Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2008–09

Finlay N. Thompson
Edward R. Abraham

Dragonfly
PO Box 27535
Wellington 6141

New Zealand Aquatic Environment and Biodiversity Report No. ??
2010

Published by Ministry of Fisheries
Wellington
2010

ISSN 1176-9440

Citation:
Thompson, F.N.; Abraham, E.R. (2010).
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. ??.

This series continues the
Marine Biodiversity Biosecurity Report series
which ceased with No. 7 in February 2005.

EXECUTIVE SUMMARY

Thompson, F.N.; Abraham, E.R. (2010). 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. ??

In this report, the number of New Zealand sea lion (*Phocarctos hookeri*) captures in New Zealand's trawl fisheries are estimated for the 1995–96 to 2008–09 fishing years. Ministry of Fisheries observers reported the capture of three New Zealand sea lions (*Phocarctos hookeri*) during the 2008–09 fishing year. This was the lowest number of observed captures in the period covered by the data. The captures were reported from fisheries around the Auckland Islands: two sea lions were caught by trawlers targeting squid, and one sea lion was caught on a tow targeting scampi. Five sea lion captures were reported by fishers, from vessels targeting squid near the Auckland Islands. Two of these animals were among those reported by the observers, resulting in a total of six reported sea lion captures during the 2008–09 fishing year.

From the observed captures, estimates of total captures were made for four different strata: trawl effort targeting squid near the Auckland Islands, other trawl effort near the Auckland Islands, trawl effort targeting southern blue-whiting near Campbell Island, and all trawl effort on the southern end of the Stewart-Snares shelf. Estimates of sea lion captures were calculated for each of these strata, and a single total estimate calculated by combining the output from all strata. The statistical methods used to make the estimates followed those used for estimating captures in 2006–07 and 2007–08.

There were 1925 tows targeting squid in the Auckland Island fishery in 2008–09, a 52% increase from the 2007–08 fishing year. In 2008–09, it was estimated that 9 (95% c.i.: 3 to 21) sea lions were captured in this fishery. This was the lowest number of estimated captures in the period covered by the data. Trawlers fishing for squid near the Auckland Islands (within the SQU6T area) use Sea Lion Exclusion Devices (SLEDs) to reduce the number of captures. These consist of a grid fitted before the codend of the net, with an open hole above the grid that sea lions can pass through. The model also estimated the number of interactions, the number of sea lions that would have been caught if no SLEDs were used. In 2008–09, the number of interactions in the Auckland Islands squid fishery was estimated at 56 (95% c.i.: 16 to 131), with a corresponding strike rate of 3.0 (95% c.i.: 0.9 to 6.4) interactions per 100 tows. This was one of the lowest strike rates within the period of the data, but was not significantly different from the strike rate of 5.65 interactions per 100 tows assumed by the Ministry of Fisheries in setting management objectives for the squid fishery.

There was a small increase in trawl effort targeting southern blue-whiting near Campbell Island, 609 tows in 2008–09 compared with 552 in 2007–08. Estimated captures in this fishery peaked at 16 (95% c.i.: 8 to 28) in the 2007 calendar year, but fell to 1 (95% c.i.: 0 to 5) in 2009.

Observed sea lion captures in other fisheries have been sporadic, and captures in these fisheries were estimated using ratio methods that assumed a constant strike rate over the period of the data. This resulted in estimates for 2008–09 of 13 (95% c.i.: 7 to 19) captures in non-squid fisheries near the Auckland Islands, and 3 (95% c.i.: 1 to 4) captures in squid fisheries on the southern Stewart-Snares shelf.

Taken together, the total estimated captures for 2008–09 were 25 (95% c.i: 16 to 39). This was the lowest number of estimated captures in 14 year period covered by the data. If interactions in the Auckland Islands squid fishery were included, the total increased to 72 (95% c.i.: 30 to 148).

1. INTRODUCTION

An endemic species, the New Zealand sea lion (*Phocarctos hookeri*) is considered to be threatened (range restricted) by the New Zealand threat management classification system (Hitchmough et al. 2007). In 2006, the population was estimated as 12 000 individuals (95% confidence interval: 10 259–13 625) (Campbell et al. 2006). In October 2008, they were added to the International Union for the Conservation of Nature and Natural Resources Red List of endangered species (IUCN 2008). New Zealand sea lions are currently considered to be vulnerable due to an almost 50% decline in pup production between 1998 and 2009 (Department of Conservation 2009).

The largest breeding colonies of New Zealand sea lion are on the Auckland Islands and on Campbell Island (Chilvers 2008), and sea lions are caught by trawlers operating in New Zealand's subantarctic. Under the Marine Mammals Protection Act 1978, New Zealand's Ministry of Fisheries is required to manage the impact of commercial fishing operations on sea lions. The Ministry runs an observer programme that monitors the capture of New Zealand sea lions by commercial fishers. Observers have reported sea lion captures in the Auckland Islands squid fishery, other trawl fisheries close to the Auckland Islands, the squid fishery at the southern end of the Stewart-Snares shelf, and in the southern blue whiting fishery near Campbell Island (Abraham et al. 2010).

This report uses the observer data to calculate metrics that are required by the Ministry of Fisheries for managing fisheries that capture sea lions. Observers are only present during some tows, and so statistical methods are required to extrapolate from captures on observed tows to captures on all tows. This report updates past reports (Thompson & Abraham 2009, Thompson et al. 2010) to include data from the 2008–09 fishing year. The same methods, Bayesian generalized linear models and using ratio estimation, that were used by Thompson et al. (2010) were used to estimate captures of sea lions for the four strata listed in Table 1. The methods and the presentation of the results, in this report closely follows the previous report (Thompson et al. 2010).

The data set used to fit the models, and make the ratio estimates, ranged over a fourteen year period from 1 October 1995 to 30 September 2009. The model used to estimate captures in the Auckland Islands squid fishery was a re-implementation of the Smith & Baird (2007b) Bayesian model, originally used to estimate captures in the 2004–05 fishing year. A simpler model was used to estimate captures in the southern blue whiting fishery east of Campbell Island, and ratio estimates are presented for the remaining two strata.

Table 1: Strata used for estimating sea lion captures.

Stratum		Estimation method
Area	Fisheries	
Auckland Islands	Squid trawl	Bayesian model
Campbell Island	Southern blue whiting trawl	Bayesian model
Auckland Islands	Other (non-squid) trawl	Ratio estimate
Stewart Snares shelf	Squid trawl	Ratio estimate

2. METHODS

2.1 Terminology

In 2001 a new bycatch mitigation method, the sea lion exclusion device (SLED), was introduced in the Auckland Islands squid fishery (specifically squid fishing within the SQU6T area) (Figure 1). Since 2004–05 almost all vessels operating in this fishery have used SLEDs that have been approved by the Ministry of Fisheries. A schematic diagram showing the various reported quantities, for tows with SLEDs, is given in Figure 2. The terminology used in this report is detailed in Table 2. On tows with SLEDs, some sea lions escape from the nets. A key metric is an estimate of the total number of sea lions that would have been caught, on both observed and not observed tows, if no SLEDs had been used. This is referred to as the interactions (Figure 2(f)). The number of interactions represents the maximum direct impact of the fishery on the sea lions. The number of sea lions excluded by SLEDs may be calculated as the difference between the interactions and the captures (Figure 2(c)). The interactions may be converted to strike rates (interactions per 100 tows) and these allow comparison between years and fisheries where there have been different numbers of tows.

In fisheries where SLEDS are not used, the terms interactions and captures are synonymous. In the Auckland Islands squid fishery, during the period 1995–96 to 1999–00, there were no SLEDs used without cover nets. During this period the number of interactions was also the same as the number of captures.

Across all observed trawl fishing between 1995–96 and 2008–09, there were 249 observed sea lion captures. Of the animals that were observed caught, 240 (96.4%) were killed by being caught. The fate of the animals that were released alive is unknown. While the estimation is based on observed captures, this is close to observed sea lion kills.

In the Auckland Islands squid fishery, the number of attributed mortalities are calculated. This is an estimate of the number of sea lions that would have been killed under the assumptions that of the sea lions involved in interactions (a) no sea lions survived unless the SLED had been approved by the Ministry of Fisheries, and (b) on tows with an approved SLED, only a proportion of the sea lions survived. Attributed mortalities are calculated with the proportion surviving being the discount rate. They are illustrated in Figure 2(d) for a discount rate of 50%, and in Figure 2(e) for a discount rate of 35%.

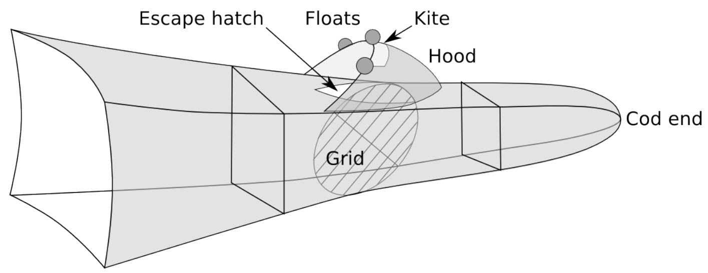

Figure 1: Schematic diagram of a sea lion exclusion device (SLED). The SLED consists of a section fitted in the net, in front of the cod end. A grid runs across the section. Sea lions are unable to pass through the grid into the cod end, but may escape through a hole above the grid. A forward facing hood fitted above the escape hatch is designed so that only actively swimming sea lions escape the net. The hood is held open by floats, and a strip of material known as a kite. A cover net may be fitted over the escape hatch to close the SLED.

Table 2: Terminology used in this report for sea lion captures in the Auckland Islands squid fishery following the definitions used in Thompson & Abraham (2009).

