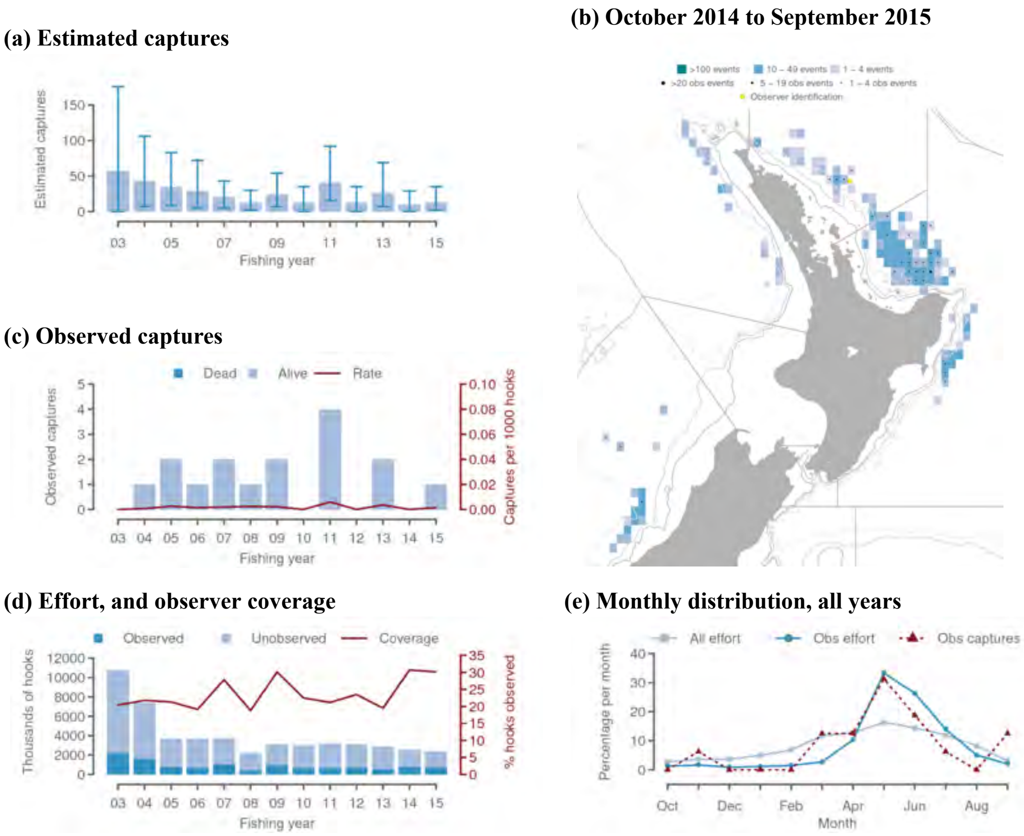


Figure A-22: Turtle captures in surface-longline fisheries. (a) Estimated captures, with 95% credible intervals, (b) Mapped effort and captures in 2014–15, coloured dots indicate observed captures, and the blue squares show fishing effort within 0.2 degree cells (because of confidentiality rules, some effort may not be displayed), (c) Observed captures, (d) Effort and observed effort, and (e) Monthly distribution of fishing effort, observed effort, and observed captures.

