Bycatch of fur seals (*Arctocephalus forsteri*) in New Zealand fisheries, 1990/91–1995/96, and observer coverage

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ABSTRACT

The data that are available on the bycatch of New Zealand fur seals (*Arctocephalus forsteri*) during fishing operations in New Zealand waters are reviewed, for the fishing years 1990/91 to 1995/96. Methods for estimating the amount of bycatch for different fisheries, based on reports from official observers and records of total fishing effort are discussed, and estimates of the bycatch are calculated using ratio estimation. The effects of factors that may influence bycatch rates are analysed. Tables showing the observer cover required to provide a 20% coefficient of variation for bycatch estimates are provided as a function of the number of tows in the fishery.

Estimates of the total bycatch range for 401 fur seals in 1990/91 up to 2110 in 1995/96, with the amount of bycatch varying significantly with the Fisheries Management Area, the target fish species, the fishing year, the season, the nationality of the fishing vessel, the green weight of the fish caught, and the duration of fishing. It is found that obtaining a coefficient of variation of 20% for the estimated bycatch requires high levels of observer cover unless the number of tows in the fishery is very large.

Manly et al. 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.

1. Introduction

Until 1989 the numbers of New Zealand fur seals (*Arctocephalus forsteri*) caught in commercial fisheries operations within the Exclusive Economic Zone (EEZ) was thought to be low. However, in that year Ministry of Agriculture and Fisheries (MAF) observers began reporting a high incidence of fur seal captures in the West Coast South Island hoki fishery (Mattlin 1994). More recently there has been a substantial increase in the estimated bycatch in other fishing areas because of improved reporting procedures (Baird 1995).

Table 1 gives information about the total number of trawls, observer coverage, and estimated bycatch for fishing years 1990/91 to 1995/96. Although the number of animals caught is high it is thought that there has been a recent increase in the size of the fur seal population, which may exceed 50,000 adults (Baird 1995). Therefore the bycatch does not seem to present an immediate threat to the population. Nevertheless, the apparent trend of increasing bycatch must be of concern.

TABLE 1. ESTIMATED BYCATCH OF FUR SEALS FOR FISHING YEARS 1990/91 TO 1995/96 FOR THE WHOLE OF THE EXCLUSIVE ECONOMIC ZONE (EEZ).

FISHING YEAR	TOTAL TRAWLS[1]	OBSERVER COVER (%)	ESTIMATED TOTAL BYCATCH[2]	COEFFICIENT OF VARIATION (%)
1990/91	27101	16.2	401	29
1991/92	47497	19.6	584	27
1992/93	48799	17.0	1091	13
1993/94	51227	15.3	1157	18
1994/95	55847	20.6	1073	17
1995/96	52089	12.5	2110	19

[1]The total trawls are for vessels over 28 m in length in Fisheries Management Areas other than Auckland East and West and Kermadec. See Section 3.1 for more details.
[2]The methods used to calculate estimates are described in Section 3.1.

2. Methods for estimation of bycatch from observer reports

It appears that the first attempt to estimate the total bycatch of a protected New Zealand marine mammals using observer records from a fraction of the fishing vessels was made by Gibson (1991) using data for the New Zealand sea lion for the four fishing seasons 1986/87 to 1989/90. He assumed that the probability of catching a sea lion was the same for each trawl within each of three geographical areas, with no more than one catch being possible from any one trawl. The probability of capture for area j was therefore estimated by $p_j = S_j / O_j$, where S_j is the total number of captures in the region for all seasons, and O_j is the total number of observed trawls, again for all seasons. Having estimated the probability of catching a sea lion, the estimate of the total number caught by all vessels in area j in season i is given by

$$\hat{T}_{ij} = p_j t_{ij} \quad (1)$$

where t_{ij} is the total number of trawls for all vessels in that area and season. There was a slight complication because some of the observed catches could not be assigned to a geographical area. These catches were allocated to the regions in proportion to the known catches in the areas.

Gibson's (1991) method for estimating the total bycatch is essentially a form of ratio estimation (Manly 1992, p. 35). He calculated confidence limits for the total bycatch assuming that the observed bycatch has a binomial distribution.

In a later note, Gibson (1994) used a bootstrap percentile method for obtaining 95% confidence limits for the total bycatch of fur seals, based on ratio estimation for the situation where more than one capture can occur from a single trawl. Although this method of deriving confidence limits is reasonable, it requires justification from simulation studies before it can be used with confidence. A bootstrap method was also used earlier for estimating the standard error of the estimated total catch of seabirds in southern fishery longline vessels in 1988 and 1989 (Murray et al. 1992).

Another approach, that takes into account the possibility of multiple captures from a single trawl, assumes that the n observed trawls in one geographical area in one year are a random sample from the N trawls in that area and year. The mean bycatch per trawl is then estimated by the sample mean and the total bycatch is estimated by

$$\hat{T} = N \quad (2)$$

with estimated variance

$$\mathrm{Var}(\hat{T}) = N^2 (s^2/n) (1 - n/N) \quad (3)$$

where s is the sample standard deviation. These are standard results from finite sampling theory (Manly 1992, p. 23).

Doonan (1995) and Manly et al. (1997) followed Gibson (1991, 1994) by using ratio estimation for the total bycatch of a protected species. However, they proposed that the variance associated with an estimate should be calculated using standard ratio estimation methods rather than being based on the assumption that the total bycatch follows a binomial distribution, or using bootstrapping. Manly et al. (1997) were concerned with the estimation of bycatch part way through a fishing season, after d days of fishing, and the following equations are for this situation. However, these equations apply for the end of the season with d equal to the total number of fishing days at that time.

TABLE 2. NOTATION USED TO DESCRIBE THE INFORMATION AVAILABLE ON N(D) SAMPLE UNITS (ASSUMED TO BE FISHING DAYS), OF WHICH N(D) ARE OBSERVED, AFTER D FISHING DAYS IN THE SEASON.

OBSERVED SAMPLE UNITS			UNOBSERVED SAMPLE UNITS		
SAMPLE UNIT	TRAWLS (KNOWN)	BYCATCH (KNOWN)	SAMPLE UNIT	TRAWLS (KNOWN)	BYCATCH (KNOWN)
1	u_1	x_1	n(d)+1	$u_{n(d)+1}$	$x_{n(d)+1}$
2	u_2	x_2	n(d)+2	$u_{n(d)+2}$	$x_{n(d)+2}$
-			-		
-			-		
-			-		
n(d)	$u_{n(d)}$	$x_{n(d)}$	N(d)	$u_{N(d)}$	$x_{N(d)}$
Total	$t_u(d)$	$t_x(d)$	Total	$t'_u(d)$	$t'_x(d)$

Suppose that at the end of fishing day d the information shown in Table 2 is available. That is to say, there are a total of N(d) sample units (vessel days), of which the bycatch is observed for the first n(d). For the i-th of the N(d) sample units the number of completed trawls is u_i, and the bycatch (the number of individuals of the protected species incidentally caught) is x_i . Then x_i is known for the first n(d) sample units only, for which the total bycatch is $t_x(d)$, based on a total of $t_u(d)$ trawls. For the unobserved trawls the total bycatch is $t'_x(d)$, based on a known number $t'_u(d)$ of trawls, while the total bycatch for the whole fishery is $T(d) = t_x(d) + t'_x(d)$, based on $t_u(d) + t'_u(d)$ trawls. It is assumed that the n(d) observed sample units are a random sample from the population of N(d) units. Note that although the sample units are assumed here to be vessel days they could equally well be vessel weeks, or all the trawls made by a single vessel over the time period of interest, as discussed below.

The average bycatch per observed trawl (the observed 'strike rate') is

$$r(d) = t_x(d)/t_u(d) \quad (4)$$

Therefore, an estimate of the total bycatch for the whole fishery at the end of day d is the sum of the bycatch for the observed trawls and an estimated bycatch for the unobserved trawls, which is

$$\hat{T}(d) = r\{t_u(d) + t'_u(d)\} = t_x(d) + r(d)t'_u(d) \quad (5)$$

An approximation for the variance of the estimator 5 that is provided by the usual theory of ratio estimation (Manly 1992, p. 35) is

$$\mathrm{Var}\{\hat{T}(d)\} = N(d)^2[\mathrm{Var}\{x - R(d)u\}/n(d)]\{1 - n(d)/N(d)\} \quad (6)$$

where

$$R(d) = \{t_x(d) + t'_x(d)\}/\{t_u(d) + t'_u(d)\}$$

is the unknown strike rate for all trawls taken by day d, and Var{x - R(d)u} is the variance of x_i – Ru_i over the entire set of N(d) sample units. An estimate of Var{x – R(d)u} for use in equation 6 is given by the variance of x_i – ru_i for the observed units, leading to an estimate of the variance of $\hat{T}$ (d) given by

$$\hat{\mathrm{Var}}\{\hat{T}(d)\} = N(d)^2 \frac{\sum_{i=1}^{n(d)} (x_i - ru_i)^2}{\{n(d)-1\}n(d)} \left\{1 - \frac{n(d)}{N(d)}\right\} \quad (7)$$

If necessary, equations 4 to 7 can be applied separately for trawls in different geographical areas. The estimate of the total bycatch is then simply the sum of the estimates for the different areas, with an estimated variance that is the sum of the estimated variances for the different areas. This is then an application of the conventional ideas of stratified sampling with ratio estimation (Scheaffer et al. 1990).

In comparing the alternative estimators that have been proposed for use with marine mammal bycatch, and different methods for estimating their variances, the following points should be considered:

a. With the ratio estimation methods there is a choice of sample units. This will not affect the estimate of total bycatch, but may be important for variance estimation. Possible sample units are individual trawls, the trawls made by all vessels on one fishing day, the trawls made by all vessels in one fishing week, all the trawls made in the period of interest by one vessel, etc. What is important here is that as far as possible the observations that are made on sample units that are a random sample from all possible observations. Therefore, if vessels are randomly chosen to have observers on them and the underlying strike rate is thought to vary from vessel to vessel, then it is probably best to use all the trawls on single vessels as the observations. On the other hand, if the underlying strike rate is thought to vary from day to day, but to be fairly constant from vessel to vessel, then all trawls made on a single day will be a more suitable unit. A related factor to be considered here is that when estimating variances from equation 7 it is desirable to have as many sample units as possible, and preferably at least 30 (Manly 1992, p. 36).

b. Variance estimation based on the binomial distribution is only valid for situations where there is a bycatch of zero or one animals per trawl and it is reasonable to assume that the outcome of each trawl is independent of what occurs on all other trawls.

c. Ratio estimators and their associated estimates of variance are biased to some extent. Some simulation results that are presented in the Appendix 1 to this report suggest that bias in the estimation of total bycatch should not be a major concern with application to New Zealand fur seals. However, the estimated standard error may tend to be too low for fisheries with low levels of observer cover. Furthermore, determining a confidence interval for the true total bycatch by taking the estimated bycatch plus or minus some multiple of the estimated standard error may be a rather approximate procedure unless the level of observer cover is quite high.

d. Estimates of bycatch obtained by taking into account the effects of factors such as vessel size and vessel age by fitting a regression model to the data or some other such analysis have the potential to be more precise than estimates based on simpler methods such as ratio estimation. However, these 'model-based' methods of estimation also have the potential for being biased if the model selected for use is not correct. For this reason it seems best to use ratio estimation as the standard method for producing time series of estimates of bycatch, possibly applying this separately for sample units that may potentially have different underlying bycatch rates, such as trawls in different geographical areas. It is then highly desirable that observer cover is allocated at random as far as possible to the sample units, as this is what justifies variance estimation using the standard ratio estimation equations. Indeed, the variance estimates are 'design-based' and reflect the variation to be expected from the different possible random allocations of observer cover that could have occurred. Model-based analyses of the data still have great value as a means of determining variables that bycatch rates are related to, as is shown, for example, by Duckworth's (1995) generalised linear model analysis of seabird bycatch rates in the Japanese southern bluefish tuna fishery. Also, having determined an important variable it may also be reasonable to apply ratio estimation separately for sample units grouped on the basis of that variable.

All of the methods for estimating total bycatch that are described in the previous two sections require the assumption that the sample units that are observed are a random sample from all of the sample units to which the total bycatch relates. This assumption can be guaranteed if the allocation of observers to units is made completely at random in the first place. However, this may be difficult if observers are required to be on individual vessels for entire voyages because the sample size (the number of voyages covered) may then be too small to allow a good estimate of the variance of the estimator of total bycatch. Therefore in practice it will often be necessary to justify the assumption of random sampling by the belief that the bycatch process itself has the necessary randomness.

