Estimation of the capture of New Zealand sea lions (*Phocarctos hookeri*) in trawl fisheries, from 1995–96 to 2007–08

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EXECUTIVE SUMMARY

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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 2007–08 fishing years. Over this period, Ministry of Fisheries observers recorded the capture of between 5 and 39 sea lions within the New Zealand Exclusive Economic Zone, within each fishing year. During the 2007–08 fishing year, 8 sea lions were observed captured on trawls. This count excludes 3 captures observed on the first day of the 2007–08 fishing year, in the last days of the southern blue whiting fishery. Seven of the 8 captured sea lions were retrieved dead, and 1 was released alive. Of the 8 sea lion captures, 5 were observed caught in the squid fishery around the Auckland Islands. This was the lowest number of observed captures in this fishery since the 1998–99 fishing year. Two sea lion captures were observed in the southern blue whiting fishery east of Campbell Island, a decrease from 6 captures the year before. There were no sea lion captures in the Auckland Islands scampi fishery or any other Auckland Islands trawl fishery. One sea lion was caught on an observed trawl in the hoki fishery south of The Snares and released alive.

From these observations, estimates of total captures were made for four different strata: the squid fishery near the Auckland Islands; the Campbell Island southern blue whiting fishery; other (non-squid) trawl fisheries near the Auckland Islands; and all trawl fisheries on the southern end of the Stewart-Snares shelf. Bayesian generalised linear models were fitted to data from the first two of these strata. A previous model, used for estimating sea lion captures in the 2006–07 fishing year, was re-implemented for the Auckland Islands squid fishery. Likewise, the model developed in 2006–07 for the Campbell Island southern blue whiting fishery was re-implemented, with minor changes. Ratio estimates were calculated for the remaining two strata.

Since 2001, trawl nets in the Auckland Islands squid fishery have increasingly been fitted with sea lion exclusion devices (SLEDs) that allow animals to escape from the net. The model estimated that the probability a sea lion failed to escape from a net fitted with a SLED (i.e., the retention probability) was 0.234 (95% c.i,: 0.14 to 0.38). This was similar to previous estimates, and correspondingly the predicted strike rate in 2007–08 of 5.2 sea lions per 100 trawls (95% c.i.: 2.2 to 9.7) was similar to estimates of the strike rate made previously. As SLEDs have been used more widely, the number of captures has fallen relative to the number of interactions, and in 2007–08 there were an estimated 14 (95% c.i.: 7 to 25) sea lion captures in the Auckland Islands squid fishery. For the same year, the model estimated that there were 65 (95% c.i.: 26 to 124) sea lion interactions, the lowest number of estimated interactions since 2002–03. This decrease was largely due to a decrease in effort from a peak of 2706 trawls in 2004–05 to 1265 trawls in 2007–08. The number of attributed mortalities in this fishery in 2007–08 was 42.1 (95% c.i.: 17 to 81), assuming a discount rate of 35%.

There were 552 trawls made in the Campbell Island southern blue whiting fishery in 2007–08, of which 41% were observed. The observed sea lion capture rate was 0.88 animals per 100 trawls, a decrease from the previous two years. The model estimated 4 captures during 2008 (95% c.i.: 2 to 10), and an estimated strike rate of 0.53 captures per hundred trawls (95% c.i.: 0.07 to 1.45). In other (non-squid) Auckland Islands trawl fisheries there were 12 estimated captures (95%c.i.: 7 to 18) in 2007–08, and 4 estimated captures (95% c.i.: 3 to 6) for all trawl fisheries on the southern Stewart-Snares shelf; numbers typical of the previous three fishing years for these strata.

Estimates for the four strata were combined for each of the fishing years 1995–96 to 2007–08. The total estimates for 2007–08 were 35 sea lion captures (95% c.i.: 25 to 48), and 86 sea lion interactions (95% c.i.: 46 to 149). This compared with a total estimate for 2006–07 of 50 captures (95% c.i.: 37 to 67) and 108 interactions (95% c.i.: 64 to 174).

1. INTRODUCTION

The New Zealand sea lion (*Phocarctos hookeri*) population consists of large colonies on the Auckland Islands (at Enderby Island, Dundas Island, and Figure of Eight Island) and smaller colonies on Campbell Island, The Snares, and the South Island near the Otago Peninsula (Chilvers 2008). An endemic species, New Zealand sea lions are considered to be threatened (range restricted) by the New Zealand threat management classification system (Hitchmough 2002). 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 since 1998 (Department of Conservation 2009).

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. A summary of the observed captures of protected species by New Zealand fisheries was given by Abraham & Thompson (2009). Sea lions are caught by trawlers operating around New Zealand's subantarctic islands. Between 1 October 1995 and 30 September 2008, the two largest clusters of captures were to the north and to the southeast of the Auckland Islands. Squid trawlers in the Auckland Islands fishery accounted for 82% of all observed sea lion captures over the 13 year period. Sea lions were also caught by trawlers targeting non-squid species in the Auckland Islands region, in the southern blue whiting trawl fishery east of Campbell Island, and in trawl fisheries on the southern end of the Stewart-Snares shelf.

Since 2003, the Ministry of Fisheries has restricted the Auckland Islands squid fishery by setting a fishing-related mortality limit (FRML) on the number of sea lion deaths caused by the fishery. This limit is translated into a maximum number of trawls that can be made by the fishery by assuming a sea lion strike rate per trawl. In the 2007–08 fishing year, the FRML was set at 81 sea lion deaths. This was equivalent to a limit of 1434 trawls, assuming a strike rate of 5.65 sea lions killed per 100 trawls. The strike rate is set by the Ministry of Fisheries at the beginning of the fishing season.

In 2001 a new bycatch mitigation method, the sea lion exclusion device (SLED), was introduced in the Auckland Islands squid fishery (Figure 1). Since 2004–05 almost all vessels operating in this fishery have used approved SLEDs. In the 2007–08 fishing year a discount rate of 35% was applied to trawls that used SLEDs approved by the Ministry of Fisheries. This increased the number of permitted trawls from 1434 to 2206; a small change from the trawl limit figures set in the previous 2006–07 fishing year (1755 and 2194, respectively).

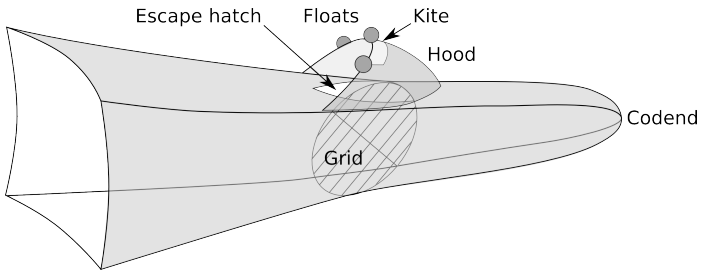

Figure 1: Schematic diagram of a sea lion exclusion device (SLED). The SLED consists of a grid fitted in the net, in front of the codend. Sea lions are unable to pass through the grid into the codend, but may escape through a hole above the grid. A forward facing hood fitted above the escape hatch is 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.