Term	Definition
Auckland Islands squid fishery	Trawlers targeting squid in the Auckland Islands part of the SQU 6T fishing area (Figure 8(d)).
SLED	Sea lion exclusion device, a mitigation device used in the Auckland Islands squid fishery. SLEDs are fitted into the trawl net, providing a way for sea lions that are inside the net to escape. A cover net can be tied down over the exit when the SLED is not being used.
Approved SLED	A SLED that has been certified by the Ministry of Fisheries as meeting specifications.
Closed net	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 net	A trawl net that has a SLED fitted with the SLED's exit being 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 (Figure 2(a)).
Captures	An estimate of the total number of sea lions captures, calculated as the sum of observed captures and the estimated captures that would have been recorded on unobserved tows, had observers been present (Figure 2(b)).
Interactions	An estimate of the number of sea lions that would have been caught if no SLEDs were used (Figure 2(f)).
Strike rate	Sea lion interactions per 100 tows.
Exclusions	An estimate of the number of sea lions interacting with a net but not being brought on board the vessel. This is calculated as sea lion captures subtracted from interactions (Figure 2(c)).
FRML (Fisheries Related Mortality Limit)	The maximum number of sea lion mortalities permitted in the Auckland Island Squid Fishery. This is converted into a permitted number of tows in this fishery by dividing by an assumed strike rate.
Discount rate	The discount rate is an incentive to vessel operators to use SLEDs. The discount rate is a percentage reduction in the assumed strike rate for tows that use approved SLEDs, used when determining the amount of fishing effort permitted in the Auckland Islands squid fishery under the FRML. In the 2008–09 fishing year a discount rate of 35% was applied to tows that used approved SLEDs.
Attributed mortality	The attributed mortality is the sum of interactions on tows with unapproved SLEDs, and a percentage (100% less the discount rate) of interactions on tows with approved SLEDs (Figure 2(d, e)). If the discount rate was 0%, the attributed mortalities would be the same as the interactions. Attributed mortality also includes any animals released alive.

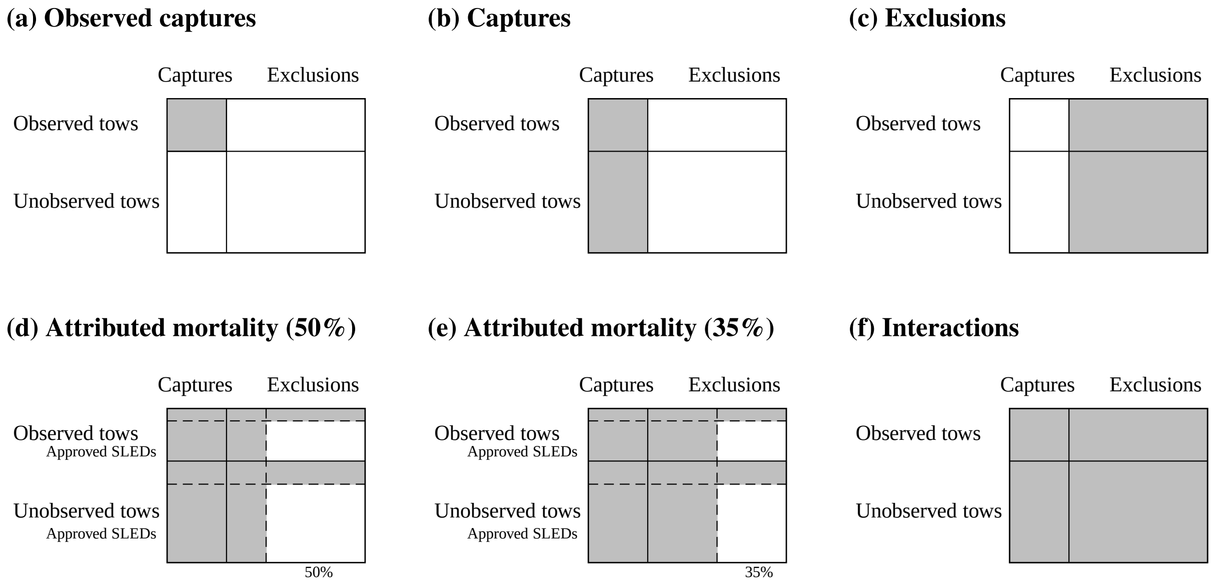

Figure 2: Quantities estimated for tows that used SLEDs. The box represents the total captures that would have occurred if no SLEDs were used, with the shading indicating the portion of the total that were included in each quantity. Tows are either observed or unobserved, and sea lions are either captured or are excluded (escaped through the SLED and would have been captured had a SLED not been used). The shaded grey areas are (a) Observed captures (b) Captures, the sum of observed captures and estimated captures on unobserved tows (c) Exclusions, sea lions that escaped being captured because SLEDs were used (d) attributed mortality at a 50% discount rate (e) attributed mortality at a 35% discount rate (f) Interactions. In (d) and (e) the horizontal line is used to indicate that not all SLEDs were approved, and the vertical line indicates the portion of interactions that were ignored because of the discount factor.

2.2 Data Sources

All commercial trawler activity reported to the Ministry of Fisheries is entered into the *warehou* database (Ministry of Fisheries 2008). The database includes a record of trawl events in the New Zealand Exclusive Economic Zone (EEZ). Deepwater trawlers, like those operating around the subantarctic islands, record details of trawl events on Trawl Catch Effort Processing Return (TCEPR) forms, including the date, time, and position of the start and end of each tow. The *warehou* data were assumed to be a complete record of trawl effort, and were used as the authoritative source for the tow date, time and location information required for the modelling.

The Ministry of Fisheries observer program collects data on mammal and sea bird captures in New Zealand fisheries, including sea lion captures. The observers identify the species of any non-fish bycatch, recording the time and location of the captures. These data are keyed into the databases managed by the National Institute of Water and Atmospheric Research (NIWA) on behalf of the Ministry (Ministry of Fisheries 2008). Both the TCEPR effort and observer records were groomed, correcting for errors in date, time, and position fields. All of the observer records were then linked to the effort data from TCEPR forms, by using the rules given in Thompson & Abraham (2009). More than 97% of observer records were matched to the effort data, in every fishing year. Data on SLED use were obtained from Deepwater Group Limited. The SLED data set included a tow by tow record of whether a SLED was used, whether the SLEDs had been approved by the Ministry, and if the cover net was closed or open.

The data were organised into four strata: the squid trawl fishery around the Auckland Islands, the Campbell Island southern blue whiting trawl fishery, other (non-squid) trawl fisheries around the

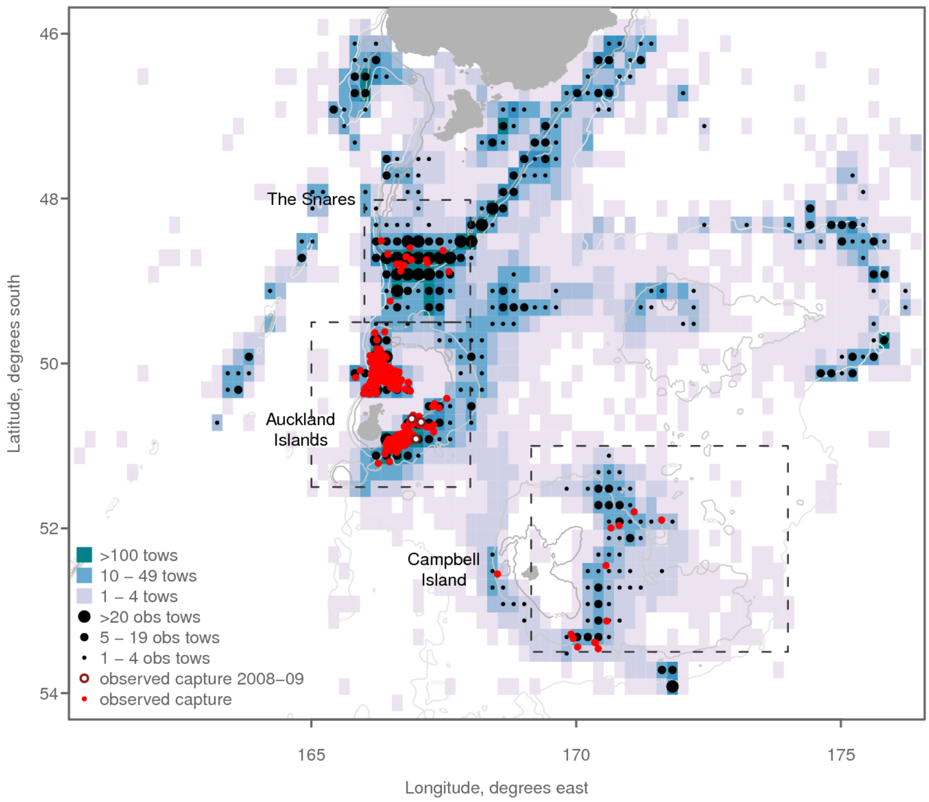

Figure 3: Annual average trawl effort, annual average observer coverage, and observed captures in the subantarctic region of New Zealand's EEZ. Data includes all trawl effort, excluding tows targeting inshore species, for the 14 years from 1 October 1995 to 30 September 2009. Dashed lines indicate the areas containing fishing effort that were used for estimating total captures and interactions.

Auckland Islands, and all trawl fisheries on the southern end of the Stewart-Snares shelf. Estimates were made for each stratum independently using appropriate methods (Table 1). The results of these four strata were also combined together to produce a total estimate of sea lion captures. A map of fishing effort in the subantarctic region is given in Figure 3. This includes trawl effort and observations that were not included in the estimates. The strata in which estimates were made are indicated by dashed lines.

There was one capture event in Figure 3 that was not included in the estimates; a sea lion captured on a hoki tow near Campbell Island on 15 February 2001. The observer initially recorded it as a fur seal, but it was subsequently identified from a photograph and physical measurement to be a sea lion. There was a short lived hoki fishery near Campbell Island, peaking in 1999–00 at 1616 tows, decreasing to 106 tows in 2004–05. There has been no further effort in this fishery since.