APPENDIX B: SUMMARIES OF MODEL PARAMETERS

B.1 Common dolphin model parameters

Table B-24: Summary of model parameters, for common dolphin captures in large-vessel West Coast North Island mackerel trawl. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Number of dolphin caught per capture event							
Poisson mean	2.096	2.093	1.754 – 2.473				
Base rates (capture events per 100 tows)							
Mean rate	0.322	0.316	0.188 – 0.487			28.9	
1995–96	0.798	0.562	0.076 – 2.954			9.9	
1996–97	0.387	0.247	0.022 – 1.581			5.8	
1997–98	0.352	0.229	0.020 – 1.410			10.6	
1998–99	0.373	0.239	0.021 – 1.522			5.5	
1999–00	0.853	0.590	0.084 – 3.225			4.3	
2000–01	0.650	0.486	0.073 – 2.187			0.3	
2001–02	0.556	0.420	0.064 – 1.793			5.0	
2002–03	2.064	1.878	0.660 – 4.535			1.7	
2003–04	1.495	1.379	0.518 – 3.184			6.5	
2004–05	1.028	0.974	0.455 – 1.910				
2005–06	0.174	0.147	0.028 – 0.466			7.7	
2006–07	0.433	0.402	0.149 – 0.904			5.8	
2007–08	0.324	0.298	0.108 – 0.676			2.4	
2008–09	0.309	0.282	0.098 – 0.667			4.0	
2009–10	0.197	0.174	0.043 – 0.483			5.5	
2010–11	0.437	0.405	0.153 – 0.906			9.9	
2011–12	0.105	0.095	0.033 – 0.229			5.8	
2012–13	0.144	0.135	0.056 – 0.283			12.9	
2013–14	0.087	0.081	0.030 – 0.179			7.4	
2014–15	0.187	0.178	0.081 – 0.351			9.5	
Headline depth, $\beta_{headline}$	-0.032	-0.032	-0.041 – -0.022				
Log trawl duration, $\beta_{duration}$	1.607	1.606	0.977 – 2.251				
Light condition, relative to Dark							
Light, $\exp(\beta_{light})$	0.352	0.340	0.198 – 0.574			2.6	
Black, $\exp(\beta_{black})$	1.105	1.048	0.494 – 2.043			2.2	
Sub-area, relative to North							
South, $\exp(\beta_{south})$	0.591	0.572	0.341 – 0.946				

Table B-25: Summary of model parameters, for common dolphin captures in all trawl fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Number of dolphin caught per capture event							
Poisson mean, WCNI pelagic trawl	2.10	2.09	1.75 – 2.47				
Poisson mean, other trawl	0.80	0.77	0.30 – 1.49				
Fishery-area base rate (capture events per 100 tows)							
Auckland Islands	0.005	0.002	0.000 – 0.027			6.4	
Bay of Plenty	0.074	0.034	0.002 – 0.390			18.4	
Chatham Rise	0.009	0.003	0.000 – 0.055			7.7	
Cook Strait	0.143	0.064	0.003 – 0.768			16.3	
East Coast North Island	0.074	0.034	0.002 – 0.399			15.5	
East Coast South Island	0.018	0.012	0.001 – 0.068			5.3	
Fiordland	0.032	0.007	0.000 – 0.220				
Kermadec	1.546	0.022	0.000 – 7.541			6.4	
Northland-Hauraki	0.023	0.005	0.000 – 0.155			3.4	
Stewart-Snares	0.003	0.001	0.000 – 0.016			2.1	
Subantarctic	0.006	0.002	0.000 – 0.034			7.1	
Taranaki	1.769	1.174	0.163 – 6.989			31.9	
Taranaki, pelagic	0.412	0.409	0.292 – 0.554				
West Coast North Island	0.304	0.164	0.014 – 1.465			23.7	
West Coast North Island, pelagic	1.930	1.913	1.370 – 2.580				
West Coast South Island	0.014	0.012	0.002 – 0.039				
Vessel size effect (relative to vessels over 90 m)							
< 28	1.00	0.66	0.11 – 4.04			34.4	
28–90	0.07	0.04	0.00 – 0.34			9.7	