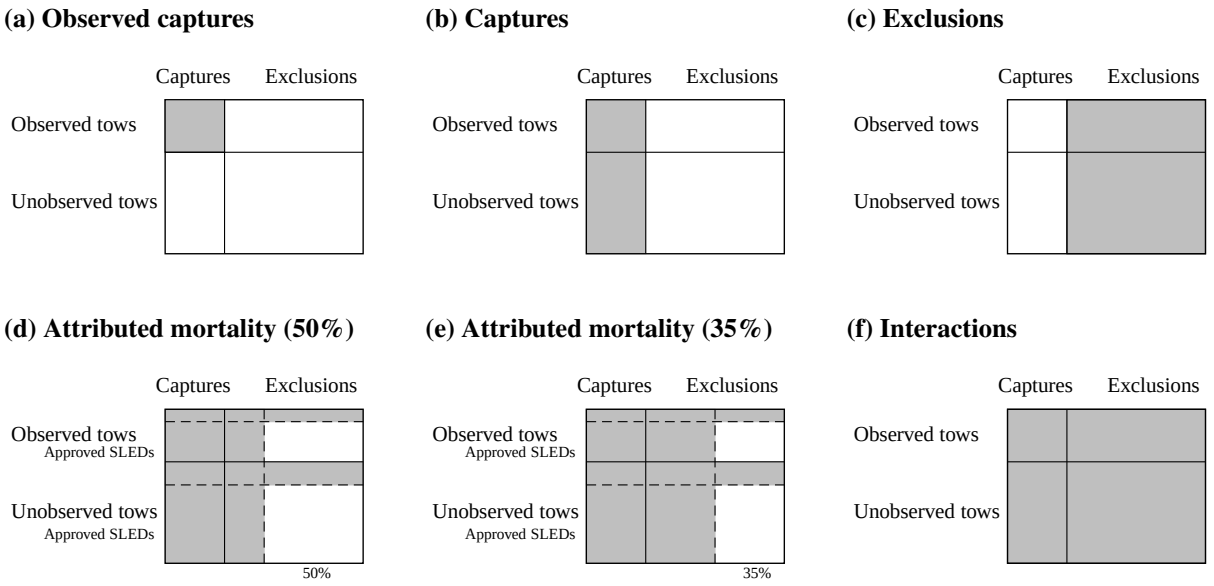

Figure 2: Quantities estimated for trawls that used SLEDs. Trawls are either observed or unobserved, and sea lions are either captured or are excluded (escaped through the SLED and would have been captured had a SLED not been used). The shaded grey areas are (a) Observed captures, (b) Captures, the sum of observed captures and estimated captures on unobserved trawls, (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.

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 present on only some trawls, and so statistical methods are required to extrapolate from captures on observed trawls to captures on all trawls. A schematic diagram showing the various reported quantities, for trawls with SLEDs, is given in Figure 2. The terminology used in this report is detailed in Table 1. On trawls 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 trawls, 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 trawls) and these allow comparison between years and fisheries where there have been different numbers of trawls.

In the Auckland Islands squid fishery, the number of attributed mortalities is calculated. This is an estimate of the number of sea lions that would have been killed under the assumptions that (a) no sea lions survived being excluded by a SLED unless the SLED had been approved by the Ministry of Fisheries, and (b) on trawls with an approved SLED, only a proportion of excluded sea lions survived. Attributed mortalities are calculated with the survival probability 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%.

This report updates Thompson & Abraham (2009) to include data from the 2007–08 fishing year. The same methods, with some minor changes, are used to estimate captures of sea lions for the four strata listed in Table 2. The data set used to fit the models, and make the ratio estimates, ranges over a 13 year period from 1 October 1995 to 30 September 2008. The model used to estimate captures in the

Table 1: Terminology used in this report for sea lion captures in the Auckland Islands squid fishery following the definitions used by Thompson & Abraham (2009).

Term	Definition
Auckland Islands squid fishery	Trawlers targeting squid in the Auckland Islands part of the SQU 6T fishing area (Figure 6(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 trawls. 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 lion captures, calculated as the sum of observed captures and the estimated captures that would have been recorded on unobserved trawls, 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 trawls.
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 Islands' Squid Fishery. This is converted into a permitted number of trawls 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 trawls that use approved SLEDs, used when determining the amount of fishing effort permitted in the Auckland Islands squid fishery under the FRML.
Attributed mortality	The attributed mortality is the sum of interactions on trawls with unapproved SLEDs, and a percentage (100% less the discount rate) of interactions on trawls 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.

Auckland Islands squid fishery is a re-implementation of the Smith & Baird (2007b) Bayesian model, originally used to estimate captures in the 2004–05 fishing year. A simpler model is used to estimate captures in the southern blue whiting fishery east of Campbell Island, and ratio estimates are presented for the remaining two strata. In these latter three strata there are no SLEDs, captures are equivalent to interactions, and there is no need to calculate exclusions or attributed mortalities.

Table 2: Summary of the estimates made for each stratum

Stratum		Estimation method	Estimated quantities
Area	Fisheries		
Auckland Islands	Squid trawl	Bayesian model	Captures, Strike rate, Interactions, Attributed mortalities, Exclusions
Campbell Island	Southern blue whiting trawl	Bayesian model	Captures, Strike rate
Auckland Islands	Other (non-squid) trawl	Ratio	Captures, Strike rate
Stewart Snares shelf	Squid trawl	Ratio	Captures, Strike rate

2. METHODS

2.1 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 trawl. The *warehou* data were assumed to be a complete record of trawl effort, and were used as the authoritative source for the trawl date, time and location information required for the modelling.

The Ministry of Fisheries observer programme 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 by Thompson & Abraham (2009). More than 97% of observer records were matched to the effort data, in every fishing year, with 99% of the observed squid trawls being matched in 2007–08. The SLED data set included a trawl by trawl 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 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 2). 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 trawl 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 1999–2000 at 1616 trawls, decreasing to 106 trawls in 2004–05. There has been no further effort in this fishery since.

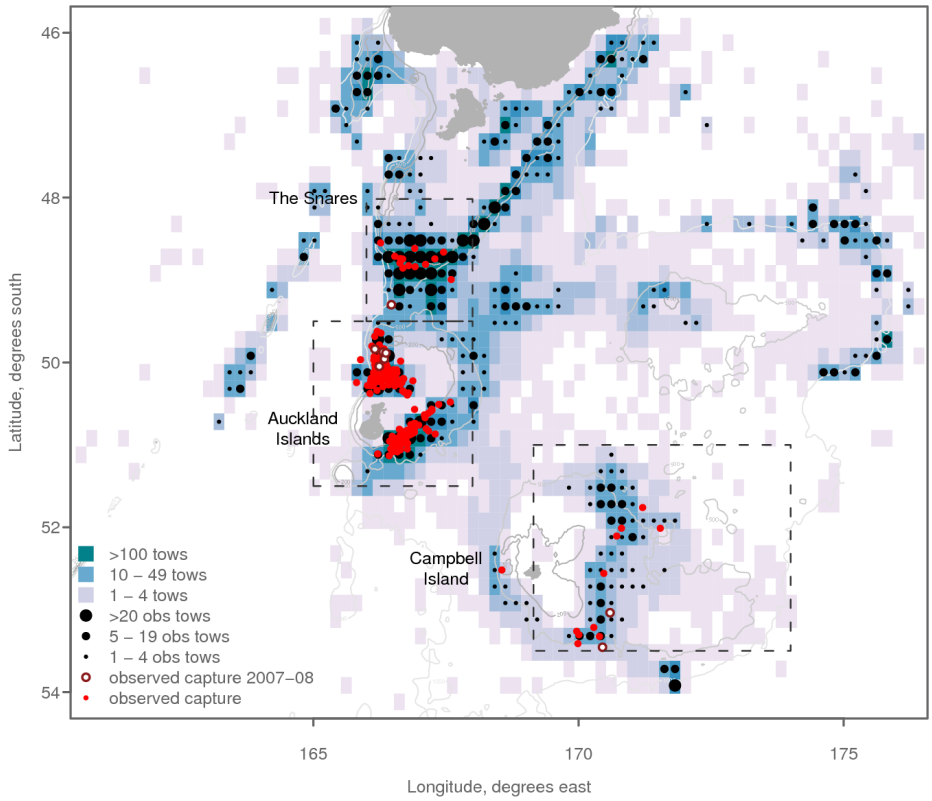

Figure 3: Trawl effort, observer coverage, and observed captures in the subantarctic region of New Zealand's EEZ. Data includes all trawl effort, excluding trawls targeting inshore species, for the 13 years from 1 October 1995 to 30 September 2008. Dashed lines indicate the strata that were used for making estimates.