2.3 The Auckland Islands squid fishery

In this report we have applied the model developed in Thompson & Abraham (2009) to estimate sea lion captures in the Auckland Islands squid trawl fishery for the 2008–09 fishing year. The basic unit of effort used in the model was a single trawl event. Observers recorded the number of sea lions caught per tow, and the objective of the estimation was to predict the expected number of captured sea lions on the unobserved tows. Tows in fishing year y were indexed by vessel key, j, and number, k, and the number of sea lions 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 over-dispersion, θ, that was the same for all tows. The negative-binomial distribution was implemented using a Poisson distribution with a gamma distributed mean. This was achieved by multiplying the mean strike 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:

$$
\begin{aligned}
c^y_{jk} &\sim \text{Poisson}(\mu^y_{jk} g_\theta), && (1)\\
g_\theta &\sim \text{Gamma}(\theta, \theta), && (2)\\
\theta &\sim \text{Uniform-shrinkage}(\mu_\theta). && (3)
\end{aligned}
$$

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

$$
\mu^y_{jk} = \lambda^y v^y_j \exp\left(\sum_b x^{yb}_{jk} \beta_b\right) \quad . \tag{4}
$$

The random year effects, λ^y, carried the mean strike 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:

$$
\begin{aligned}
\log \lambda^y &\sim \text{Normal}(\mu_\lambda, \sigma_\lambda), && (5)\\
\mu_\lambda &\sim \text{Normal}(-4, 100), && (6)\\
\sigma_\lambda &\sim \text{Half-Cauchy}(0, 25). && (7)
\end{aligned}
$$

For each vessel and year combination there was a vessel-year random effect, v^y_j, that was drawn from a gamma distribution with mean one. This allowed the strike rate for each vessel in each year to have a mean different from the year effect λ^y. The shape of the gamma distribution was defined by the hyper-parameter, θ_v. The shape parameter was given the uniform shrinkage prior, with mean 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 v^y_j was drawn from the gamma distribution:

$$
\begin{aligned}
v^y_j &\sim \text{Gamma}(\theta_v, \theta_v), && (8)\\
\theta_v &\sim \text{Uniform-shrinkage}(\mu_{vs}). && (9)
\end{aligned}
$$

The covariates used in the model were those selected by Smith & Baird (2007b) and are listed in Table 3. The choice of these covariates followed work specifically focussed on identifying the factors associated with sea lion captures (Smith & Baird 2005), and a subsequent estimation of sea lion captures in the 2003–04 fishing year (Smith & Baird 2007a). 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,

$$
\beta_b \sim \text{Normal}(0, 100). \tag{10}
$$

The presence or absence of a SLED with the cover off was treated as a covariate along with the others. However, the regression coefficient $\beta_{open\text{-}net}$ was transformed into the SLED retention probability, $\pi = \exp\left(\beta_{open\text{-}net}\right)$, and was given a uniform prior,

$$\pi \sim \text{Uniform}(0,1). \tag{11}$$

The model was coded in the BUGS language, a domain specific language for describing Bayesian models. The JAGS (Plummer 2005) software package provides tools for fitting models described in the BUGS language using Markov chain Monte Carlo (MCMC) methods. This system is similar to the WinBUGS (Spiegelhalter et al. 2003) software used by Smith & Baird (2007b).

To ensure that the model had converged, a burn-in of 100 000 iterations was made. From there the model was run for another 100 000 iterations and every 20$^{\text{th}}$ iteration was kept. Two chains were fitted to the model, and the output included 5000 samples of the posterior distribution from each chain. Model convergence was checked using diagnostics provided by the CODA package for the R statistical system (Plummer et al. 2006, version 1.0.3), including Heidelberger and Welch's (Heidelberger & Welch 1983), and Geweke's (Geweke 1992) criteria.

2.3.1 Model estimates of interactions, captures and strike rate

From the fitted model, posterior distributions were calculated for the captures, interactions, strike rate, attributed mortalities, and exclusions. These quantities are defined in Table 2, and illustrated in Figure 2. For each sample from the Markov chain, the estimated number of sea lion interactions i_{jk} were calculated for each tow (here, and in what follows, the year index y is assumed). The mean interaction rate was given by the linear predictor, μ_{jk} (Equation 4), but with the net assumed to be closed, irrespective of whether or not a SLED was used. This was enforced by setting the *open-net* covariate to the value corresponding to a closed net. The number of interactions on a tow can be interpreted as the number of sea lions 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 1, 2, and 3). From the interactions, the captures were calculated by sampling from a binomial distribution with probability given by the SLED retention probability and size given by the number of interactions,

$$c_{jk} \sim \begin{cases} \text{Binomial}(\pi, i_{jk}) & \text{(open net)}, \\ i_{jk} & \text{(closed net)}. \end{cases} \tag{12}$$

This procedure simulated the independent random capture of interacting sea lions, with probability π. It ensured that, on any tow, the number of captures was less than or equal to the number of interactions.

Table 3: Covariates used in the Auckland Islands squid model.

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 is located. The Auckland Islands part of the SQU 6T area was divided into two sub-areas, NW (north of 50.45° south and west of 166.95° east), and S&E (South and East: the rest of the Auckland Islands part of SQU 6T),
open-net	A factor variable, indicating that the net had a SLED attached and that the cover net was open.

The number of sea lion exclusions on a tow was calculated as the difference between the interactions and the captures, $e_{jk} = i_{jk} - c_{jk}$.

Tow level attributed captures, a_{jk}, were calculated from the interactions in a similar way, by sampling from a binomial distribution,

$$a_{jk} \sim \begin{cases} \text{Binomial}((1 - DR/100) - \pi, i_{jk}) & \text{(open net, approved SLED)}, \\ \text{Binomial}(1 - \pi, i_{jk}) & \text{(open net, unapproved SLED)}, \\ 0 & \text{(closed net)}, \end{cases} \quad (13)$$

where *DR* is the percentage discount rate. With this definition, the attributed captures on a tow are always less than the number of interactions. The SLED retention probability is subtracted from the probability in Equation 13, so that the captures are not included in a_{jk}.

The estimated quantities were calculated as follows:

$$\begin{aligned} \text{Captures} \quad C &= \sum_u c_{jk} + C_o, & (14) \\ \text{Interactions} \quad I &= \sum_u i_{jk} + \sum_o e_{jk} + C_o, & (15) \\ \text{Strike rate} \quad \mu &= I/n, & (16) \\ \text{Exclusions} \quad E &= I - C, & (17) \\ \text{Attributed captures} \quad A &= C + \sum_a a_{jk}, & (18) \end{aligned}$$

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 the total number of tows in the fishery is denoted by n. The attributed captures were calculated for discount rates of 20%, 35%, and 50%.

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

2.4 The Campbell Island southern blue whiting fishery

In the southern blue whiting fishery east of Campbell Island observed sea lion captures (per calendar year) peaked at 6 in 2007. During 2009, there were no observed captures in this fishery. A simple Bayesian model was used to estimate the captures in the southern blue whiting fishery. There were a total of only 15 observed sea lion captures in the data set, so the model was necessarily much simpler than the squid fishery model.

It was more natural to use calendar years rather than fishing years in the southern blue whiting fishery, as the season extended beyond the end of the fishing year (September 30). The fishery was focused in a short part of the year, with all the fishing effort between August and November. Sea lion captures occurred throughout the weeks the fishery was operating, with the possible exception of fishing before the beginning of September. Despite observer coverage from earlier years, the first sea lion capture was observed in 2002.

The southern blue whiting fishery operates on the Pukaki rise, and to the east of Campbell island, while all sea lion captures have been observed on the shelf to the east of Campbell Island. The data set was restricted to the effort near Campbell Island, and is plotted in Figure 9.

The southern blue whiting model was a variation of the squid model described above. Simplifications were necessary, primarily due to the very small number of observed captures. Vessel-year random effects were not feasible due to the small number of vessels that had observed captures. The model used a Poisson error model, and included only random year effects. The year effects allowed for a varying strike rate, without assuming any trend over the years. The same model was used by Thompson & Abraham (2009) and by Thompson et al. (2010), with the exception that the date range was extended to include all data from 1996 to 2009.

2.5 Other strata

Ratio estimates of sea lion captures were calculated for the two remaining strata: the Auckland Islands non-squid trawl fisheries, and all trawl fisheries at the south end of the Stewart-Snares shelf. The non-squid Auckland Islands trawl fisheries were defined as all tows in the Auckland Islands part of the SQU 6T fishing area not targeting squid, and the southern end of the Stewart-Snares shelf was defined as south of 48.02°, north of 49.5°, west of 168°, and east of 166°.

Both of these strata had few observed captures, due in part to low observer coverage. A general linear model was used to test if there was a significant trend in the observed strike rate over the years. No trend was found. For this reason, ratio estimates were calculated using data from the fishing years 1995–96 to 2008–09, by assuming a constant capture rate over these years. This contrasts with Thompson & Abraham (2009), who only used data from three years. The estimated number of captures in a year, y, was

$$C^y = C_o^y + C_u^y, \tag{19}$$

where C_o^y were the observed captures and C_u^y were the estimated captures during unobserved fishing. The unobserved captures were estimated by calculating an average rate from the observed data, and applying that to the unobserved effort. If the number of observed tows in a year was o^y, then the average sea lion capture rate was

$$r = \sum_y C_o^y / \sum_y o^y, \tag{20}$$

where the sum was over all the fishing years that were included in the estimate. The unobserved captures in each year were then estimated as

$$C_u^y = r(n^y - o^y), \tag{21}$$

where n^y was the total number of tows in year y. The uncertainty in the captures, C^y, was estimated using bootstrap resampling (e.g. Davison & Hinkley 1997). Data from the observed tows were resampled 5000 times, and the total bycatch was recalculated for each sample from Equations 19, 20 and 21. The 95% confidence interval in the estimate was calculated from the 2.5% and 97.5% quantiles of the distribution of resampled captures.

