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M. H. Smith
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M. H. Smith
S. J. Baird

NIWA
Private Bag 14901
Wellington

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EXECUTIVE SUMMARY

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This document describes the analysis carried out for addressing Specific Objective 1 of ENV2000/02: *to examine factors that may influence the rate of capture of New Zealand [Hooker's] sea lions in the SQU 6T squid fishery, including spatial and temporal variability in capture rates.*

Twenty variables were examined to measure their effects on the capture rate of New Zealand sea lions in the SQU 6T squid trawl fishery for the seasons (January–June) 1992–2002, using data primarily from the Ministry of Fisheries observer programme. Capture models were fitted to all sea lion captures, female sea lion captures, and male sea lion captures using stepwise regression for Poisson Generalised Linear Models with log link functions.

After each model was fitted, variables were ranked in importance by the change in deviance that occurred when the variable was removed, if the variable were already included in the model, or when the variable was added, if it were not already included in the model.

The two most important variables affecting capture rate, for female sea lions, were year followed by the distance from the nearest rookery. For male sea lions, year was the most important variable and second in importance was the number of days into the season. Both these results make biological sense because females need to be close to their pups and males leave the rookeries to feed early in the squid-fishing season after mating. The variable identifying whether a net has the sea lion exclusion device fitted with the cover net open was also important and affected capture rates of males differently, though the difference was not significant. Duration of tow was also an important variable for females, but not for males.

Other variables, for which some effects were indicated, were, for females, whether the tow included a change in direction and, for males, the time of day. Most other variables show effects that are too small for this data set to identify as being significant. Care was taken to ensure that the models were not over-fitted.

1. INTRODUCTION

The New Zealand (Hooker's) sea lion, *Phocarctos hookeri*, is the only endemic pinniped in New Zealand, with 95% of the annual pup production occurring at the three breeding locations in the Auckland Islands group, on Enderby Island, Dundas Island, and Figure of Eight Island (Figure 1) (Gales & Fletcher 1999). New Zealand sea lions are gazetted as "threatened" under the World Conservation Union (IUCN) and the New Zealand Department of Conservation (DoC) threat classification systems (Hilton-Taylor 2000, Hitchmough 2002). The species is protected under the Wildlife Act 1953 and the Marine Mammals Protection Act 1978. Statutory obligations require the Ministry of Fisheries (MFish) to monitor the bycatch of associated or dependent species during commercial fishing operations in New Zealand waters. The MFish Scientific Observer Programme collects data on the incidental catch of New Zealand sea lions as part of its monitoring programme.

The total population was estimated at 11 376 (with a 95% confidence interval of 9896 to 13 058) in 2001 (I. Wilkinson, DoC, pers. comm.). Mature sea lions return to the colonies during October-November and pupping occurs from the first week in December to the third week in January (Gales & Fletcher 1999, Lalas & Bradshaw 2003). After the birth of a single pup, mating occurs. Males then disperse away from the islands, and females remain with their single pup, with their foraging zone restricted until weaning is over (by October) (Cawthorn 1993).

New Zealand sea lions are generalist feeders with a diet comprised mainly of fish, cephalopods, and crustaceans. They forage over most of the Auckland Islands shelf, preying on pelagic and benthic species in shallow waters and waters deeper than 300 m (Childerhouse et al. 2001). These sea lions can dive to at least 550 m (mean maximum dive depth of 353 ± 164 m), with a mean diving depth of 124 ± 36 m (Costa & Gales 2000). Gales & Mattlin (1997) suggest, that the foraging strategy of lactating female sea lions is determined by bathymetry and food availability in areas within their foraging range and noted that sea lions were feeding close to Enderby Island. Their study indicated that a lactating sea lion could access the entire Auckland Islands Shelf in one foraging trip.

The foraging area and depths used by New Zealand sea lions overlap with the concentration of the squid (*Nototodarus* spp.) trawl fishery around the Auckland Islands during February to June, resulting in the incidental capture of sea lions. The fishery has an allowable catch of over 32 000 t of squid, though since 1996 catches have fluctuated, with annual reported catches between 950 t and 19 840 t (Annala et al. 2003). In recent years the fishery has been restricted by management policies aimed at protecting New Zealand sea lions. This is managed by a limit placed on the incidental take of sea lions for each season, known as the MALFiRM (maximum allowable level of fishing related mortality). This is monitored by in-season estimation based on data from the industry and Ministry of Fisheries observers.

Vessels operate under a code of practice designed to minimise marine mammal capture and have been restricted to fishing outside a 12 n. mile zone around the Auckland Islands since 1982. In recent squid fishing seasons, mitigation devices known as Sea Lion Exclusion Devices (SLEDs) (Anon. 2002) have been used in the trawl nets as part of at-sea trials to test the effectiveness of the device in ejecting sea lions. When a SLED is in place, the net has a cover net that provides a potential escape route for the animals when it is left open. Video recordings of the net area have been made in recent years for many tows, both with and without SLEDs, in an attempt to evaluate the effectiveness of the device, but results are not conclusive because of visibility difficulties.

All captured New Zealand sea lions that were landed dead and returned to shore were autopsied under a Conservation Services Programme (CSP) project (see Duignon et al. 2003). For the years spanned by this project, New Zealand sea lions were autopsied for all seasons since 1996, except 1998, when no animals were returned. In that year, a mass mortality event occurred and was reported by DoC researchers during their fieldwork at the Dundas Island and Sandy Bay (Enderby Island) colonies.

Doonan (2001) showed evidence of an increase in strike rate of New Zealand sea lions through time and recommended that further data would be needed to examine the trend in sea lion strike rate. More than 10 years of data now exist for the sea lion-squid fishery interaction.

Many different variables may influence the rate at which sea lions are caught in fishing operations. The variables can be grouped into those that are associated with the abundance of sea lions local in time and space, and those that are associated with fishing practices that may affect the catchability of sea lions. In the former category there are the position variables and depth (relating to sea lions' preferred feeding habitat), distance from rookery, year (or season), time of year, time of day, and environmental variables such as sea temperature. In the latter category are vessel characteristics such as length and power, vessel nationality, mitigation methods used, application of Industry Code of Practice, gear type, tow path used, duration of tow, speed of tow, headline height, amount of squid caught, whether a SLED is present and if the cover net is open, and the presence of the video camera.

2. METHODS

2.1 Fishery data sources and treatment

Data were extracted from Ministry of Fisheries observer database *obs* for the fishing seasons January-June for 1992 to 2002. The Ministry of Fisheries also provided vessel specification data for the trawlers observed during this period, including nationality, length, breadth, and power. The New Zealand sea lion data are from the *obs_lfs* database, and the first records of New Zealand sea lion captures in this database are from 1992.

Data were extracted for all tows that targeted squid (*Nototodarus* spp.) in the Auckland Islands part of SQU 6T (see Figure 1). Initially all available variables were extracted to determine which had consistent records and were appropriate to the investigation. Some data that relate to the fishing operation were recorded only on the Stock Monitoring Programme Non-fish Bycatch forms, but not on the observer forms that provide the basis for the Ministry of Fisheries *obs* database. Thus, some information is available only for those tows that caught a New Zealand sea lion. For example, the timing of dumping of offal is recorded only on bycatch forms.

Error checking of the data included correcting where possible, any obviously incorrect or unlikely positions, gear codes, nationality, depth, etc. Where there were equivalent variables, commercial effort data were used to amend records. This was especially important in the reporting of gear code. The use of these data in other work (S.J. Baird & N.W. Bagley, pers. comm.) has shown that, for some tows, observers have reported where the net fished, rather than the actual net type used. For example, a midwater net used on or near the bottom has been recorded as a bottom tow. Observers also record the path of each tow as a code representing: where the net fished in the water column; the configuration of the tow (straight line, "U" bend, etc) that also included options such as pinnacle fishing or following a constant depth contour; and the number of turns per tow. These variables are not strictly comparable. However, 58% of observed tows were recorded as straight line tows on the seafloor with no turns made. Another 22% were straight-line tows along a constant depth contour with no turns made. A breakdown of these records is given in Table 1.

Inconsistent recording of sea surface temperature (SST) and headline temperature by observers resulted in these variables being dropped: 51% of records have no SST values and 46% of the New Zealand sea lions captures were observed during tows with no SST values. About 30% of headline temperature records had no values and the associated tows accounted for 30% of the sea lion captures. Sea surface temperature data for the date and position of all observed tows were subsequently obtained from the NIWA satellite database, as were the SST anomaly data (difference from the average sea surface temperature for the date and start position of the tow).

The following observed variables were included to characterise the fishery: start date, time, and position data (latitude and longitude); end time, depth of fishing gear and seabed; gear type and headline height; towing speed; tow path (where fished in the water column, configuration, and number of turns); vessel size, power, and nationality, number of New Zealand sea lions observed caught (including sex and life status).

Other data sources

Autopsy reports (for example, Duignan et al. 2003) were used to obtain verification of the species caught as well as sex for each New Zealand sea lion. This autopsy information is available for all seasons since 1996, except 1998.

Sea surface temperature data were sourced from the NIWA satellite SST database. This was used in preference to the observer recorded SST readings because of many missing values and possible calibration problems of thermometers between vessels. Locations of the New Zealand sea lion colonies in the Auckland Islands group were used to estimate distance of each capture from the nearest colony (see Figure 1, right hand panel). The provenance of only a few of the animals caught is known (from tagging studies undertaken by DoC on the breeding population at Sandy Bay on Enderby Island).

2.2 Variables examined for their effects on capture rates

From the variables that were recorded in the data sources the following were chosen to be examined for their capacity to predict capture rates of sea lions (the name given each variable is written in Courier font):

- Year — `year`, this fishery generally operates between January and June, with most fishing carried out in of February to May. Calendar year is used and this variable equates to season.
- Distance from the nearest rookery — `dist.col`, great circle distance from the start position of the tow to the nearest sea lion rookery. This is a variable describing position of the tow.
- Day of year — `day.no`, day of tow numbered from the start of the calendar year.
- Nation — `nation`, nation of origin of vessels. Vessels from Russia and Ukraine are grouped as CIS (Commonwealth of Independent States). All vessels under charter to New Zealand companies were classified according to their nation of origin. One Chinese vessel was observed in the years 1995 and 1997 and vessels originating from Japan, Korea, New Zealand, and Poland have been observed through in the period 1992–2002 (Table 2 and Figure 2). Of the 129 vessels that appeared in the fishery, 63 were observed at least once (see Smith & Baird 2005, table 4).
- Power — `power`, power of vessel (kW).
- Length — `length`, overall length of vessel (m)
- Gear type — `gear`, whether a midwater (MW) or bottom trawl (BT) net type is used. Of the observed effort 76% used midwater nets, the main gear type used by CIS (94% observed tows) and Polish (100% observed tows) vessels. The remaining 25% used bottom trawl nets; 100% of New Zealand tows, 97% for Korean tows, and 70% of Chinese and Japanese tows used bottom nets.
- Headline height — `headline`, height of the headline above the ground-rope.
- Netdepth — `netdepth`, depth of ground-rope of the net at the start of each tow.
- Tow path — this descriptor comprises three separate variables: `towpath`, where the net fished in the water column; `towconfig`, the tow configuration (see Table 3 for the categories of `towpath` and `towconfig`); and `number.turns`, the number of turns by the vessel during the trawl. Table 4 gives the numbers of observed tows in the various *combinations of the three variables.*

- Day/night category — DN. An algorithm (from Meeus 1998) was used to calculate the local position of the sun at the start and end of each tow. Each tow was then assigned to one of four categories: entirely in daytime, entirely at nighttime, including dawn, including dusk.
- Duration of tow — `duration`, this was determined from the start and end times of each tow, where the start time represents the time the net began to fish (hours).
- Sea surface temperature — `sst`, the sea surface temperature is assigned to each tow from the NIWA satellite database using date and position.
- Sea surface temperature anomaly — `sst.anom`, the deviation of the SST at a position and date from the average over past years.
- SLED — `sled`, whether the SLED was present or not, and if so whether the cover net was open or tied down.
- Catch — `catch`, catch of squid for the tow (kg).
- Speed — `speed`, speed of vessel during tow (knots).
- Camera — `camera`, whether a net video camera was present.