Nevertheless, it is always highly desirable to introduce random sampling into the observer process to the extent that it is possible, because this minimises the need to rely on randomness in the bycatch process. If there are unrecognized systematic differences between bycatch rates for different sample units, then this can introduce large biases in estimates of total bycatch if the sample units are not randomly sampled. The point to be remembered here is that random sampling protects against biases that are due to unknown factors affecting bycatch rates. The effects of known factors can be taken into account by stratified sampling.

3. Estimates of total bycatch

The table in Appendix 2 summarises the observer coverage rates and the estimated bycatch of fur seal for the fishing years 1990/91 to 1995/96. This bycatch occurs throughout many parts of the EEZ, which is conveniently stratified in terms of the official Fisheries Management Areas (FMA) as shown in Fig. 1. In terms of the FMA, bycatch has been substantial at certain times with trawlers targeting barracouta, hoki, jack mackerel and squid in CEE, CHA, SEC and SOU, off the west coast and south coasts of the South Island, and with trawlers targeting southern blue whiting and squid in SUB to the south of the South Island. Most animals caught by trawlers are killed (93.5% of the cases in the database considered here). Fur seal bycatch also occurs in the southern tuna longline fishery but in that case most animals are released alive.

The Appendix 2 table shows the total number of tows, the number of tows with an official observer, the estimated bycatch of fur seals, with its estimated standard error, for the areas CEE, CEW, CHA, SEC, SOE, SOU and SUB, for various target species, for fishing years 1990/91 to 1995/96. No fur seal bycatch has been reported in the northern areas of KER, AKE and AKW, no doubt because rookeries and haul out sites are only found around the South Island, on the adjacent offshore islands, and on the islands further south. These two areas are therefore not included in the table.

The procedures used to construct the Appendix 2 table must be described in some detail because the estimates of bycatch are partly a function of these procedures. First, consider the data on the bycatch recorded by official observers. These were provided by the Ministry of Fisheries in the form of several files. One file from the obs_lfs database (Sanders & Mackay 1999) had one record for each tow observed on vessels from 26 February 1990 to 30 September 1996. There were 43 999 such records altogether. Another file contained a record of the number of fur seals captured for those tows where this took place. However, this file did not start until 19 June 1991. Thus for estimating bycatch rates, observer data were available for part of the 1990/91 fishing year and all of the 1991/92 to 1995/96 fishing years. Two other files supplied by the Ministry of Fisheries contained information on vessel size and nationality.

Apart from the loss of data due to not having bycatch numbers for the first part of the 1990/91 fishing year, 18 records were removed because of absence of key information such as the location of the tow, the weight of fish caught being recorded as zero or missing. None of these 18 records involved bycatch of any type. A small number of other records were also modified. For example, if a series of tows were made by a vessel and some of the starting latitudes or longitudes were missing then these were replaced by the ending latitudes or longitudes of the previous tow, providing that subsequent tows were also in approximately the same location. Only a very small fraction of the total records were modified in this way, the vast majority appearing to contain satisfactory data. This initial 'grooming' of the data resulted in a file with information on 36 011 tows, including the date, FMA, target fish species, and any fur seal bycatch.

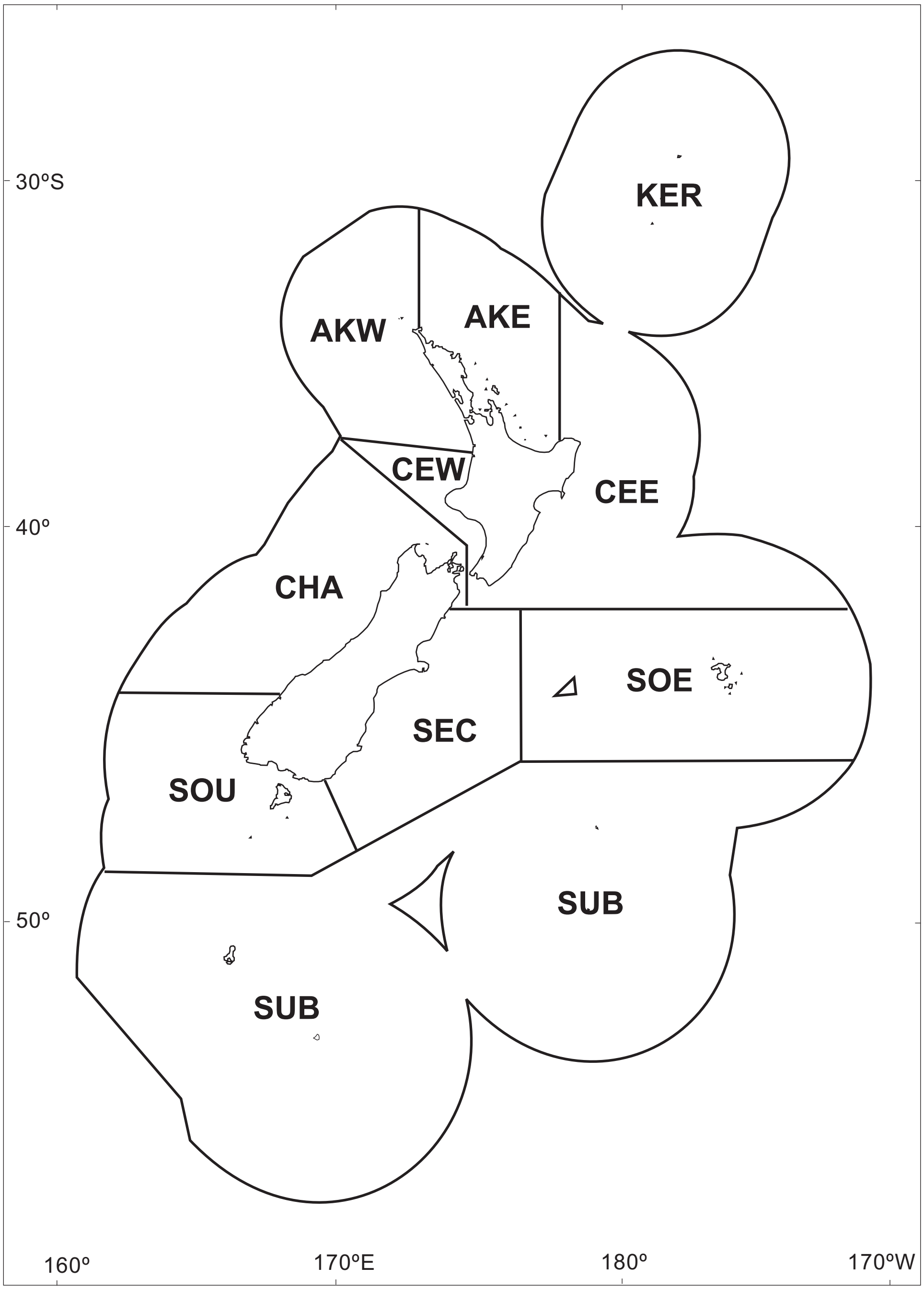

Figure 1. Fisheries Management Areas (FMAs) in the New Zealand Exclusive Economic Zone (EEC). The FMAs are: KER (Kermadec), AKE (Auckland East), AKW (Auckland West), CEE (Central East), CEW (Central West), CHA (Challenger), SEC (Southeast Coast), SOE (Southeast), SOU (Southland), and SUB (Sub-Antarctic).

The other component involved in the estimation of the total bycatch for the entire fishing fleet is the information on the total number of tows carried out in each fishing year, in each FMA, with each target species. For this purpose it was decided to use effort information from the Ministry of Fisheries' commercial Trawl Catch Effort Processing Return (TCEPR) database. The possibility of using effort information from the Ministry's Catch Effort Landing Returns (CELR) database was also considered. However, this database is only used for smaller vessels that do not usually have observers on board (C. Sutton, pers. comm.), and for which fur seal bycatch does not seem to occur.

The TCEPR database provided 4903 records of the effort, in terms of tows, applied during the fishing years 1990/91 to 1995/96, classified by Fisheries

Statistical Areas (FSA) and the target species. Of these, 3029 were used in constructing Table 4, the rest being omitted because of missing information on the statistical area (212 records), because the statistical area was outside the EEZ (22 records), or because no bycatch was observed with the target fish species concerned (1640 records).

A complication with using the effort information from the TCEPR database is that the FSA, of which there are 120, are sometimes in more than one FMA, of which there are 10. To overcome this problem, the tows recorded in FSA that included more than one FMA were allocated to the different FMA concerned in proportion to the geographical areas involved. For example, one-third of the tows in a FSA were allocated to a particular FMA if this FMA covered one-third of the Statistical Area.

Estimates are provided for all species that are the recorded target for at least one tow in which bycatch occurred for the available data. The 'other' category are those species which fit this category but were only very occasionally the target over the full 5-year fishing period being considered.

In looking through Appendix 2 it will be found that there are a number of occasions where the total number of tows and the observed number of tows is the same. For example, this occurs in 1990/91 when SCI was the target species in the area SEC. In all cases this is because the number of tows obtained from the TCEPR database was lower than the number recorded in the observer database. In all except one instance there was no bycatch when this occurred so that the estimated total bycatch is not affected. The one instance where there is bycatch is for SBW targeted in SOU in 1992/93. Here the observer database claims that there were 22 tows resulting in the capture of 11 fur seals. However the TCEPR database only records one tow taking place under these conditions.

There are a number of reasons why there can be a discrepancy like this between the observer database and the effort database: (a) some records could not be used from the TCEPR database because of missing information, (b) the target species may not be recorded the same in both databases, (c) there may be some errors in recording either the SMA or the FMA, and (d) some errors are introduced when the tows in a SMA are allocated to FMA in proportion to areas. For the purpose of constructing the table the total number of tows has been set equal to the observed number when this is greater than what is obtained from the TCEPR database.

The estimated bycatch rates per 1000 tows shown in the table are the number of fur seals captured in observed tows, divided by the number of observed tows, and multiplied by 1000. This is the 'strike rate' of equation 4 multiplied by 1000. The estimated total bycatch is the 'strike rate' multiplied by the total number of tows for the particular fishing year, FMA and target species concerned, following equation 5.

For calculating the standard errors shown in the table it was necessary to decide on a suitable sample unit. Initially individual tows were considered. It was, however, apparent that there were sometimes a series of tows on one vessel in which fur seal bycatch was common. Taking the sample unit as the tows in one day or one week on the same target species in the same FMA with the same gear (mid-water or bottom) did not seem to entirely remove this problem so that it was eventually decided to make the sample units as large as possible. Each unit was therefore chosen to be a series of tows carried out on one vessel, with the same target species, in the same FMA, with the same gear. A sample unit therefore terminated when a vessel changed the target species, moved to a new FMA, or changed the gear type. This definition resulted in 2824 sample units altogether. A Microsoft Excel spreadsheet holds the data for these units[1].

Equation 7 was used for calculating the individual standard errors shown in the table for the different combinations of fishing year, target species, and FMA.

Situations where the estimated bycatch exceeds 100 animals are highlighted in Appendix 2. There is some variation from year to year but these high estimates occur at different times with barracouta in CHA, hoki in CHA, SEC and SOU, jack mackerel in CHA and SEC, southern blue whiting in SUB, and squid in SOU.

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[1] The data on bycatch used in this study are held by the Department of Conservation in the file FURSEAL.XLS. This is a Microsoft Excel file containing the data on fur seal bycatch that was used to produce the estimates of total bycatch shown in Table 3.1, and analysed for studying the factors and variables related to bycatch as described in Section 4. Each row in this table relates to one sample unit which comprises a series of consecutive tows by one vessel in one FMA, targeting one fish, with the same gear. There are 2824 such rows in the table. In the interests of confidentiality, the information in this 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/furseal.xls

4. Factors affecting bycatch rates

Our analysis of factors affecting the bycatch rates of fur seals is based on the 2824 sample units referred to in Section 3, as derived from observer reports. Thus each sample unit comprises a series of tows on one vessel in one FMA, with the same target species of fish, and the same gear type (bottom or midwater). As explained in Section 3, this unit was chosen because the use of smaller units such as individual tows, the tows by one vessel in one day, or the tows by one vessel in one week could be seen in some cases to lead to a succession of units with fur seal bycatch for one vessel, indicating some correlation between the results for different units.

Two dependent variables were analysed. The first was the presence or absence of any bycatch with a sample unit. The second was the total number of fur seals caught in the tows comprising a sample unit. The variables that were examined as being potentially related to these dependent variables were:

Tows: the number of tows for the sample unit;

VSize: an index of the size of the vessel, derived from a principal components analysis, as explained below;

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;

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 order of the number of tows made as (1) hoki, (2) orange roughy, (3) squid, (4) scampi, (5) jack mackerel, (6) southern blue whiting, (7) barracouta, (8) hake and (9) blue mackerel, frostfish, ling, southern kingfish, silver warehou and blue warehou;

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

FMA: the fisheries management area (Fig. 1) coded as (1) for CEE, (2) for CEW, (3) for CHA, (4) for SEC, (5) for SOE, (6) for SOU, and (7) for SUB;

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.