B.2 Fur seal capture model parameters

Table B-26: Summary of model parameters, for New Zealand fur seal captures in all trawl fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base rate (captures per 100 tows)							
2002–03	0.230	0.226	0.146 – 0.340			59.4	
2003–04	0.284	0.278	0.181 – 0.422			59.3	
2004–05	0.443	0.433	0.285 – 0.656			65.4	
2005–06	0.328	0.321	0.211 – 0.484			58.3	
2006–07	0.239	0.235	0.152 – 0.355			59.7	
2007–08	0.360	0.352	0.233 – 0.529			60.3	
2008–09	0.222	0.217	0.138 – 0.331			60.1	
2009–10	0.201	0.197	0.127 – 0.297			58.5	
2010–11	0.201	0.196	0.123 – 0.307			58.2	
2011–12	0.199	0.195	0.125 – 0.296			56.3	
2012–13	0.207	0.203	0.132 – 0.303			61.1	
2013–14	0.185	0.181	0.116 – 0.275			63.2	
2014–15	0.246	0.241	0.158 – 0.358			60.0	
Day of year coefficient							
Sine coefficient	-1.018	-1.017	-1.205 – -0.839			24.1	
Cosine coefficient	-0.942	-0.942	-1.128 – -0.755			27.6	
Area effect, relative to Stewart-Snares shelf							
East Coast South Island	1.251	1.231	0.870 – 1.740			39.4	
West Coast South Island	0.832	0.817	0.558 – 1.197			57.7	
Auckland Islands	0.209	0.202	0.117 – 0.336			6.8	
West Coast North Island	0.331	0.316	0.173 – 0.575			29.4	
Subantarctic	6.312	5.586	1.948 – 14.795			83.9	
Campbell Island	1.230	1.089	0.389 – 2.870			92.4	
Cook Strait	2.137	2.068	1.255 – 3.419			53.6	
Puysegur	1.052	1.013	0.564 – 1.761			30.4	
Bounty Islands	19.469	17.131	5.989 – 46.351			92.8	
North-eastern New Zealand	0.076	0.067	0.018 – 0.185			43.6	
Fishery effect, relative to Hoki/Hake/Ling							
Squid	2.788	2.730	1.825 – 4.099			26.4	
Deepwater	0.010	0.007	0.001 – 0.033			81.5	
Middle depth	0.805	0.794	0.557 – 1.122			12.6	
Jack mackerel	1.119	1.089	0.679 – 1.728			9.0	
Southern blue whiting	0.798	0.700	0.275 – 1.885			92.9	
Scampi	0.356	0.328	0.135 – 0.729			3.4	
Inshore	0.205	0.187	0.066 – 0.445				
Distance coefficients relative to Near (between 25 km and 90 km)							
Coastal (< 25 km)	1.985	1.960	1.450 – 2.637			17.4	
Far (> 90 km & < 180 km)	0.840	0.831	0.630 – 1.096			23.3	
Ocean (> 180 km)	0.396	0.383	0.222 – 0.641			8.9	
Fishery-area interaction							
Deepwater-Subantarctic	27.594	15.011	2.913 – 129.656			71.5	
Overdispersion							
$1/\theta$	15.047	14.941	11.074 – 19.557			94.7	
Vessel-year effect							
Standard deviation	0.719	0.718	0.594 – 0.853			66.8	

Table B-27: Summary of model parameters, for New Zealand fur seal captures in surface-longline fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base capture rate (captures per 1000 hooks)							
Intercept	0.0514	0.0508	0.0365 – 0.0700			30.0	
Fishery effect, relative to southern bluefin tuna							
Bigeye tuna	0.064	0.053	0.007 – 0.186				
Other surface longline	0.038	0.031	0.004 – 0.108				
Area effect, relative to West Coast South Island							
Eastern North Island	1.662	1.625	1.083 – 2.442			24.5	
Kermadec	0.096	0.001	0.000 – 0.888				
Other North Island	0.691	0.625	0.218 – 1.511				
Other South Island	0.614	0.604	0.425 – 0.857			29.5	
Year effect (multiplier)							
2002–03	1.485	1.461	0.955 – 2.153			6.1	
2003–04	0.764	0.752	0.464 – 1.133			2.0	
2004–05	0.610	0.598	0.337 – 0.966			2.5	
2005–06	0.539	0.521	0.272 – 0.897				
2006–07	0.290	0.278	0.136 – 0.508			3.6	
2007–08	0.745	0.719	0.366 – 1.263				
2008–09	0.691	0.678	0.393 – 1.076			7.3	
2009–10	0.892	0.871	0.503 – 1.411				
2010–11	0.843	0.823	0.464 – 1.353				
2011–12	1.602	1.569	1.004 – 2.389				
2012–13	1.206	1.175	0.703 – 1.877				
2013–14	2.052	2.012	1.339 – 2.995			4.9	
2014–15	1.279	1.253	0.788 – 1.926			7.7	