2.6 Total estimates

Estimates from the four strata were combined to give an estimate of total sea lion captures in each year. The posterior distribution of estimated captures in each of the four strata was described by a set of 5000 samples, from the Markov chain in the case of the Bayesian models, and from the bootstrap resampling for the ratio estimated strata. The samples were added together to give 5000 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 Island squid fishery and estimated captures in the other three strata. The mean, and 95% confidence intervals were calculated for each year from the samples.

3. RESULTS

3.1 Observed captures

There were three sea lion captures reported by observers during 2008–09. This was the lowest number of captures observed in any year during the period covered by the data. Photographs of the three captured animals are shown in Figure 4. A single sea lion was observed caught in the Auckland Islands scampi fishery. This animal was not returned for necropsy, but was identified by the observer as a female sea lion Figure 4(a). In the Auckland Islands squid fishery one female and one male sea lion capture were reported by observers. Both these animals were caught in nets fitted with SLEDs. Both animals were caught anterior to the grid, with the female recorded by the observer as first seen wedged between the bars of the SLED. The photographs of these animals shown in Figure 4(b, c) were taken before the animals were removed from the SLED. Both animals were necropsied, and both were found to have been sexually mature (Roe 2009).

(a) **(b)** **(c)**

Figure 4: Photographs of sea lion captures taken by Ministry of Fisheries observers (a) a female sea lion caught in the scampi fishery in November 2008 (b) a male sea lion caught in the squid fishery in February 2009 (c) a female sea lion caught in the squid fishery in April 2009. Photographs reproduced by permission of the Ministry of Fisheries.

In the 2008–09 fishing year, fishers began reporting captures of protected species on the new Non-fish/protected species catch return (NFPSCR) form. The two sea lions captures reported by the observers from the squid fishery were also reported by fishers on NFPSCR forms. The sea lion observed caught in the scampi fishery was reported by the fisher as a fur seal. In addition, there were three captures reported by fishers on trips that did not have Ministry of Fisheries observers. These three captures were all in the Auckland Islands squid fishery. One of these fisher reported animals was returned for necropsy and identified as an adult female.

3.2 Squid fishery model diagnostics

The distribution of the model covariates during tows made in the Auckland Islands squid fishery in 2008–09 are shown in Figure 5. The observed tows were broadly representative of the unobserved effort. Tow duration increased until the 2006–07 fishing year, and since then the median duration has decreased slightly (Figure 5(a)). Distance to the nearest colony (Figure 5(b)) varied from 20 to 120 kilometres, with a strong peak between 40 and 50 kilometres. Tows were evenly divided between the two sub-areas (Figure 5(c)), with a small bias towards the north-west sub-area in the observer data. In 1999–2000, the fishing was concentrated in the south-west sub-area. Since then there has been an increase in the proportion of tows that were in the north-east sub-area, with approximately 80% of tows being in the north-east in 2008–09. Functioning SLEDs were progressively introduced into the Auckland Islands squid fishery from 2000–01, with most tows within the SQU6T area after 2003–04 using SLEDs.

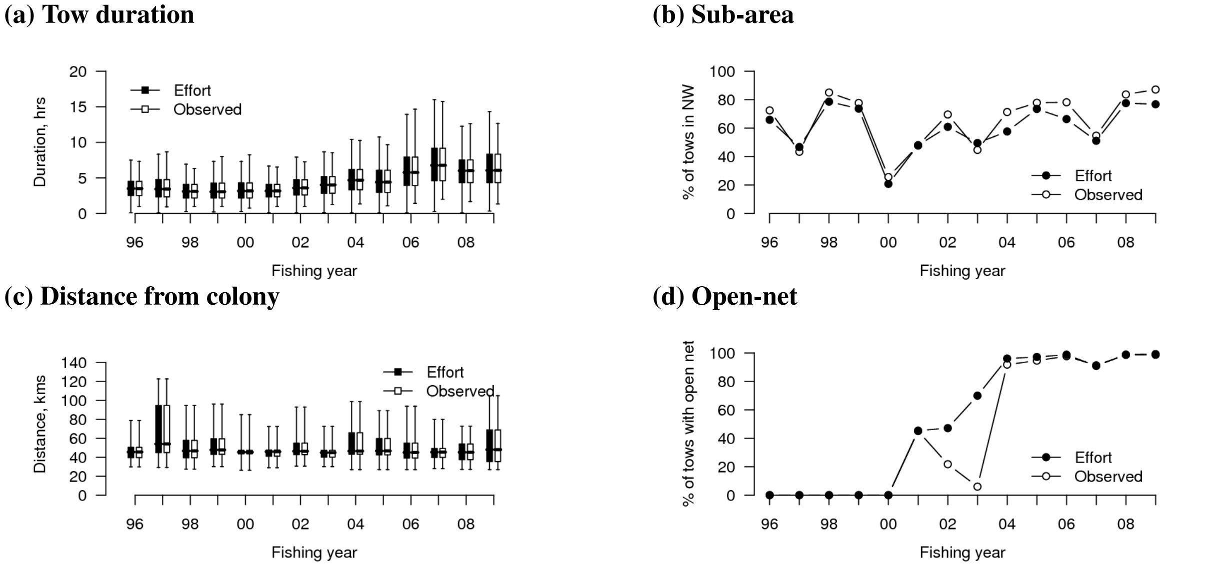

Figure 5: Time series of (a) tow duration, (b) percentage of tows in the north-west sub area, (c) distance from the nearest colony, and (d) percentage of tows using SLEDs with an open net. Plots include all trawl effort from the Auckland Islands squid fishery, with the observed effort for comparison. The boxes indicate the inter-quartile range, the whiskers extend to the 95% interval. In these figures the year refers to the second year of the fishing year, e.g.'08' is the 2007–08 fishing year

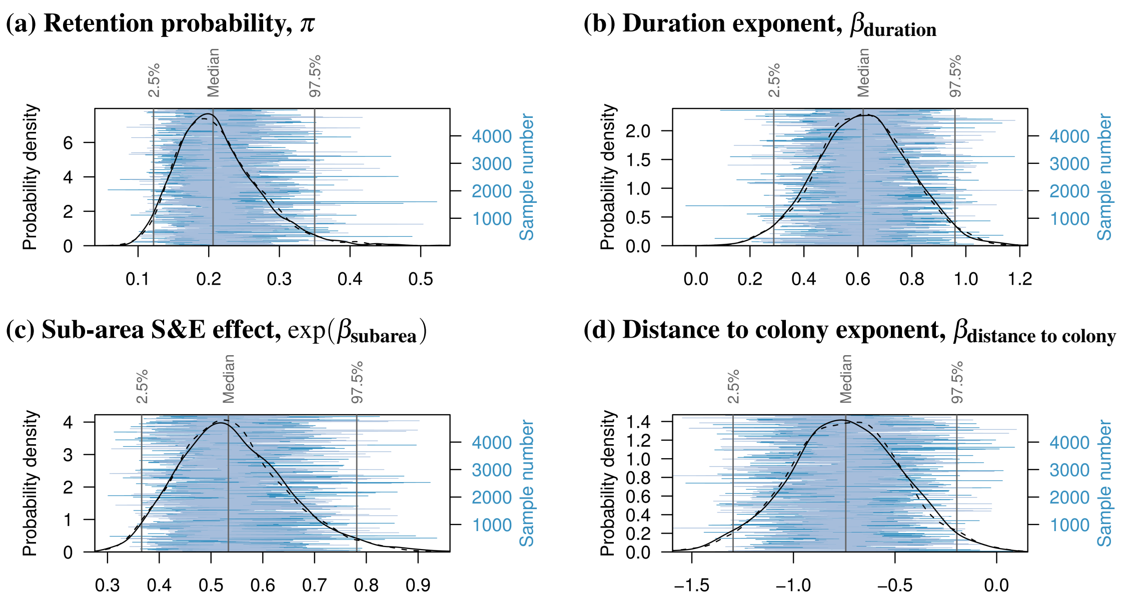

Figure 6: MCMC chain output, and the densities of the four covariant regression coefficients for (a) SLED retention probability (b) duration exponent (c) Sub-area S&E effect (d) distance to colony exponent. The dotted and solid lines are the posterior densities from the two independent chains.

Table 4: Summary of the posterior distribution of the covariate coefficients from the Auckland Islands squid fishery model.

	Mean	2.5%	50%	97.5%
Retention probability, π	0.214	0.122	0.206	0.350
Dist. to colony exponent,$\beta_{\text{distance to colony}}$	-0.743	-1.297	-0.743	-0.196
Duration exponent, β_{duration}	0.622	0.288	0.619	0.960
Subarea S&E effect, $\exp(\beta_{\text{sub-area}})$	0.543	0.366	0.534	0.782

A summary of the coefficients of the Bayesian model covariates is given in Table 4. The SLED retention probability (the coefficient of the open-net covariate) had a mean of 0.214, meaning that the probability of catching a sea lion on a tow with a SLED was 21.4% of the probability of catching a sea lion on a similar tow, but without a SLED. The mean coefficient of the logarithm of the distance to colony was -0.749, indicating that the probability of catching a sea lion during a tow decreased with distance from the nearest colony. This value was not significantly different from -1.0, which would have implied an inverse relation between the distance from the colony and the probability of a sea lion being caught. The mean coefficient of the logarithm of the tow duration was 0.622; this implies that the chance of catching a sea lion grew sublinearly as the tow duration increased (the tow duration coefficient was not significantly different from 0.5, which would have implied a square-root relation between tow duration and the probability of a sea lion being caught on a tow). The exponentiated value of the coefficient for the sub-area factor was 0.543; the chance of catching a sea lion in the south and east areas, during an otherwise similar tow, was half that of the north-west area. These coefficients are all close to the values estimated from fitting the model to data from previous years (Thompson & Abraham 2009, Thompson et al. 2010).

