# Bycatch of sea lions (*Phocarctos hookeri*) in New Zealand fisheries, 1987/88 to 1995/96, and observer coverage

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# Bycatch of sea lions (*Phocarctos hookeri*) in New Zealand fisheries, 1987/88 to 1995/96, and observer coverage

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ABSTRACT

The official observer data that are available on the bycatch of New Zealand sea lions (*Phocarctos hookeri*) during fishing operations in New Zealand waters are reviewed for the fishing years 1987/88 to 1995/96. Estimates of bycatch are either summarised from earlier reports, or calculated using ratio estimation with Ministry of Fisheries data for 1990/91 to 1995/96. The effects of factors that may influence bycatch rates are analysed. A diagram is provided showing likely levels for the coefficient of variation of bycatch estimates as a function of the total number of tows carried out, and the percentage of these tows covered by Ministry of Fishery observers.


Manly et al. 2002. Bycatch of sea lions (*Phocarctos Hookeri*) in New Zealand fisheries, 1987/88 to 1995/96, and observer coverage. *DOC Science Internal Series 42*. Department of Conservation, Wellington. 21 p.

# 1. Introduction

The accidental bycatch of the New Zealand sea lion (*Phocarctos hookeri*) occurs almost entirely during squid fishing in the area around Auckland Islands to the South of New Zealand (Fig. 1). This bycatch is of particular concern because the current size of the sea lion population is believed to be approximately 13,000, making this one of the rarest sea lions in the world. Furthermore, almost all breeding is centred on a few sites on the Auckland Islands. For these reasons the population is considered to be threatened (Department of Conservation 1997). Since 1992 the Ministers of Conservation and Fisheries have set maximum limits to the total number of sea lions and the number of female sea lions that can be caught in one fishing season (October to September).

Official government observers have been present on fishing vessels in the Auckland Islands area since the 1988/89 season, with the percentage of tows observed varying from about 6% in 1994/95 to about 24% in 1987/88. Based on the information from the observed tows it is possible to estimate the bycatch rate (sea lions per tow), and hence the total bycatch in the whole fishery.

Table 1 shows the estimated bycatch numbers obtained in this way for each of the fishing seasons 1988/89 to 1995/96. The table is in two parts. The left-hand side shows estimates for 1987/88 to 1994/95 as provided by Baird (1996) for the squid fishery in the area SQU 6T only, where this is the area shown in Fig. 1. In fact, bycatch only occurs in the area around the Auckland Islands. The right-hand side of Table 1 shows estimates for 1991/92 to 1995/96 for Fisheries Statistical Area 602, which is slightly larger than the part of SQU 6T that includes the Auckland Islands, and also includes bycatch for target fisheries other than squid.

Most sea lions are killed on capture. In our database, 41 out of 45 captures (91%) resulted in the death of the animal.

TABLE 1. ESTIMATED BYCATCH OF SEA LIONS FOR FISHING YEARS 1987/88.

| | ESTIMATES FOR THE SQUID FISHERY IN SQU 6T ONLY[1] | | | ESTIMATES FOR FISHERIES STATISTICAL AREA 602 FOR ALL TARGET FISHERIES[2] | | | |
|---|---|---|---|---|---|---|---|
| FISHING SEASON | TOTAL TOWS | OBSERVER COVER (%) | ESTIMATED BYCATCH | TOTAL TOWS | OBSERVER COVER (%) | ESTIMATED BYCATCH | CV (%) |
| 1987/88 | 1790 | 24 | 33 | | | | |
| 1988/89 | 3766 | 19 | 141 | | | | |
| 1989/90 | 5218 | 12 | 117 | | | | |
| 1990/91 | 3252 | 10 | 21 | | | | |
| 1991/92 | 2168 | 10 | 82 | 3260 | 15 | 79 | 93 |
| 1992/93 | 666 | 29 | 17 | 1797 | 19 | 34 | 62 |
| 1993/94 | 4675 | 9 | 32 | 6106 | 12 | 43 | 54 |
| 1994/95 | 3909 | 7 | 109 | 5557 | 6 | 112 | 32 |
| 1995/96 | | | | 5917 | 11 | 173 | 49 |

[1]Data for the seasons 1987/88 to 1994/95 are from Baird (1996).
[2]The method used to calculate estimates is described in Section 4.