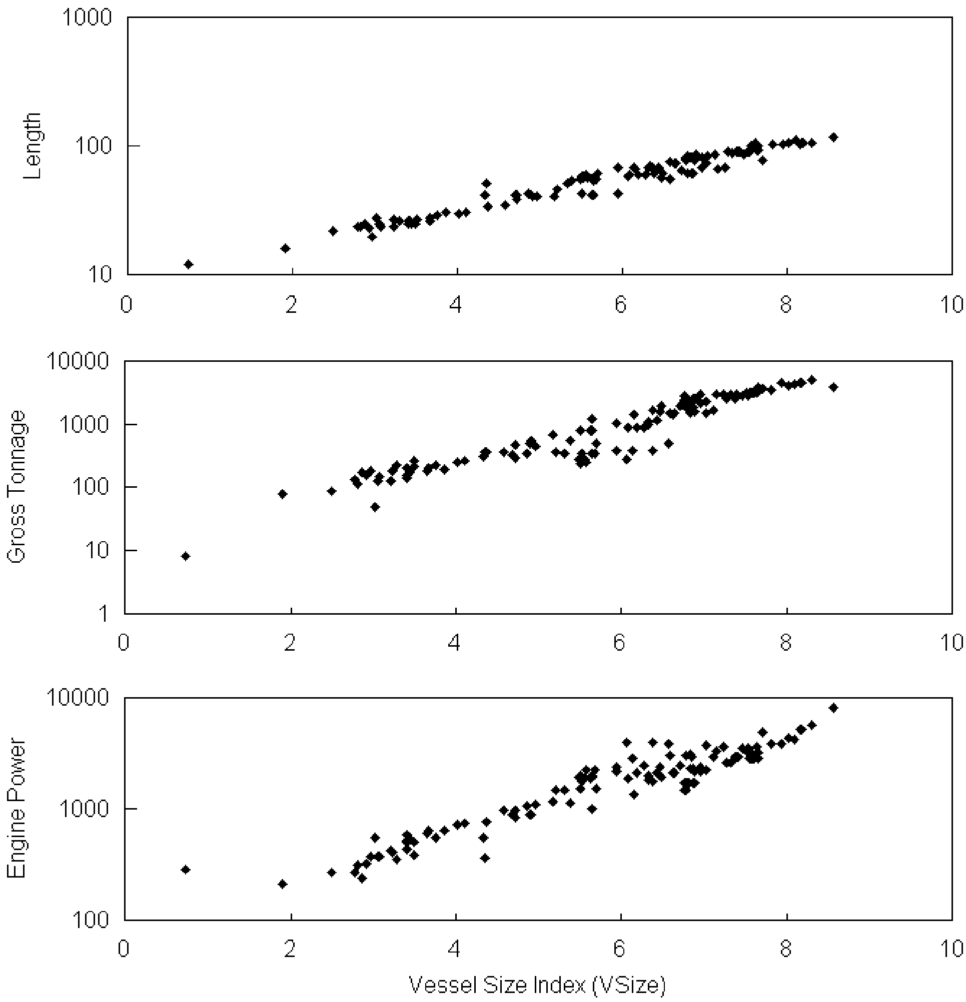
The vessel size index was developed using the three variables that were available for each of 166 vessels. These variables were the overall length in metres (Length), the gross tonnage (Tonnes), and the engine power in kilowatts (Power). Taking logarithms resulted in an approximately linear relationship between the variables. A principal components analysis on the logarithms (Manly 1994, Chapter 6) gave a first component that accounted for 89% of the variation in the data. The values of this principal component were taken as the size index, with 6 added to ensure that all values are positive.

In terms of the original variables measured on vessels, the size index is

$$\text{VSize} = 6 + 0.573[\log(\text{Length}) - 1.77]/0.22 + 0.568[\log(\text{Tonnes}) - 2.98]/0.54 + 0.590[\log(\text{Power}) - 3.21]/0.35 \quad (8)$$

Figure 2 shows the relationship between the length, gross tonnage and the engine power of vessels and the size index.

Figure 2. Relationship between the length (m), gross tonnage and engine power (kilowatts) of vessels and the developed size index Vsize.



The nationality codes were developed for the full observer database, including the two Auckland FMAs where there was no bycatch. In fact codes 4 and 5 for Denmark and Faroe do not occur for the other FMAs where there was bycatch.

An initial idea of the relationship between bycatch and the other variables described above can be obtained by plotting the total bycatch and the bycatch per tow against the other variables. These plots are shown in Fig. 3. Horizontal scale values are not provided on these plots in order to keep them as simple as possible. With the coded variables such as nationality the results are plotted from code 1 on the left to the last code on the right. With continuous variables such as VSize low values are on the left and high values on the right.

From Fig. 3 it can be seen that high total bycatch is associated with larger vessels, the 6th and 12th nationalities (Japan and Ukraine), the later years (1992/93 to 1995/96), the 4th season (Spring), the 1st and 6th target species (hoki and southern blue whiting), the 1st gear type (midwater), the 3rd and 7th FMA (CHA and SUB), longer fishing times, and higher catches of fish. On the other hand, high bycatch per tow is associated with units with a small number of tows, larger vessel sizes, the 6th, 11th and 12th nationalities (Japan, Russia and Ukraine), the last fishing year (1995/96), the 4th season (Spring), the 7th and 8th target species (barracouta and hake), the 1st type of gear (midwater), the 3rd FMA (CHA), moderate durations of fishing, and low total amounts of fish caught.

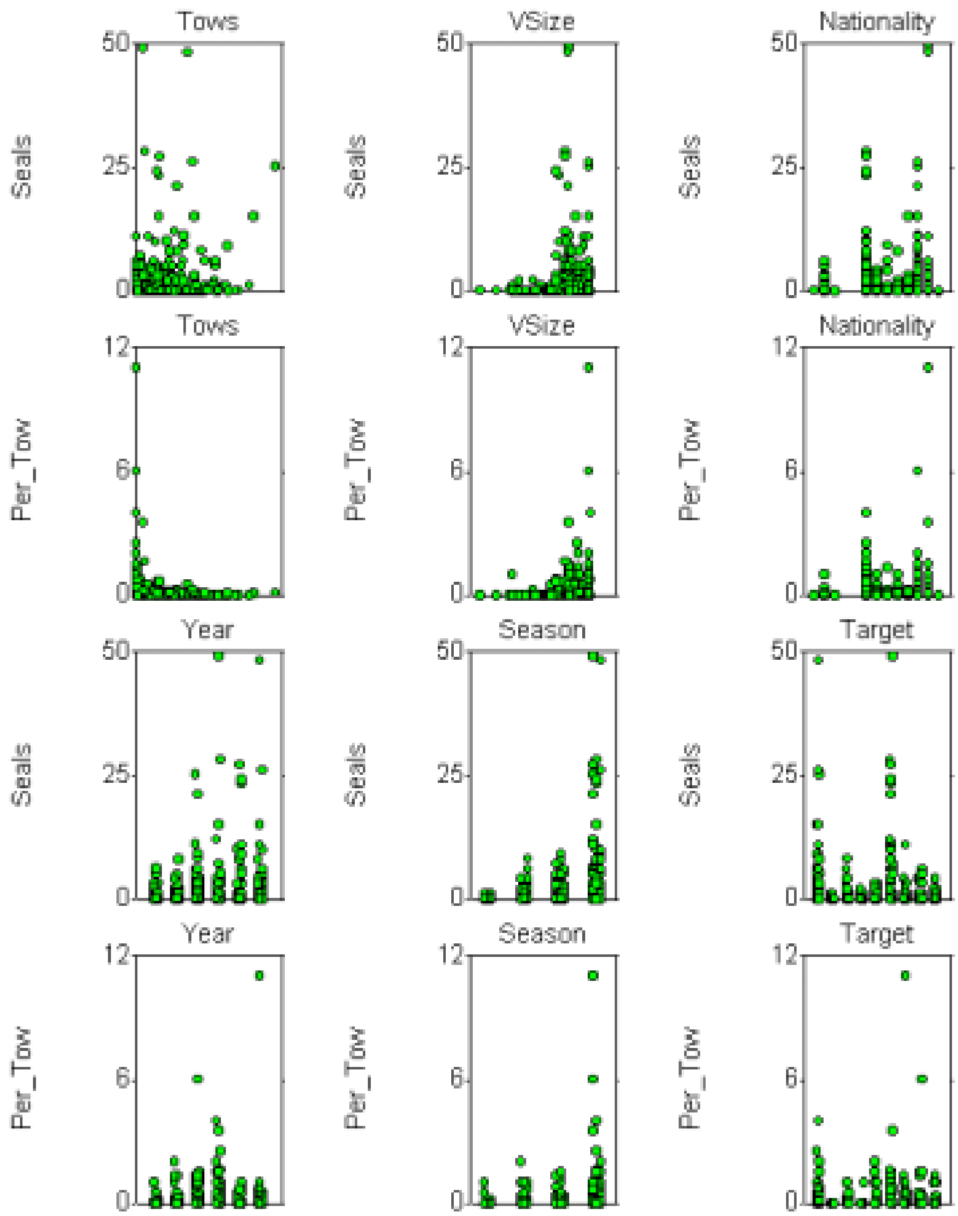
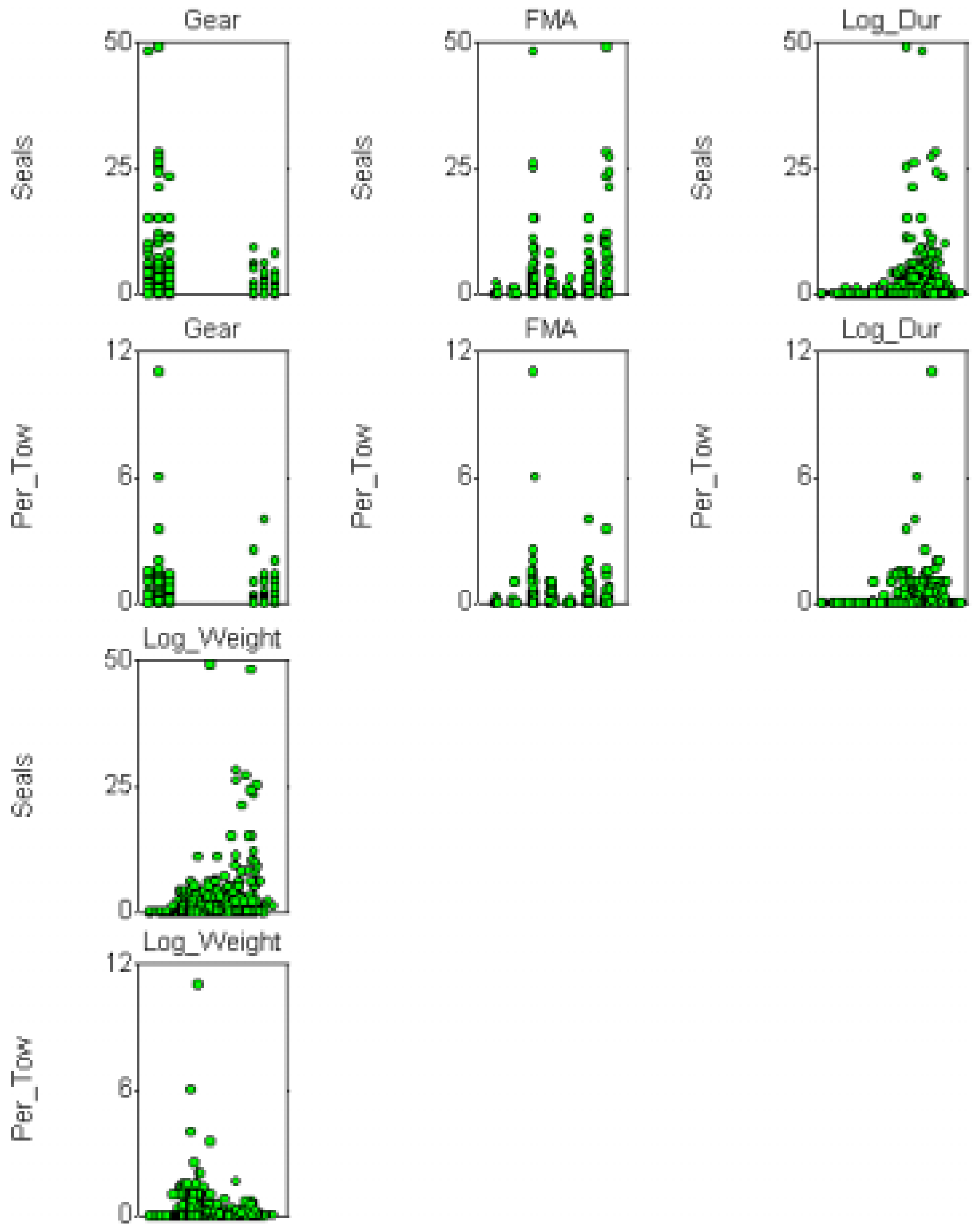


Figure 3. Plots of the total bycatch (Seals) and the bycatch per tow (Per_Tow) observed in sample units against the number of tows, the vessel size index, the nationality code, the fishing year code, the season code, the target species code, the gear type, the FMA code, the logarithm of the total duration of fishing, and the logarithm of the total green weight of fish caught. The positions of points have been jittered slightly to avoid too many points plotting in the same place.