The model converged successfully, passing the diagnostic criteria for the key parameters. The posterior densities of the four regression coefficients, β_b, are presented in Figure 6, together with traces of the two chains. The densities for the two chains were very similar, an indication of model convergence. In Table 5 the distribution of the number of predicted captures per tow is compared with the observed data. The close similarity between the observed and predicted distributions indicates that the negative-binomial model was an appropriate description of the capture data.

Table 5: A comparison of the distribution of number of sea lion captures per tow for observed captures, and predicted captures on the observed data, for the 12 fishing years 1995–96 to 2008–09 for the Auckland Islands squid fishery.

Number	Observed	Predicted	
		Median	95% c.i.
0	7618	7740	(7701 - 7775)
1	171	168	(135 - 204)
2	13	14	(6 - 24)
3	1	2	(0 - 6)
4	1	0	(0 - 2)

3.3 Total estimates for all strata

Combined effort, observed and estimated captures, and estimated interactions, for all four strata over the 14 year period are given in Table 6 and Figure 7. Because the model was re-run with new data, the

2007–08 model results presented here differ slightly from those reported for the same year by Thompson et al. (2010).

The estimated number of total interactions in all four strata decreased from 83 (95% c.i.: 43 to 141) in 2007–08 to 72 (95% c.i.: 30 to 148) in 2008–09, despite a slight increase in the total effort within all the areas included in the estimation. In 2008–09, total estimated captures were the lowest in 14 years at 25 (95% c.i.: 16 to 39). Observed effort was largely representative of the total fishing effort, peaking from February to April, during the squid season, and in September, during the southern blue whiting season (Figure 7(e)). Observed sea lion captures across all fisheries were highest from February to April.

3.4 The Auckland Islands squid fishery

The 14 year time series of trawl effort, observed effort, observed captures, estimated captures, estimated interactions, and the estimated strike rate are presented in Table 7 and Figure 8. The 2000–01 fishing year was particularly well observed (99%), and had the highest observed capture rate of 6.7 sea lions per 100 tows. The observed capture rate has been trending down since then, reaching 0.3 sea lions per 100 tows in 2008–09; the lowest catch rate in the 14 year period for which we present data. This trend was in part due to the progressive introduction of SLEDs.

Estimated captures were highest in 1995–96 and 1996–97 when fishing effort was also at a peak, with more than 3700 tows per year. Estimated captures have been generally declining since then with an estimated 9 sea lion captures in 2008–09 (95% c.i.: 3 to 21). Interactions were estimated to be greater than 150 sea lions for the three fishing years 2003–04 to 2005–06. Since then, the number of interactions has decreased, and in 2008–09, sea lion interactions were estimated to be 56 (95% c.i.: 16 to 131) (Table 7).

The strike rate was estimated in 2008–09 to be 3.0 sea lion interactions per tow (95% c.i.: 0.9 to 6.5). Although this was the lowest mean strike rate since 1995–96, the confidence interval for the strike rate was large. The 2008–09 strike rate was not significantly different from the value of 5.65 sea lions per 100 tows that was assumed by the Ministry of Fisheries while setting the FRML.

3.5 The Campbell Island southern blue whiting fishery

A summary of the effort, observed and estimated captures in the southern blue whiting fishery for the 14 year time series is presented in Table 8 and Figure 9. The estimated number of captures, and the strike rate, steadily increased after 2003, peaking in 2007 at 16 captures (95% c.i.: 8 to 28). In 2009 there was an estimated 1 sea lion capture (95% c.i.: 0 to 5).

3.6 Non-squid Auckland Islands fisheries

A summary of the effort, observed and estimated captures in other trawl fisheries in the Auckland Islands area for the 14 year time series is presented in Table 9 and Figure 10. Scampi trawl made up 77% of the non-squid effort over the whole period, and 90% in 2008–09. Total effort in these non-squid trawl fisheries ranged from 1369 to 2228 trawls per year, and observed captures ranged between 1 and 4. Of the 15 captures, 11 were observed in the scampi fishery, which operated in the region south and east of the Auckland Islands. The other four captures, all before 2003, were observed on tows targeting jack mackerel in April 1996, orange roughy in December 1997 and 1998, and hoki in October 2002. These four captures were north of the Auckland Islands.

The bootstrap estimate of the strike rate was 0.74 sea lions per 100 tows (95% c.i.: 0.39 to 1.13). Estimated captures in 2008–09 were 13 sea lions (95% c.i.: 7 to 19), an increase in the mean from 11 captures in 2007–08, reflecting the increase in the fishing effort.

3.7 All trawl fisheries on the southern end of the Stewart Snares shelf

A summary of the observed and estimated captures, and effort in all trawl fisheries on the southern end of the Stewart-Snares shelf for the 14 year time series is presented in Table 10 and Figure 11. As with the Auckland Islands non-squid trawl fisheries, there were too few captures to develop a model for this stratum; a ratio estimation method with a single strike rate over the entire 14 year period was used. Nine of the 14 captures were observed on squid tows, two were observed on tows targeting hoki, two on tows targeting jack mackerel, and one on a tow targeting barracouta. No captures were observed in the 2008–09 fishing year.

The bootstrap estimated strike rate was 0.10 sea lions per 100 tows (95% c.i.: 0.05 to 0.16), less than one seventh of the rate in non-squid tow near the Auckland Islands. The estimated number of captures in 2008–09 was 3 (95% c.i.: 1 to 4), the lowest since 1995–96. Trawl effort in this area was at its lowest also at its lowest since 1995–96, decreasing by 22% between 2007–08 and 2008–09.

3.7.1 Total estimated sea lion captures and interactions

Table 6: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures (with 95% confidence intervals), and interactions (with 95% confidence intervals), from the four estimated strata.

	All tows	Observed			Est. captures		Est. interactions	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2008–09	6656	27	3	0.2	25	(16 - 40)	73	(30 - 148)
2007–08	6536	32	8	0.4	32	(22 - 45)	83	(43 - 147)
2006–07	6728	24	15	0.9	47	(34 - 64)	107	(62 - 179)
2005–06	9313	18	14	0.8	56	(40 - 78)	174	(91 - 308)
2004–05	11106	23	14	0.5	58	(41 - 83)	173	(89 - 303)
2003–04	10021	23	21	0.9	66	(49 - 91)	206	(113 - 367)
2002–03	8265	19	11	0.7	38	(28 - 52)	65	(41 - 102)
2001–02	9954	19	23	1.2	70	(52 - 94)	99	(67 - 143)
2000–01	8909	40	46	1.3	67	(59 - 75)	87	(64 - 114)
1999–00	9049	23	28	1.4	91	(64 - 131)	91	(64 - 131)
1998–99	10551	16	6	0.4	37	(25 - 53)	37	(25 - 53)
1997–98	10064	15	15	1	82	(52 - 126)	82	(52 - 126)
1996–97	10948	15	28	1.7	156	(103 - 228)	156	(103 - 228)
1995–96	10035	10	16	1.6	154	(88 - 255)	154	(88 - 255)

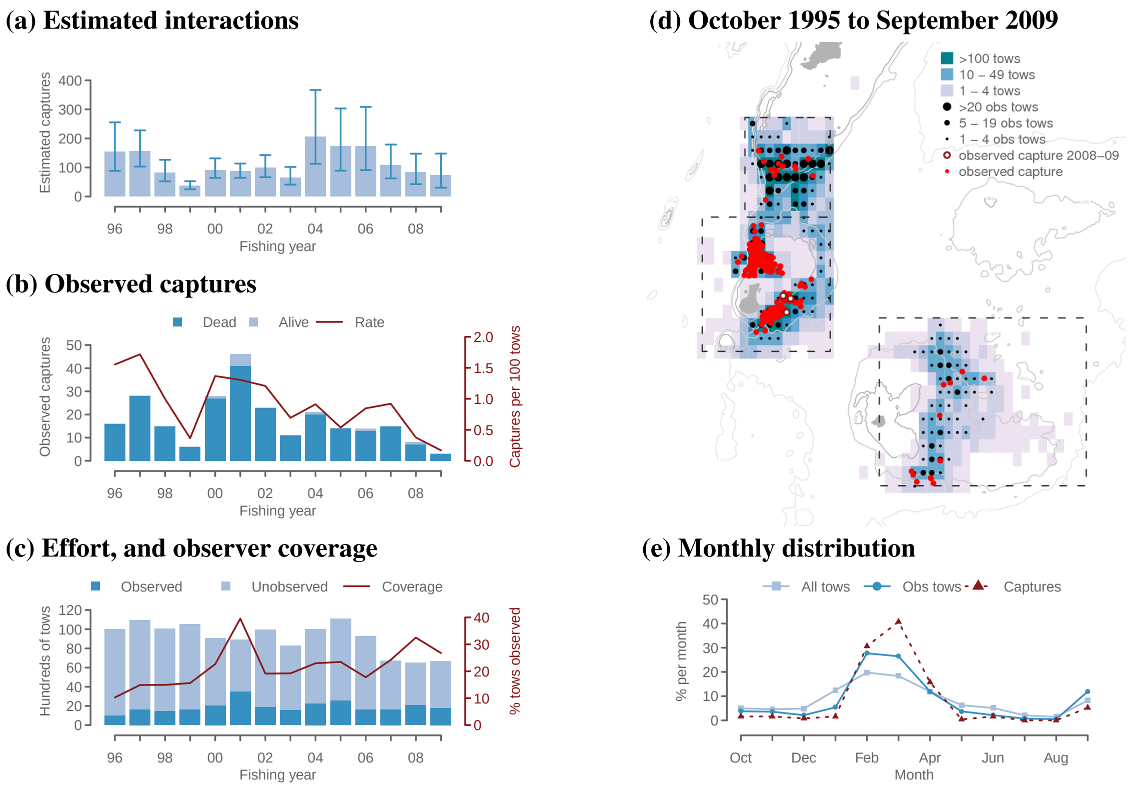

Figure 7: Annual time series of (a) estimated sea lion interactions, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, for data from the four estimated strata from 1995–95 to 2008–09. In map (d) average effort is plotted in a blue colour scale, observer coverage is indicated with black dots, and observed captures with red dots. The data used for estimating captures are marked with a dashed line. Plot (e) shows mean monthly distribution of total effort, observed effort and observed captures.