Closer examination of the three tow type variables indicated a great imbalance in the number of tows present in the various combinations of the three variables. With the approval of the Aquatic Environment Working Group (AEWG) three new variables were defined to replace the three tow type variables. Each of the new variables has only two categories since parsimony is desirable because, though there are 4490 tows in the complete data set, only 157 of these have sea lion capture incidents. The new variables `towbot`, `towline`, and `towturn` are defined in Table 5 by regrouping the categories of the old variables.

It is expected that a net with the SLED present and the cover net tied down will have a similar sea lion catch rate to a net with no SLED device; thus a new variable, `cover`, is also defined by grouping two categories of `sled` (see Table 5). This variable is examined in conjunction with `sled` in the fitting process, though only one of the variables will be included in any model. Similarly the DN variable categorising timing of the tow was regrouped to give a variable with only two categories. The variable is `light` and the details of the regrouping are given in Table 5. Again, both DN and `light` are available to be included in any model, but only one can be.

Analysis of any differences in the predictive capacity of the variables between the sexes requires the sex of the captured animals to be identified. The sex of autopsied sea lions (n = 119) is taken from the DoC autopsy reports, where available, otherwise the observer records are used (n = 52). The sex of one of the 172 sea lions captured is undetermined.

Finally two observed tows had zero duration and did not appear in the TCEPR effort data. It is likely that these were aborted tows and they were omitted from the data used for the model fitting. This left the 4490 tows in the complete data set for model fitting.

The complete set of variables used in the analysis is given in Table 6 along with the classification as a factor variable (i.e., categorical) or a continuous variable.

2.3 Model fitting

To determine the importance of the variables as predictors of the capture rate of New Zealand sea lions we will first fit a Generalised Linear Model (GLM) to the sea lion capture data. Once a model is fitted, the importance of a variable that is included in the model is determined by the magnitude of the change in deviance when that variable is omitted from the model. The order of importance of each remaining variable is determined by the reduction in deviance that occurs when adding that variable alone to the model. We use number of sea lions captured as the response variable, which includes both dead and live captures. Little is known about the subsequent survival of animals captured live and then released and it seems prudent to use all the data and model all captures rather than just captures of dead animals.

Because the response variable is in the form of counts of the number of sea lions captured, it is natural to use the Poisson probability model, and it is especially appropriate for this study where the counts are small. However, the data comprise many zeros (n = 4333 tows), and only 157 of the 4490 tows had sea lion capture incidents (Table 7). Most information relating variables to capture rates is contained in the capture incidents, and the absence of captures effectively only contributes to the size of the mean capture rate. Because of the paucity of data, there is a real danger of over-fitting models and modelling random incidents as if they are real effects.

If a Poisson model is fitted to the raw data with no explanatory variables, then the residuals will usually have a variance that is bigger than the fitted mean. This indicates "over-dispersion", which is to be expected because we hope to fit a model where the important variables explain some of the variation. We use the size of the over-dispersion as an indication of possible over-fitting. There is likely to be over-fitting when the estimated over-dispersion parameter of a model is well below 1. The over-dispersion parameter for a particular model is estimated by refitting the model using the quasi-likelihood Poisson method (see Venables & Ripley 2002, chapter 7).

The statistical package R (Ihaka & Gentleman 1996) is used to fit the models and create the tables and figures. The procedure will fit the GLM Poisson models with the log link function in a stepwise manner. In this form the log link function means that variables act on the mean capture rate in a multiplicative way. The stepwise process starts with the null model that has a constant capture rate and the null deviance (deviance for the null model) is calculated. Variables are added one at a time until no variable will reduce the deviance by more than 1% of the null deviance. Additional checks are made on the over-dispersion parameter as a measure of over-fitting. Also the Akaike Information Criterion (AIC) is calculated for reference, in particular when one of the pairs of variables (`sled`, `cover`) or (DN, `light`) enter the model. At each step the effect on the change in deviance of replacing a variable already in the model with a prominent candidate variable is also checked in an informal manner. The effect on the estimates and standard errors of the model components, of adding the new variable, is also examined because colinearity can make estimates become very unstable and the standard errors blow out. This is often a problem when interaction terms are added to a model.

Continuous variables can be fitted as polynomial functions of the variable and, in some cases, as polynomial functions of the logarithm of the variable. It is appropriate to use the logarithm of a variable, when the variable is always positive and has a natural reference point that it is measured against. For example `day.no` is not appropriate as the start of the year is arbitrary. `sst.anom` takes negative values. `sst` could be measured relative to absolute zero, but because the changes are so small relative to temperatures measured on the Kelvin scale there will be very little difference whether the logarithm is used or not. It would also be possible to measure `sst` relative to the boiling point of water, as this is an absolute upper limit for sea surface temperature. Again the variation is relatively small compared with the temperature as measured from the boiling point of water and consequently log(`sst`) was not considered.

Except for `netdepth`, the other continuous variables, `duration`, `dist.col`, `length`, `power`, `speed`, `catch` and `headline`, can appear in the model either in logarithm form or not. The order of polynomial to be used for a continuous variable was determined by using the order for which the highest order coefficient is significant in the fitted model. The order of the polynomial was determined for each variable and for the logarithm if appropriate. The logarithm of the variable was used if it gave a larger reduction in deviance. For every variable where the logarithm was available, it resulted in a larger reduction in deviance.

The data set we used for fitting models was reduced by 23 tows from the original data set containing 4490 tows by removing tows with missing values for any of the predictor variables. Twenty-three tows were removed from the data set for this reason. Missing values obstruct the stepwise fitting process but it should be noted that no sea lion captures were recorded for any of the tows removed.

Most incidents caught one sea lion only (see Table 4). Therefore the tow in the 2002 season that caught four sea lions was omitted from the analysis (with the approval of the AEWG) because its strong influence would distort the analysis. The final data set for fitting the model for sea lion captures comprised 4466 tows.

Part of the requirement for the project was to examine any differences between the sexes in those variables that might affect capture rates. We decided to carry out the model fitting described above separately for female sea lion captures and male sea lion captures and produce a list of the important variables for each. The models for each sex can then include different variables. The tow that had one sea lion capture where the sex of the animal was undetermined was omitted from the data set used to fit females and males separately. This meant that 4465 tows were used to fit the female and male sea lion capture models.

3. RESULTS AND DISCUSSION

3.1 Exploratory analysis

Some exploratory tabulation of capture numbers and plotting of start positions of observed tows with capture incidents was carried out to investigate the relationships between some of the variables. These can be misleading as they look only at the variables in question on their own and may suggest spurious associations. We include them for interest. but rely on the fitted models for measuring the importance of variables.

The distribution of the start positions of observed tows with capture incidents relative to that for all observed tow positions for all years is given in Figure 1 and for individual years in Figure 3. These plots show where effort and captures occurred but do not reveal much information about capture rates. For this reason the series of plots in Figure 4 made, in which the SQU 6T region was divided into rectangles with sides of length 0.05° latitude and 0.05° longitude. The plots show the density of the start positions of observed tows in each rectangle and capture rates in each cell for the years 1992–2002 and all years combined. However, there are so few annual capture incidents (ranging between 3 and 35) that little emphasis should be placed on the capture rate plots. The combined plot, which includes all 157 capture incidents, does show that the rate is a little raised in the intensive fishing ground due north of the Auckland Islands, compared with the rest of the fishery.

Vessel effects were examined by plotting the total effort and the total number of captures for each vessel through the 11 seasons in Figure 2. The numbers of captures for each vessel in a season are drawn on a scale related to the mean rate for all tows in that season. If the bar for the number of captures is longer than the effort bar, then the capture rate for the vessel is higher than the season average; alternatively, if it is shorter then the capture is lower than the season rate. The plot indicates that there could be vessel effects, though we have not modelled them in this analysis. Any vessel effects are best modelled as random effects that contribute to the overall variance as has been done in Smith & Baird (2005).

Tows completed entirely in the night appear to have a lower capture rate than tows at other times(Table 8). For this reason we defined the variable `light`, which grouped the three categories of DN that had at least part of the tow in daylight.

The relationship between capture rates and SLED use is an interesting example of how examining the effect of a variable on its own can be misleading in an undesigned experiment. The use of a SLED with the cover tied down appears to have a higher rate of sea lion capture than a net with no SLED

(Table 9). This is because SLEDs with covers tied down were extensively used in 2001 when the capture rate was much higher than in other years.

3.2 Model fitting

After the preliminary round of model fitting we were asked to look at the additional variables `speed` and `catch`, that is the speed of the vessel during the tow and the total catch of squid for the tow. There are 153 tows in the data that were used for fitting the model with missing values for either the speed or the catch variable (67 tows with speed missing and 88 tows with catch missing including 2 tows with both missing) and, of these tows, 3 had sea lion capture incidents. To maintain the maximum possible data set, we decided to continue to use the original data set but to check back at each stage of the stepwise process for any effect of each of the `speed` and `catch` variables by fitting the current model to the data set with missing values for the variable removed. The effect of adding the variable to the current model can then be checked on that data set. At no time did either variable become a candidate for inclusion in any of the three models (all sea lions, female sea lions, and male sea lions) that were fitted.

The `power` variable appeared to have substantial predictive capacity in the models as a second order polynomial in the logarithm of `power`. This was reported, following the preliminary results, at an Aquatic Environment Working Group meeting where it was suggested that the effect might be strongly influenced by the substantial numbers of sea lions that were caught in the early years covered in this study by vessels of relatively low power. This was true, and when the data set was restricted to those vessels with power greater than 1500 kW the relative importance of the `power` variable was greatly reduced. In the fitting process, when `power` was a candidate variable it was checked against the reduced data set of the higher powered vessels in the same manner as for the `speed` and `catch` variables. Vessels with power less than or equal to 1500 kW carried out 114 tows and caught 11 sea lions (4 females and 7 males).

Details of the model fitting process for the three models follow and summaries are given in Table 10.

All sea lions

For this model the sex of the animal caught is ignored and the fitted model will be in some sense an average of the models for females and males.

From Table 10 we see that the null model has a residual deviance of 1135 on 4465 degrees of freedom with an over-dispersion estimate of 1.105, or about 10.5% over-dispersed. Asymptotic normal theory for GLMs suggests that a model with a residual deviance approximately equal to the number of residual degrees of freedom is fitting well. For Poisson models where the capture rate is about 3.76%, the mean rate over all years, the expected residual deviance is only 0.251 per degree of freedom; so we are fitting models in situations where the asymptotic normal inference results do not apply. This means that p-values and confidence intervals should be treated with great scepticism. What this also means is that the null model is fitting data quite well because the residual deviance for the null model is 0.254 times the residual number of degrees of freedom. This highlights the lack of information that can be extracted about the effects of variables on the capture rate and that there is danger of over-fitting models.

The rule that stops the fitting procedure when the change in deviance for every new variable is below 1% of the residual deviance of the null model may or not be sufficient to guarantee that the model is not over-fitted. However, it does appear to give reasonable results in the three models and does not reduce the estimated over-dispersion parameter below 1.

We decided to add `year` to the model first, even though `dist.col` had a slightly larger change in deviance. We added `year` first to each of the three models because there is considerable variation between years and each year is treated separately for management purposes. Next log(`dist.col`) was added (see Table 10). Following that, `sled` and `cover` were the next candidates at changes in deviance of 28.07 and 27.99 respectively. `cover` was added next because the extra category of `sled` contributed almost nothing extra (0.08) to the change in deviance. Interaction terms were considered and the interaction between `year` and log(`dist.col`) was the candidate with the largest change in deviance in the next step followed by log(`duration`). The interaction term, when added to the model, produced very strong evidence of over-fitting with the many coefficients of variables already in the model changing to ridiculous values with standard errors increasing by factors of 5 to 10 fold, so this interaction term was not considered further. log(`duration`) was added and after that no other variables produced a change in deviance of more than 1% of the null model residual deviance. The final model for all sea lion captures can be expressed as

log(mean all sea lions capture rate) = `year` + log(`dist.col`) + `cover` + log(`duration`).

Note (Table 10) that the over-dispersion estimate of this model is 1.024 and this being close to 1 does not provide any evidence that the model is over-fitted. Residual plots can be used to check model fits, but for count data these plots are hard to interpret as the points appear in three bands; one for zero catches, one for single catches, and one for double catches. Instead, a plot of the randomised quantile residuals against the square root of the fitted values (to spread out the smaller fitted values) was used, applying the method of Dunn & Smyth (1996). The plot of the randomised quantile residuals against the fitted values and the QQ-normal plot of the randomised quantile residuals in Figure 5 showed no unusual structure. Plots of the randomised residuals against latitude and longitude, though not included in this report, showed no structure suggesting that the `dist.col` variable accounts for most of the positional variation in mean catch rate.