Figure 3. *continued*



Generalised linear models were fitted to the data using GLIM (McCullagh & Nelder 1989; Francis et al. 1993). The model for the probability of bycatch was developed by assuming that the probability of no bycatch for a single tow takes the form

$$p = \exp\{-\exp(\Sigma\beta_i X_i)\}$$

where the expression $\Sigma\beta_i X_i$ represents a linear combination of X variables that account for differences related to the area, time of fishing, vessel size, etc., with β coefficients to be estimated. Assuming that this is correct, and that results from successive tows are independent, the probability of no bycatch with the number of tows equal to Tows is $p^{Tows} = \exp\{-\exp(\Sigma\beta_i X_i)Tows\}$, so that the probability of bycatch is

$$P(\text{Bycatch}) = 1 - \exp\{-\text{Tows} \times \exp(\Sigma\beta_i X_i)\}$$

$$= 1 - \exp[-\exp\{\log(\text{Tows}) + \Sigma\beta_i X_i\}] \quad (9)$$

This model can be fitted in GLIM assuming a binomial distribution for errors with one trial per sample unit, a complementary log-log link, and log(Tow) as an offset.

The variables used to account for the probability of bycatch were those listed above, except that Log_Dur and Log_Weight were calculated on a per tow basis, i.e. were the logarithm of the mean duration of fishing per tow and the logarithm of the mean green weight of fish caught per tow.

The results of fitting the model described by equation 9 to the data are summarised in Table 3 as an analysis of deviance (McCullagh & Nelder 1989, p. 35). It is seen that the probability of bycatch seems to be related to all of the factors and variables considered except VSize and Gear. As bycatch numbers clearly vary with VSize and Gear (Fig. 3), the appropriate interpretation of this result is that these variables do not seem to be important predictors after allowing for the other variables in the model.

TABLE 3. ANALYSIS OF DEVIANCE FROM FITTING THE MODEL OF EQUATION 9 TO DATA ON 2824 SAMPLE UNITS.

			CHANGE BY ADDING EXTRA TERM	
MODEL	DEVIANCE[1]	DEGREES OF FREEDOM	DEVIANCE[2]	DEGREES OF FREEDOM
Constant	1684.4	2823		
+ FMA	1510.9	2817	173.6***	6
+ Target	1446.6	2809	63.3***	8
+ Year	1398.0	2804	48.58***	5
+ Season	1358.5	2801	39.47***	3
+ Nation	1301.5	2791	57.0***	10
+ Log_Weight	1274.0	2790	27.5***	1
+ VSize	1273.2	2789	0.8	1
+ Log_Dur	1269.2	2788	4.0*	1
+ Gear	1268.3	2787	0.9	1

[1]Deviances for fitted models cannot be used to assess goodness of fit because observations are for the presence and absence of bycatch only.

[2]Changes in deviance can be tested against the chi-squared distribution to see whether the added variable significantly improves the fit (McCullagh & Nelder 1989, p. 119).

Significance levels: * (5% level) or *** (0.1% level).

Residual plots were examined to assess the adequacy of the model (McCullagh & Nelder 1989, p. 398). It appears from these plots that the model is quite satisfactory, although there are difficulties in interpreting such plots for presence and absence data unless there is some grouping of results. One grouping approach is illustrated in Fig. 4. This figure shows that the probabilities predicted by the model give about the correct number of sample units with bycatch, when the units are grouped in order of probabilities of bycatch. To obtain this plot, the 2824 sample units were ordered in terms of the estimated probability of bycatch from those with a zero probability to those with a probability of bycatch close to unity. The units were then grouped starting from the bottom of the list so that the expected bycatch was at least 5 in

Figure 4. Residual plot from the model of equation 9 for the probability of bycatch occurring, with a grouping of results according to the magnitude of the probability. See the main text for a description of how this plot was constructed.

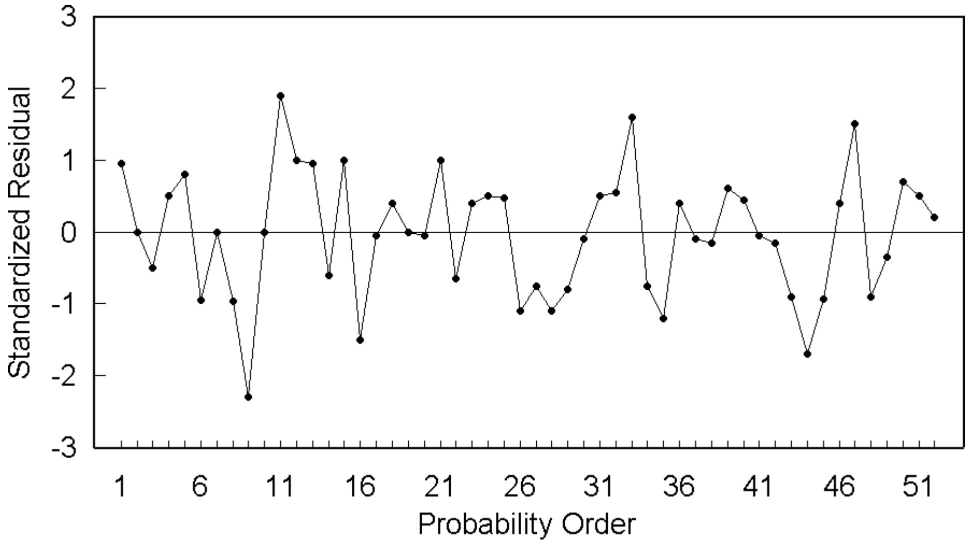


Figure 5. Standardised, studentised deviance residuals for log-linear models fitted to counts of the fur seals caught in sample units without weighting of the data (DevRes1) and with weighting of the data with a different weight for each season (DevRes2). The positions of points have been jittered slightly to avoid too many points plotting in the same place.

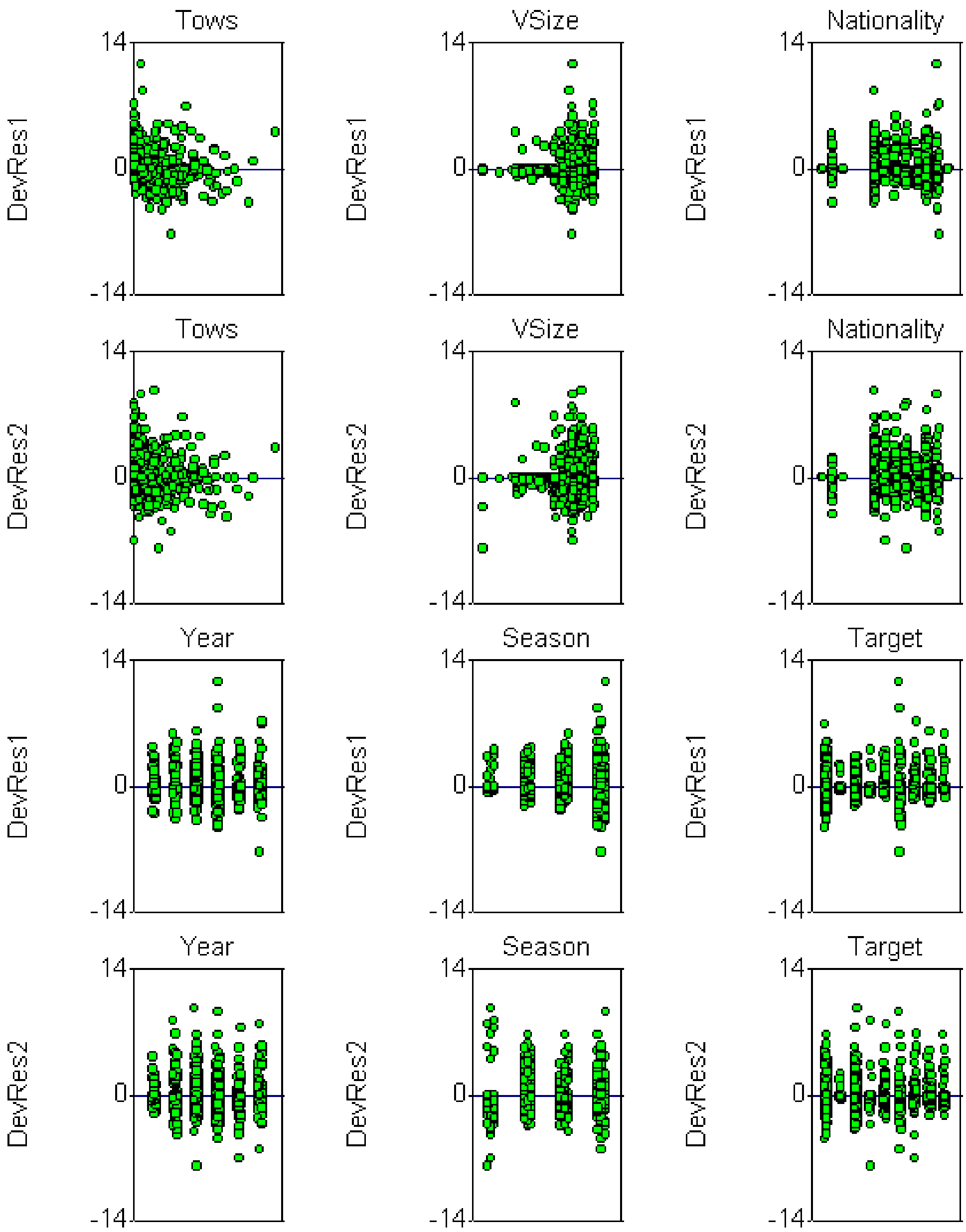
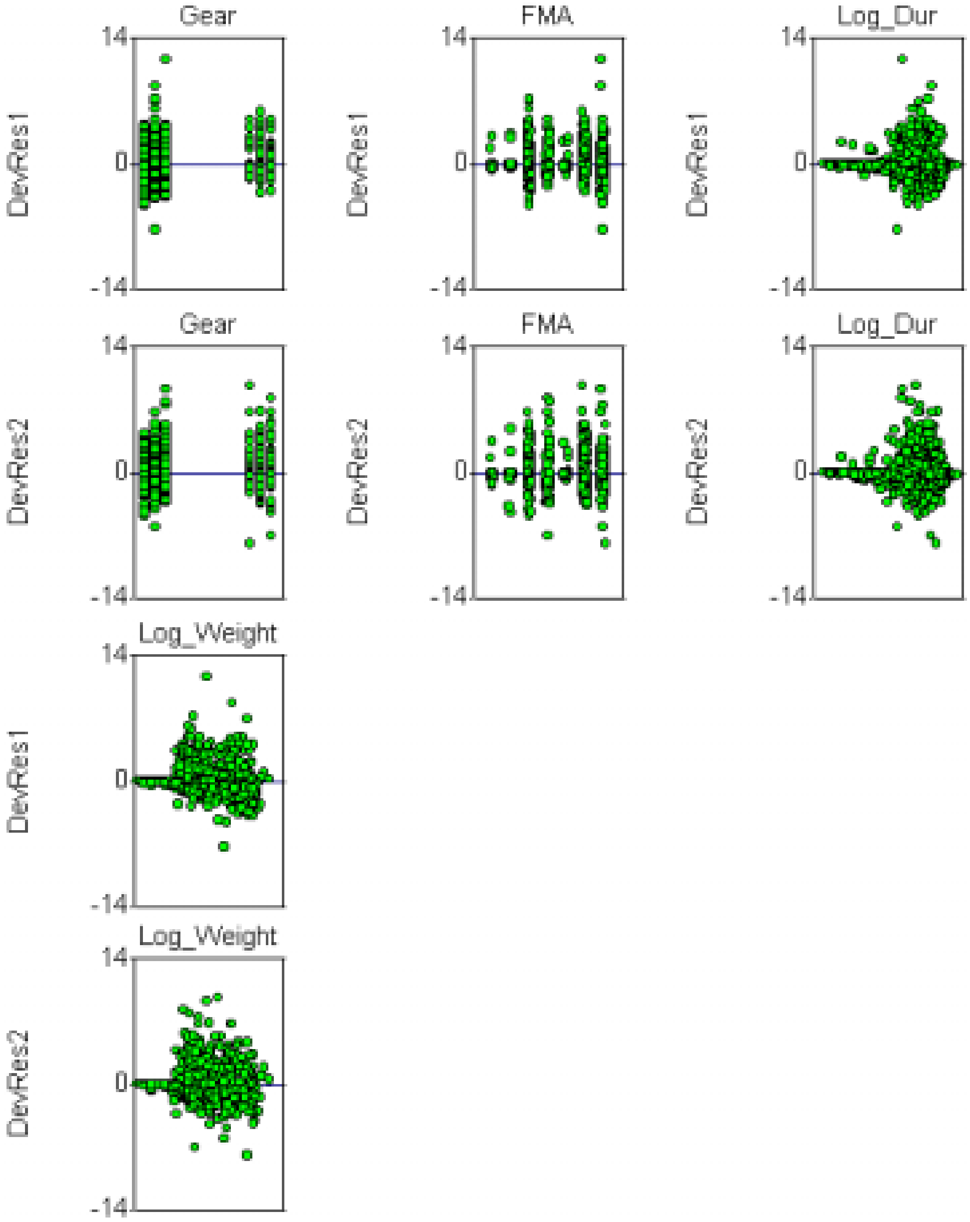