2.2 The Auckland Islands squid fishery

In this report we have applied the model developed by Thompson & Abraham (2009) to estimate sea lion captures in the Auckland Islands squid trawl fishery for the 2007–08 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 trawl, and the objective of the estimation was to predict the expected number of captured sea lions on the unobserved trawls. Trawls in fishing year y were indexed by vessel key, j, and number, k, and the number of sea lions captured on trawl 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 trawl to trawl, and with an over-dispersion, θ, that was the same for all trawls. 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 trawl, μ_θ:

$$c^y_{jk} \sim \text{Poisson}(\mu^y_{jk} g_\theta), \quad (1)$$

$$g_\theta \sim \text{Gamma}(\theta, \theta), \quad (2)$$

$$\theta \sim \text{Uniform-shrinkage}(\mu_\theta). \quad (3)$$

The mean strike rate μ_{jk}^{y} was composed of three components multiplied together: a random year effect λ_i, a random vessel-year effect v_j^y, and a linear regression component that depended on the value of covariates x_{jk}^{yb} and the regression coefficients β_b,

$$\mu_{jk}^{y} = \lambda^{y} v_j^{y} \exp\left(\sum_b x_{jk}^{yb} \beta_b\right) \quad . \tag{4}$$

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_j^y, 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_j^y was drawn from the gamma distribution:

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

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 focused 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*, *trawl duration*, and *sub-area* were non-informative normal distributions,

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

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,
trawl duration	A continuous variable, the logarithm of trawl duration,
sub-area	A two level factor variable, indicating in which sub-area the start of the trawl 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 (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 presence or absence of a SLED with the cover off was treated as a covariate along with the others. However, the regression coefficient $\beta_{\textit{open-net}}$ was transformed into the SLED retention probability, $\pi = \exp\left(\beta_{\textit{open-net}}\right)$, 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.

2.2.1 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 1, and illustrated in Figure 2. For each sample from the Markov chain, the estimated number of sea lion interactions i_{jk} was calculated for each trawl (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 trawl 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 trawl, the number of captures was less than or equal to the number of interactions. The number of sea lion exclusions on a trawl 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,

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

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:

$$\text{Captures} \quad C = \sum_u c_{jk} + C_o, \tag{14}$$

$$\text{Interactions} \quad I = \sum_u i_{jk} + \sum_o e_{jk} + C_o, \tag{15}$$

$$\text{Strike rate} \quad \mu = I/n, \tag{16}$$

$$\text{Exclusions} \quad E = I - C, \tag{17}$$

$$\text{Attributed captures} \quad A = C + \sum_a a_{jk}, \tag{18}$$

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

2.3 The Campbell Island southern blue whiting fishery

There were a small number of sea lion captures in the southern blue whiting fishery east of Campbell Island. In the 2008 season, 2 sea lions were observed captured, compared to 5 in the squid fishery around the Auckland Islands. A simple Bayesian model was used to estimate the captures in the southern blue whiting fishery. There was 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 (Figure 3).

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), with the exception that the date range was extended to include all data from 1996 to 2008.

2.4 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 other

non-squid Auckland Islands trawl fisheries were defined as all trawls in the Auckland Islands part of the SQU 6T fishing area not targeting squid (Figure 8(d)), 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° (Figure 9(d)).

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 2007–08, by assuming a constant capture rate over these years. This contrasts with Thompson & Abraham (2009), who used data only from three years. The estimated number of captures in a year, y, was

$$C^y = C^y_o + C^y_u, \tag{19}$$

where C^y_o were the observed captures and C^y_u 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 trawls in a year was o^y, then the average sea lion capture rate was

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

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

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

where n^y was the total number of trawls in year y. The uncertainty in the captures, C^y, was estimated using bootstrap resampling (e.g., Davison & Hinkley 1997). Data from the observed trawls 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.

2.5 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 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 captures in each year. Interactions were calculated as the sum of estimated interactions in the Auckland Islands' 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 Auckland Islands squid fishery model

The distributions of the model covariates during trawls made in the Auckland Islands squid fishery are shown in Figure 4. The observed trawls were broadly representative of the unobserved effort. Trawl duration was relatively stable across the fleet from 1995–96 to 2002–03, rising to a peak in 2006–07 and decreasing again in 2007–08 (Figure 4(a)), with the median trawl duration being 6.0 hours. There were many more trawls in the northwest area compared with the southeast area (Figure 4(b)) for both the observed (83.8%) and unobserved (77.5%) data in 2007–08. The distance to the nearest colony (Figure 4(c)) varied from 27 to 73 km, with a peak between 40 and 50 km in 2007–08. The median distance remained stable for the 13 year period at around 45 km. The open-net data are shown in Figure 4(d)). Nearly all trawls (98.6%) in the 2007–08 Auckland Islands squid fishery used nets

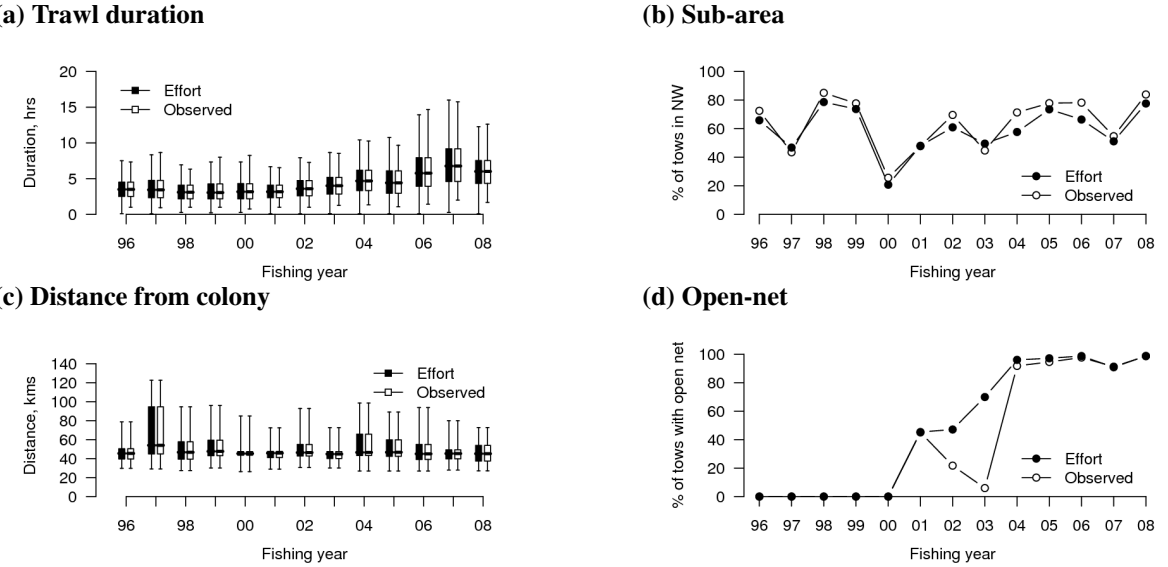

Figure 4: Time series of (a) trawl duration, (b) percentage of trawls in the northwest sub area, (c) distance from the nearest colony, and (d) percentage of trawls using SLEDs with an open net. Plots include all trawl effort from the Auckland Islands squid fishery, with the observed effort for comparison. The boxes indicate the inter-quartile range, the whiskers extend to the 95% interval.