Female sea lions

The null model has a null deviance of 696 on 4464 degrees of freedom with an over-dispersion estimate of 1.073 (see Table 10). The expected deviance per degree of freedom for a null Poisson model with rate = 1.95% (the overall capture rate for female sea lions) is 0.155 (giving an expected deviance of 689 for 4464 degrees of freedom). Again there does not appear to be a lot of information about the effects of variables.

Although `sled` followed by log(`dist.col`) followed by `year` had the largest deviance change, we added `year` first for reasons given in the all sea lion fitting. Next log(`dist.col`) had the largest change followed by `sled` and `cover` second equal, and the order that the first three variables were added does not affect any model that includes all three. After log(`dist.col`) was added, the candidate variables were `sled` and `cover` with changes in deviance of 21.79 and 21.70 respectively. We added cover because `sled` and `cover` are effectively the same as predictors. Following that, the second order polynomial in log(`power`) was slightly ahead of log(`duration`), deviances 14.64 and 14.47 respectively. Checking the effect of adding `power` to the model on the data set with vessels of power over 1500 kW reduced the change in deviance for the polynomial in log(`power`) to 8.88, so log(`duration`) was added instead. The next three candidates are the interaction terms `year:`log(`dist.col`), `year:`log(`duration`), and again the second order polynomial in log(`power`). All three were rejected; the interaction terms because of over-fitting and the `power` term because the low-powered vessel influence. The other two candidates were `towline` and `towbot` with changes in deviance of 7.56 and 7.35 respectively. As these two variables arise from rearranging the tow type variables, both were included, even though, after first adding `towline`, `towbot` would be below the 1% deviance change cut-off. Apart from `power` and the two interaction terms, no other variables had change in deviance above the 1% threshold. This gives the female sea lion model:

log(mean female capture rate) = `year` + log(`dist.col`) + `cover` +
log(`duration`) + `towline` + `towbot`.

The plot of the randomised quantile residuals against the square root of the fitted values and the QQ-normal plot for females in Figure 5 showed no evidence of lack of fit. The estimate of over-dispersion is 0.966, which could suggest that the model may be over-fitted. Again `dist.col` appears to account for most of the positional variation in capture rate.

Male sea lions

The null model has a residual deviance of 659 on 4464 degrees of freedom with an over-dispersion estimate of 1.057 (Table 10). The expected deviance per degree of freedom for a null Poisson model with rate = 1.79% (the overall capture rate for male sea lions) is 0.1450 (giving an expected deviance of 647 for 4464 degrees of freedom). As for the other two models, there appears to be little information about effects of variables.

The `year` variable was added first. The next candidates were the third order polynomial in `day.no` followed by log(`dist.col`) with changes in deviance of 19.01 and 11.67 respectively. The third order polynomial in `day.no` was included and that was followed by log(`dist.col`). After this step the interaction term of year with log(`dist.col`) had the largest change in deviance, but this was rejected because of over-fitting. The next four candidate variables are, in order, `camera`, DN, `sled`, and `cover`, with changes 7.66, 5.85, 4.27, and 4.27 respectively. `camera` is correlated with the `sled/cover` pair and will be standing in for some SLED effect plus any direct `camera` effect. It is known that `sled/cover` affects capture rate, so it was decided to add `cover` (the same deviance as `sled`) and then check back on the other variables. At this point, apart from the interaction term, the candidate variable with the largest change in deviance of 5.69 was DN with `camera` next with a change in deviance of 3.45. Both are below the 1% cut-off although DN is quite close at 0.86%. Neither variable was added to the model and the model for male captures is

log(mean male capture rate) = `year` + poly(`day.no`, 3) + log(`dist.col`) + `cover`

The residual plots in Figure 5 show no structure to suggest that the model is not fitting. The estimated over-dispersion at 0.998 is very close to 1. `dist.col` accounts for most of the positional variation in capture rates.

3.3 Importance of variables

Tables 11, 12, and 13 order the variables by importance for the three response variables: all sea lion captures, female sea lion captures, and male sea lion captures respectively. For each the order is determined by: firstly, the importance of the variables included in the model and, secondly, for the variables not included, the change in deviance that would result if each variable was added to the model. All variables not included in the model have changes in deviance of less than 1% of the residual deviance for the null model. The p-value of each variable is given in the tables and for the variables not included in the model, with the exception of the third order polynomial in `day.no` and the `towline` variable for all sea lions, these are not significant at the 5% level. The p-values are approximate but are likely to be underestimates of the p-values because the models we have used do not allow for any within trip/vessel correlation of sea lion captures (see Smith & Baird 2005). In the presence of positive correlation within groups, standard errors are underestimated (see comments in Doonan 2001).

When examining individual variables we will look at the female and male capture models first because the all sea lions model is, in some sense, an average of the separate male and female models. The effects for each level of the factor variables that appear in the models are given in Table14, the functional forms of the continuous variables that appear in the models in Table 15, and the estimated changes in capture rates for the two variables `dist.col` and `duration` that would occur if the variable is increased by 25% but all other variables are kept the same in Table 16. Figures 6, 7 and 8 show the relative effects, keeping all other variables constant, of the 12 most important variables for the all, female and male sea lions captures respectively are shown in Figures 6, 7, and 8.

The most important variable in all three models is `year`, but what causes the differences in capture rates between years is not obvious. The differences in the year effects are given relative to the base year of 2002 (see Table 14) so that, for example, the female capture rate in 2001 is 2.688 times that in 2002, keeping all other variables the same. It is clear that the relative rates for the different years are dissimilar for males and females (and consequently all sea lions). For males the capture rates in 1997, 1998, and 2000 are almost as high as the capture rate for 2001, whereas for females, 2001 is the only year that really stands out (Figures 7 and 8).

The variable log(`dist.col`) is second in importance for females and all sea lions and third in importance for males. The difference between the coefficients of this term for females and males is interesting and makes biological sense. The coefficient for females is less than -2 (see Table 15), which means the capture rate changes even faster than the inverse square law in distance from the nearest rookery. For males the coefficient is about -1, which means the capture rate is approximately proportional to the reciprocal of the distance from the nearest rookery. This implies that males range more freely over much greater distances from the Auckland Islands than females, presumably because females cannot be too far from the pups they are suckling. The change in capture rates from doubling the distance from the nearest rookery while keeping all other variables the same is given in Table 16, with 95% confidence limits. Comparison of the plots for `dist.col` (Figures 7 and 8) shows the much steeper drop-off in capture rate with distance that occurs for females.

The second most important variable (after `year`) for males is the third order polynomial in `day.no`. The coefficients of the three polynomial components (linear, quadratic, and cubic) are difficult to interpret and it is easier to examine the plot of capture rate against `day.no` in Figure 8. This shows a sharp drop in the capture rate at the start of the season until mid February when males leave the area after mating, and there is some evidence that some do return to the area around the end of March. However, the `day.no` variable is ranked ninth for females and represents a change of only 0.47% in the null residual deviance. There is little evidence of any `day.no` effect for females, and this suggests little change in female abundance, and hence foraging habits, during the squid fishing season.

Next in importance is the `cover` variable, which is the variable signalling whether there is a SLED present with the cover open. The apparent effect of having a SLED with the cover open appears to be different for males and females. From Table 14, the capture rate is estimated to be reduced to 13% for female and 30% for males, but the large c.v.s imply that the difference is not significant. The `sled` variable had almost exactly the same deviance change as the `cover` variable despite having another degree of freedom. Thus, for these data, there was no detectable difference between the effect of the SLED with the cover tied down and no SLED at all.

The duration of the tow variable is important for females, but not males. The coefficient of 0.78 for females means that the capture rate increases with the 0.78 power of the duration of the tow. It is expected that the capture rate would increase with the duration of the tow because of the increased opportunity for capture. However, `duration` was ranked only ninth equal for males and reduced the deviance by 0.34% of the null residual deviance; this suggests that capture rates for males are relatively unaffected by duration of tow. It is apparent that the tow type configuration related variables (`duration`, `towline`, and `towbot`) and vessel power are much more important predictors of capture rate for females than for males, `towline` and `towbot` being included in the female model. For females, a tow with a turn has 2.33 times the capture rate of a straight-line tow and a midwater tow has 3.6 times the capture rate for a tow that touches the bottom. These variables are ranked 14th and 8th for males (see Table 13). It is interesting to note (from Figures 7 and 8) that the effect of the `towbot` variable for males is the opposite to that for females with the midwater tow having a capture rate that is about 0.27 times that for a tow that touches the bottom. The `power` variable for females was ranked seventh and it appears that lower powered and higher powered vessels have a greater capture rate than mid-powered vessels.

Ranked fifth to seventh for males, but not included in the model, are the variables DN, `camera` and `light`, all light related variables. The same variables are ranked only 11th, 20th, and 17th respectively for females. The night-time capture rate appears to be lower than at other times for males, but the day/night difference is a lot less for females, which is why the variable is less important for them. The presence of the camera (see Figure 8) appears to be associated with a capture rate four times that when there is no camera, but this is not significant with a p-value of 0.06 (see Table 13). However, `camera` is one of the lowest ranked variables for females.

The variable `nation` was ranked eighth for females and nineth for males. From Figures 7 and 8 there appears to be a considerable difference between the capture rates of females and males for New Zealand vessels. This could be misleading because there are so few data; New Zealand vessels carried out 14 tows and caught one male sea lion.

Net type used (the variable `gear`) was lowly ranked, as were the sea surface temperature and the sea surface temperature anomaly variables. `length`, `speed`, and `catch` ranked even lower for both males and females and in this study appear to have little or no predictive power for capture rates.

It should be noted that, for the male and female sea lion capture models, the only variables with significant effects were the variables that appeared in the final models.

This study has found some variables that are associated with differences in capture rates of New Zealand sea lions. Sex differences have also been highlighted, and a number of these seem to have a biological basis. However, in an observational study such as this, statistical association cannot be equated to cause and effect and some variables can easily be "standing in" for causal variables merely because the "stand in" variables vary in a similar way. A further note of caution needs to be added because of the paucity of the data. For capture count data, it is the number of captures observed that determines the size of the errors, not the number of sample units (tows) observed.

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6. TABLES AND FIGURES

TABLES

Table 1: Trawl fishing effort targeting squid at SQU 6T, January-June, 1992–2002.

	All vessels*			Observed vessels†			
Year	No.	No. tows per vessel (range)	Total no. tows	No.	No. tows per vessel (range)	Total no. tows	% tows observed
1992	49	1–127	2 153	7	4–76	219	10
1993	38	1–89	656	9	2–85	197	30
1994	45	2–220	2 677	7	18–149	434	16
1995	50	2–185	4 000	7	2–104	286	7
1996	52	5–167	4 460	9	11–127	555	12
1997	42	24–132	3 708	14	5–105	731	20
1998	36	2–113	1 442	10	3–83	337	23
1999	35	1–57	399	11	2–58	156	39
2000	26	2–106	1 206	11	7–106	438	36
2001	23	1–106	588	23	1–105	576	98
2002	28	9–107	1 635	12	1–135	564	34

* Data from Trawl Catch Effort Processing Return (*warehou* catch and effort database).

† Data from observer logbooks (*obs* database) for all observed trips.

Table 2: Frequency of vessels observed, by nation for 1992–2002.

No. years observed	China	CIS	Japan	Korea	NZ	Poland
1		25	2	2	2	4
2	1	7	3	3		1
3		1		2		
4		3		3		
5		2				
6		1		1		

Table 3: Key to the codes of the tow type (`towpath`) and vessel path (`towconfig`) variables.

Variable	Code	Description
`towpath`		
	1	Bottom throughout the tow
	2	Midwater tow, constant depth
	3	Midwater tow, varying depth
	4	Mixed bottom and midwater tow
`towconfig`		
	A	Straight line vessel path
	B	U shaped vessel path
	C	Zigzag shaped vessel path
	D	Closed vessel path, including a circle
	E	Vessel path follows a depth contour
	F	Vessel path over a pinnacle

Table 4: Number of observed tows for combinations of the levels of the `towpath`, `towconfig`, and `number.turns` variables for the observed squid target tows in SQU 6T, January-June 1992–2002.