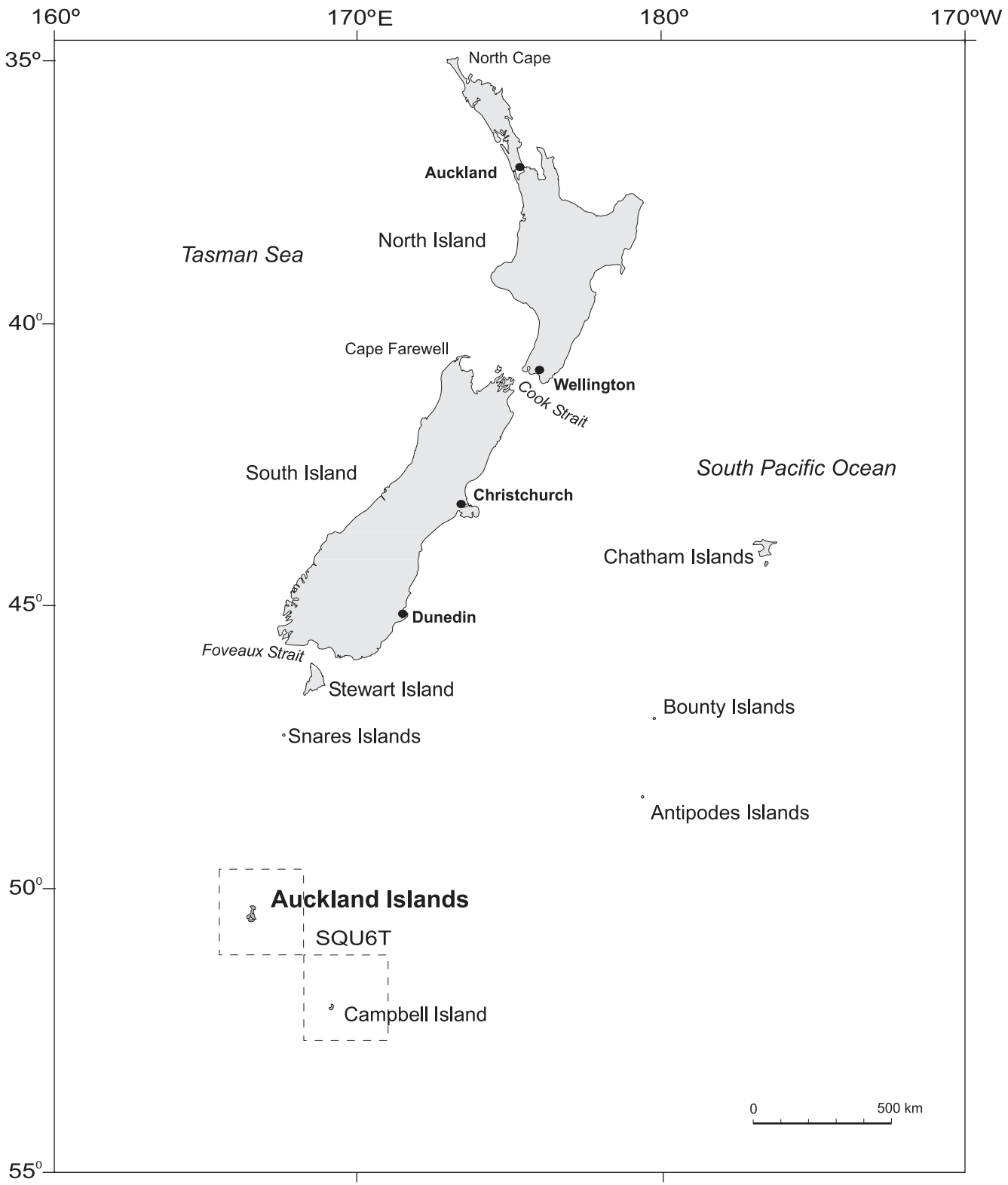


Figure 1. Location of the Auckland Islands to the south of New Zealand, where New Zealand sea lions mainly breed. The squid fishery area SQU 6T is shown to the south of the two main islands. Almost all bycatch of sea lions occurs in the part of this area that is centred on the Auckland Islands.

# 2. Methods for estimation of bycatch from observer reports

The methods used to estimate bycatch for this report are fully described by Manly et al. (1997, 2002). In summary, the data available are the number of tows $u_1, u_2, \ldots, u_n$, with corresponding bycatch numbers $x_1, x_2, \ldots, x_n$, for n sample units. Each sample unit consists of one or more tows made under similar conditions. From these data the bycatch rate (the number of sea lions per tow) is estimated by

$$r = t_x/t_u \tag{1}$$

where $t_x = \sum x_i$ is the number of sea lions caught in $t_u = \sum u_i$ observed tows. The total number of sea lions caught in the entire fishery is then estimated by

$$\hat{T} = r(t_u + t'_u) \tag{2}$$

Where $t'_u$ is the number of unobserved tows in the fishery. This is essentially just a straightforward application of ratio estimation (Manly 1992, p. 35), and the variance of the estimated bycatch can be approximated by

$$\hat{Var}(\hat{T}) = N^2[\sum_{i=1}^{n}(x_i - ru_i)^2]/[(n-1)n][1-n/N]. \tag{3}$$

where N is the total number of possible sample units for the fishery.

In using these equations, an important assumption is that the n observed sample units are effectively a random sample from the N possible sample units. For the estimates calculated for this report a sample unit consists of a series of all consecutive tows by one vessel with the same target. This unit was used in preference to single tows because inspection of the data suggests that there is at times a tendency for a series of tows by one vessel over a short period of time to incur bycatch incidents, and therefore not to represent the equivalent of a random sample. Our definition gives 126 sample units altogether, for fisheries years 1991/92 to 1995/95, from 2785 observed tows.

# 3. Bycatch estimates

For the estimation of the bycatch of sea lions a database described by Manly et al. (2002) was used. The information was supplied by the Ministry of Fisheries, on a tow-by-tow basis for observed tows starting from 19 June 1991 and ending 30 September 1996. In addition, effort information was available from the Ministry's Trawl Catch Effort Processing Return (TCEPR) database.

There were 46 recorded instances of sea lion bycatch in the period considered[1]. Of these, one was in the SEC Fishing Management Area off the east coast of the South Island, targeting hoki in 1995/96, one was just outside the SQU 6T area surrounding the Auckland Islands (Fig. 1), and the remainder were in SQU 6T. The estimates presented here are therefore only for the area around the Auckland Islands. The 46 instances of bycatch involved 40 cases where one sea lion was captured in a single tow, and three cases where two sea lions were captured in a single tow.

The information on total fishing effort provided by the Ministry of Fisheries from the TCEPR database is classified by Fisheries Statistical Areas (FSA). One of these areas, FSA 602, is very close to the SQU 6T area surrounding the Auckland Islands. It is bounded to the west by longitude 165°E, to the east by 168°E, to the north by latitude 49°S, and to the south by 52°S. This compares with SQU 6T which has the same boundaries on the east and west, but covers 49.30°–51.30°S. Thus FSA 602 extends slightly further than SQU 6T to the north and south. It is FSA 602 that is used for the production of bycatch estimates for the present report.

Ratio estimation was used to estimate the bycatch separately for each of the fishing years 1991/92 to 1995/96, for tows targeting squid, scampi, and other species. Initially the same nine categories of target species as used for fur seals by Manly et al. (2002) were considered, with the 'other' category comprising a range of species that are individually seldom targeted in New Zealand waters. However, sea lion bycatch has only been recorded with tows targeting squid, scampi and 'other' species (*Trachurus murphyi* in one incident only) so these are the categories used here. The very incomplete observer data for 1990/91 precluded estimates being made for that year.

Estimates of bycatch for FSA 602 are provided in Table 2, together with information on the total number of tows, the number of observed tows, and estimated standard errors.

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[1] The data on bycatch used in this study are held by the Department of Conservation in the file SEALIONS.XLS. This is a Microsoft Excel file containing the information on the sample units used to produce the estimates of total bycatch shown in this report, and also the sample units that were used for the log-linear model analysis described in Section 4. The first sheet of the file contains 126 rows of data, where each row relates to a series of consecutive tows by one vessel with one target fish species. The second sheet of the file contains 269 rows of data, where each row relates to all the observed tows carried out by one vessel with one target species, in one season of one year, with one type of gear, in one part of the day, in the statistical area 602. In the interests of confidentiality, the information in the file does not allow individual vessels to be identified and latitudes and longitudes for the position of vessels at the time of the first tow are rounded to the nearest 0.1 of a degree.
http://csl.doc.govt.nz/sealions.xls

# 4. Factors affecting bycatch

Our analysis of the factors affecting sea lion bycatch is based on sample units consisting of all the observed tows carried out by one vessel with one target species in one season of one year, with one type of gear, in one part of the day, in the statistical area 602. There were 269 sample units altogether on this basis.