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	0.234	0.137	0.226	0.375
Dist. to colony exponent	-0.749	-1.298	-0.745	-0.221
Duration exponent	0.641	0.313	0.639	0.978
Subarea S&E effect	0.508	0.341	0.501	0.722

fitted with SLEDs and with the cover nets either open or absent entirely. In 2001–02 and 2002–03 observer protocol dictated they observe a proportion of trawls with the cover net tied down, to allow direct estimation of the SLED retention (Smith & Baird 2007a). In these two years, there were few trawls with open nets (21.7% and 6%, respectively) and observed trawls were not representative of all effort.

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 0.234; a small decrease from 0.242 in 2006–07. 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 trawl decreases with distance from the nearest colony. This effect is not significantly different from -1.0, which would imply an inverse relation. The mean coefficient of the logarithm of the trawl duration decreased slightly from 0.685 in 2006–07 to 0.641 in 2007–08. The exponentiated value of the coefficient for the sub-area factor remained at 0.508; the chance of catching a sea lion in the south and east areas, during an otherwise similar trawl, was half that of the northwest area.

The diagnostic tests confirmed that the model had converged. The Heidelberger test checks that the sampled model parameters come from a stationary distribution, and all parameters passed for both chains. The dispersion parameters of the two gamma distributions in the model were slowest to converge. The Geweke diagnostic compares samples from the first 10% with those in the final 50%, to test whether they are from the same distribution. There was no evidence of the two chains not converging.

3.2 Estimated captures

3.2.1 Total captures for all strata

Combined effort and observed and estimated captures for all four strata over the 13 year period are given in Table 5 and Figure 5. Because the model was re-run, the 2006–07 model results presented here differ slightly from those reported for the same year by Thompson & Abraham (2009).

The estimated number of total interactions in all four strata decreased from 108 (95% c.i.: 64 to 174) in 2006–07 to 86 (95% c.i.: 46 to 149) in 2007–08 for only a small decrease in effort (3.0%). The term interactions was synonymous with captures for the period 1995–96 to 1999–2000 when SLEDS were not used. Estimated captures decreased overall and in 2007–08 they were the lowest in 13 years at 35 (95% c.i.: 25 to 48). Observer 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 5(e)). Observed sea lion captures across all fisheries were highest from February to April.

3.2.2 The Auckland Islands squid fishery

The 13 year time series of trawl effort, observed effort, observed captures, estimated captures, estimated interactions, and the estimated strike rate are presented in Table 6 and Figure 6. The 2000–01 fishing year was particularly well observed (99%), and had the highest observed capture rate of 6.7 sea lions per 100 trawls. The observed capture rate has been trending down since then, reaching 0.9 sea lions per 100 trawls in 2007–08; the lowest catch rate in the 13 year period for which we present data. This trend was in part due to the progressive introduction of SLEDs. In the 2007–08 fishing year only five sea lions were observed captured, the lowest number of captures since 1998–99. Of these, three were female and two were male.

In the Auckland Islands squid fishery, observers were requested to record the location where the sea lion was first observed. Of the five observed captures: one was stuck in the SLED; one was recovered from the SLED lengthener, before the grid; two were first seen in the pounds, with the observer recording that the net was only opened on the codend side of the grid; and there was one sea lion where the capture location was not reported. The monthly distribution of observer coverage in this fishery was representative of the effort, and observed captures closely followed monthly variation in the observations (Figure 6(e))

Estimated captures were highest in 1995–96 and 1996–97 when fishing effort was also at a peak, with more than 3700 trawls per year. Estimated captures have been generally declining since then with an estimated 14 sea lion captures in 2007–08 (95% c.i.: 7 to 25). Sea lion interactions include animals that escape through open SLEDs, with the chance that a sea lion fails to escape being given by the SLED retention probability (Table 4). Interactions were estimated to be greater than 140 sea lions for the three fishing years 2003–04, 2004–05, and 2005–06, matching estimated captures in the years 1995–96 and 1996–97. In 2007–08, sea lion interactions were estimated to be 65 (95% c.i.: 26 to 124) (Table 6). The decrease was largely due to a decrease in fishing effort.

The strike rate was estimated in 2007–08 to be 5.2 sea lions per trawl (95% c.i.: 2.2 to 9.7), and was consistent with the estimated strike rate for the five fishing years since 2003–04. The confidence interval for the strike rate was large, partly due to uncertainty in the SLED retention probability. The confidence intervals over the last five years were much greater than the variation in the mean, so no significant change in the strike rate can be determined.

3.2.3 The Campbell Island southern blue whiting fishery

A summary of the effort and observed and estimated captures in the southern blue whiting fishery for the 13 year time series is presented in Table 7 and Figure 7. The estimated number of captures, and the strike rate, had been steadily increasing since 2003, peaking in 2007 at 16 captures (95% c.i.: 8 to 28). In 2008 there were an estimated 4 sea lion captures (95% c.i.: 2 to 10). The estimated strike rate in 2008 was lower than the observed strike rate. This was because the model fitted a mean strike rate across all the data and represented the year-to-year variation as a random deviation from this mean. This had a tendency to pull the extreme values in towards the mean.

3.2.4 Other strata

A summary of the effort and observed and estimated captures in other trawl fisheries for the 13 year time series is presented in Table 8 and Figure 8. Total effort in these non-squid trawl fisheries ranged from 1369 to 2227 trawls per year over the 13 year period and observed captures ranged between 1 and 4. Ten of the 14 captures 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 trawls 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 small number of captures, low observer coverage, and lack of evidence of a trend over the 13 years suggested the use of a single estimate of the capture rate. The bootstrap estimate of the strike rate was 0.81 sea lions per 100 trawls (95% c.i.: 0.46 to 1.22). This was consistent with the observed capture rate of 0.68 across Auckland Island trawls not targeting squid. Estimated captures in 2007–08 were 12 sea lions (95% c.i.: 7 to 18), the same as the previous 3 years, reflecting the fact that effort had been constant at around 1400 trawls per year for the last four years.

The mean monthly distribution of effort and observer coverage and observed captures shows no clear trends. There was fishing effort throughout the year, and observed captures peaked in November and June. The variability in the captures directly reflects the low number of observed captures in these fisheries.

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 13 year time series is presented in Table 9 and Figure 9. 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 13 year period was used. Nine of the 14 captures were observed on squid trawls, two were observed on trawls targeting hoki, two on trawls targeting jack mackerel, and one on a trawl targeting barracouta. Only one capture was observed in the 2007–08 fishing year, on a trawl targeting hoki, at the southern end of the selected area.

The bootstrap estimated strike rate was 0.11 sea lions per 100 trawls (95% c.i.: 0.05 to 0.17), less than one-eighth of the rate in non-squid trawl near the Auckland Islands. The estimated number of captures in 2007–08 was 4, the lowest since 1995–96 (95% c.i.: 3 to 6). This corresponded with declining effort in this area, also at its lowest since 1995–96. Estimated captures peaked at 10 in 2004–05 (95% c.i.: 6 to 14) when fishing effort was high.