Figure 5. *continued*



each group. This resulted in 52 groups. For each group the difference between the observed (O) and expected (E) number of units with bycatch was used to compute a standardised residual R = (O – E)/SD, where SD is the binomial standard deviation $\sqrt{[np(1 - p)]}$, where p is the expected proportion of units with bycatch, and n is the number of sample units. These standardised residuals are plotted. The plot shows that the fitted model gives about the correct proportion of sample units with bycatch both when the probability is low (left half of plot) or high (right half of plot). All except one of the residuals is within the range –2 to +2, showing a good fit of the model for all levels of the bycatch probability.

Following the fitting of the model for the probability of bycatch, a log-linear model was fitted for the total number of fur seals caught for a sample unit. Thus it was assumed that the count of fur seals follows a Poisson distribution with a mean given by

$$\mu = (\text{Tows})\exp(\sum \beta_i X_i) \quad (10)$$

where $\sum\beta_i X_i$ is a linear combination of effects for the factors and variables such as the FMA, season, duration of fishing, etc., and Tows is the number of tows made for the sample unit. GLIM was again used to fit the model. The number of tows was allowed for by including log(Tows) as an offset in the model.

After fitting this model to the full set of data with all possible effects, it was found that the deviations from the model showed a distinctive pattern associated in particular with the seasons of the year. This is shown by the residual plots in Fig. 5, where DevRes1 denotes the standardised, studentised deviance residuals for the model. These are the type of residuals that are recommended for model checking by McCullagh & Nelder (1989). There is clearly a problem due to the spread of residuals being small for season 1, moderate for seasons 2 and 3, and high for season 4.

To overcome this problem, log-linear models were fitted separately for each of the four seasons. The reciprocals of the mean deviances obtained were then used to weight the observations, with a different weight for each season, and models were again fitted to the full set of data. The residuals denoted by DevRes2 in Fig. 5 were obtained for the model in which all possible effects were included, with different estimates for each of the seasons. These residuals no longer display obvious seasonal differences.

Although the different weighting of results for different seasons is not altogether satisfactory, it does seem to be necessary to produce a reasonable account of the data. It certainly seems to be true that in comparison with what is expected from Poisson variation the results for season 1 show remarkably little variation, the results for seasons 2 and 3 show rather low variation, and the results for season 4 show high variation. This is seen from the fact that the mean deviation from Poisson variation is expected to be about 1. However, from fitting the data separately for each season the mean deviances are found to be

TABLE 4. ANALYSIS OF DEVIANCE FOR THE MODEL OF EQUATION 10 FOR THE NUMBER OF FUR SEALS CAUGHT FROM THE ANALYSIS WITH DATA WEIGHTED DIFFERENTLY FOR EACH SEASON.

MODEL	DEVIANCE	DEGREES OF FREEDOM	CHANGE BY ADDING THE EXTRA TERM: DEVIANCE[1]	DEGREES OF FREEDOM
Constant	6453.5	2823		
+ FMA	5426.3	2817	1027.2***	6
+ Target	4535.1	2809	891.3***	8
+ Year	4337.1	2804	197.9***	5
+ Season	3809.6	2801	527.5***	3
+ Nation	3658.3	2791	151.3***	10
+ Log_Weight	3625.4	2790	32.9***	1
+ VSize	3584.8	2789	40.6***	1
+ Log_Dur	3578.1	2788	6.7**	1
+ Gear	3577.8	2787	0.3	1
All interactions with Season[2]	2700.0	2700	877.8***	87

[1]Because of the weighting used with the data, the mean deviance for the full model (the deviance divided by the degrees of freedom) is exactly 1. Approximate tests for the significance of the terms added to the model therefore involve comparing the changes in deviance with the chi-squared distribution: Significance levels: ** (1% level) or *** (0.1% level).

[2]The final term added to the model allows the effects of all the factors to vary with the season.

0.067, 0.328, 0.655 and 1.584 for seasons 1 to 4, respectively. We note that fitting log-linear models to data for which the mean deviance differs substantially from 1 can be justified by the theory of quasi-likelihood (McCullagh & Nelder 1989, Chapter 9).

Table 4 shows the analysis of deviance for the model fitted with weighted data. All effects are highly significant except for the gear type. However, when the results are considered separately for each season, the gear type effect is significant at about the 5% level for season 1 and at about the 0.1% level for season 3. It is therefore not appropriate to remove it from the model altogether.

The fitted model of equation 9 has 35 parameters (excluding the effects for VSize and Gear, which are not significant). Many of these parameters are not estimated very accurately. The fitted model of equation 10 has 124 parameters, with very poor accuracy in many cases. For this reason the implications of the models are best considered in terms of their outputs for the distribution of bycatch.

Figure 6. Estimated values for the probability of bycatch on a single tow (P_Tow), and the average number of fur seals caught per two (Count_Tow), plotted against the levels of the other factors and variables. The positions of points have been jittered slightly to avoid too many points plotting in the same place.

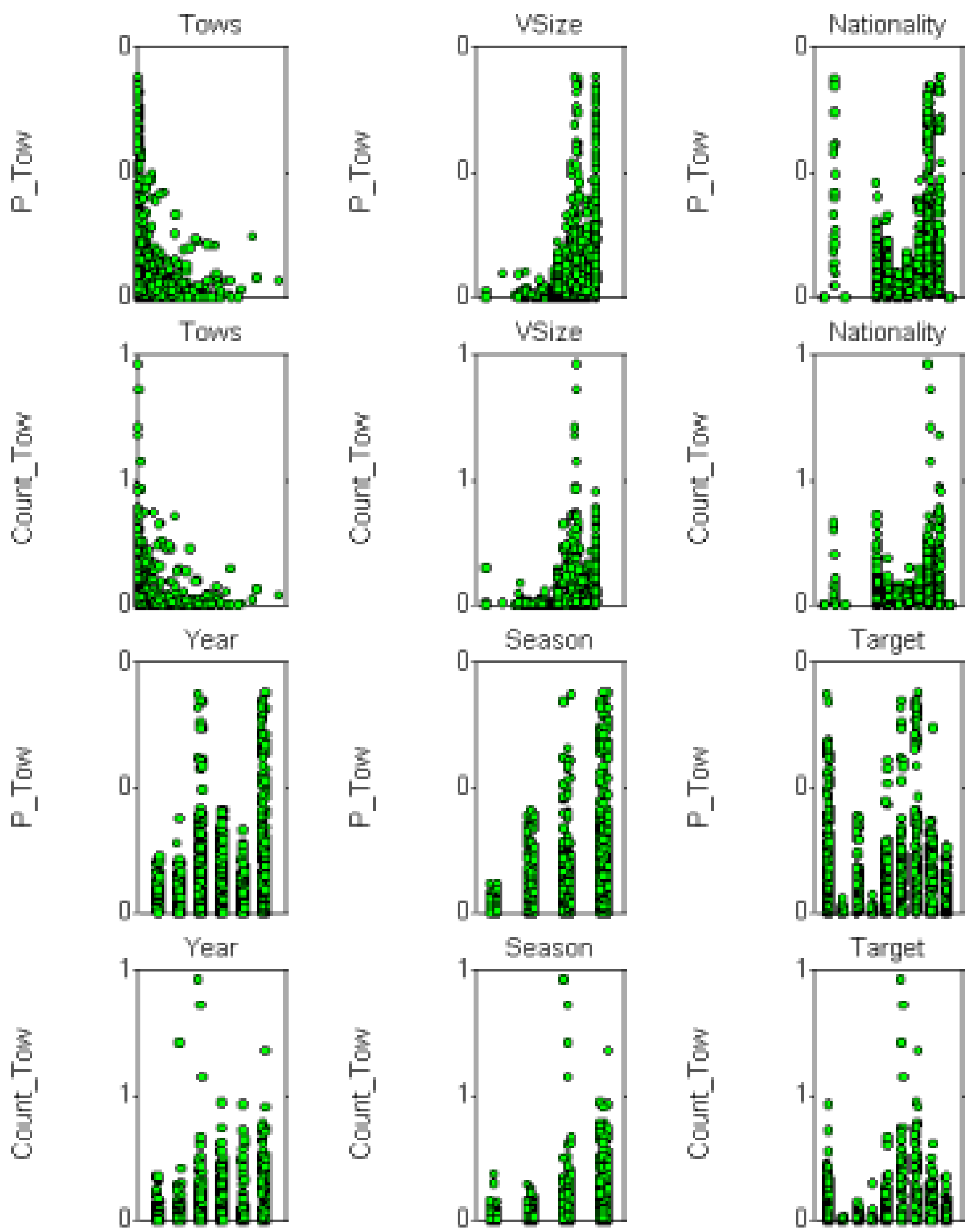
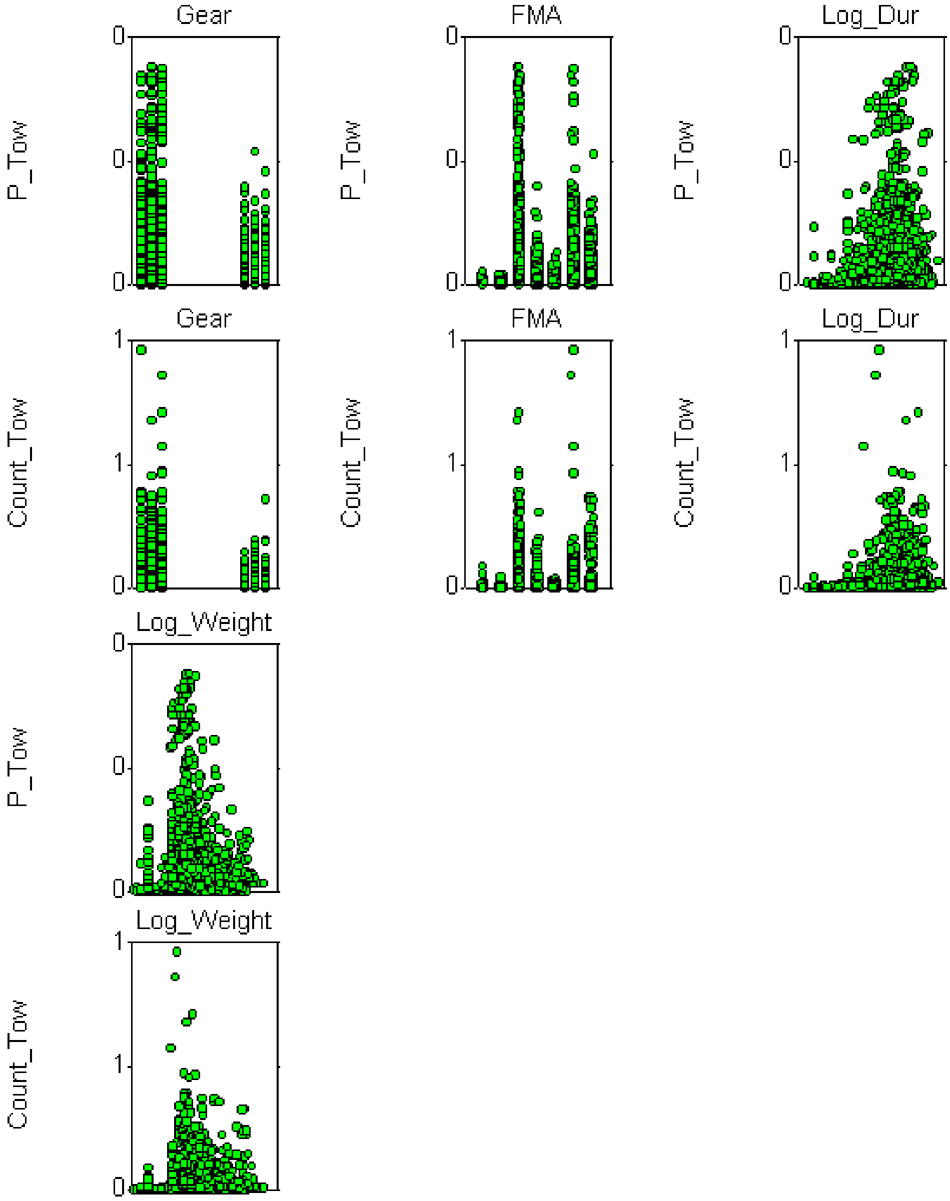


Figure 6. *continued*



This can be done for equation 9 by plotting the estimated probabilities of obtaining bycatch on a single tow against the levels for the different factors and variables, for each of the sample units. These estimates are obtained from equation 9 by setting Tow = 1 and replacing the unknown β values by their estimates. For equation 10 estimating the mean with Tow = 1 gives an estimate of the bycatch of fur seals per tow, which can again be plotted against the levels for variables and factors.