`towpath`	`towconfig`	`number.turns`				
		0	1	2	3	Total
Bottom						
	Straight line	2 608	61	6		2 675
	"U" turn	2	190	18	2	212
	Zigzag	87	16	3	4	110
	Circle	16	4			20
	Depth contour	1 005	127	25	10	1 167
	Pinnacle	73	4			77
	Total	3 791	402	52	12	4 261
Mid-water constant depth						
	Straight line	35				35
	"U" turn		2			2
	Zigzag	1				1
	Circle					
	Depth contour					
	Pinnacle					
	Total	36	2			38
Mid-water varying depth						
	Straight line	2				2
	"U" turn					
	Zigzag	1				1
	Circle					
	Depth contour	32	1	7		40
	Pinnacle					
	Total	35	1	7		43
Mixed bottom and midwater						
	Straight line	49	1			50
	"U" turn	25	3	2		30
	Zigzag					
	Circle					
	Depth contour	47		2		49
	Pinnacle					
	Total	121	4	4		129
Total						
	Straight line	2 694	62	6		2 762
	"U" turn	27	195	20	2	244
	Zigzag	89	16	3		112
	Circle	16	4			20
	Depth contour	1 084	128	34	10	1 256
	Pinnacle	73	4			77
Total	Total	3 983	409	63	16	4 471

Table 5: Extra variables defined from existing variables by combining categories. The variables `towbot`, `towline`, and `towturn`, which have 1 degree of freedom each, replace the variables number of turns, `towpath` and `towconfig`. `cover` is defined from `sled`, and `light` is defined from DN.

Name	Description
`towbot`	tow on bottom or not. From `towpath` categories: onbot = {bottom, mixed bottom and midwater} offbot = {midwater constant depth, midwater varying depth}
`towline`	tow is in a straight or curved line. From `towconfig` categories: st.line = {straight line, depth contour, pinnacle}, curve = {"U" turn, zigzag, circle}
`towturn`	From number of turns noturn = 0 turns turns = 1 or more turns.
`cover`	whether net exit is available. From `sled` categories: shut = {nosled, cover} open = nocover
`light`	tow is entirely in night or not. From DN dark = night, {day, dawn, dusk}

Table 6: Description of variables considered

Name	Type	Description
`year`	factor	fishing year
`dist.col`	continuous	distance of start of tow from nearest rookery (km)
`day.no`	continuous	day of calendar year
`nation`	factor	nationality of vessel
`power`	continuous	power of vessel (kw)
`length`	continuous	length of vessel (m)
`gear`	factor	type of net used: midwater or bottom.
`headline`	continuous	headline height of net (m)
`netdepth`	continuous	depth of net at start of tow (m)
`towbot`	factor	tow is on bottom or not
`towline`	factor	tow is straight or curved
`towturn`	factor	tow includes at least one turn or not
DN	factor	tow is in day or night, or includes dawn or dusk
`light`	factor	tow is at night or not
`duration`	continuous	duration of tow (hr)
`sst`	continuous	sea surface temperature at start of tow (°C)
`sst.anom`	continuous	deviation of sst from position and date average (°C)
`sled`	factor	whether sled is used and cover net is or is not tied down.
`cover`	factor	whether exit from net is open or shut
`catch`	continuous	total squid catch for tow (kg)
`speed`	continuous	speed of vessel (knots)
`camera`	factor	video camera attached to net

Table 7: Observed tows and the frequency of New Zealand sea lion captures by year. Catch rates, numbers of incidents and rates are also included.

Captures per tow											Year	Total
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	
0	211	192	430	278	543	706	322	151	414	541	545	4 333
1	6	5	2	8	11	21	15	5	23	32	16	144
2	1		1		1	4			1	3	1	12
3												
4											1	1
Total tows	218	197	433	286	555	731	337	156	438	576	563	4 490
Sea lion captures	8	5	4	8	13	29	15	5	25	38	22	172
Catch rate (%)	3.7	2.5	0.9	2.8	2.3	4.0	4.5	3.2	5.7	6.6	3.9	3.8
Incidents	7	5	3	8	12	25	15	5	24	35	18	157
Incident rate (%)	3.2	2.5	0.7	2.8	2.2	3.4	4.5	3.2	5.5	6.1	3.2	3.5

Table 8: Observed tows and the frequency of New Zealand sea lion captures by time of day.

				DN	
Captures per tow	dawn	day	dusk	night	Total
0	314	3 260	458	301	4 333
1	13	109	19	3	144
2	1	9	1	1	12
3					
4	1				1
Total sea lions	19	127	21	5	172
Total tows	329	3 378	478	305	4 490
Capture rate (%)	5.8	3.8	4.4	1.6	3.8

Table 9: Capture rates (%), with numbers of observed tows in parentheses, for the different levels of the `sled` variable

						Year
Levels	1992	1993	1994	1995	1996	1997
cover						
nocover						
nosled	3.7 (218)	2.5 (197)	0.9 (433)	2.8 (286)	2.3 (555)	4.0 (731)
Total	3.7 (218)	2.5 (197)	0.9 (433)	2.8 (286)	2.3 (555)	4.0 (731)

					Year	Total
Levels	1998	1999	2000	2001	2002	All years
cover			7.1 (154)	11.1 (297)	3.4 (262)	7.4 (713)
nocover				1.8 (278)	0 (125)	1.2 (403)
nosled	4.5 (337)	3.2 (156)	4.9 (284)	0 (1)	7.4 (176)	3.4 (3 374)
Total	4.5 (337)	3.2 (156)	5.7 (438)	6.6 (576)	3.9 (563)	3.8 (4 490)

Table 10: The order variables are introduced into the model during the stepwise model selection process. When a continuous variable is bracketed by poly it appears in the model as a polynomial of order given by the number. For example day.no appears in the model as a polynomial of order 3. Details of change in deviance, p-values and estimates of the over-dispersion are included for the three models fitted f to all sea lions, female sea lions and male sea lions.

	Term	Change in deviance	Change in AIC	DF	p-value	Residual deviance	Residual DF	Over dispersion
All sea lions								
	null model					1135.45	4 465	1.105
	+ year	-33.56	-13.56	10	0.0002	1101.89	4 455	1.131
	+ log(dist.col)	-34.76	-32.76	1	< 0.0001	1067.13	4 454	1.065
	+ cover	-27.99	-25.99	1	< 0.0001	1039.14	4 453	1.032
	+ log(duration)	-12.56	-10.56	1	0.0004	1026.58	4 452	1.024
Females								
	null model					696.32	4 464	1.073
	+ year	-21.80	-1.8	10	0.02	674.52	4 454	1.054
	+ log(dist.col)	-25.09	-23.09	1	< 0.0001	649.43	4 453	0.942
	+ cover	-21.70	-19.7	1	< 0.0001	627.73	4 452	0.911
	+ log(duration)	-14.47	-12.47	1	0.0001	613.25	4 451	0.909
	+ towline	-7.56	-5.56	1	0.01	605.69	4 450	0.939
	+ towbot	-6.63	-4.63	1	0.01	599.06	4 449	0.966
Males								
	null model					651.84	4 464	1.057
	+ year	-34.82	-14.82	10	0.0001	617.02	4 454	1.036
	+ poly(day.no, 3)	-19.01	-13.01	3	0.0003	598.01	4 451	1.100
	+ log(dist.col)	-7.29	-5.29	1	0.01	590.72	4 450	1.054
	+ cover	-4.27	-2.27	1	0.04	586.46	4 449	0.998

Fitted models

All sea lions	year + log(dist.col) + cover + log(duration)
Females	year + log(dist.col) + cover + log(duration) + towline + towbot
Males	year + log(dist.col) + cover + poly(day.no, 3)

Table 11: The effects of the variables in order of importance for all sea lions. This table gives the change in deviance from dropping a single variable (-), included in the final model, or by adding a single variable (+), not included in the model.

Variable	Increase in deviance	Increase in AIC	DF	F ratio	p-value	Residual deviance	Residual DF
- year	55.14	35.14	10	5.514	< 0.0001	1081.72	4 462
- log(dist.col)	36.04	34.04	1	36.037	< 0.0001	1062.61	4 453
- cover	29.40	27.40	1	29.397	< 0.0001	1055.97	4 453
- log(duration)	12.56	10.56	1	12.559	< 0.0001	1039.14	4 453
Model						1026.58	4 452
+ poly(day.no, 3)	-10.25	-4.25	3	3.415	0.020	1016.33	4 449
+ towline	-5.42	-3.42	1	5.421	0.020	1021.16	4 451
+ DN	-3.87	2.13	3	1.290	0.280	1022.71	4 449
+ nation	-3.73	6.27	5	0.747	0.590	1022.84	4 447
+ poly(log(power), 2)*	-3.07	0.93	2	1.533	0.220	961.82	4 334
+ towturn	-2.74	-0.74	1	2.736	0.100	1023.84	4 451
+ light	-2.27	-0.27	1	2.267	0.130	1024.31	4 451
+ log(headline)	-1.64	0.36	1	1.642	0.200	1024.93	4 451
+ gear	-1.57	0.43	1	1.567	0.210	1025.01	4 451
+ sst	-1.40	0.60	1	1.399	0.240	1025.18	4 451
+ sst.anom	-1.11	0.89	1	1.108	0.290	1025.47	4 451
+ towbot	-0.86	1.14	1	0.860	0.350	1025.72	4 451
+ netdepth	-0.85	1.15	1	0.849	0.360	1025.73	4 451
+ camera	-0.48	1.52	1	0.481	0.490	1026.10	4 451
+ catch*	-0.37	1.63	1	0.366	0.540	1014.78	4 362
+ sled	-0.14	1.86	1	0.136	0.710	1026.44	4 451
+ speed*	-0.05	1.95	1	0.053	0.820	1014.24	4 382
+ log(length)	0.00	2.00	1	0.002	0.960	1026.57	4 451

* fitted using a reduced data set

Table 12: The effects of the variables in order of importance for female sea lions. This table gives the change in deviance from dropping a single variable, included in the final model, or by adding a single variable, not included in the model.

Variable	Increase in deviance	Increase in AIC	DF	F ratio	p-value	Residual deviance	Residual DF
- year	43.89	23.89	10	4.389	< 0.0001	642.95	4 459
- log(dist.col)	26.63	24.63	1	26.627	< 0.0001	625.69	4 450
- cover	24.70	22.70	1	24.703	< 0.0001	623.77	4 450
- log(duration)	10.85	8.85	1	10.848	0.001	609.91	4 450
- towline	6.85	4.85	1	6.846	0.010	605.91	4 450
- towbot	6.63	4.63	1	6.629	0.010	605.69	4 450
Model						599.06	4 449
+ poly(log(power), 2)*	-5.49	-1.49	2	2.745	0.060	558.78	4 331
+ nation	-4.58	5.42	5	0.917	0.470	594.48	4 444
+ poly(day.no, 3)	-2.68	3.32	3	0.892	0.440	596.39	4 446
+ gear	-2.01	-0.01	1	2.006	0.160	597.06	4 448
+ DN	-1.28	4.72	3	0.425	0.730	597.79	4 446
+ log(headline)	-1.09	0.91	1	1.089	0.300	597.97	4 448
+ netdepth	-0.99	1.01	1	0.987	0.320	598.08	4 448
+ speed*	-0.83	1.17	1	0.829	0.360	589.90	4 379
+ sst.anom	-0.67	1.33	1	0.675	0.410	598.39	4 448
+ log(length)	-0.62	1.38	1	0.616	0.430	598.45	4 448
+ light	-0.48	1.52	1	0.479	0.490	598.58	4 448
+ sst	-0.21	1.79	1	0.210	0.650	598.85	4 448
+ catch*	-0.09	1.91	1	0.095	0.760	597.53	4 359
+ camera	-0.02	1.98	1	0.015	0.900	599.05	4 448
+ sled	-0.01	1.99	1	0.013	0.910	599.05	4 448
+ towturn	0.00	2.00	1	0.001	0.970	599.06	4 448

* fitted using a reduced data set

Table 13: The effects of the variables in order of importance for male sea lions. This table gives the change in deviance from dropping a single variable, that is included in the final model, or by adding a single variable, that is not included in the final model.