3.2.5 Total estimated sea lion captures and interactions

Table 5: 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), from the four estimated strata.

		Observed			Est. captures		Est. interactions	
	Effort	% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.
2007–08	6539	30	8	0.4	35	(25 - 48)	86	(46 - 149)
2006–07	6742	24	15	0.9	50	(37 - 67)	108	(64 - 174)
2005–06	9313	18	14	0.8	60	(42 - 82)	172	(94 - 291)
2004–05	11105	23	14	0.5	61	(43 - 87)	170	(94 - 293)
2003–04	10021	23	21	0.9	68	(51 - 92)	193	(112 - 323)
2002–03	8265	19	11	0.7	43	(31 - 56)	70	(44 - 106)
2001–02	9953	19	23	1.2	73	(55 - 96)	102	(70 - 147)
2000–01	8921	40	46	1.3	69	(61 - 78)	86	(65 - 112)
1999–00	9049	23	28	1.4	92	(67 - 127)	91	(63 - 129)
1998–99	10551	16	6	0.4	40	(27 - 55)	40	(26 - 56)
1997–98	10062	15	15	1	85	(58 - 127)	85	(56 - 128)
1996–97	10947	15	28	1.7	160	(110 - 229)	160	(106 - 232)
1995–96	10035	10	16	1.6	165	(95 - 275)	165	(95 - 273)

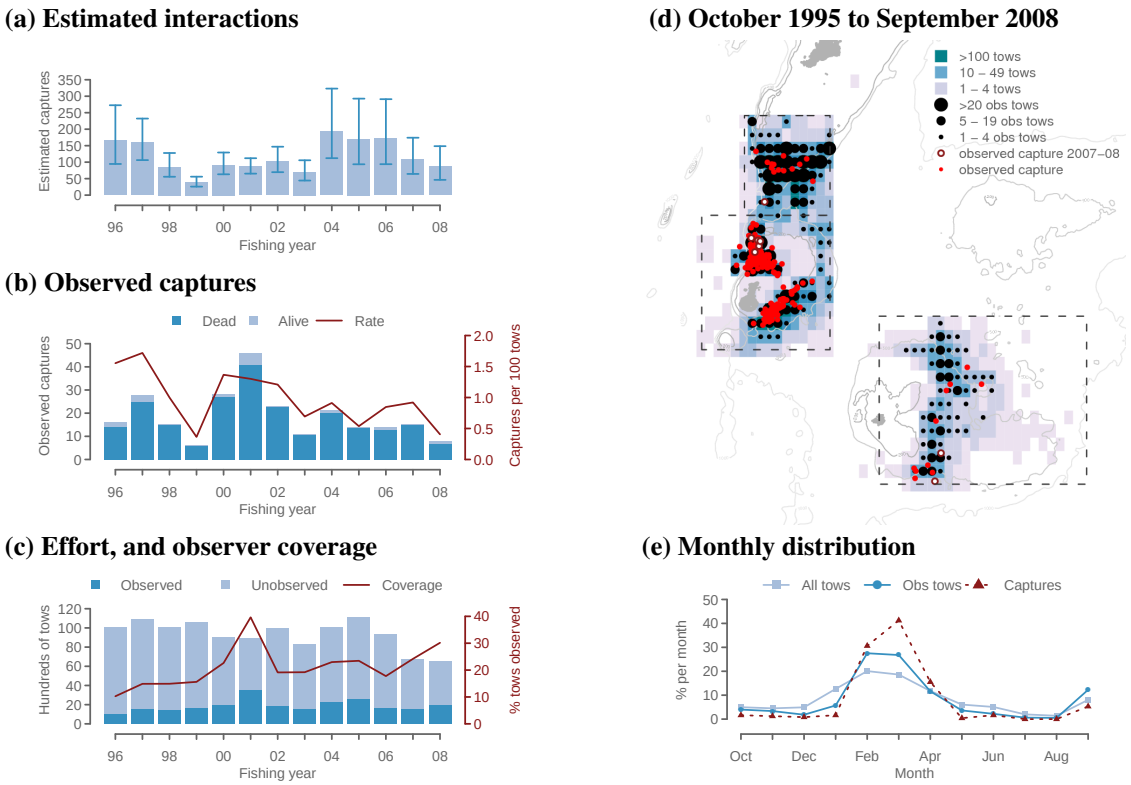

Figure 5: Annual time series of (a) estimated sea lion interactions, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, for data from the four estimated strata from 1995–95 to 2007–08. In map (d) average effort is plotted in a blue colour scale, observer 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.

3.2.6 The Auckland Islands squid fishery

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, interactions, and the estimated strike rate (with 95% confidence intervals), in the Auckland Islands squid fishery.

		Observed			Est. captures		Est. interactions		Est. strike rate (%)	
	Effort	% obs.	Cap.	Rate	Mean	95% c.i.	Mean	95% c.i.	Mean	95% c.i.
2007–08	1265	46	5	0.9	14	(7 - 25)	65	(26 - 124)	5.2	(2.2 - 9.7)
2006–07	1320	41	7	1.3	17	(10 - 28)	76	(33 - 140)	5.7	(2.7 - 10.2)
2005–06	2462	22	9	1.6	34	(20 - 55)	146	(70 - 267)	5.9	(3.0 - 10.7)
2004–05	2706	30	9	1.1	35	(19 - 59)	144	(69 - 269)	5.3	(2.6 - 9.8)
2003–04	2594	30	16	2	43	(27 - 66)	169	(88 - 301)	6.5	(3.5 - 11.5)
2002–03	1470	29	11	2.6	21	(13 - 32)	48	(24 - 82)	3.3	(2.0 - 5.2)
2001–02	1648	34	21	3.7	45	(30 - 66)	73	(43 - 116)	4.4	(3.0 - 6.6)
2000–01	583	99	39	6.7	39	(39 - 40)	57	(37 - 81)	9.8	(8.3 - 12.0)
1999–00	1208	36	25	5.7	65	(42 - 101)	65	(39 - 102)	5.4	(3.8 - 8.0)
1998–99	402	38	5	3.3	15	(7 - 28)	15	(5 - 29)	3.8	(2.3 - 6.2)
1997–98	1470	23	14	4.1	62	(35 - 101)	62	(34 - 104)	4.2	(2.6 - 6.7)
1996–97	3733	20	28	3.8	141	(91 - 210)	141	(88 - 212)	3.8	(2.5 - 5.5)
1995–96	4460	12	13	2.4	143	(73 - 249)	143	(73 - 245)	3.2	(1.7 - 5.4)