In the analysis the dependent variable was the number of sea lions captured for the sample unit. The variables and factors that were used in an attempt to account for variation in the dependent variable were:

Tows: the number of tows for the sample unit;

VSize: the index of the size of a vessel, as described in Manly et al. (2002);

Nationality: the nationality of the vessel, treated as a factor with the levels (1) Australia, (2) China, (3) CIS, (4) Denmark, (5) Faroe, (6) Japan, (7) Korea, (8) Norway, (9) NZ, (10) Poland, (11) Russia, (12) Ukraine, and (13) USA;

Year: the fishing year coded from (1) for 1990/91 to (6) for 1995/96, with no sample units having code (1);

Season: the season of the year, coded (1) for summer (December to February), (2) for autumn (March to May), (3) for winter (June to August), and (4) for spring (September to November) as determined for time of the first tow in the series of tows comprising a sample unit;

Target: the target fishery, coded in the same way as for the analysis of fur seal bycatch by Manly et al. (2002) with the relevant codes being (3) for squid, (4) for scampi, and (9) for other species (*Trachurus declivis*, smooth oreo and silver warehou);

Gear: the gear type, coded as (1) for midwater and (2) for bottom tows;

TDay: the time of day when tows began, coded (1) for 12 midnight to 6 am, (2) for 6 am to 12 noon, (3) for 12 noon to 6 pm, and (4) for 6 pm to 12 midnight;

Log_Dur: the natural logarithm of the average time of fishing per tow for the tows in the sample unit;

Log_Weight: the natural logarithm of the average green weight of fish caught per tow for all the tows in the sample unit.

Figure 2 shows plots of the sea lions caught in the sample units and the mean catch per tow against the values for the codes and variables of those units. There are no horizontal scales, but codes and values of variables are low on the left and high on the right. It can be seen from these plots that catches of 2 or 3 sea lions for a sample unit are associated with low numbers of tows, somewhat large vessels, nationalities 7 and 11 (Korea and Russia), season 2 (autumn), moderately long average durations of fishing, and a moderately high green weight of fish caught. In terms of the average number of sea lions caught per

tow, the situation is similar except that the highest values occur when the green weight of fish caught is low.

A log-linear model was fitted to the data using GLIM (Francis et al. 1993). Thus it was assumed that the count of sea lions for a sample unit follows a Poisson distribution with a mean given by

$$\mu = (\text{Tows})\exp(\Sigma\beta_i X_i) \qquad (4)$$

Where $\Sigma\beta_i X_i$ is a linear combination of effects for the variables and factors that may affect the bycatch rate, and Tows is the total number of tows for the sample unit.

Table 3 summarises the results obtained as an analysis of deviance (Manly 1992: section 8.5). From this table it appears that only the variables Target and Log_Weight account for a significant part of the variation in bycatch numbers. However, removing the Season factor from the equation gives a significant increase in the deviance if Log_Weight is also in the equation, so there is also some evidence of variation in the bycatch rate associated with the time of year.

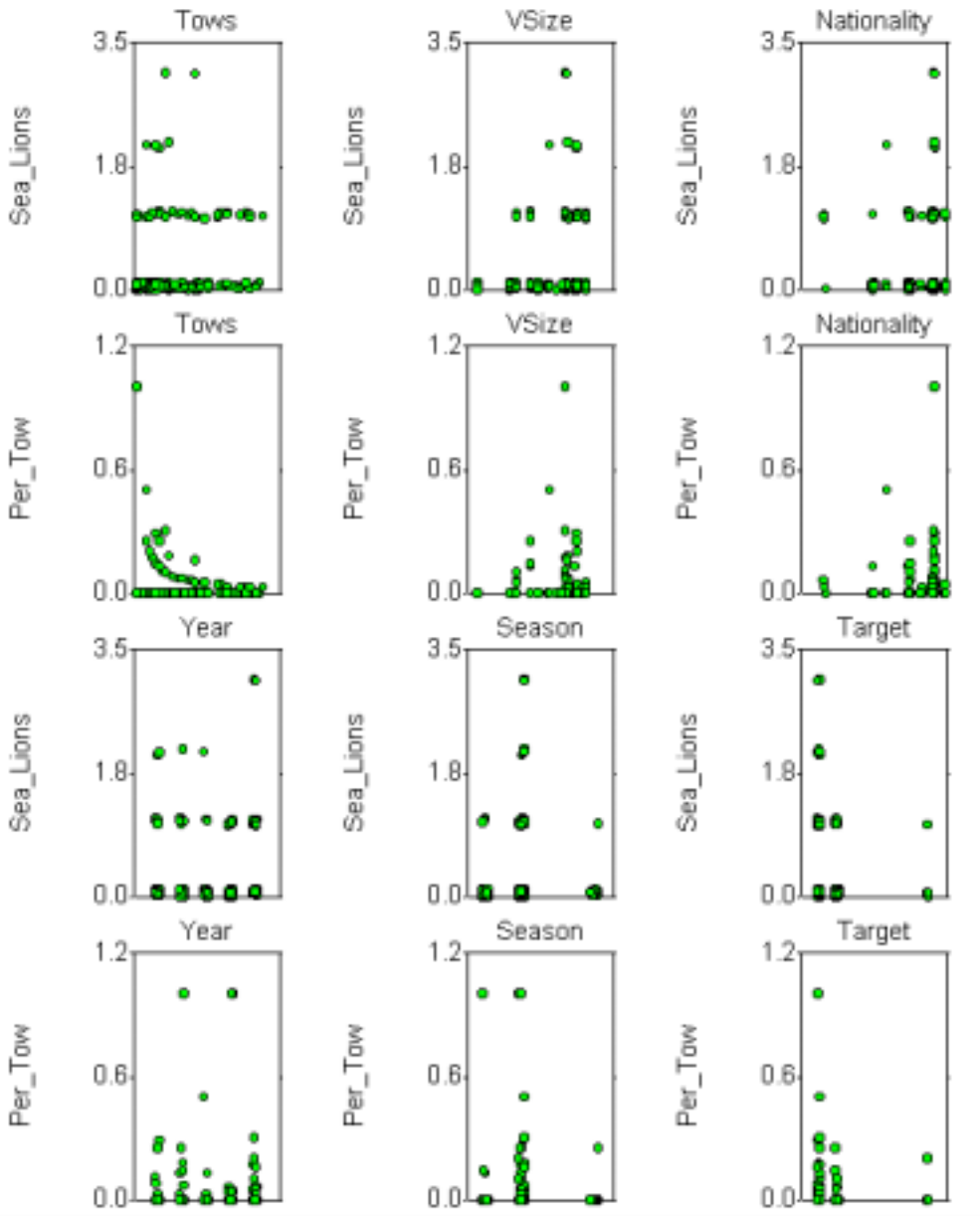
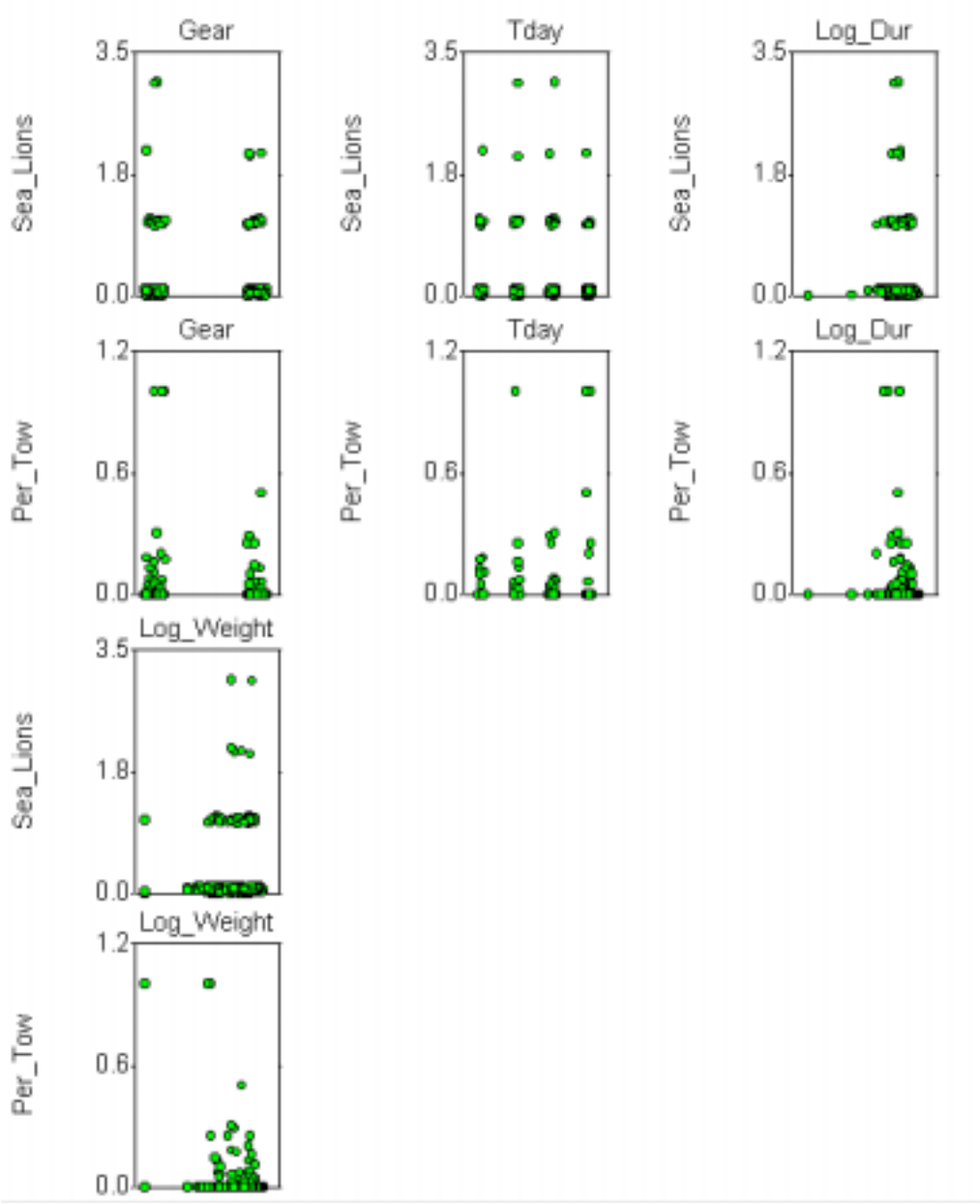