3.7.2 The Auckland Islands squid fishery

Table 7: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures, interactions, and the estimated strike rate (with 95% confidence intervals), in the Auckland Islands squid fishery.

	All tows	Observed			Est. captures		Est. interactions		Est. strike rate (%)	
		% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
2008–09	1925	39	2	0.3	9	(3 - 21)	56	(15 - 132)	2.9	(0.9 - 6.6)
2007–08	1265	46	5	0.9	13	(6 - 22)	64	(24 - 127)	5.0	(2.1 - 9.7)
2006–07	1320	41	7	1.3	16	(9 - 27)	76	(32 - 146)	5.8	(2.7 - 10.8)
2005–06	2462	22	9	1.6	32	(19 - 53)	150	(67 - 286)	6.1	(2.9 - 11.4)
2004–05	2706	30	9	1.1	33	(18 - 56)	149	(66 - 281)	5.5	(2.5 - 10.4)
2003–04	2594	30	16	2	42	(27 - 66)	182	(89 - 340)	7.0	(3.6 - 12.8)
2002–03	1470	29	11	2.6	20	(13 - 30)	46	(23 - 81)	3.1	(1.9 - 5.1)
2001–02	1648	34	21	3.7	44	(30 - 65)	72	(42 - 117)	4.4	(2.9 - 6.6)
2000–01	583	99	39	6.7	39	(39 - 40)	59	(38 - 84)	10.0	(8.5 - 12.6)
1999–00	1208	36	25	5.7	67	(44 - 105)	67	(40 - 107)	5.5	(3.9 - 8.3)
1998–99	402	38	5	3.3	15	(7 - 27)	15	(5 - 29)	3.6	(2.2 - 6.1)
1997–98	1470	23	14	4.1	61	(34 - 104)	61	(32 - 104)	4.2	(2.5 - 6.9)
1996–97	3734	20	28	3.8	140	(89 - 214)	140	(87 - 214)	3.7	(2.5 - 5.6)
1995–96	4460	12	13	2.4	134	(70 - 230)	134	(69 - 235)	3.0	(1.6 - 5.1)

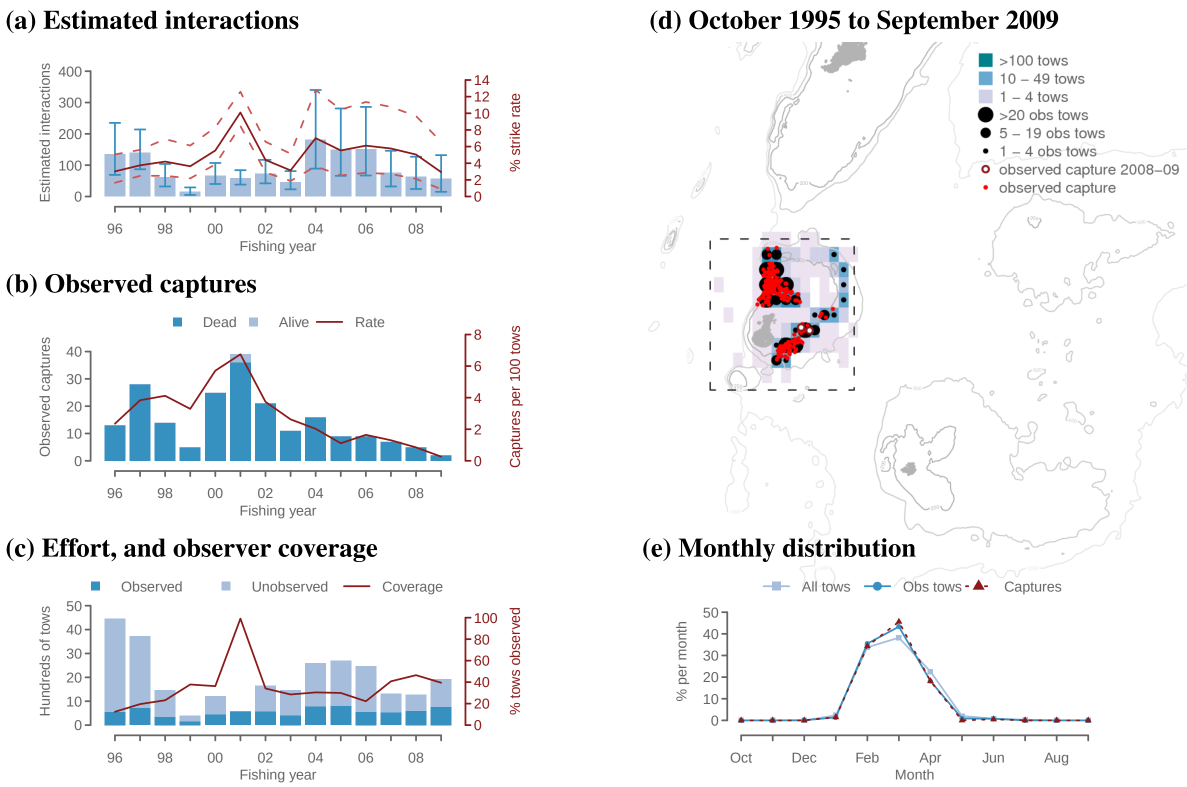

Figure 8: Annual time series of (a) estimated sea lion interactions, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the Auckland Islands squid fishery from 1995–95 to 2008–09. In map (d) average effort is plotted in a blue colour scale, observer coverage is indicated with black dots, and observed captures with red dots. The data used for estimating captures are marked with a dashed line. Plot (e) shows mean monthly distribution of total effort, observed effort and observed captures.

3.7.3 The Campbell Island southern blue whiting fishery

Table 8: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures, interactions, and the estimated strike rate (with 95% confidence intervals), in the Campbell Island southern blue whiting fishery.

	All tows	Observed			Est. captures		Est. strike rate (%)	
		% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2009	609	20	0	-	1	(0 - 5)	0.1	(0 - 0.55)
2008	552	41	2	0.88	4	(2 - 10)	0.52	(0.06 - 1.46)
2007	542	32	6	3.51	16	(8 - 28)	2.46	(0.79 - 4.99)
2006	518	28	3	2.1	7	(3 - 15)	1.07	(0.19 - 2.76)
2005	725	37	2	0.74	5	(2 - 11)	0.53	(0.07 - 1.48)
2004	678	34	1	0.43	3	(1 - 8)	0.36	(0.02 - 1.27)
2003	575	43	0	-	0	(0 - 3)	0.11	(0 - 0.58)
2002	978	27	1	0.37	4	(1 - 12)	0.32	(0.02 - 1.15)
2001	667	60	0	-	0	(0 - 2)	0.08	(0 - 0.4)
2000	446	52	0	-	0	(0 - 3)	0.11	(0 - 0.58)
1999	782	28	0	-	1	(0 - 5)	0.09	(0 - 0.49)
1998	964	29	0	-	1	(0 - 4)	0.09	(0 - 0.45)
1997	639	34	0	-	0	(0 - 3)	0.11	(0 - 0.56)
1996	472	27	0	-	1	(0 - 4)	0.14	(0 - 0.81)

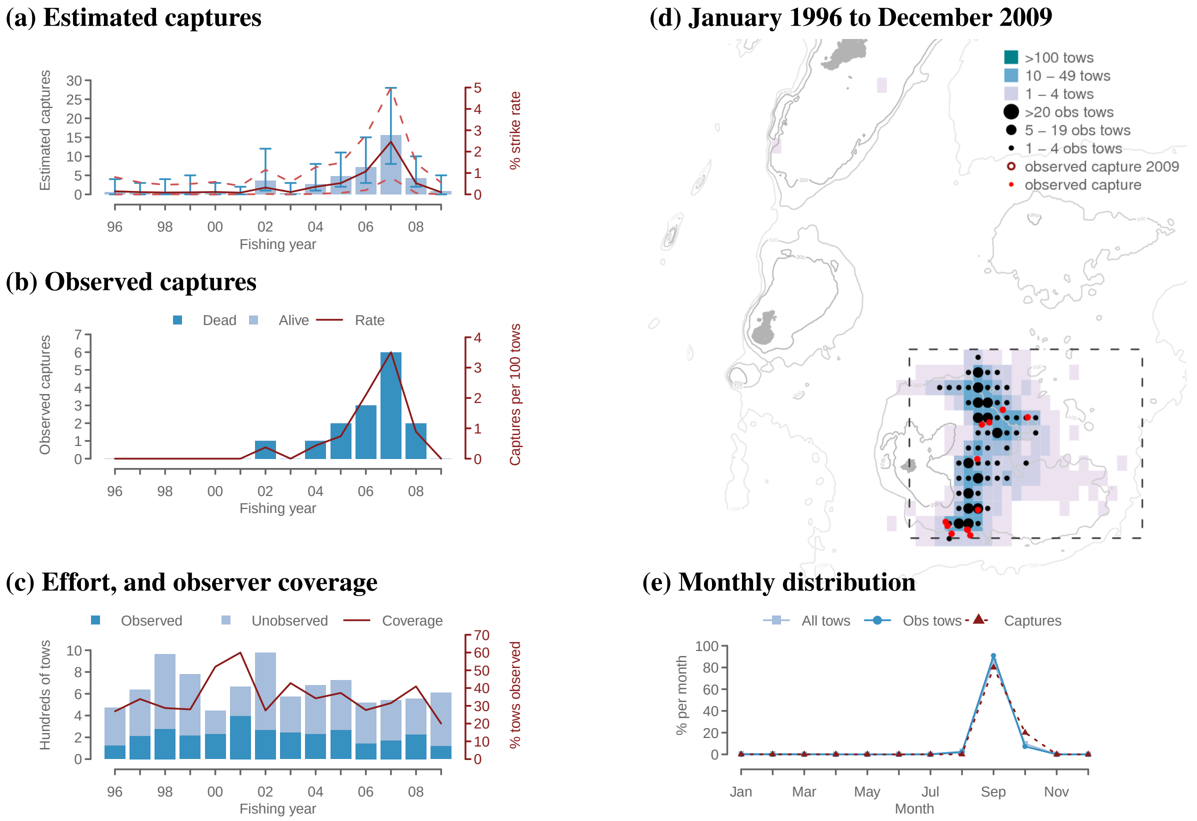

Figure 9: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the Campbell Island southern blue whiting fishery from 1996 to 2009. In map (d) average effort is plotted in a blue colour scale, observer coverage is indicated with black dots, and observed captures with red dots. The data used for estimating captures is marked with a dashed line. Plot (e) shows mean monthly distribution of total effort, observed effort and observed captures.