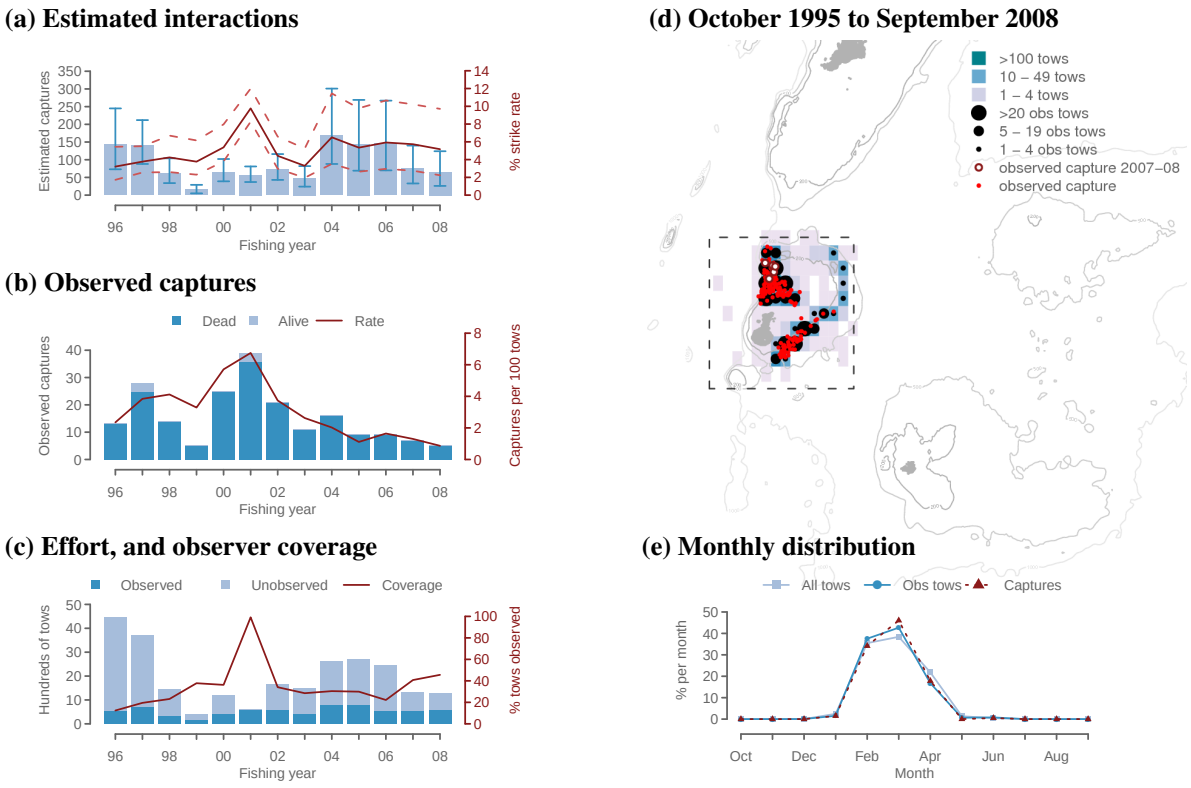

Figure 6: Annual time series of (a) estimated sea lion interactions, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the Auckland Islands squid fishery from 1995–95 to 2007–08. In map (d) average effort is plotted in a blue colour scale, observer coverage 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.

3.2.7 The Campbell Island southern blue whiting 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 Campbell Island southern blue whiting fishery.

	Observed				Est. captures		Est. strike rate (%)	
	Effort	% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2008	552	41	2	0.88	4	(2 - 10)	0.53	(0.07 - 1.45)
2007	542	32	6	3.51	16	(8 - 28)	2.45	(0.78 - 5.06)
2006	518	28	3	2.1	7	(3 - 16)	1.1	(0.21 - 2.85)
2005	725	37	2	0.74	5	(2 - 12)	0.53	(0.08 - 1.57)
2004	678	34	1	0.43	3	(1 - 8)	0.38	(0.02 - 1.38)
2003	575	43	0	-	0	(0 - 3)	0.12	(0 - 0.59)
2002	978	27	1	0.37	4	(1 - 11)	0.32	(0.02 - 1.13)
2001	667	60	0	-	0	(0 - 2)	0.09	(0 - 0.41)
2000	446	52	0	-	0	(0 - 3)	0.12	(0 - 0.58)
1999	782	28	0	-	1	(0 - 5)	0.1	(0 - 0.5)
1998	963	29	0	-	1	(0 - 4)	0.1	(0 - 0.46)
1997	639	34	0	-	1	(0 - 3)	0.12	(0 - 0.56)
1996	472	27	0	-	1	(0 - 4)	0.16	(0 - 0.86)

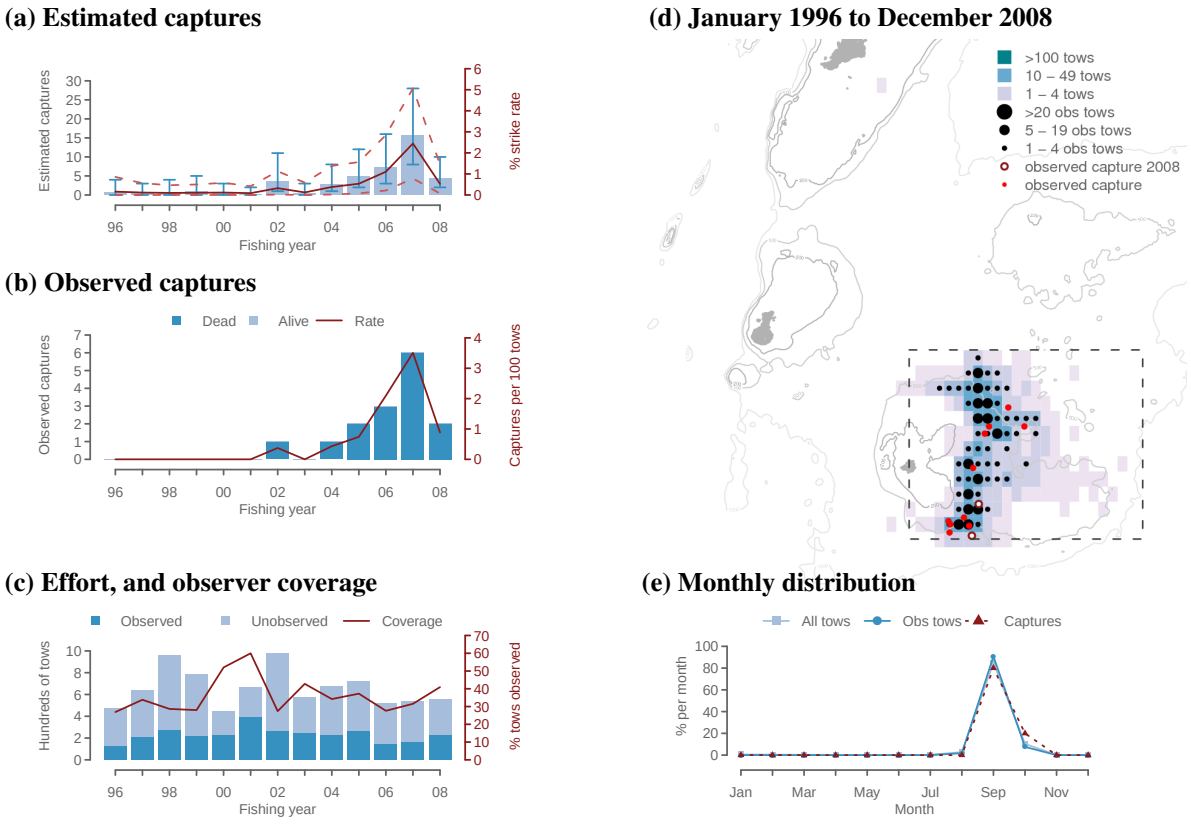

Figure 7: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the Campbell Island southern blue whiting fishery from 1996 to 2008. In map (d) average effort is plotted in a blue colour scale, observer 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.

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

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 trawl fisheries near the Auckland Islands, excluding squid trawl. Scampi trawl makes up 77% of this effort over the whole period, and 90% in 2007–08.