Figure 2. Plots of the total bycatch of sea lions (Sea_Lions) and the bycatch per tow (Per_Tow) observed in sample units plotted against the number of tows, the vessel size index, the nationality code, the fishing year code, the season code, the target species code, the gear type, the time of day code, the logarithm of the mean duration of fishing per tow, and the logarithm of the average green weight of fish caught per tow. The plotted points have been jittered where necessary, to avoid many points falling at the same position.

Figure 2 *continued*




In assessing the results in Table 3 it is assumed that the change in deviance due to adding an extra term into the model (column 4 in the table) is approximately distributed as a chi-squared variable when the bycatch is not related to the extra term. It is generally believed that this type of approximation is often more reasonable than the assumption that the deviance for the full model (column 2 in the table) has a chi-squared distribution when the model is correct (Francis et al. 1993, p. 279). In the present context the deviance for the maximum model considered is 133.60, which is much lower than the expected value of 250 based on the degrees of freedom. We assume that this is a result of the chi-squared approximation being rather poor for the deviance of the maximum model because of the many zero bycatch values in the data. It must be noted, however, that for the situation being considered significance tests based on chi-squared distributions should be regarded as general guides is assessing different models rather than producing 'exact' p-values.

Figure 3 shows standardised, studentised residuals from the fitted model with only the significant effects of Target, Season and Log_Weight included (MCCullagh & Nelder 1989). There are no particular patterns in these residuals, indicating that the model seems reasonable.

Figure 4 shows the expected number of sea lion captures for sample units plotted against the variables and factors used for modelling. The expected number of sea lion captures per tow is also shown on this figure, plotted against

TABLE 2. TOTAL TOWS, OBSERVED TOWS, AND ESTIMATED BYCATCH OF SEA LIONS IN FISHERIES STATISTICAL AREA 602.

| FISHING SEASON | | TARGET | | | | | COEF. OF OBSERVER VARIATION |
|---|---|---|---|---|---|---|---|
| | | SCAMPI | SQUID | OTHER | TOTAL | COVER (%) | (%) |
| 1991/92 | Total tows | 964 | 2155 | 141 | 3260 | | |
| | Observed tows | 266 | 219 | 0 | 485 | 14.9 | |
| | Observed bycatch | 0* | 8 | | 8 | | |
| | Estimated bycatch/1000 tows | 0.0 | 36.5 | | | | |
| | Estimated total bycatch | 0.0 | 78.7 | | 78.7 | | |
| | Standard error | 0.0 | 73.3 | | 73.3 | | 93.1 |
| 1992/93 | Total tows | 862 | 656 | 279 | 1797 | | |
| | Observed tows | 148 | 197 | 0 | 345 | 19.2 | |
| | Observed bycatch | 3 | 5 | | 8 | | |
| | Estimated bycatch/1000 tows | 20.3 | 25.4 | | | | |
| | Estimated total bycatch | 17.5 | 16.6 | | 34.1 | | |
| | Standard error | 16.2 | 14.1 | | 21.5 | | 62.9 |
| 1993/94 | Total tows | 1314 | 4676 | 116 | 6106 | | |
| | Observed tows | 280 | 434 | 1 | 715 | 11.7 | |
| | Observed bycatch | 0 | 4 | 0 | 4 | | |
| | Estimated bycatch/1000 tows | 0.0 | 9.2 | | | | |
| | Estimated total bycatch | 0.0 | 43.1 | | 43.1 | | |
| | Standard error | 0.0 | 23.4 | | 23.4 | | 54.3 |
| 1994/95 | Total tows | 1339 | 4009 | 209 | 5557 | | |
| | Observed tows | 50 | 286 | 1 | 337 | 6.1 | |
| | Observed bycatch | 0 | 8 | 0 | 8 | | |
| | Estimated bycatch/1000 tows | 0.0 | 28.0 | | | | |
| | Estimated total bycatch | 0.0 | 112.1 | | 112.1 | | |
| | Standard error | 0.0 | 36.7 | | 36.7 | | 32.7 |
| 1995/96 | Total tows | 1300 | 4461 | 156 | 5917 | | |
| | Observed tows | 67 | 555 | 15 | 637 | 10.8 | |
| | Observed bycatch | 3 | 13 | 1 | 17 | | |
| | Estimated bycatch/1000 tows | 44.8 | 23.4 | 66.7 | | | |
| | Estimated total bycatch | 58.2 | 104.5 | 10.4 | 173.1 | | |
| | Standard error | na | 84.5 | 10.1 | n.a. | | 49.2 |