Variable	Increase in deviance	Increase in AIC	DF	F ratio	p-value	Residual deviance	Residual DF
- year	31.32	11.32	10	3.132	0.001	617.78	4 459
- poly(day.no, 3)	11.78	5.78	3	3.928	0.010	598.24	4 452
- log(dist.col)	7.55	5.55	1	7.549	0.010	594.01	4 450
- cover	4.27	2.27	1	4.265	0.040	590.72	4 450
Model						586.46	4 449
+ DN	-5.69	0.31	3	1.896	0.130	580.77	4 446
+ camera	-3.45	-1.45	1	3.450	0.060	583.01	4 448
+ light	-3.37	-1.37	1	3.374	0.070	583.08	4 448
+ towbot	-2.74	-0.74	1	2.740	0.100	583.72	4 448
+ nation	-2.51	7.49	5	0.501	0.780	583.95	4 444
+ log(duration)	-1.97	0.03	1	1.973	0.160	584.49	4 448
+ sst	-1.97	0.03	1	1.966	0.160	584.49	4 448
+ towturn	-1.47	1.31	1	1.468	0.230	584.99	4 448
+ poly(log(power), 2)	-1.17	2.83	2	0.587	0.560	585.29	4 447
+ towline	-0.69	3.80	1	0.686	0.410	585.77	4 448
+ log(headline)	-0.66	1.34	1	0.657	0.420	585.80	4 448
+ speed*	-0.55	1.45	1	0.546	0.460	605.44	4 381
+ gear	-0.47	1.53	1	0.473	0.490	585.99	4 448
+ log(length)	-0.36	1.64	1	0.359	0.550	586.10	4 448
+ catch*	-0.06	1.94	1	0.061	0.800	611.77	4 361
+ netdepth	-0.01	1.99	1	0.005	0.940	586.45	4 448
+ sst.anom	0.00	2.00	1	0.001	0.970	586.46	4 448
+ sled	0.00	2.00	1	0.000	0.990	586.46	4 448

* fitted using a reduced data set

Table 14: Table of scale effects of levels of factor variables, relative to the base level, in the fitted models for all seal lion , female sea lion and male sea lion captures. Degree of significance (of the difference from the scale factor of 1) is indicated by ., *, ** and *.**

Variable	Base level	Level	All sea lions			Female sea lions			Male sea lions		
			Estimate	c.v. (%)	Sig.	Estimate	c.v. (%)	Sig.	Estimate	c.v. (%)	Sig.
`year`	2002	1992	0.857	167	*	0.451	71		3.257	85	
		1993	0.712	45		0.436	74		1.628	115	
		1994	0.227	54		0.170	89	*	0.690	115	
		1995	0.570	60	**	0.307	64	*	2.726	90	
		1996	0.580	45		0.731	45		1.126	99	
		1997	1.194	38		0.419	45	*	5.960	73	**
		1998	1.157	31		0.298	63	*	6.393	78	**
		1999	0.868	36		1.073	62		0.908	168	
		2000	1.413	54		1.001	44		6.091	79	**
		2001	2.874	32		2.688	37	**	7.801	73	**
`cover`	shut	open	0.134	50	***	0.076	85	***	0.302	72	.
`towline`	st. line	curve				2.331	31	**			
`towbot`	onbot	offbot				3.618	47	**			

Table 15: Table of the relative scale effects on the mean capture rate, of continuous variables in the fitted models for all seal lion, female sea lion and male sea lion captures. The Coefficients (coef), standard errors of the coefficients (se coef) of the scale effects, and the degree of the significance of the difference from 1 (Sig.) are given. P1, P2, P3 refer to the 1st, 2nd and 3rd order polynomial effects.

Variable x	form of scale effect	All sea lions			Female sea lions			Male sea lions		
		coef	se coef	Sig.	coef	se coef	Sig.	coef	se coef	Sig.
`dist.col`	x^{coef}	-1.739	0.302	***	-2.229	0.447	***	-1.053	0.397	**
`duration`	x^{coef}	0.580	0.171	***	0.784	0.250	**			
`day.no`, P1	$e^{coef*P_1(x)}$							-5.33	16.08	
`day.no`, P2	$e^{coef*P_2(x)}$							-33.51	13.59	*
`day.no`, P3	$e^{coef*P_3(x)}$							-27.46	10.14	**

Table 16: The effect of increasing the distance from nearest colony and of increasing duration by 25%, keeping all other variables the same. Effect is the change in the mean capture rate, expressed as a percentage, and 95% confidence intervals for the increase are given.

	All sea lions			Female sea lions			Male sea lions		
	Effect	95% conf. limits		Effect	95% conf. limits		Effect	95% conf. limits	
`dist.col`	-32	-41	-22	-39	-50	-26	-21	-34	-6
`duration`	14	5	23	19	7	33			

FIGURES

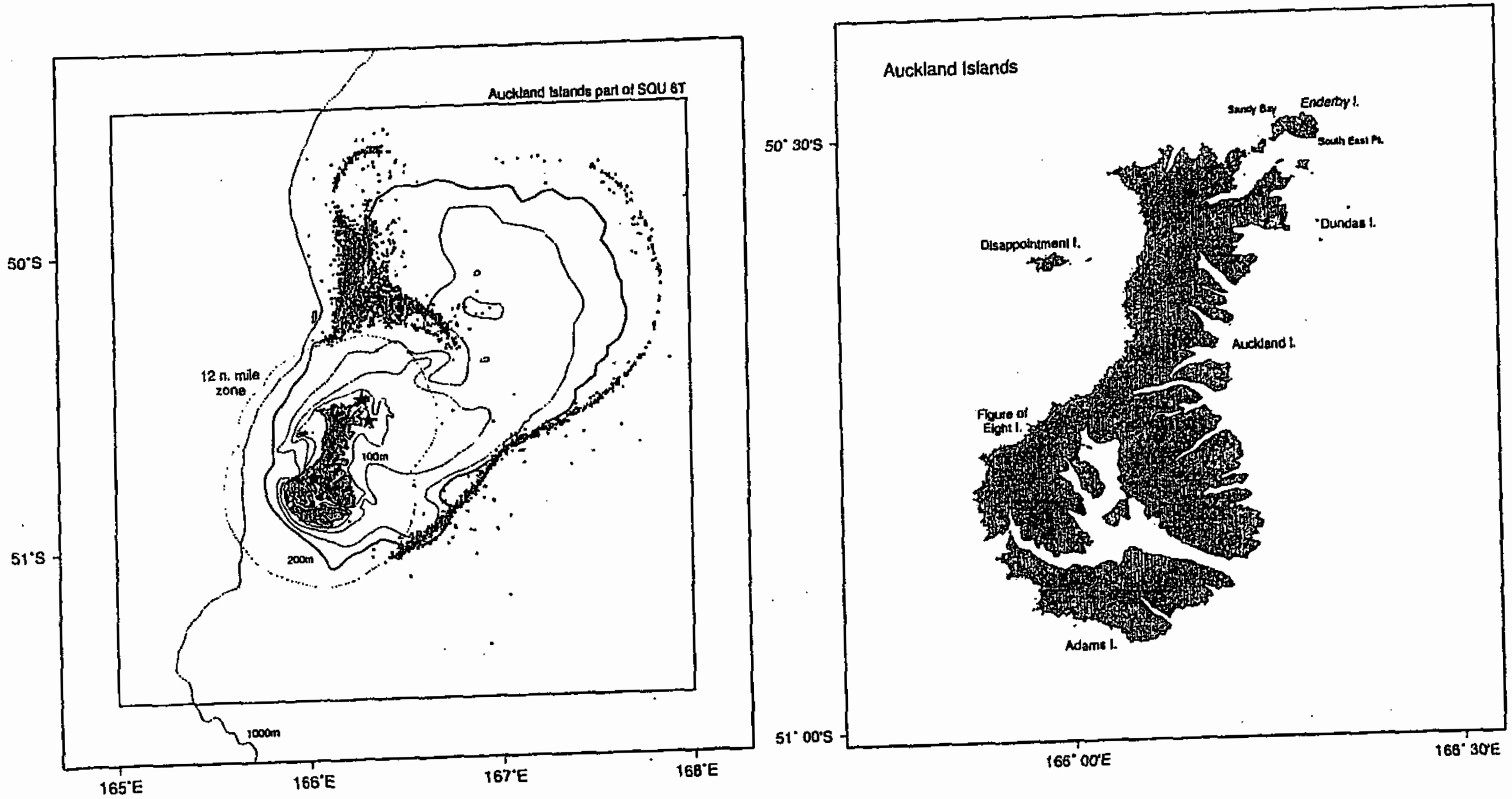

Figure 1: Start positions of observed tows (light grey points in left panel), *including those* that caught New Zealand sea lions (dark grey points), January-June 1992–2002 within the Auckland *Islands part of* SQU 6T; and locations of the New Zealand sea lion breeding colonies on Enderby, Dundas and figure of Eight Islands (indicated by ★ in the left panel).

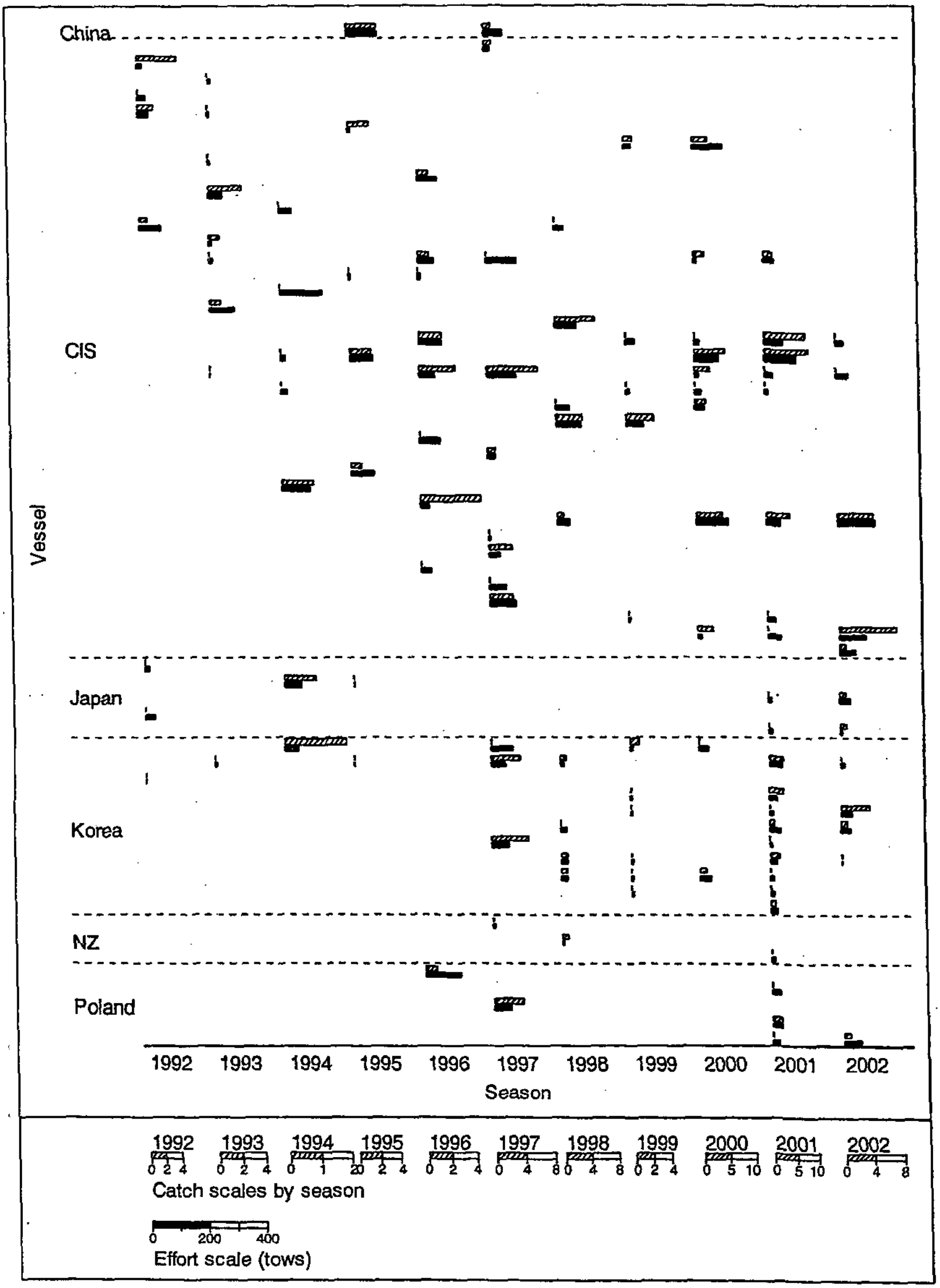

Figure 2: A horizontal bar plot of New Zealand sea lion captures and observed tows by season and vessel in the SQU 6T area. Each row is a single vessel. The capture scales for each season have been chosen so that if the catch and effort bars are of equal length for a vessel then the vessel catch rate is the same as the mean catch rate in the whole fishery for that season.