		Observed			Est. captures		Est. strike rate (%)	
	Effort	% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2007–08	1480	11	0	0	12	(7 - 18)	0.81	(0.46 - 1.22)
2006–07	1369	7	1	1.03	12	(7 - 18)	0.81	(0.46 - 1.22)
2005–06	1369	9	1	0.82	12	(7 - 18)	0.81	(0.46 - 1.22)
2004–05	1456	1	0	0	12	(7 - 18)	0.81	(0.46 - 1.22)
2003–04	1656	13	3	1.38	16	(11 - 23)	0.81	(0.46 - 1.22)
2002–03	1894	12	0	0	16	(10 - 24)	0.81	(0.46 - 1.22)
2001–02	2227	8	0	0	18	(10 - 27)	0.81	(0.46 - 1.22)
2000–01	2007	6	4	3.17	20	(13 - 28)	0.81	(0.46 - 1.22)
1999–00	2152	8	0	0	18	(10 - 26)	0.81	(0.46 - 1.22)
1998–99	1799	4	1	1.33	16	(9 - 23)	0.81	(0.46 - 1.22)
1997–98	1821	14	1	0.4	16	(9 - 23)	0.81	(0.46 - 1.22)
1996–97	1540	13	0	0	14	(8 - 20)	0.81	(0.46 - 1.22)
1995–96	1728	5	3	3.45	17	(11 - 24)	0.81	(0.46 - 1.22)

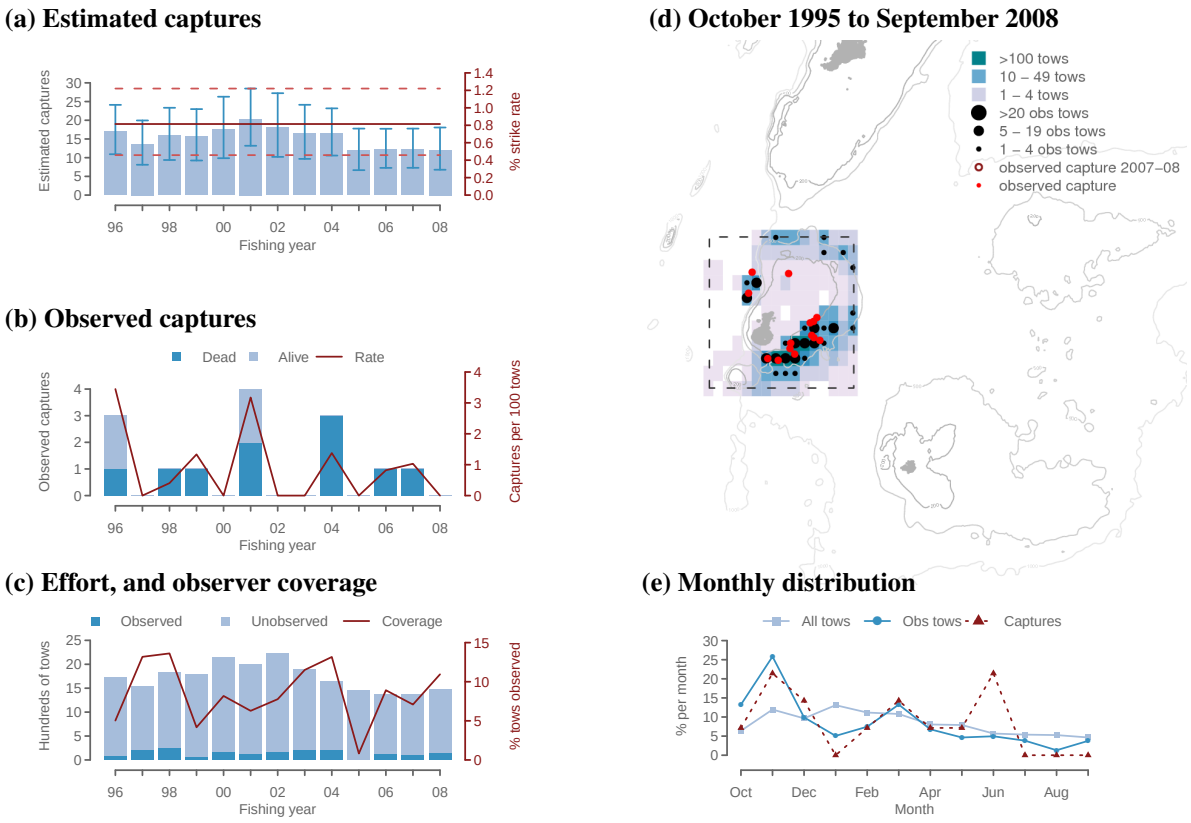

Figure 8: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in the scampi and other fisheries near the Auckland Islands from 1995–1996 to 2007–08. In map (d) average effort is plotted in a blue colour 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.

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

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, and the estimated strike rate (with 95% confidence intervals), for all trawl fisheries on the southern end of the Stewart-Snares shelf.

		Observed			Est. captures		Est. strike rate (%)	
	Effort	% obs.	Capt.	Rate (%)	Mean	95% c.i.	Mean	95% c.i.
2007–08	3246	31	1	0.1	4	(3 - 6)	0.11	(0.05 - 0.17)
2006–07	3514	23	1	0.12	5	(3 - 7)	0.11	(0.05 - 0.17)
2005–06	4964	17	1	0.12	6	(4 - 9)	0.11	(0.05 - 0.17)
2004–05	6230	24	3	0.2	10	(6 - 14)	0.11	(0.05 - 0.17)
2003–04	5097	21	1	0.09	6	(4 - 10)	0.11	(0.05 - 0.17)
2002–03	4337	16	0	0	5	(2 - 7)	0.11	(0.05 - 0.17)
2001–02	5119	18	1	0.11	6	(4 - 10)	0.11	(0.05 - 0.17)
2000–01	5681	43	3	0.12	9	(6 - 13)	0.11	(0.05 - 0.17)
1999–00	5264	23	3	0.25	9	(6 - 12)	0.11	(0.05 - 0.17)
1998–99	7583	16	0	0	8	(4 - 13)	0.11	(0.05 - 0.17)
1997–98	5836	11	0	0	6	(3 - 10)	0.11	(0.05 - 0.17)
1996–97	5044	10	0	0	5	(3 - 9)	0.11	(0.05 - 0.17)
1995–96	3385	8	0	0	4	(2 - 6)	0.11	(0.05 - 0.17)