*In cases where no bycatch is observed the estimated bycatch per 1000 tows, the total bycatch and the estimated standard error are set at zero, based on equations 1 to 3. These estimates may be rather poor for the small numbers of tows observed.

the same variables and factors. Taking the expected number of captures per tow as the more meaningful output from the model, it can be seen from Fig. 4 that the model predicts high values with a small number of tows per sample unit, moderately large vessels, nationalities 10 and 12 (Polish and Ukraine), seasons 1 and 2 (summer and autumn), target species 3 and 9 (squid and other), times of the day 2 and 3 (from 6 am to 6 pm), short average durations of fishing per tow, and low green weights of fish caught.

At first sight it may seem strange that the model predicts high bycatch for some variables and factors that have insignificant effects according to the analysis of deviance. The explanation must be that the distributions for these variables and factors are not independent of the distributions for Target, Log_Weight and Season, which implies that it is not really possible to untangle the effects of the different variables and factors recorded on the sample units.

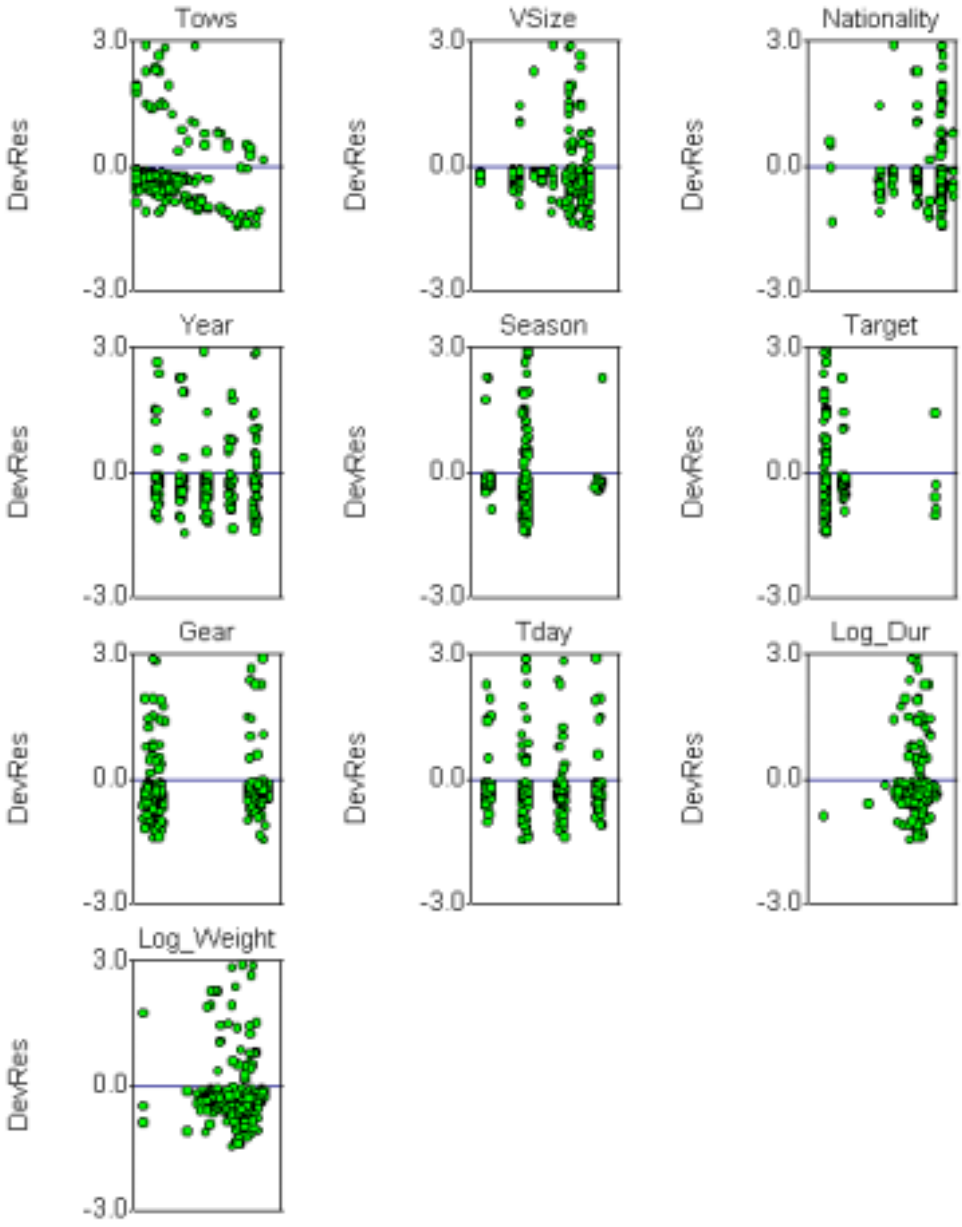



Figure 3. Standardised, studentised deviance residuals for the log-linear model fitted to the counts of sea lions caught in sample units plotted against codes and values for other recorded factors and variables. The plotted points have been jittered where necessary, to avoid many points falling at the same position.

TABLE 3. ANALYSIS OF DEVIANCE FROM FITTING MODEL 4 TO COUNTS OF SEA LION BYCATCH ON SAMPLE UNITS.

| MODEL | DEVIANCE[1] | DEGREES OF FREEDOM | CHANGE FROM ADDING EXTRA TERM DEVIANCE | DEGREES OF FREEDOM |
|---|---|---|---|---|
| Constant mean per tow | 168.86 | 269 | | |
| + Target | 159.61 | 266 | 9.24** | 2 |
| + Season | 155.04 | 264 | 4.58 | 2 |
| + Year | 146.86 | 260 | 8.18 | 4 |
| + VSize | 145.88 | 259 | 0.98 | 1 |
| + Log_Dur | 144.65 | 258 | 1.22 | 1 |
| + Nationality | 138.62 | 252 | 6.03 | 6 |
| + Gear | 137.93 | 251 | 0.69 | 1 |
| + Log_Weight | 133.60 | 250 | 4.33* | 1 |

[1]Deviances in this column can be tested against the chi-squared distribution:
* significant at 5% level, ** significant at 1% level.