Figure 6 shows the plots of estimated values for the probability of bycatch on a single tow (P_Tow) and the estimated bycatch per tow (Count_Tow). It can be seen that the highest values for P_Tow tend to occur with a small number of tows in the sample unit, larger vessels, nationalities 2, 11 and 12 (China, Russia and the Ukraine), in years 3 and 6 (1992/93 and 1995/96), seasons 3 and 4 (winter and spring), with target species 1, 6 and 7 (hoki, southern blue whiting and barracouta), gear type 1 (midwater), FMAs 3 and 6 (CHA and SOU), moderately large values for log(Dur), and values for log(Weight) that are slightly lower than the mean. Generally, a similar pattern is found for Count_Tow. The

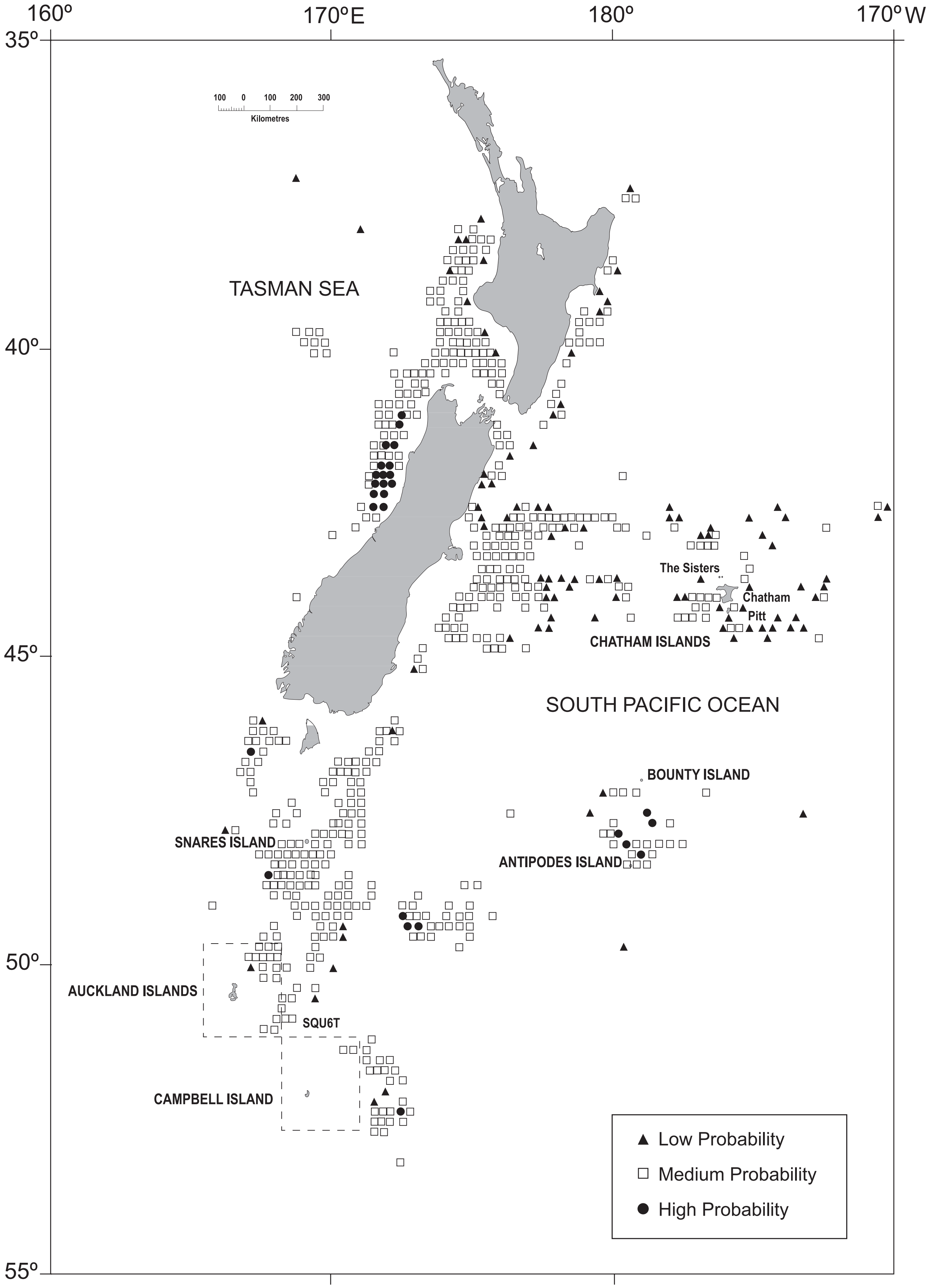


Figure 7. Locations of observed sample units for fur seals at the time of the first tow. Low, medium and high bycatch rates are defined in the text.

highest values are found with sample units with a small number of tows, vessels that are moderately large, of nationality 11 (Russia), in year 3 (1992/93), in seasons 3 and 4 (winter and spring), with target species 6 (southern blue whiting), gear type 1 (midwater), in FMAs 3 and 6 (CHA and SOU), with average or slightly higher values for log(Dur), and values for log(Weight) that are slightly lower than the mean.

Finally, Fig. 7 shows the positions of vessels at the time of the first tow in a sample unit, with an indication of whether the estimated bycatch rate for the sample unit was high, medium or low. High estimated bycatch was defined for this purpose as an estimated probability of bycatch on a single tow of 0.1 or more, an estimated mean bycatch per tow of 0.5 or more, or both of these conditions. Low estimated bycatch was defined as both the estimated bycatch per tow and the estimated mean bycatch per to both being less than 0.001. Medium estimated bycatch was defined as anything other than high or low. High estimated bycatch rates occur on the west coast of the South Island, east of Antipodes Island, and in four other locations to the south of New Zealand.

5. Assessment of the observer coverage required in the future

In developing guidelines for levels of observer coverage required in future seasons, we have chosen the coefficient of variation (CV, the standard error/ divided by estimate expressed as a percentage) 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 is 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 overall CV as the standard deviation of the relative errors.

Figure 8 shows the CVs that are expected with this definition, for various levels of observed cover. Ratio estimation is used, with equation 5, with the sample units being defined as in the analyses in Sections 3 and 4 of this report, i.e. a series of 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 2824 sample units that were used for the analyses in Sections 3 and 4 from observed tows 1990/91 to 1995/96 were used to represent a source population for future data.

b. Units are selected at random from the source population until the accumulated number of tows exceeds N – 26. 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 200. The set of selected units provides a simulated fishery, with total bycatch B.

c. Each unit in the simulated fishery is given a probability P/100 of being observed.

d. Equation 5 is used to obtain the estimate E of the total bycatch for all selected units, using the information from the observed units.

e. The percentage relative error in the estimate is calculated as RE = 100(E – B)/B.

f. Steps b to e are repeated 1000 times, and the standard deviation of RE is the estimated CV.

Where stratification is desirable, the results shown in Fig. 8 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:

$$CV = 100\sqrt{[\sum (CV_i)^2 T_i^2]}/T \qquad (11)$$

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 8 shows that to obtain a CV of 20%, which is a reasonable general level of precision, requires 90% observer cover for a fishery with 1000 tows, 70% cover with 5000 tows, 50% cover with 10 000 tows, 40% cover with 20 000 tows, and 20% cover with 50 000 tows. There were about 50 000 tows in each of the fishing years 1991/92 to 1995/96 that were used to estimate the total bycatch of fur seals in New Zealand waters, and about 27 000 in 1990/91 (Table 1).

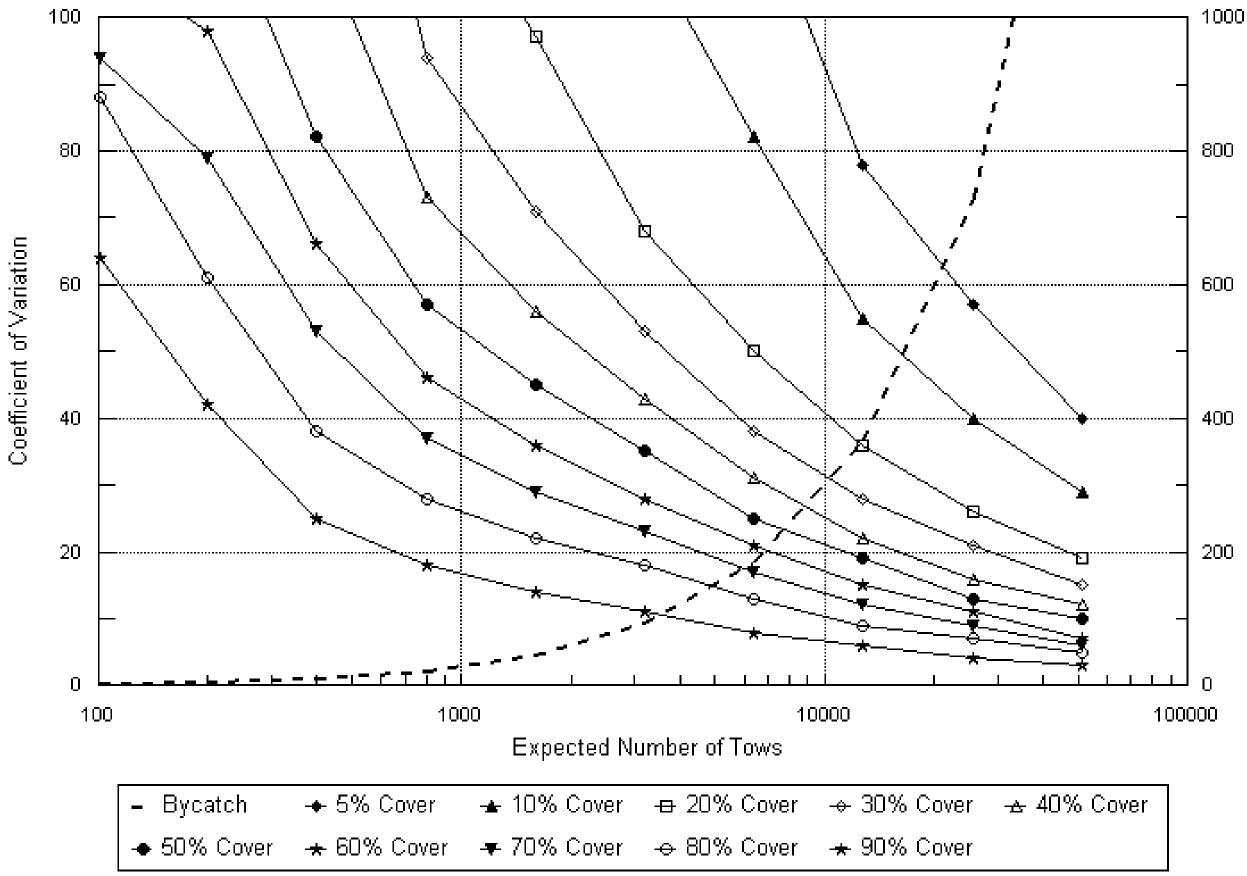


Figure 8. Coefficients of variation for estimates of the total bycatch as a function of the expected total number of tows and the level of observer cover, assuming that future bycatch levels are similar to those for fishing years 1990/91 to 1995/96. The expected bycatch is based on the overall rate observed for these fishing years, which is 0.029 fur seals per tow.