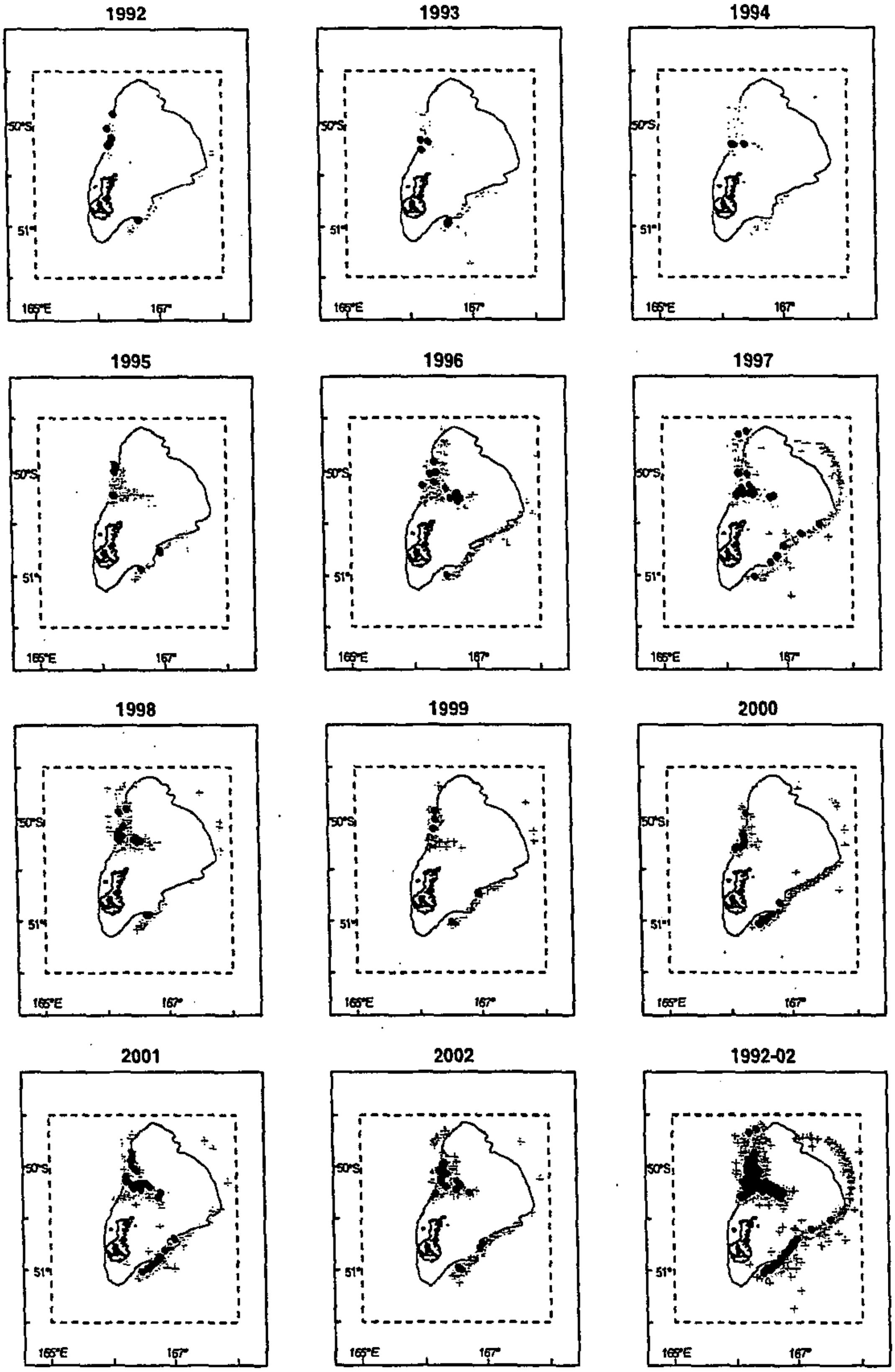

Figure 3: Plots of start positions of observed tows (+) by year including tows that caught New Zealand sea lions (•). The bottom right panel combines all years. The 200 m depth contour and the boundary of the SQU 6T area are included.

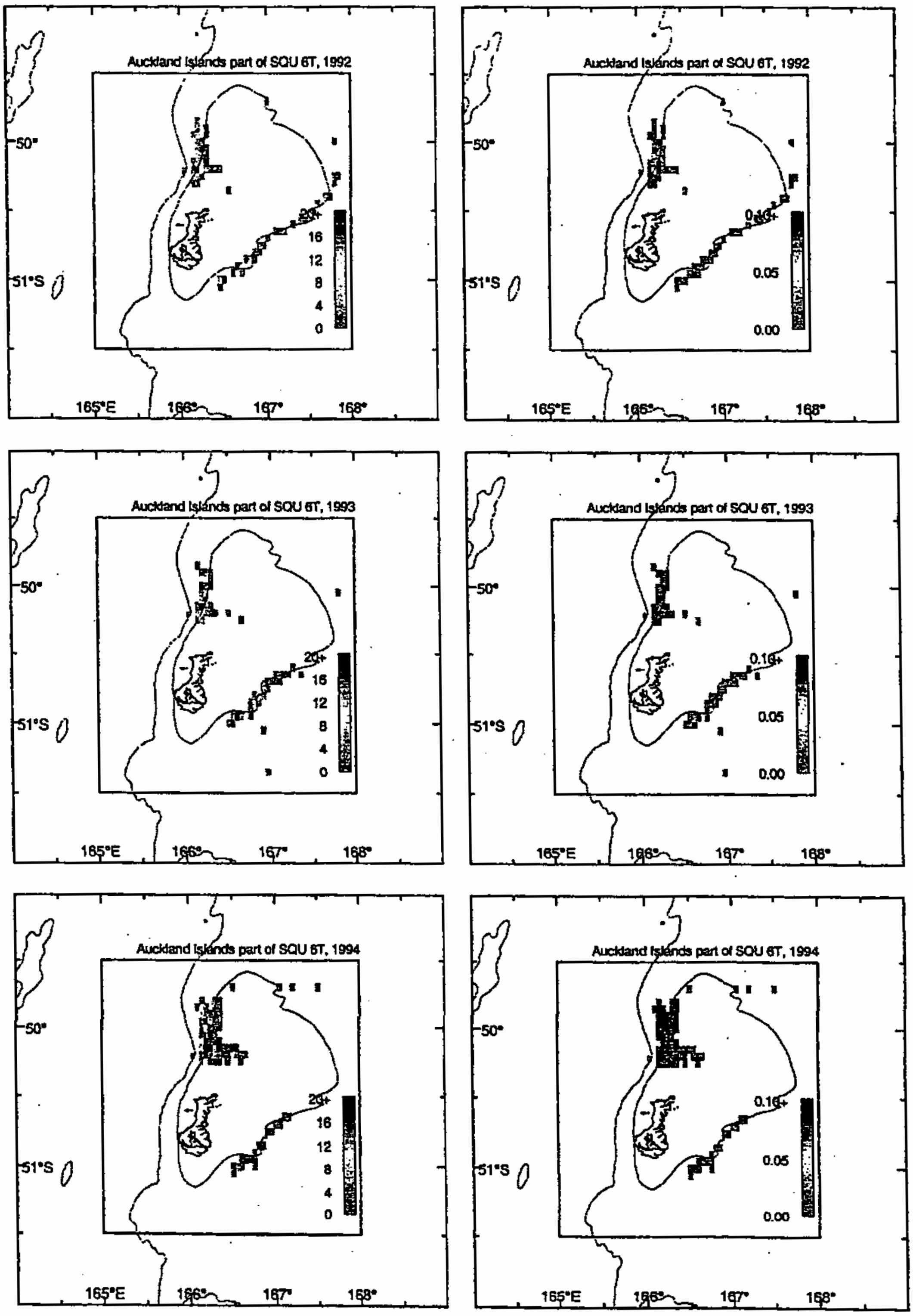

Figure 4: Annual density at 0.05° cells for observed squid tows (left) and catch per unit effort (CPUE), measured in numbers caught per tow for the cell, of New Zealand sea lions (right), for 1992 to 1994.

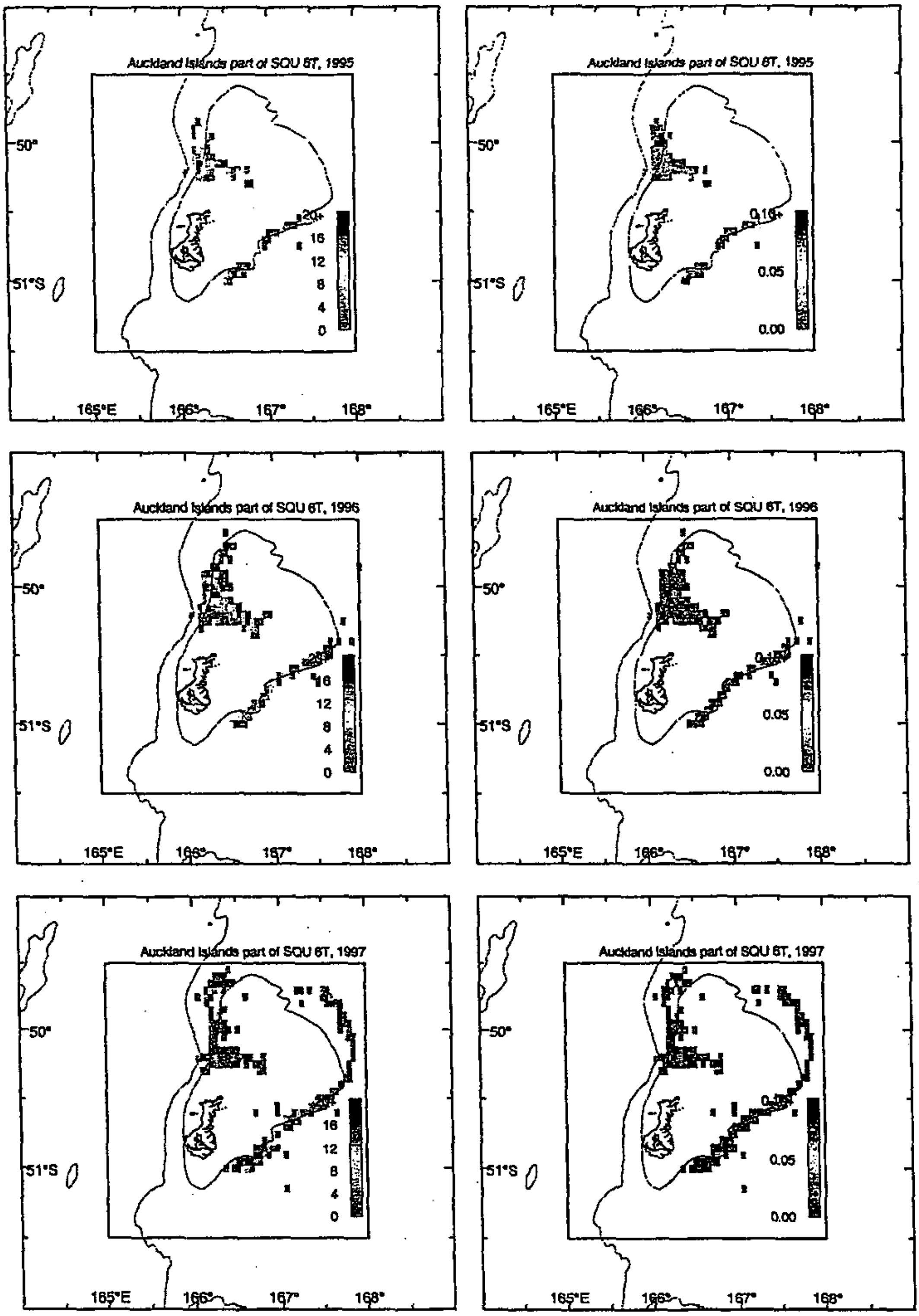

Figure 4 (continued): Annual density at 0.05° cells for observed squid tows (left) and catch per unit effort (CPUE), measured in numbers caught per tow for the cell, of New Zealand sea lions (right), for 1995 to 1997.