3.7.4 Other (non-squid) fisheries near the Auckland Islands

Table 9: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures, interactions, and the estimated strike rate (with 95% confidence intervals), in the trawl fisheries near the Auckland Islands, excluding squid trawl.

	All tows	Observed			Est. captures		Est. strike rate (%)	
		% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2008–09	1579	8	1	0.81	13	(7 - 19)	0.74	(0.39 - 1.13)
2007–08	1477	11	0	0	11	(6 - 17)	0.74	(0.39 - 1.13)
2006–07	1369	7	1	1.03	11	(6 - 16)	0.74	(0.39 - 1.13)
2005–06	1369	9	1	0.82	11	(6 - 16)	0.74	(0.39 - 1.13)
2004–05	1456	1	0	0	11	(6 - 16)	0.74	(0.39 - 1.13)
2003–04	1656	13	3	1.38	15	(9 - 22)	0.74	(0.39 - 1.13)
2002–03	1894	12	0	0	14	(7 - 21)	0.74	(0.39 - 1.13)
2001–02	2228	8	0	0	16	(9 - 25)	0.74	(0.39 - 1.13)
2000–01	2007	6	4	3.17	19	(12 - 27)	0.74	(0.39 - 1.13)
1999–00	2152	8	0	0	16	(8 - 24)	0.74	(0.39 - 1.13)
1998–99	1799	4	1	1.33	14	(8 - 21)	0.74	(0.39 - 1.13)
1997–98	1822	14	1	0.4	14	(8 - 22)	0.74	(0.39 - 1.13)
1996–97	1540	13	0	0	11	(6 - 17)	0.74	(0.39 - 1.13)
1995–96	1728	5	3	3.45	16	(10 - 22)	0.74	(0.39 - 1.13)

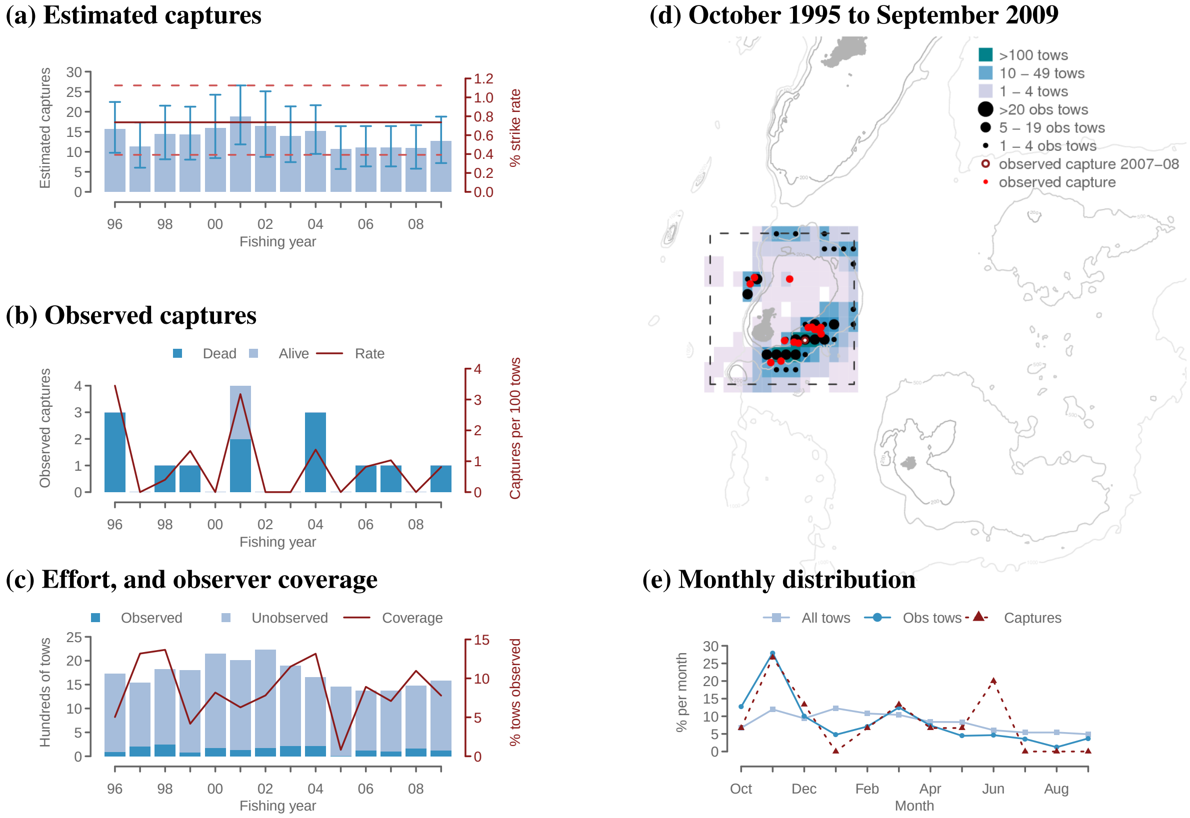

Figure 10: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the scampi and other fisheries near the Auckland Islands from 1995–1996 to 2008–09. In map (d) average effort is plotted in a blue colour scale, observer coverage is indicated with black dots, and observed captures with red dots. The data used for estimating captures is marked with a dashed line. Plot (e) shows mean monthly distribution of total effort, observed effort and observed captures.

3.7.5 All trawl fisheries on the southern end of the Stewart-Snares shelf

Table 10: Annual trawl effort, observer coverage, observed numbers of sea lions captured, observed capture rate (sea lions per 100 trawls), estimated sea lion captures, and the estimated strike rate (with 95% confidence intervals), for all trawl fisheries on the southern end of the Stewart-Snares shelf.

	All tows	Observed			Est. captures		Est. strike rate (%)	
		% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2008–09	2546	31	0	0	3	(1 - 4)	0.1	(0.05 - 0.16)
2007–08	3246	35	1	0.09	4	(3 - 6)	0.1	(0.05 - 0.16)
2006–07	3500	24	1	0.12	5	(3 - 7)	0.1	(0.05 - 0.16)
2005–06	4964	17	1	0.12	6	(3 - 9)	0.1	(0.05 - 0.16)
2004–05	6231	24	3	0.2	9	(6 - 13)	0.1	(0.05 - 0.16)
2003–04	5097	21	1	0.09	6	(4 - 9)	0.1	(0.05 - 0.16)
2002–03	4337	16	0	0	4	(2 - 7)	0.1	(0.05 - 0.16)
2001–02	5119	18	1	0.11	6	(4 - 9)	0.1	(0.05 - 0.16)
2000–01	5669	43	3	0.12	9	(6 - 12)	0.1	(0.05 - 0.16)
1999–00	5264	23	3	0.25	8	(6 - 11)	0.1	(0.05 - 0.16)
1998–99	7583	16	0	0	8	(4 - 12)	0.1	(0.05 - 0.16)
1997–98	5836	11	0	0	6	(3 - 9)	0.1	(0.05 - 0.16)
1996–97	5044	10	0	0	5	(3 - 8)	0.1	(0.05 - 0.16)
1995–96	3385	8	0	0	3	(2 - 5)	0.1	(0.05 - 0.16)