B.3 Sea lion model parameters

Table B-28: Summary of model parameters, for New Zealand sea lion captures in Auckland Islands squid trawl fisheries, with a single SLED retention probability. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base rate (captures per 100 tows)							
1995–96	0.738	0.698	0.354 – 1.344			28.8	
1996–97	1.242	1.189	0.676 – 2.112			15.1	
1997–98	1.056	0.996	0.489 – 1.989			7.1	
1998–99	0.966	0.890	0.373 – 1.985			3.2	
1999–00	1.817	1.703	0.918 – 3.428			12.7	
2000–01	2.812	2.688	1.488 – 4.817			7.9	
2001–02	1.161	1.105	0.593 – 2.062			6.6	
2002–03	0.810	0.771	0.374 – 1.485				
2003–04	1.893	1.820	0.989 – 3.272			9.1	
2004–05	1.461	1.381	0.695 – 2.710			2.8	
2005–06	1.165	1.108	0.544 – 2.111				
2006–07	1.207	1.139	0.535 – 2.256				
2007–08	1.012	0.949	0.402 – 1.981			5.5	
2008–09	0.589	0.548	0.186 – 1.231			8.0	
2009–10	1.129	1.038	0.403 – 2.392			6.9	
2010–11	0.573	0.524	0.122 – 1.290			10.1	
2011–12	0.584	0.529	0.121 – 1.330			16.6	
2012–13	0.780	0.734	0.274 – 1.560			6.1	
2013–14	0.857	0.787	0.272 – 1.832			5.0	
2014–15	0.669	0.617	0.180 – 1.447			10.0	
Tow duration	0.558	0.556	0.242 – 0.875			7.8	
Distance to colony	-0.658	-0.658	-1.109 – -0.221				
Subarea, relative to North and West							
South and East	0.439	0.433	0.298 – 0.619			5.7	
SLED retention probability	0.148	0.143	0.087 – 0.243			12.6	
Vessel-year effect							
Standard deviation	0.538	0.542	0.194 – 0.867			93.8	
Overdispersion							
$1/\theta$	2.831	2.705	1.037 – 5.263			99.4	

Table B-29: Summary of model parameters, for New Zealand sea lion captures in Auckland Islands squid trawl fisheries, with a split SLED retention probability. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base rate (captures per 100 tows)							
1995–96	0.865	0.817	0.379 – 1.631			35.7	
1996–97	1.377	1.326	0.723 – 2.364			14.8	
1997–98	1.202	1.143	0.543 – 2.250			9.0	
1998–99	1.100	1.025	0.394 – 2.224			12.2	
1999–00	1.945	1.838	0.973 – 3.559			14.2	
2000–01	2.875	2.766	1.506 – 4.910			16.1	
2001–02	1.284	1.226	0.640 – 2.273				
2002–03	0.931	0.883	0.392 – 1.722			22.6	
2003–04	1.866	1.779	1.042 – 3.179			8.0	
2004–05	1.490	1.420	0.737 – 2.656			6.2	
2005–06	1.209	1.164	0.592 – 2.117			2.2	
2006–07	1.253	1.195	0.569 – 2.307			7.1	
2007–08	1.205	1.125	0.432 – 2.446			18.2	
2008–09	0.749	0.688	0.197 – 1.624			47.5	
2009–10	1.328	1.221	0.430 – 2.886			9.7	
2010–11	0.758	0.692	0.145 – 1.735			37.9	
2011–12	0.768	0.700	0.146 – 1.777			47.9	
2012–13	0.992	0.926	0.296 – 2.073			25.8	
2013–14	1.053	0.978	0.301 – 2.218			21.3	
2014–15	0.871	0.801	0.205 – 1.921			31.4	
Tow duration	0.550	0.547	0.238 – 0.879				
Distance to colony	-0.661	-0.658	-1.117 – -0.212				
Subarea, relative to North and West							
South and East	0.447	0.441	0.306 – 0.633			15.9	
SLED retention probability							
Earlier period	0.174	0.168	0.091 – 0.293			19.9	
Later period	0.106	0.061	0.008 – 0.492			45.1	
Change year	2006	2007	2005 – 2007			10.5	
Vessel-year effect							
Standard deviation	0.554	0.560	0.186 – 0.889			91.2	
Overdispersion							
$1/\theta$	2.829	2.767	1.105 – 5.070			99.4	