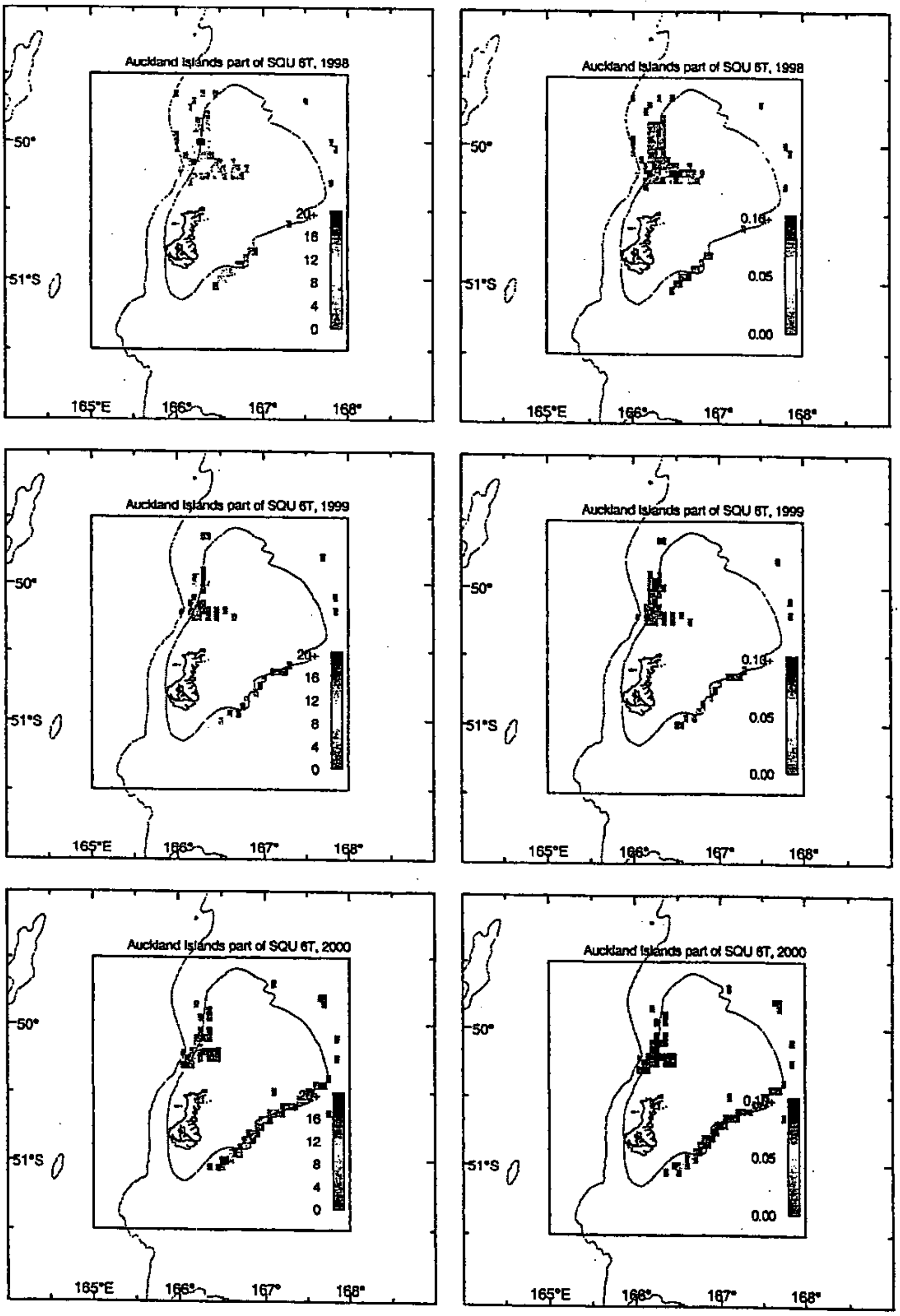

Figure 4 (continued): Annual density at 0.05° cells for observed squid tows (left) and catch per unit effort (CPUE), measured in numbers caught per tow for the cell, of New Zealand sea lions (right), for 1998 to 2000.

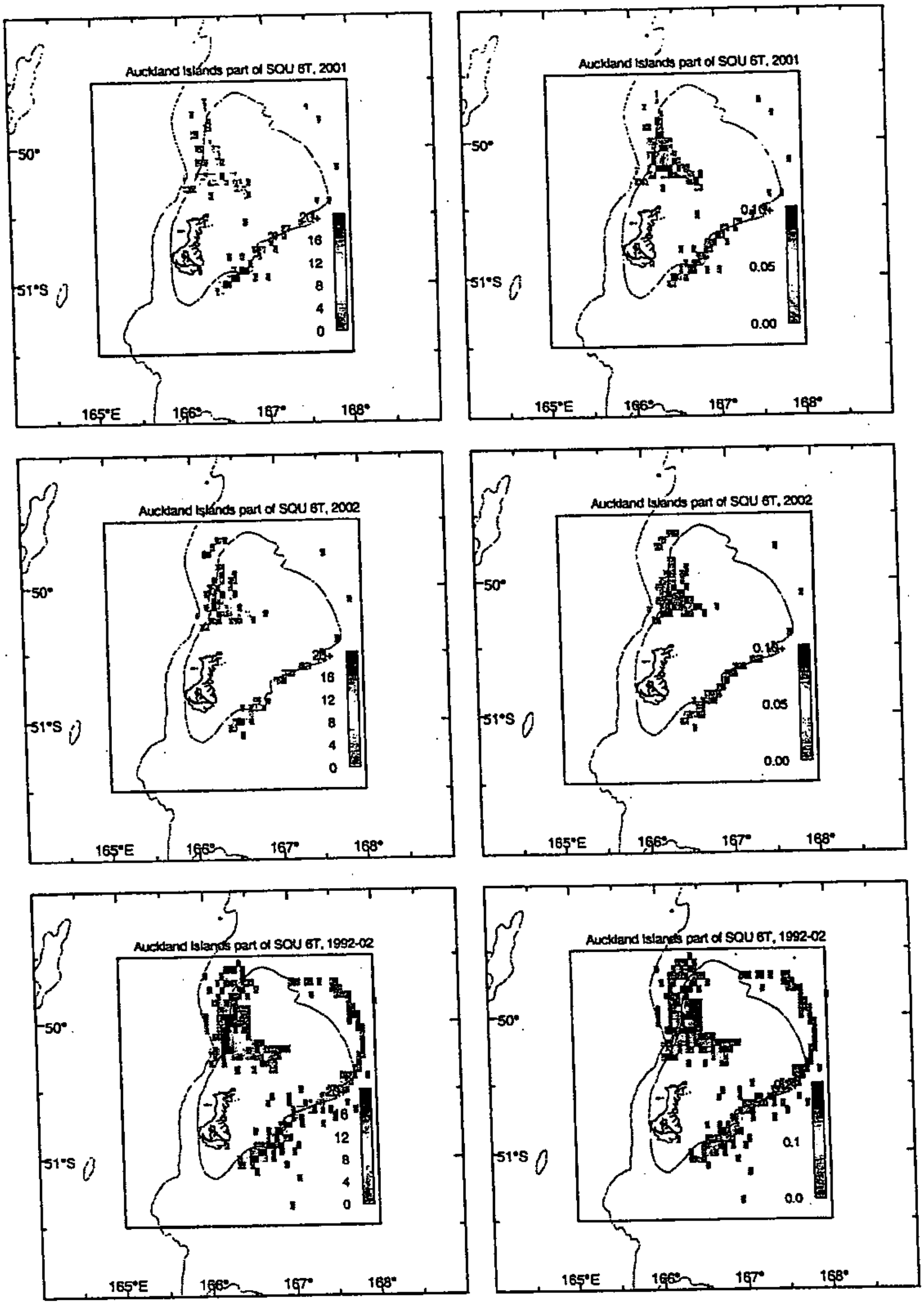

Figure 4 (continued): Annual density at 0.05° cells for observed squid tows (left) and catch per unit effort (CPUE), measured in numbers caught per tow for the cell, of New Zealand sea lions (right), for 2001, 2002 and 1992–2002 combined.

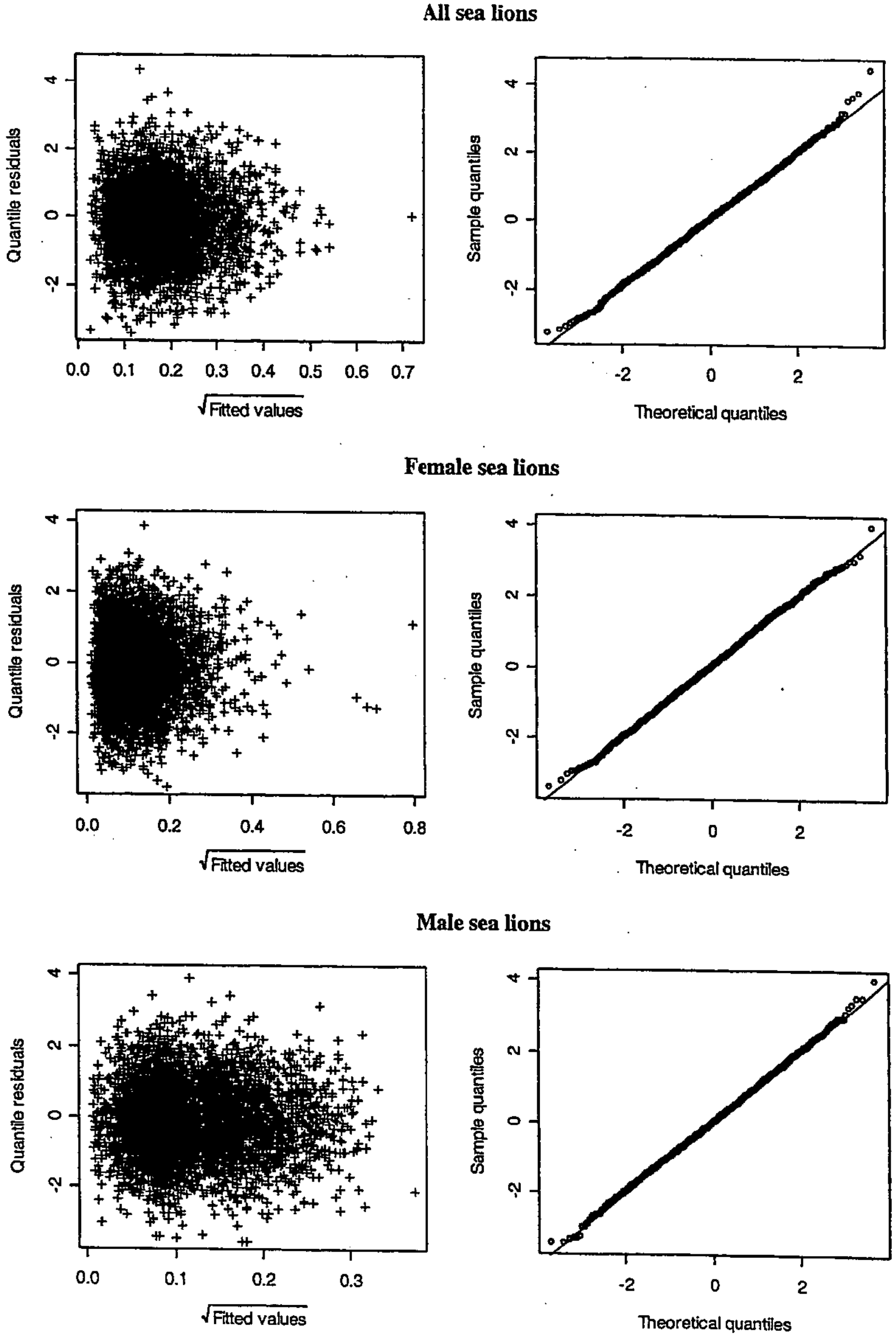

Figure 5: Residual plots and QQ-normal plots of the randomised quantile residuals for the fitted models of sea lion captures