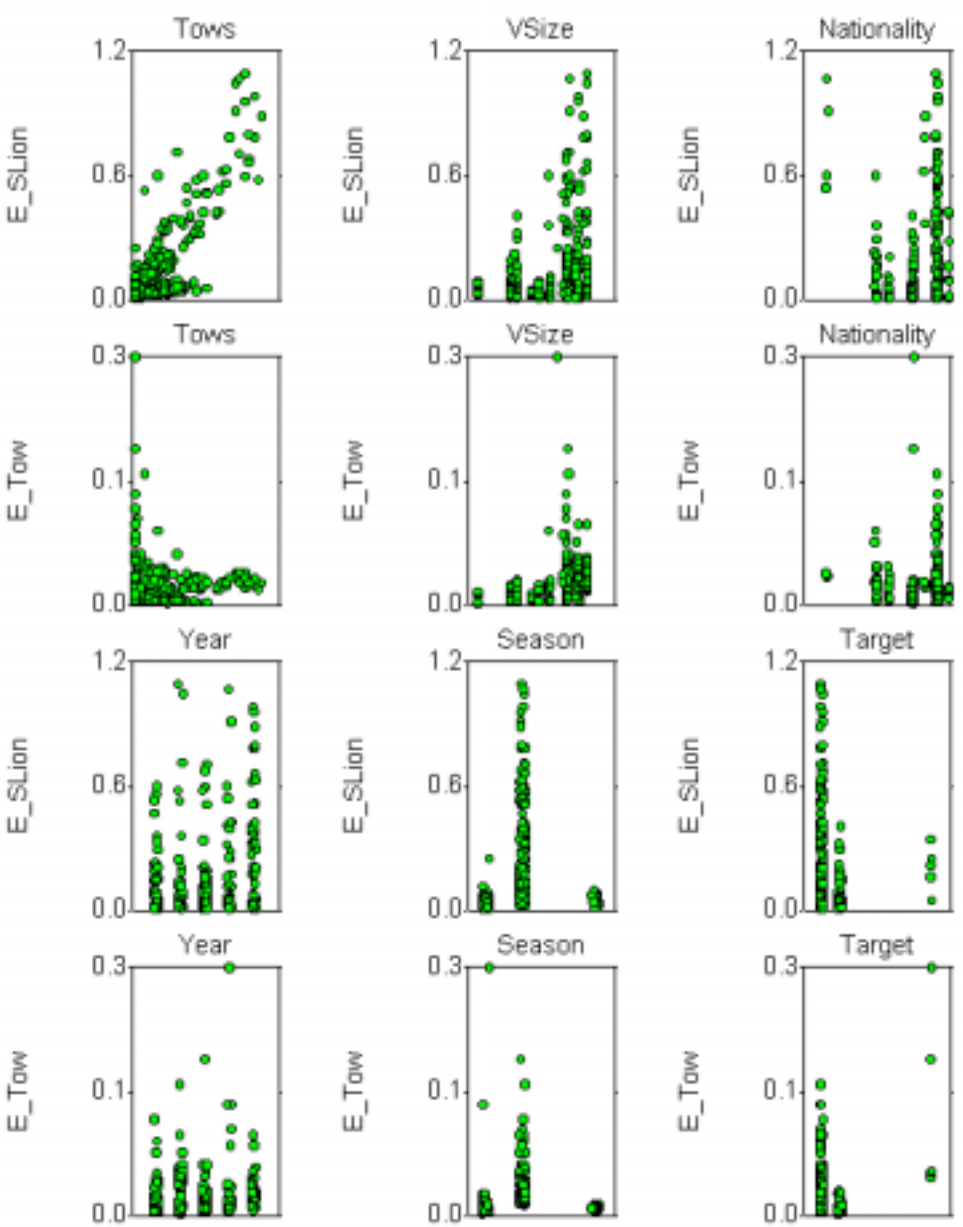
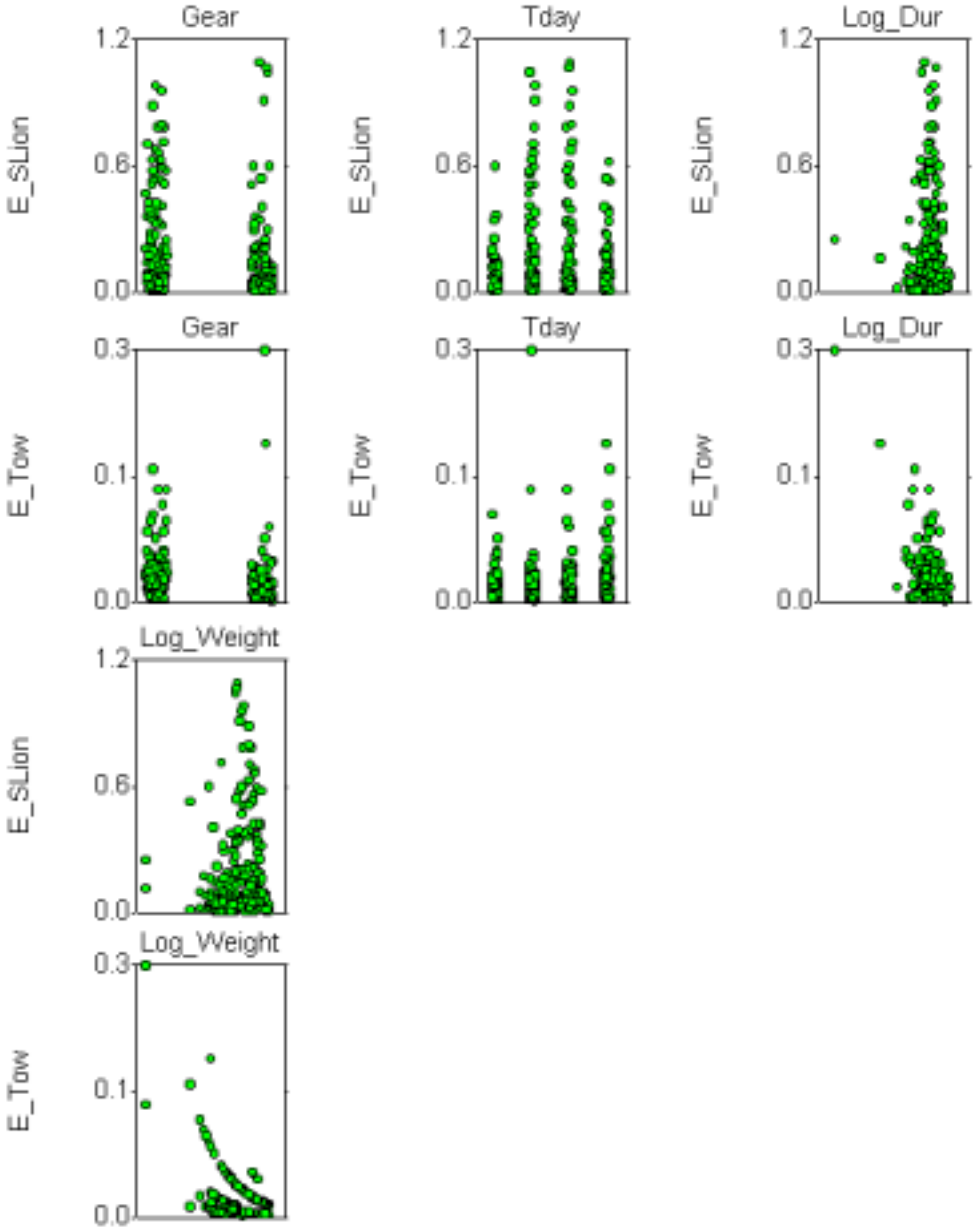