Table B-30: Summary of model parameters, for New Zealand sea lion captures in Campbell Island southern blue whiting trawl fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base rate (captures per 100 tows)							
1995–96	0.232	0.105	0.001 – 1.209			14.3	
1996–97	0.168	0.082	0.001 – 0.832			21.3	
1997–98	0.146	0.073	0.000 – 0.697			20.8	
1998–99	0.165	0.081	0.000 – 0.819			25.4	
1999–00	0.160	0.079	0.001 – 0.777			24.4	
2000–01	0.111	0.058	0.000 – 0.526			27.2	
2001–02	0.395	0.297	0.025 – 1.301				
2002–03	0.148	0.074	0.000 – 0.721			27.0	
2003–04	0.452	0.336	0.030 – 1.549				
2004–05	0.714	0.603	0.106 – 1.931				
2005–06	1.849	1.641	0.392 – 4.485				
2006–07	3.192	2.989	1.136 – 6.355			1.6	
2007–08	0.826	0.697	0.122 – 2.242	1			
2008–09	0.248	0.111	0.001 – 1.325			18.1	
2009–10	4.448	4.313	2.200 – 7.488				
2010–11	1.640	1.544	0.602 – 3.232				
2011–12	0.103	0.054	0.000 – 0.485			27.4	
2012–13	5.643	5.535	3.388 – 8.455			4.1	
2013–14	2.700	1.965	0.264 – 9.525				
2014–15	5.615	5.069	1.634 – 12.750			2.2	
SLED retention probability	0.128	0.115	0.044 – 0.282				

Table B-31: Summary of model parameters, for New Zealand sea lion captures in other trawl fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base rate (captures per 100 tows)							
All years	0.096	0.094	0.059 – 0.141				
Fishery-area strata, relative to all trawl, Stewart-Snares shelf							
Scampi trawl, Auckland Islands	8.283	7.771	3.562 – 15.984				
Other trawl, Auckland Islands	4.590	3.905	0.859 – 12.310				

B.4 Turtle capture model parameters

Table B-32: Summary of model parameters, for turtle captures in surface-longline fisheries. For each parameter, the table gives summary statistics of the posterior distribution (mean, median, and 95% credible interval, based on the 2.5% and 97.5% quantiles), and diagnostics (the number of chains that fail convergence and half-width tests) (Heidelberger & Welch 1983), and the reduction in the effective length of the chains due to autocorrelation. Trace plots of the chains are also shown.

Parameter	Statistic			Diagnostics			
	Mean	Median	95% c.i.	Conv.	H.W.	Loss (%)	Trace
Base capture rate (captures per 1000 hooks)							
Intercept	0.0074	0.0070	0.0029 – 0.0143			5.4	
Vessel size effect (multiplier), relative to small vessels							
Large vessels, 45 m or over	0.063	0.031	0.001 – 0.319				
Area effect (multiplier), relative to East Coast North Island							
Kermadec	8.557	6.379	1.101 – 29.036			2.8	
Other North Island	1.719	1.445	0.449 – 4.535				
Other South Island	0.233	0.001	0.000 – 1.310				
West Coast South Island	0.069	0.001	0.000 – 0.653				
Year effect (multiplier)							
2002–03	0.714	0.673	0.011 – 1.913			8.1	
2003–04	0.912	0.866	0.149 – 2.110			5.0	
2004–05	1.282	1.115	0.364 – 3.160				
2005–06	0.984	0.924	0.179 – 2.291				
2006–07	0.814	0.781	0.155 – 1.781			3.0	
2007–08	0.862	0.825	0.141 – 1.959				
2008–09	1.171	1.057	0.313 – 2.738			3.2	
2009–10	0.638	0.606	0.016 – 1.518			18.3	
2010–11	1.632	1.399	0.624 – 3.899			17.0	
2011–12	0.694	0.669	0.023 – 1.711			6.9	
2012–13	1.460	1.230	0.425 – 3.723			6.4	
2013–14	0.770	0.742	0.028 – 1.880			3.3	
2014–15	1.098	0.987	0.210 – 2.771			8.5	