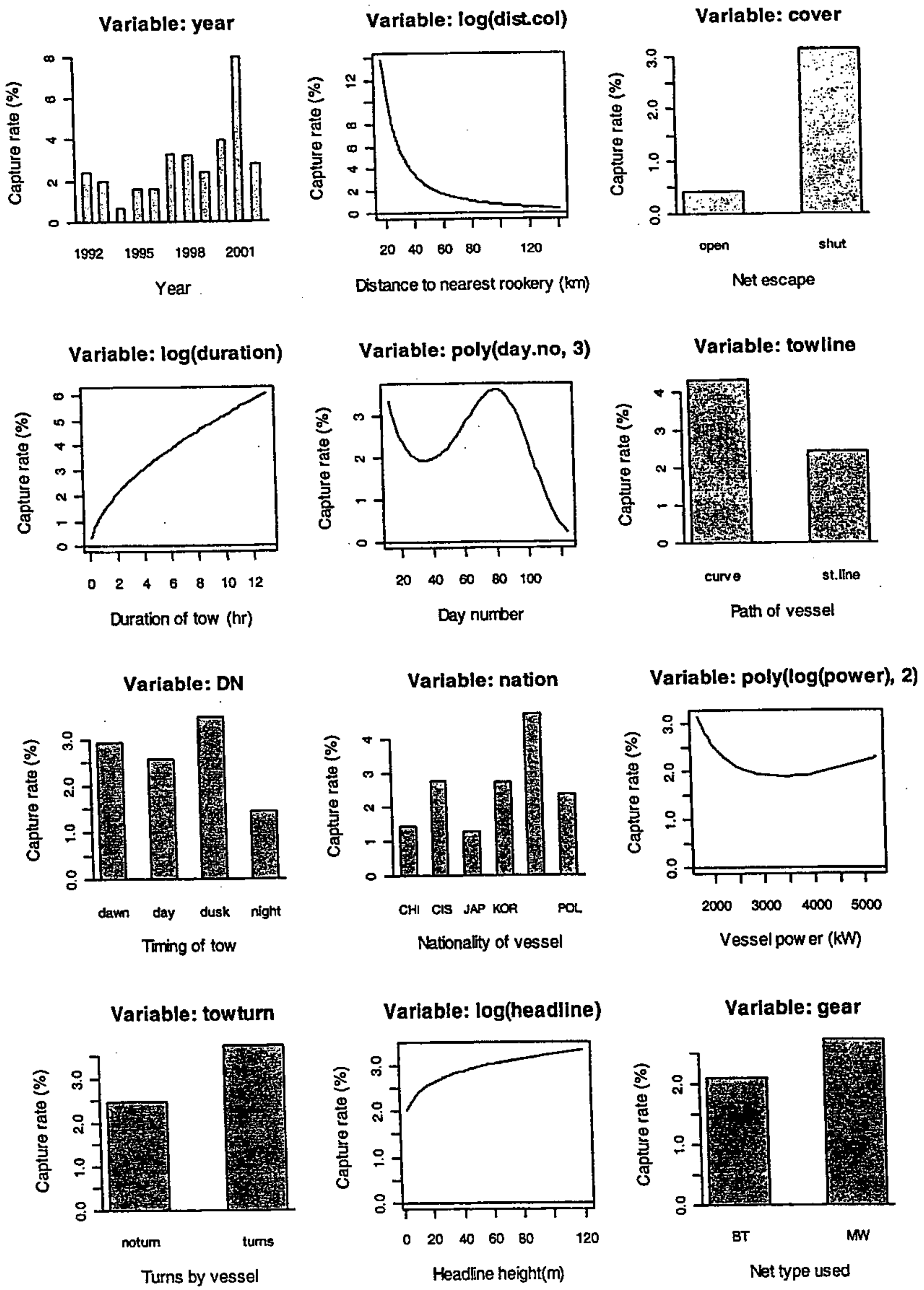

Figure 6: The effects the 12 most important variables for all New Zealand sea lion captures in order of importance plotted as bar plots for factor variables and line plots for continuous variables.

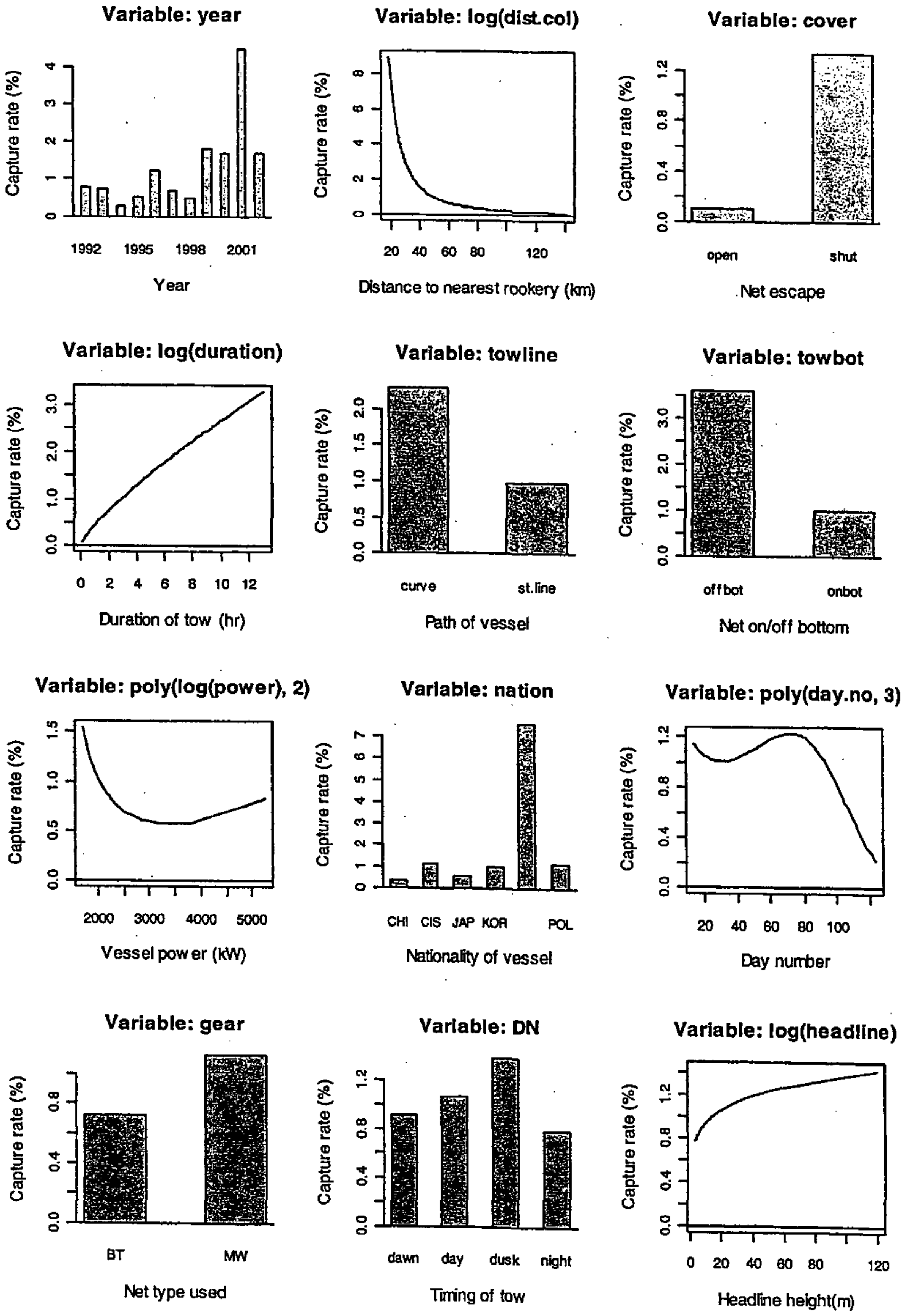

Figure 7: The effects the 12 most important variables for female New Zealand sea lion captures in order of importance plotted as bar plots for factor variables and line plots for continuous variables.

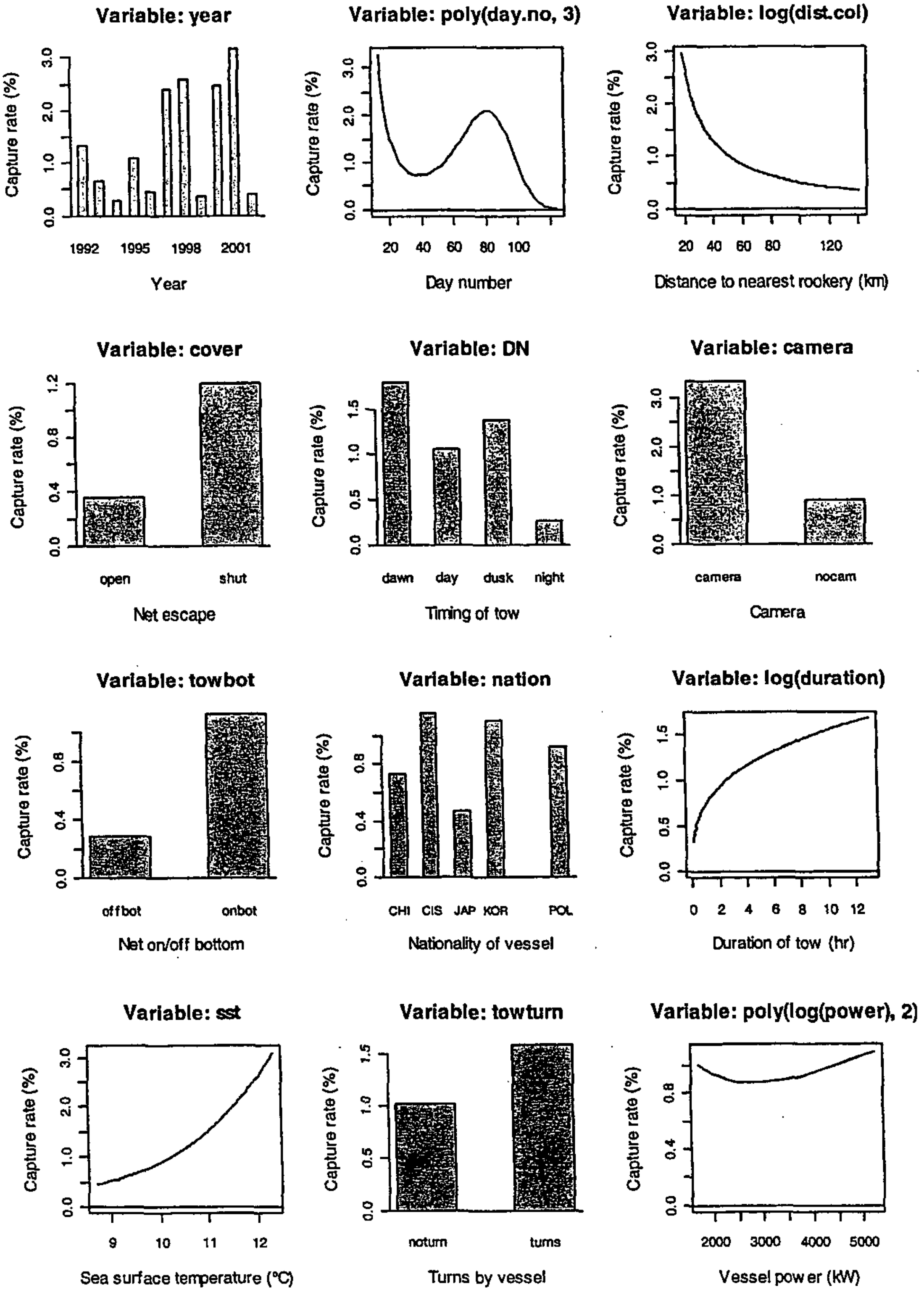

Figure 8: The effects the 12 most important variables for male New Zealand sea lion captures in order of importance plotted as bar plots for factor variables and line plots for continuous variables.