Figure 4. Estimated values for the expected bycatch of sea lions per sample unit (E_SLion) and per tow (Per_Tow) plotted against other variables and factors. The plotted points have been jittered where necessary, to avoid many points falling at the same position.

Figure 4. *continued*




Finally, Fig. 5 shows the location of the starting points of tows with an indication of whether the fitted model shows a high (greater than 0.05), medium (0.01 to 0.05) or low (less than 0.01) probability of bycatch per tow. To maintain the confidentiality of the position of individual tows, latitude and longitude values have been rounded to the nearest 0.1 of a degree and a small random perturbation added.

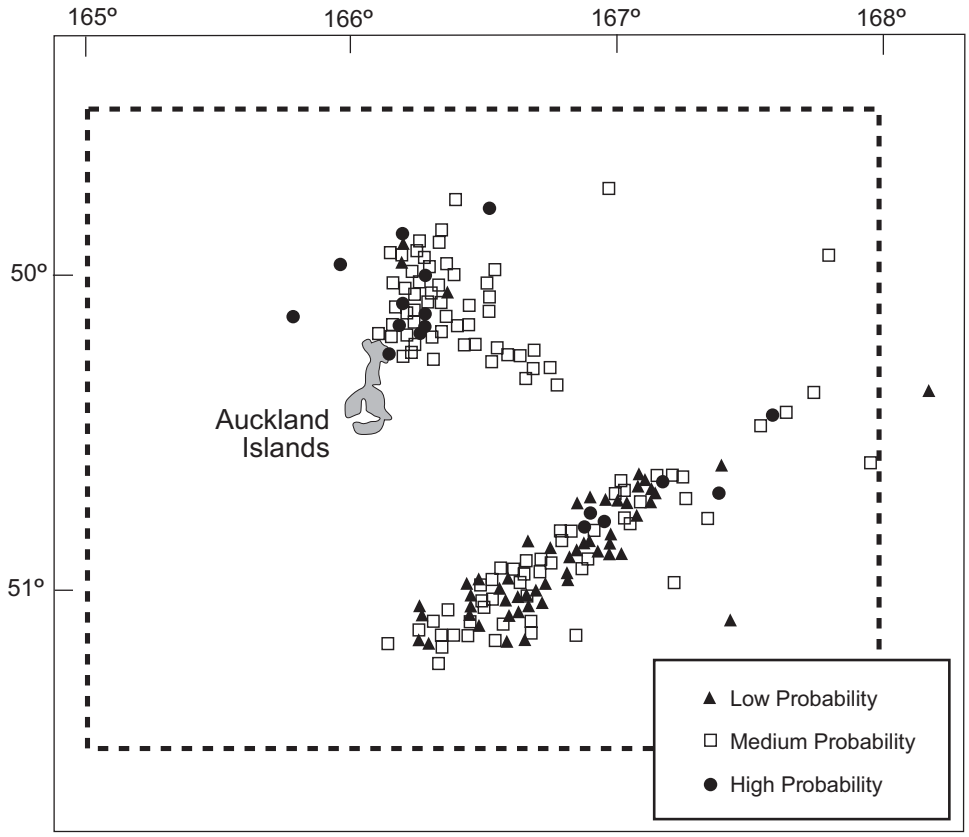



Figure 5. Starting locations for observed sample units and whether the estimated by catch rate per tow was high (greater than 0.05), medium (from 0.01 to 0.05), or low (less than 0.01). The locations have received a small random perturbation to separate the clusters slightly. The boundary for fishing area SQU6T is shown by the broken lines.

# 5. Assessment of the observer coverage needed in the future

For determining the levels of observer coverage required in future seasons, the coefficient of variation (CV, the standard error/estimate expressed as a percentage) is used as the measure of precision. In general, a CV of 20% or less is desirable. Then, for example, if the estimated bycatch is 100 animals the standard error is about 20, and an approximate 95% confidence interval for the true bycatch is 100 ± 40 animals. Depending upon the decisions to be made, this may or may not provide sufficient precision.

The CV gives an indication of the variation expected from sampling errors. It is important to realise that it cannot tell us anything about bias in the sampling procedure. Thus we may have a high level of observer coverage and still have a poor estimate of bycatch if the sample units used for estimation are not selected in a manner that is as close to random as possible.

The CV is the standard error as a percentage of the mean, which is also the standard deviation of percentage relative errors, i.e., the standard deviation of

$$RE = \frac{100(\text{Estimate} - \text{True Value})}{\text{True Value}}$$

Thus when a series of bycatch estimates are obtained with a different true value for each one, it is reasonable to regard the achieved CV as the standard deviation of the relative errors.

Fig. 6 shows the CVs that are expected with this definition, for various levels of observed cover. It is assumed that ratio estimation will be used as described in Section 2, with the sample units being defined as in the analyses in Sections 3 and 4 of this report, i.e., a series of consecutive tows carried out on one vessel, with the same target species, in the same FMA, with the same fishing gear.

The procedure used to obtain the CV with an observer cover of P% and an expected number of tows of N is as follows:

a. The 126 sample units that were used for the estimation of bycatch as described in Section 3 were used to represent a source population for future data, except that the observed bycatch rate on these units of 0.018 sea lions per tow was increased to 0.023 sea lions per tow to better reflect the estimated level for 1995/96. This was done by multiplying the observed bycatch per sample unit by a constant and rounding to the nearest integer.

b. Units were selected at random from the source population until the accumulated number of tows exceeds N – 22. Stopping before N tows ensures that the expected total number of tows in the sample units is close to N, taking into account the fact that the number of tows in individual sample units varies from 1 to over 100. The set of selected units provides a simulated fishery, with total bycatch B.

c. Each unit in the simulated fishery was given a probability P of being observed.

d. Equation 2.2 was used to obtain the estimate $\hat{T}$ of the total bycatch for all selected units, using the information from the observed units.

e. The percentage relative error in the estimate was calculated as RE = 100($\hat{T}$ – B)/B.

f. Steps b. to e. were repeated 5000 times, and the standard deviation of RE was calculated. The CV estimated from the simulation was taken as the standard deviation of RE.