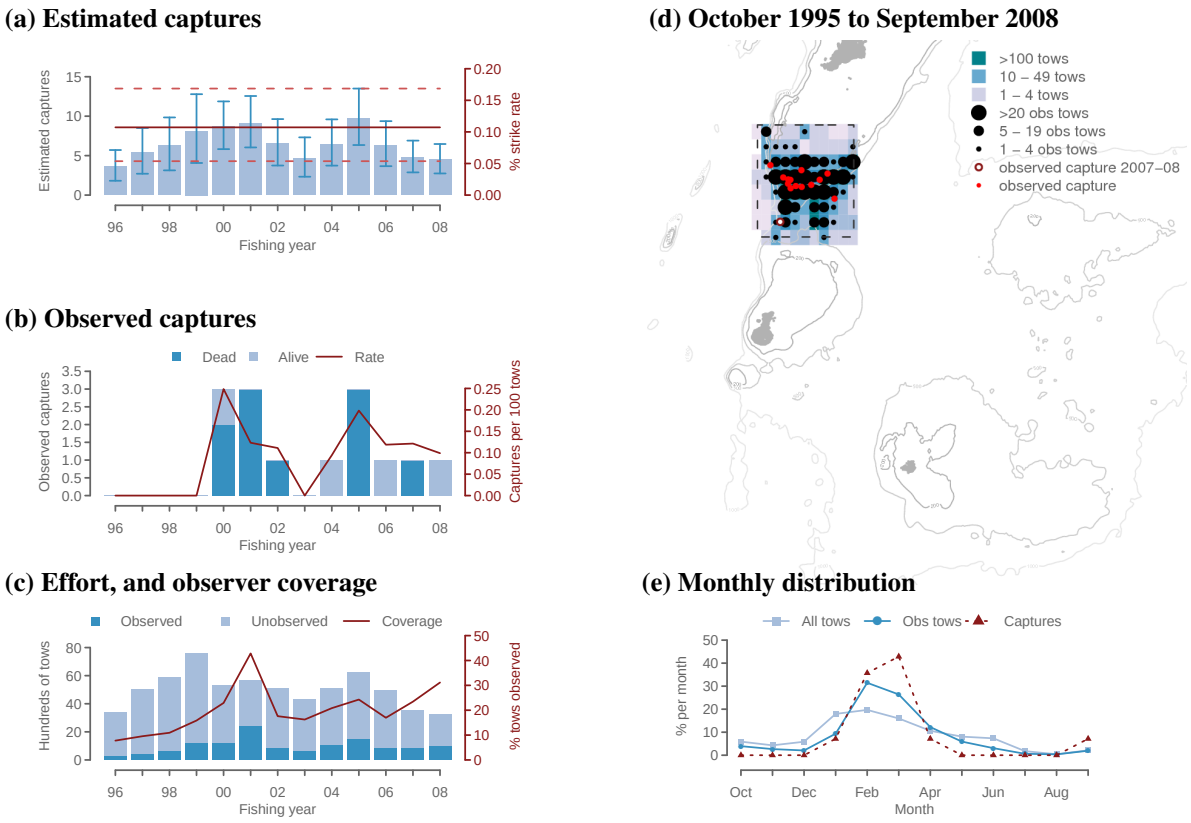

Figure 9: Annual time series of (a) estimated sea lion captures, (b) observed sea lion captures and the capture rate, and (c) trawl effort and observer coverage, in all trawl fisheries on the southern end of the Stewart-Snares shelf from 1995–1996 to 2007–08. In map (d) average effort is plotted in a 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.

4. DISCUSSION

In this report the model and ratio estimation methods of Thompson & Abraham (2009) were re-run to estimate the captures of sea lions in the four strata for each year between 1995 and 2008. The model of the Auckland Islands squid fishery was based on that of Smith & Baird (2007b), with the specific difference that their model was fitted to observer data and then applied to effort data, whereas the model developed by Thompson & Abraham (2009) was fitted to the observed component of the effort data and then fitted to the unobserved component of the same data set. This latter method is not affected by any systematic differences between observer and fisher collected data.

Estimated captures in the Auckland Islands squid fishery in 2007–08 (14 sea lions, 95% c.i.: 7 to 25) were the lowest since 1998–99. 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 since 1998 (Department of Conservation 2009). The estimated interactions have decreased since 2006–07 from 76 (95% c.i.: 33 to 140) to 65 (95% c.i.: 26 to 124) in 2007–08. 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 are affected by the assumption that the SLED retention probability has remained constant. There were changes made to SLED design, specifically aimed at reducing the number of sea lions that went through the bars into the codend (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 0.234 (95% c.i.: 0.137 to 0.375). On a tow with an open SLED, about three-quarters of the sea lions that would otherwise have been captured exit the net. The fate of sea lions that leave the net through a SLED is not known.

In Table 10, a more detailed breakdown of the predictions is given for the Auckland Islands squid fishery in the 2006–07 and 2007–08 fishing years, with different discounts applied to trawls using SLEDs. The discount rate set for 2007–08 was 35%; with this rate the model estimated 42.1 attributed mortalities (95% c.i.: 17 to 81). The mean value is about half of the FRML of 81 mortalities set by the Ministry of Fisheries in 2007–08, and the upper confidence limit reaches the FRML. Table 10 gives the results for the 2006–07 year, from the current model. It updates the similar table given by Thompson & Abraham (2009). 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 75.9 interactions in the Auckland Islands squid fishery in 2006–07. Thompson & Abraham (2009) estimated that there were 73.6 interactions in the same fishery in the same year. Given the uncertainties, these differences are not significant. Comparing between the two years, it can be seen that the mean values of all of the metrics have decreased since the 2006–07 fishing year. In particular there was a 14% decrease in the number of interactions. This compares with a 10% decrease in the strike rate between the two years, and a 4% decrease in the effort in this fishery.

There have been relatively few sea lion captures observed in the southern blue whiting fishery during the 13 year period covered by the data, with no observed captures before 2002. Observed captures peaked at 6 sea lions in 2007, and dropped to 2 in 2008, despite observer coverage increasing from 171 to 226 trawls between the two years. In Thompson & Abraham (2009) the southern blue whiting data set used for modelling was restricted to the years 2002 to 2007. In this report we have extended this data set to include the years 1996 to 2008. This allows a direct comparison to be made across the four strata. After the fitting the model it was found that, although there were no sea lion captures observed between 1996 and 2001, there may have been a small number of captures (0 to 5) in the unobserved portion of the fishery during these years. The inclusion of these additional six years to the model did not alter the

Table 10: Predicted total interactions, attributed interactions at discount rates (DR) of 20%, 35%, and 50%, captures, exclusions, and strike rate for the 2007–08 and 2006–07 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%
2007–08				
Interactions	65.3	26	62	124
Attributed mortalities, 20% DR	52.0	22	49	100
Attributed mortalities, 35% DR	42.1	17	40	81
Attributed mortalities, 50% DR	32.3	13	31	62
Captures	13.8	7	13	25
Exclusions	51.5	16	48	107
Strike rate, %	5.17	2.23	4.92	9.71
2006–07				
Interactions	75.9	33	72	140
Attributed mortalities, 20% DR	60.9	27	58	112
Attributed mortalities, 35% DR	49.7	22	47	91
Attributed mortalities, 50% DR	38.4	18	36	71
Captures	17.4	10	17	28
Exclusions	58.6	19	55	118
Strike rate, %	5.73	2.75	5.46	10.22

estimated captures or the strike rate between 2002 and 2008 significantly. Estimated captures peaked in 2007 at 16 (95% c.i.: 8 to 28) corresponding to a peak in observed captures. The estimated captures decreased to 4 (95% c.i.: 2 to 10) in 2007–08; a figure similar to that estimated for the all trawl stratum on the southern end of the Stewart-Snares shelf.

Other (non-squid) Auckland Islands trawl fisheries continue to be relatively poorly observed (with 11% coverage in 2007–08) and yet these fisheries have higher effort than the Auckland Islands squid fishery. In 2007–08, 90% of the Auckland Islands non-squid effort was targeting scampi. Although observed sea lion captures were low (fewer than 4 per year, and none in 2007–08), estimated captures (a mean of 12, 95% c.i.: 7 to 18, in 2007–08) were the second highest of the four strata. Improved observer coverage in the scampi fishery would reduce the uncertainty in this estimate.

The combined estimate of sea lion interactions across all four strata was 86 (95% c.i.: 46 to 149) in 2007–08. The decrease from 108 (95% c.i.: 64 to 174) 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, from 5.7 and 2.45 in 2006–07 to 5.2 and 0.53 in 2007–08, respectively. There was also a 4.2% decrease in effort in the Auckland Islands squid fishery from 2006–07 to 2007–08.

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