6. Summary

- Ratio estimation is recommended for the estimation of the total fur seal bycatch based on observed tows. Estimators are biased with small samples, but the bias is small compared to the standard error of estimators and is therefore not of much importance. However, estimated standard errors may tend to be too low with low levels of observer cover.
- The estimated total bycatch numbers for different fishing years, with the coefficient of variation in parentheses are: 1990/91, 401 (29%); 1991/92, 584 (27%); 1992/93, 1091 (13%); 1993/94, 1157 (18%); 1994/95, 1073 (17%); and 1995/96, 2110 (19%).
- The probability of bycatch occurring on a tow varies significantly with the Fisheries Management Area (FMA), the target fish species, the fishing year, the season, the nationality of the vessel, the average green weight of fish caught per tow, and the duration of fishing. Having allowed for the effects of these variables, there is no significant relationship between the probability of bycatch and the vessel size and the fishing gear, although a relationship is apparent for these two variables if the effects of other variables are ignored.
- The number of fur seals caught varies significantly with the FMA, the target fishery, the fishing year, the season, the nationality of the vessel, the average green weight of fish caught per tow, the vessel size, the duration of fishing, and the type of gear used.
- A simulation based on the 1990/91 to 1995/96 observer data suggests that to obtain a coefficient of variation (the standard error of a estimate divided by the true amount of bycatch, expressed as a percentage) of about 20%, requires about 90% observer cover with a fishery involving a total of 1000 tows, about 70% observer cover for a fishery of 5000 tows, about 50% observer cover for a fishery of 10000 tows, about 40% observer cover for a fishery of 20 000 tows, and about 20% observer cover for a fishery of 50 000 tows.

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Appendix 1

SIMULATION OF RATIO ESTIMATION OF TOTAL BYCATCH

To examine the properties of ratio estimation using equations 4 to 7 a small simulation experiment was carried out, using methods similar to those used by Doonan (1995) and Manly et al. (1997). The simulation was based on records for the number of trawls per vessel week for the first 10 weeks of the 1993/94 season of the Auckland Islands squid fishery. There were 302 vessel weeks, with a total of 4160 trawls in this period. The 302 vessel weeks are therefore the sample units for ratio estimation, rather that the vessel days that were used for the derivation of equations 4 to 7.

For the purpose of the simulation, if the observer cover was to be P% then each vessel week was given a probability of P/100 of being observed. Similarly if the expected total bycatch was to be E(T) then a sample unit with u trawls was assigned a bycatch which was chosen as a random variable with a Poisson distribution with mean (u/4160)E(T). Thus the total expected bycatch was allocated out to the sample units in proportion to the number of trawls for the unit.

Five levels of observer cover were considered (5%, 10%, 20%, 40% and 80%), for each of three levels for the expected total bycatch on the 302 sample units (30, 50 and 70). The output variables considered were

1. the mean and standard deviation of the estimation error (the estimated bycatch minus the true total bycatch);
2. the obtained percentage coefficient of variation

   CV = 100(Standard Deviation of Estimates/Overall Mean Bycatch);
3. the mean and standard deviation of the estimated standard error for the estimated total bycatch;
4. the mean and standard deviation of the statistic

   t = (Estimation Error)/(Estimated Standard Error);

   and
5. the number of zero estimates of bycatch obtained (which occurs with low observer cover when none of the observed sample units have bycatch).

The mean estimation error was considered because this represents the bias in estimation which is preferably small relative to the expected total bycatch. It is also desirable that the standard deviation of the estimation error should be small, and it is important that the estimated standard errors should be close to this. That is to say, the mean of the estimated standard error should preferably be close to the standard deviation of the estimation error, and the standard deviation of this estimated standard error should preferably be relatively small. The obtained coefficient of variation was considered because this is often used as a general measure of estimation accuracy. The t-statistic was considered because if this has a mean close to zero and a standard deviation close to one then limits of the form

Estimated Total Bycatch ± 1.96(Estimated Standard Error)

will contain the true total bycatch approximately 95% of the time. Finally, the number of zero estimates is important because these represent situations where bycatch probably occurs but is missed by the monitoring process.

The simulations were carried out using the @RISK add-on to Lotus 123 (Palisade Corporation 1995; Lotus Corporation 1996). For each of the five levels of observer cover and the three levels of expected bycatch 1000 replications of the simulation were performed.

Table A1 summarises the results from the simulations. Points to note are:

a. The bias in ratio estimation is generally relatively low, even with only 5% observer cover. The worse case is the mean estimation error of –2.0 with 5% observer cover and an expected bycatch of 50. Even here this bias is minor in comparison with the standard deviation of estimates of 32.4.

b. The number of zero estimates for total bycatch is rather high with 5% observer cover. Furthermore, with an expected total bycatch of 30 there were 51 zero estimates out of 1000 even with 10% cover.

c. For a given level of observer cover the coefficient of variation reduces as the expected total bycatch increases. Thus to obtain an acceptable level for the coefficient of variation is likely to require a high level of observer cover in fisheries where bycatch is rare.

d. The mean of estimated standard errors is lower than the observed standard deviation of estimation errors for 5% to 40% observer cover. However, with 20% or more cover the difference is quite small and the standard deviation of the estimated standard errors is also fairly small. It appears, therefore, that if observer cover is less than 20% then consideration should be given to the possibility that the estimated standard error for the estimated total bycatch may be misleadingly low.

e. The t-statistics have a negative mean for all situations except when the observer cover is 5% and the expected total bycatch is 30. This situation is also the one of only cases where the standard deviation of the t-statistic is less than one. No doubt this anomalous result is due to 23.7% of the estimates of total bycatch being zero, with a zero estimated standard error. The t-statistics for these zero estimates are treated as being undefined and therefore not included in the calculation of the mean and standard deviation. Thus the mean of 0.17 and the standard deviation of 0.75 are for the 76.3% of positive estimates only. The means and standard deviations for the other situations in the table are only reasonably close to zero and one, respectively with 80% observer cover when the expected total bycatch is 30 or 50, and when the observer cover is 40% or 80% when the expected total bycatch is 70. If nothing else, these results suggest that confidence limits for the total bycatch based on taking the estimated total bycatch plus and minus some multiple of the estimated standard deviation should be treated with some reservations with the observer cover levels in common use.

This simulation study was originally conducted to assess the properties of ratio estimation of the bycatch of sea lions in the squid fishery around the Auckland Islands. However, the results are also indicative of the properties of ratio estimation of the bycatch of fur seals in one fishing year, in one Fisheries

Management Area, for one target species of fish. The total number of tows under such circumstances varies from about 100 to 25 000 or more, while the bycatch varies from none to several hundred (Appendix 2). This is a much wider range of situations than is covered by Table A1, which is based on 4160 tows and has a maximum expected bycatch of 70 animals. However, in general it can be expected that estimation will improve as the total number of tows and/or the expected level of bycatch increases, when the level of observer cover is kept fixed. Therefore this study probably gives a reasonable indication of the performance of ratio estimation with fur seal bycatch.

TABLE A1. SUMMARY OF THE RESULTS OF A SIMULATION EXPERIMENT ON THE USE OF EQUATIONS 4–7 FOR ESTIMATING THE TOTAL BYCATCH.

EXPECTED BYCATCH	OBSERVER COVER (%)	MEAN ESTIMATION ERROR	SD OF ESTIMATION ERROR	COEFFICIENT OF VARIATION (%)	MEAN OF SE ESTIMATES	SD OF SE ESTIMATES	MEAN OF T-STATISTICS	SD OF T-STATISTICS	NUMBER OF ZERO ESTIMATES
30	5	0.9	24.5	82	20.1	14.0	0.17	0.75	237
30	10	0.9	17.1	57	15.7	6.4	-0.11	1.06	51
30	20	0.7	11.4	38	10.8	2.7	-0.14	1.17	4
30	40	0.0	7.2	24	6.6	1.2	-0.14	1.22	0
30	80	0.0	2.8	9	2.7	0.4	-0.03	1.07	0
50	5	-2.0	32.4	65	27.1	14.0	-0.13	1.03	110
50	10	-0.7	21.5	43	20.2	6.5	-0.26	1.22	15
50	20	0.5	14.3	29	13.9	2.9	-0.14	1.15	0
50	40	0.2	9.0	18	8.6	1.3	-0.08	1.09	0
50	80	0.0	3.4	7	3.5	0.4	-0.02	0.97	0
70	5	-0.6	37.2	53	34.2	14.5	-0.17	1.09	49
70	10	0.4	25.5	37	24.5	6.9	-0.20	1.22	5
70	20	-0.6	16.8	24	16.5	3.1	-0.18	1.10	0
70	40	0.7	10.5	15	10.2	1.4	-0.02	1.06	0
70	80	-0.1	4.2	6	4.2	0.5	-0.06	1.02	0

Appendix 2

BYCATCH ESTIMATES

The following table shows the total tows, observed tows, estimated bycatch and its standard error by fishing management area (FMA), the target fish, and the fishing year. See the main text for an explanation of the data and procedures used to construct this table. See Fig. 1 for the locations of the FMAs. Situations with an estimated bycatch of 100 or more are shaded. In cases where no bycatch is observed for a series of tows the estimated bycatch is zero, with an estimated standard error of zero, based on equations 4 to 7. These estimates may be rather poor when the number of tows is small. The target species codes are BAR (barracouta), HAK (hake), Hoki (HOK), JMA (jack mackerel) ORH (orange roughy), SBW (southern blue whiting), SCI (scampi), SQU (squid), and OTHER (blue mackerel, frostfish, ling, southern kingfish, silver warehou, and blue warehou).

FISHING YEAR	FMA		TARGET BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	% OBS
1990/91	CEE	Total tows							2252		25	2277	
		Observed tows							132		1	133	5.8
		Estimated Bycatch/1000 tows							0		0	0	
		Estimated total bycatch							0		0	0	
		Standard error							0		0	0	
	CEW	Total tows				603						603	
		Observed tows				144						144	23.9
		Estimated Bycatch/1000 tows				0						0	
		Estimated total bycatch				0						0	
		Standard error				0						0	
	CHA	Total tows	693		9227	950					94	10964	
		Observed tows	219		1277	950					18	2446	22.3
		Estimated Bycatch/1000 tows	0		13	0					167	12	
		Estimated total bycatch	0		116	0					16	131	
		Standard error	0		31	0					10	33	
	SEC	Total tows			2420				97		527	3044	
		Observed tows			5				97		94	196	6.4
		Estimated Bycatch/1000 tows			0				0		0	0	
		Estimated total bycatch			0				0		0	0	
		Standard error			0				0		0	0	
	SOE	Total tows	294				2309				216	2819	
		Observed tows	98				189				192	479	17.0
		Estimated Bycatch/1000 tows	0				0				0	0	
		Estimated total bycatch	0				0				0	0	
		Standard error	0				0				0	0	
	SOU	Total tows			1973						751	2724	
		Observed tows			95						39	134	4.9
		Estimated Bycatch/1000 tows			137						0	99	
		Estimated total bycatch			270						0	270	
		Standard error			110						0	110	