Where stratification is desirable, the results shown in Fig. 6 can be applied separately for each stratum. The following calculation can then be used to determine the CV for the estimate of bycatch in the whole fishery:

$$CV = 100\%[\sum (CV_i)^2 T_i^2]/T$$

where $CV_i$ and $T_i$ are CV and estimated bycatch in stratum i, $T = \sum T_i$ is the overall estimated bycatch, and the summation is over all strata.

Figure 6 shows that to obtain a CV of 20%, which is a reasonable general level of precision, requires about 90% observer cover for a fishery with 500 tows, about 80% cover with 1000 tows, about 50% cover with 3000 tows, about 40% cover with 5000 tows, and about 30% cover with 10000 tows. There were between about 1500 and 6000 tows in the fishing years 1991/92 to 1995/96 that were used to estimate the total bycatch of sea lions in FSA 602 (Table 1).

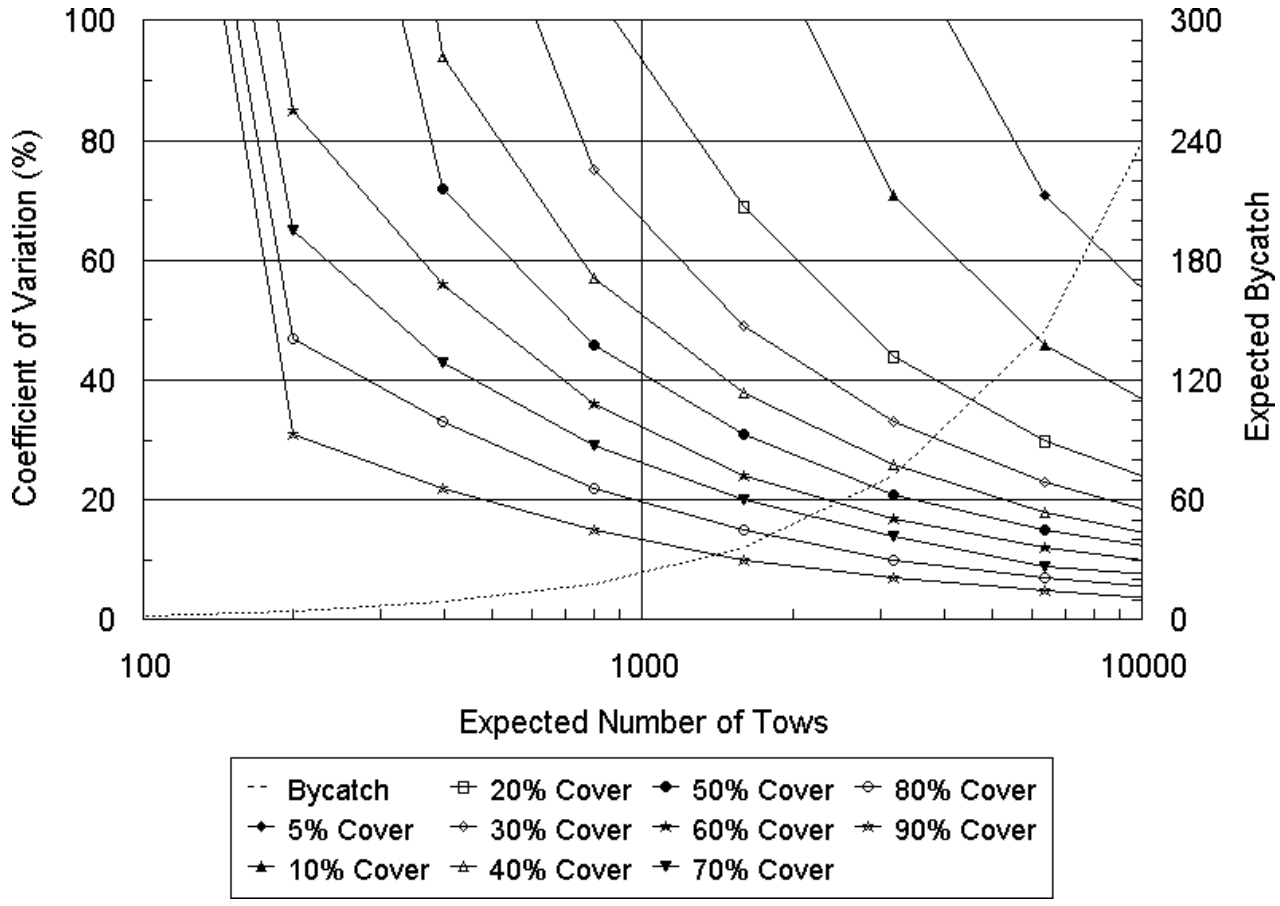



Figure 6. Coefficients of variation for estimates of total bycatch as a function of the expected total number of tows and the level of observer cover, assuming a bycatch rate of 0.023 per tow.

# 6. Summary

- Ratio estimation is recommended for the estimation of the total sea lion bycatch based on observed tows, with the sample unit being a series of consecutive tows by one vessel with the same target fish.
- Using ratio estimation, the estimated total bycatch numbers of sea lions for different fishing seasons, with the coefficient of variation in parentheses are: 1991/92, 79 (93%); 1992/93, 34 (63%); 1993/94, 43 (54%); 1994/95, 112 (33%); and 1995/96, 173 (49%).
- The probability of bycatch occurring on a single tow varies significantly with the target fish species, and the logarithm of the green weight of fish caught. The season of the year is also significant when included with these two variables, although almost all tows are in one of the four seasons considered.
- A simulation based on past observer data suggests that to obtain a CV (the standard error of the estimated total bycatch divided by the estimated total bycatch expressed as a percentage) of 20% requires about 90% observer cover for a fishery with 500 tows, about 80% cover with 1000 tows, about 50% cover with 3000 tows, about 40% cover with 5000 tows, and about 30% cover with 10000 tows.

# 7. References


Baird, S.J. 1996. Nonfish species and fisheries interactions working group report—May 1996. New Zealand Fisheries Assessment Working Group Report 96/1. New Zealand Ministry of Fisheries, Wellington.

Department of Conservation 1997. The New Zealand Sea Lion Population Management Plan. New Zealand Department of Conservation, Wellington.

Francis, B.; Green, M.; Payne, C. 1993. *The GLIM System, Release 4 Manual*. Clarendon Press, Oxford.

Manly, B.F.J. 1992. *The Design and Analysis of Research Studies*. Cambridge University Press, Cambridge.

Manly, B.F.J.; Seyb, A.; Fletcher, D. 1997. Fisheries bycatch monitoring and control. *Statistics in Ecology and Environmental Monitoring 2: Decision Making and Risk Assessment in Biology*. Otago University Press, Dunedin.

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

McCullagh, P.; Nelder, J.A. 1989. *Generalized Linear Models*, 2nd edit. Chapman and Hall, London.