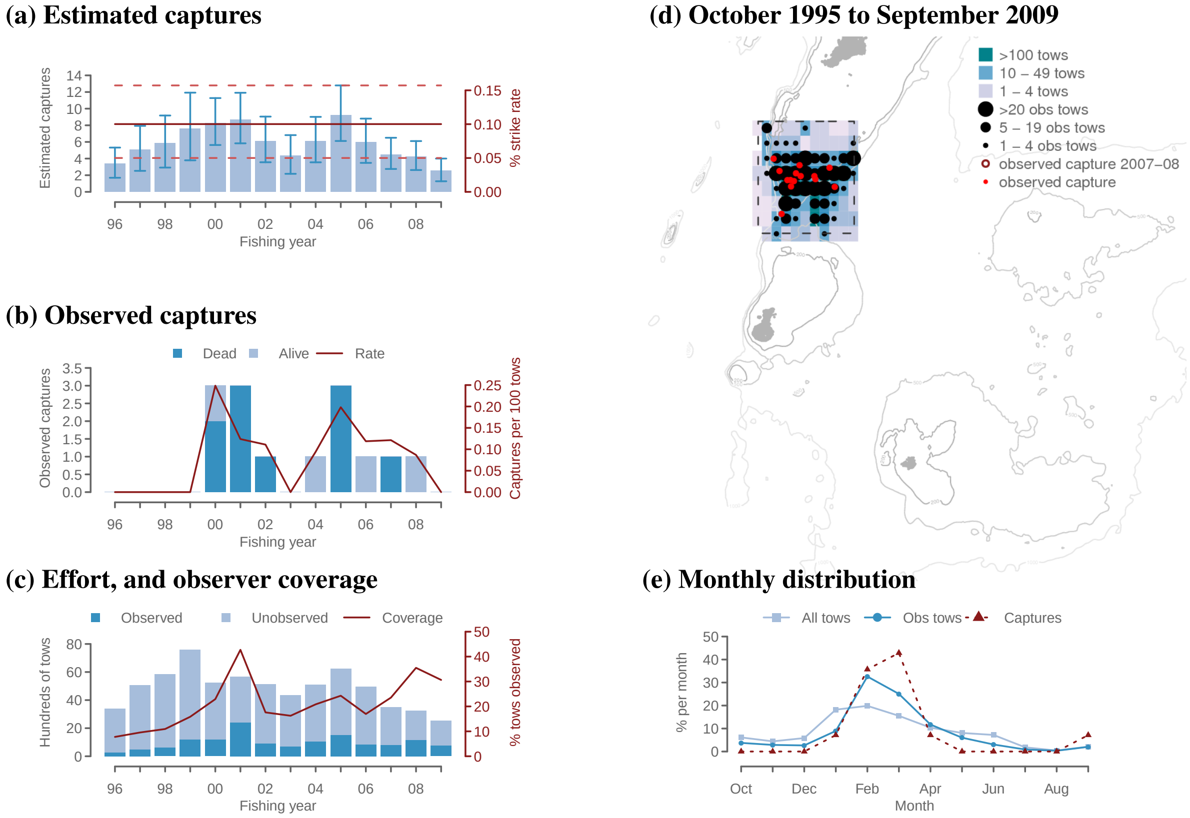

Figure 11: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in all trawl fisheries on the southern end of the Stewart-Snares shelf from 1995–1996 to 2008–09. In map (d) average effort is plotted in a blue colour scale, observer coverage is indicated with black dots, and observed captures with red dots. The data used for estimating captures is marked with a dashed line. Plot (e) shows mean monthly distribution of total effort, observed effort and observed captures.

4. DISCUSSION

In this report the model and ratio estimation methods of Thompson & Abraham (2009) and Thompson et al. (2010) were re-run to estimate the captures of sea lions in the four strata, for each fishing year between 1995–96 and 2008–09. The model of the Auckland Islands squid fishery was based on that of Smith & Baird (2007b). Estimated captures in the Auckland Islands squid fishery in 2008–09 (9 sea lions, 95% c.i.: 3 to 21) were the lowest in the period covered by the data. The decrease in the number of captures during this period was largely due to the introduction of SLEDs, and more recently to a decrease in the fishing effort. It is also possible that there were fewer sea lions in the region, with an almost 50% decline in sea lion pup production being recorded between 1998 and 2009 (Department of Conservation 2009). The estimated interactions have decreased since 2007–08 from 63 (95% c.i,: 24 to 120) to 56 (95% c.i,: 26 to 131) in 2008–09. Because of the high uncertainty around these figures, the change cannot be regarded as significant.

In addition to the uncertainty arising from the model, the estimated interactions in the Auckland Islands squid fishery are affected by the assumption that the SLED retention probability has remained constant. Estimating the SLED retention probability depends on comparing observed sea lion capture rates on tows with and without SLEDs. As the period when SLEDs were not used becomes increasingly distant in time, confidence in this comparison decreases. There have been changes made to SLED design, specifically aimed at reducing the number of sea lions that went through the bars into the cod-end (Chilvers 2008). These changes are likely to have caused the retention probability to decrease with time. The model presented in this report estimated that the retention probability was 0.214 (95% c.i.: 0.122 to 0.350). On tows with functional SLEDs, there were 21.4% of the captures that would have been recorded if SLEDs were not used. The fate of sea lions that leave the net through a SLED is not known.

In Table 11, a more detailed breakdown of the predictions is given for the Auckland Islands squid fishery in the 2007–08 and 2008–09 fishing years, with different discounts applied to tows using SLEDs. The discount rate set for 2008–09 was 35%; with this rate the model estimated 36.1 attributed mortalities (95% c.i.: 10 to 84). Table 11 gives the results for the 2007–08 year, from the current model.

Table 11: Predicted total interactions, attributed interactions at discount rates (DR) of 20%, 35%, and 50%, captures, exclusions, and strike rate for the 2007–08 and 2008–09 fishing years in the Auckland Islands squid fishery. Columns give the mean and selected percentiles of the posterior distribution.

	Mean	2.5%	50%	97.5%
2008–09				
Interactions	56.3	15	51	132
Attributed mortalities, 20% DR	44.6	12	40	104
Attributed mortalities, 35% DR	35.8	9	32	84
Attributed mortalities, 50% DR	26.9	7	24	64
Captures	9.4	3	9	21
Exclusions	46.9	10	42	112
Strike rate, %	2.93	0.88	2.65	6.57
2007–08				
Interactions	63.6	24	59	127
Attributed mortalities, 20% DR	50.9	20	47	100
Attributed mortalities, 35% DR	41.3	16	39	82
Attributed mortalities, 50% DR	31.8	13	30	64
Captures	12.6	6	12	22
Exclusions	51.1	14	47	109
Strike rate, %	5.04	2.13	4.74	9.67

Table 11 updates the similar table given in Thompson et al. (2010). Because the model now includes additional data, the values have changed slightly between the two reports. For example, from the current model there were an estimated 63.1 interactions in the Auckland Islands squid fishery in 2007–08. In Thompson et al. (2010) it was estimated that there were 65.3 interactions in the same fishery in the same year. Given the uncertainties, these differences are not significant.

Comparing between 2007–08 and 2008–09, the most marked decrease is in the strike rate, which fell from a mean value of 5.04 in 2007–08 to 2.96 in 2008–09. There was also a small decrease in interactions, attributed mortalities, and captures, and these decreases occurred despite an increase in the total number of tows in the SQU6T squid fishery (from 1265 to 1925).

The combined estimate of sea lion interactions across all four strata was 72 (95% c.i.: 30 to 148) in 2008–09. The decrease in the mean estimate from 83 (95% c.i.: 43 to 141) in the previous year being explained by the decrease in strike rate in both the Auckland Islands squid fishery and the Campbell Island southern blue whiting fishery. Of the total estimate of 25 sea lion captures (95% c.i.: 16 to 39) in these four strata, over half were in non-squid fisheries in the Auckland Islands area. Since the introduction of SLEDs in squid fisheries in this region, the proportion of captures in non-squid fisheries has grown. Observer coverage in non-squid fisheries in the Auckland Islands region was relatively low (at 8% in 2008–09). Increasing the observer coverage in these fisheries would decrease the uncertainty in the capture estimates.

5. ACKNOWLEDGMENTS

This work is dependent on the many observers of the Ministry of Fisheries Observer Programme who collected the data, and this effort is gratefully acknowledged. Thanks are also due to the Ministry of Fisheries, in particular Craig Loveridge, and NIWA database teams, who supplied the data and handled our questions and queries. We also appreciate continued input from Ministry of Fisheries staff, in particular Eric Mellina who made detailed comments on the draft manuscript, and from other members of the Aquatic Environment Working Group. This research was funded by Ministry of Fisheries project PRO2007/02.

6. REFERENCES

Abraham, E.R.; Thompson, F.N.; Oliver, M.D. (2010). Summary of the capture of seabirds, marine mammals and turtles in new zealand commercial fisheries, 1998–99 to 2007–08. *New Zealand Aquatic Environment and Biodiversity Report No. 45*. 148 p.

Campbell, R.; Chilvers, B.; Childerhouse, S.; Gales, N. (2006). Conservation management issues and status of the New Zealand (*Phocarctos hookeri*) and Australian (*Neophoca cinerea*) sea lions. In Trites, A.; DeMaster, D.; Fritz, L.; Gelatt, L.; Rea, L.; Wynne, K. (Eds.), Sea lions of the world. Lowell Wakefield Fisheries Symposium, Alaska, pp. 455–471.

Chilvers, B.L. (2008). New Zealand sea lions *Phocarctos hookeri* and squid trawl fisheries: Bycatch problems and management options. *Endangered Species Research 5*: 193–204.

Davison, A.C.; Hinkley, D.V. (Eds.). (1997). Bootstrap methods and their application. Cambridge University Press.

Department of Conservation (2009). New Zealand sea lion species management plan: 2009–2014. Department of Conservation, Wellington, New Zealand. Retrieved 19 August 2009, from http://www.doc.govt.nz/upload/documents/science-and-technical/sap251entire.pdf

Gelman, A. (2006). Prior distributions for variance parameters in hierarchical models (Comment on article by Browne and Draper). *Bayesian Analysis 1*: 515–534.

Geweke, J. (1992). Evaluating the acuracy of sampling-based approaches to the calculation of posterior moments (with discussion). *Bayesian Statistics 4*: 169–194.

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

Hitchmough, R.; Bull, L.; Cromarty, P. (2007). New Zealand threat classification system lists 2005. Department of Conservation, Wellington.

IUCN (2008). 2008 IUCN Red List of threatened species. Retrieved 5 May 2009, from http://www.iucnredlist.org

Ministry of Fisheries. (2008). Research database documentation. Retrieved 5 May 2009, from http://tinyurl.com/fdbdoc

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 15 January 2009, from http://www-fis.iarc.fr/ martyn/software/jags

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

Roe, W.D. (2009). Necropsy of marine mammals captured in new zealand fisheries in the 2008–09 fishing year. *New Zealand Aquatic Environment and Biodiversity Report No. 47*. 22 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.

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

Thompson, F.N.; Abraham, E.R. (2009). Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2006–07. *New Zealand Aquatic Environment and Biodiversity Report No. 41*. 31 p.

Thompson, F.N.; Oliver, M.D.; Abraham, E.R. (2010). Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2007–08. Draft New Zealand Aquatic Environment and Biodiversity Report.