FISHING YEAR	FMA		TARGET BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	% OBS
1990/91	SUB	Total tows			2304			2144			222	4670	
		Observed tows			102			292			103	497	10.6
		Estimated Bycatch/1000 tows			0			0			0	0	
		Estimated total bycatch			0			0			0	0	
		Standard error			0			0			0	0	
	All	Total tows	987		15924	1553	2309	2144	2349		1835	27101	
		Observed tows	317		1479	1448	189	292	229		447	4401	16.2
		Estimated Bycatch/1000 tows	0		24	0	0	0	0		9	15	
		Estimated total bycatch	0		386	0	0	0	0		16	401	
		Standard error	0		115	0	0	0	0		10	115	
		CV (%)			30						64	29	
1991/92	CEE	Total tows							1585			1585	
		Observed tows							357			357	22.5
		Estimated Bycatch/1000 tows							0			0	
		Estimated total bycatch							0			0	
		Standard error							0			0	
	CEW	Total tows	40			1491				277		1808	
		Observed tows	23			228				277		528	29.2
		Estimated Bycatch/1000 tows	43			0				0		1	
		Estimated total bycatch	2			0				0		2	
		Standard error	1			0				0		1	
	CHA	Total tows	431	181	7004	1389	981	16		60	165	10227	
		Observed tows	11	76	788	119	62	1		60	31	1148	11.2
		Estimated Bycatch/1000 tows	364	26	20	8	0	0		0	32	31	
		Estimated total bycatch	157	5	142	12	0	0		0	5	321	
		Standard error	134	2	65	8	0	0		0	5	149	
	SEC	Total tows	1311		3369		718		35	1408	434	7275	
		Observed tows	78		258		4		8	6	43	397	5.5
		Estimated Bycatch/1000 tows	0		4		0		125	0	0	2	
		Estimated total bycatch	0		13		0		4	0	0	17	
		Standard error	0		13		0		4	0	0	14	
	SOE	Total tows		292	3112		1908		2020		186	7518	
		Observed tows		11	283		771		893		791	2749	36.6
		Estimated Bycatch/1000 tows		0	0		0		0		0	0	
		Estimated total bycatch		0	0		0		0		0	0	
		Standard error		0	0		0		0		0	0	
	SOU	Total tows	593		3277	191	710		25	4630	629	10055	
		Observed tows	108		415	6	22		25	372	122	1070	10.6
		Estimated Bycatch/1000 tows	19		19	0	0		0	30	33	23	
		Estimated total bycatch	11		63	0	0		0	137	21	232	
		Standard error	5		24	0	0		0	40	19	51	
	SUB	Total tows		82	2427		528	3818	979	661	534	9029	
		Observed tows		1	514		528	716	266	485	534	3044	33.7
		Estimated Bycatch/1000 tows	1000*	0	0		0	3	0	2	0	1	
		Estimated total bycatch		0	0		0	11	0	1	0	12	
		Standard error		0	0		0	7	0	1	0	7	
	All	Total tows	2375	555	19189	3071	4845	3834	4644	7036	1948	47497	
		Observed tows	220	88	2258	353	1387	717	1549	1200	1521	9293	19.6
		Estimated Bycatch/1000 tows	71	9	11	4	0	3	1	20	13	12	
		Estimated total bycatch	169	5	218	12	0	11	4	138	26	584	
		Standard error	134	2	70	8	0	7	2	40	19	158	
		CV (%)	79	50	32	69		62	47	29	74	27	

FISHING YEAR	FMA		TARGET										%
			BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	OBS
1992/93	CEE	Total tows			742		2638		1326			4706	
		Observed tows			14		35		135			184	3.9
		Estimated Bycatch/1000 tows			0		0		0			0	
		Estimated total bycatch			0		0		0			0	
		Standard error			0		0		0			0	
	CEW	Total tows				1422	451					1873	
		Observed tows				449	451					900	48.1
		Estimated Bycatch/1000 tows				0	0					0	
		Estimated total bycatch				0	0					0	
		Standard error				0	0					0	
	CHA	Total tows	728	469	7732	1065	1052				147	11193	
		Observed tows	113	223	1291	66	78				25	1796	16.0
		Estimated Bycatch/1000 tows	18	108	39	121	0				40	44	
		Estimated total bycatch	13	50	299	129	0				6	498	
		Standard error	9	14	105	64	0				4	124	
	SEC	Total tows	1369		3874	466				1019	476	7204	
		Observed tows	38		106	80				23	144	391	5.4
		Estimated Bycatch/1000 tows	0		38	0				0	14	21	
		Estimated total bycatch	0		146	0				0	7	153	
		Standard error	0		89	0				0	6	89	
	SOE	Total tows	369	588	2916		1972		1409	8	616	7878	
		Observed tows	33	86	238		613		144	3	616	1733	22.0
		Estimated Bycatch/1000 tows	0	0	0		0		7	0	0	1	
		Estimated total bycatch	0	0	0		0		10	0	0	10	
		Standard error	0	0	0		0		10	0	0	10	
	SOU	Total tows	445	8	2893	129	807	22	26	6469	611	11410	
		Observed tows	67	8	447	35	51	22	8	1425	208	2271	19.9
		Estimated Bycatch/1000 tows	15	0	25	0	0	500	0	18	14	19	
		Estimated total bycatch	7	0	71	0	0	11	0	118	9	216	
		Standard error	6	0	26	0	0	0	0	31	5	41	
	SUB	Total tows		14	2302			1231		661	327	4535	
		Observed tows		2	293			395		288	39	1017	22.4
		Estimated Bycatch/1000 tows		0	20			134		3	0	47	
		Estimated total bycatch		0	47			165		2	0	215	
		Standard error		0	37			41		2	0	55	
	All	Total tows	2911	1079	20459	3082	6920	1253	2761	8157	2177	48799	
		Observed tows	251	319	2389	630	1228	417	287	1739	1032	8292	17.0
		Estimated Bycatch/1000 tows	7	47	28	42	0	141	4	15	10	22	
		Estimated total bycatch	20	50	564	129	0	176	10	120	21	1091	
		Standard error	11	14	115	64	0	41	10	31	7	143	
		CV (%)	54	28	20	49		23	102	26	35	13	
1993/94	CEE	Total tows			1088		3046		1415		721	6270	
		Observed tows			42		58		265		67	432	6.9
		Estimated Bycatch/1000 tows			48		0		0		0	8	
		Estimated total bycatch			52		0		0		0	52	
		Standard error			56		0		0		0	56	
	CEW	Total tows				1273						1273	
		Observed tows				272						272	21.4
		Estimated Bycatch/1000 tows				4						4	
		Estimated total bycatch				5						5	
		Standard error				4						4	

FISHING YEAR	FMA		BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	% OBS
1993/94	CHA	Total tows	757	222	9861	1195	1180				100	13315	
		Observed tows	56	54	1597	334	61				7	2109	15.8
		Estimated Bycatch/1000 tows	179	130	26	39	0				286	37	
		Estimated total bycatch	135	29	253	47	0				29	492	
		Standard error	52	15	82	14	0				19	101	
	SEC	Total tows			3267	690	884		672	2985	287	8785	
		Observed tows			361	39	117		133	266	169	1085	12.4
		Estimated Bycatch/1000 tows			0	26	0		15	8	0	6	
		Estimated total bycatch			0	18	0		10	22	0	50	
		Standard error			0	17	0		7	16	0	25	
	SOE	Total tows		371	1656	70	3262		1111	201	67	6738	
		Observed tows		15	568	6	792		200	201	6	1788	26.5
		Estimated Bycatch/1000 tows		0	2	0	1		0	0	0	1	
		Estimated total bycatch		0	3	0	4		0	0	0	7	
		Standard error		0	2	0	4		0	0	0	4	
	SOU	Total tows	239	19	1984	73	1699			2312	655	6981	
		Observed tows	23	14	337	3	366			357	16	1116	16.0
		Estimated Bycatch/1000 tows	43	0	68	0	3			17	0	27	
		Estimated total bycatch	10	0	135	0	5			39	0	189	
		Standard error	0	0	80	0	3			21	0	83	
	SUB	Total tows			652		183	710	1397	4693	230	7865	
		Observed tows			48		17	226	281	437	18	1027	13.1
		Estimated Bycatch/1000 tows			21		0	429	0	9	0	46	
		Estimated total bycatch			14		0	305	0	43	0	361	
		Standard error			11		0	148	0	20	0	150	
	All	Total tows	996	612	18508	3301	10254	710	4595	10191	2060	51227	
		Observed tows	79	83	2953	654	1411	226	879	1261	283	7829	15.3
		Estimated Bycatch/1000 tows	146	47	25	21	1	429	2	10	14	23	
		Estimated total bycatch	146	29	457	69	9	305	10	104	29	1157	
		Standard error	52	15	128	16	4	148	3	29	19	207	
		CV (%)	35	53	28	23	51	49	26	28	67	18	
1994/95	CEE	Total tows					3798		921		632	5351	
		Observed tows					182		403		246	831	15.5
		Estimated Bycatch/1000 tows					0		0		0	0	
		Estimated total bycatch					0		0		0	0	
		Standard error					0		0		0	0	
	CEW	Total tows				757						757	
		Observed tows				757						757	100.0
		Estimated Bycatch/1000 tows				0						0	
		Estimated total bycatch				0						0	
		Standard error				0						0	
	CHA	Total tows	969	812	9683	1241	824				132	13661	
		Observed tows	775	812	813	41	131				132	2704	19.8
		Estimated Bycatch/1000 tows	0	0	34	0	0				0	24	
		Estimated total bycatch	0	0	333	0	0				0	333	
		Standard error	0	0	90	0	0				0	90	
	SEC	Total tows	1008		3567	882	571		544	2177	512	9261	
		Observed tows	173		222	5	29		216	217	156	1018	11.0
		Estimated Bycatch/1000 tows	0		23	200	0		0	0	0	28	
		Estimated total bycatch	0		80	176	0		0	0	0	257	
		Standard error	0		65	211	0		0	0	0	221	

FISHING YEAR	FMA		BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	% OBS
			TARGET										
1994/95	SOE	Total tows	221	404	4881		3267		1090		995	10858	
		Observed tows	221	231	280		925		1090		995	3742	34.5
		Estimated Bycatch/1000 tows	0	0	11		0		0		0	5	
		Estimated total bycatch	0	0	52		0		0		0	52	
		Standard error	0	0	58		0		0		0	58	
	SOU	Total tows	1100		1856	200	202			4672	776	8806	
		Observed tows	1100		132	17	12			440	28	1729	19.6
		Estimated Bycatch/1000 tows	0		98	59	0			7	0	26	
		Estimated total bycatch	0		183	12	0			32	0	226	
		Standard error	0		140	11	0			16	0	141	
	SUB	Total tows			1036		240	440	1351	4028	106	7201	
		Observed tows			103		33	240	50	285	25	736	10.2
		Estimated Bycatch/1000 tows			0		30	383	0	7	0	28	
		Estimated total bycatch			0		7	169	0	28	0	204	
		Standard error			0		2	33	0	17	0	37	
	All	Total tows	3298	1216	21023	3080	8902	440	3906	10877	3153	55895	
		Observed tows	2269	1043	1550	820	1312	240	1759	942	1582	11517	20.6
		Estimated Bycatch/1000 tows	0	0	31	61	1	383	0	6	0	19	
		Estimated total bycatch	0	0	649	188	7	169	0	60	0	1073	
		Standard error	0	0	176	18	2	33	0	23	0	182	
		CV (%)			27	10	23	19		39		17	
1995/96	CEE	Total tows			2766		1744		908			5418	
		Observed tows			26		22		113			161	3.0
		Estimated Bycatch/1000 tows			38		0		0			20	
		Estimated total bycatch			106		0		0			106	
		Standard error			73		0		0			73	
	CEW	Total tows				265						265	
		Observed tows				178						178	67.2
		Estimated Bycatch/1000 tows				0						0	
		Estimated total bycatch				0						0	
		Standard error				0						0	
	CHA	Total tows	616	178	10143	1145	500				126	12708	
		Observed tows	70	11	1078	73	122				126	1480	11.6
		Estimated Bycatch/1000 tows	329	0	127	0	0				0	117	
		Estimated total bycatch	202	0	1289	0	0				0	1491	
		Standard error	99	0	379	0	0				0	392	
	SEC	Total tows			7700	506	288		397	3073	296	12260	
		Observed tows			688	88	24		123	135	76	1134	9.2
		Estimated Bycatch/1000 tows			22	11	0		0	0	0	14	
		Estimated total bycatch			168	6	0		0	0	0	174	
		Standard error			91	5	0		0	0	0	92	
	SOE	Total tows			2645	232	2144		498		404	5923	
		Observed tows			226	232	358		418		404	1638	27.7
		Estimated Bycatch/1000 tows			0	0	0		0		0	0	
		Estimated total bycatch			0	0	0		0		0	0	
		Standard error			0	0	0		0		0	0	
	SOU	Total tows	598		2363	745	452			2583	703	7444	
		Observed tows	425		198	49	85			177	93	1027	13.8
		Estimated Bycatch/1000 tows	0		51	0	0			28	0	26	
		Estimated total bycatch	0		119	0	0			73	0	192	
		Standard error	0		44	0	0			25	0	50	

FISHING YEAR	FMA		TARGET BAR	HAK	HOK	JMA	ORH	SBW	SCI	SQU	OTHER	TOTAL	% OBS
	SUB	Total tows	7		879	21	614	576	1314	4476	184	8071	
		Observed tows	3		62	5	16	144	67	556	41	894	11.1
		Estimated Bycatch/1000 tows	0		16	0	0	118	0	14	0	18	
		Estimated total bycatch	0		14	0	0	68	0	64	0	147	
		Standard error	0		15	0	0	28	0	23	0	39	
	All	Total tows	1221	178	26496	2914	5742	576	3117	10132	1713	52089	
		Observed tows	498	11	2278	625	627	144	721	868	740	6512	12.5
		Estimated Bycatch/1000 tows	166	0	64	2	0	118	0	14	0	41	
		Estimated total bycatch	202	0	1697	6	0	68	0	137	0	2110	
		Standard error	99	0	389	2	0	28	0	34	0	404	
		CV (%)	49		23	40		41		25		1	