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EXECUTIVE SUMMARY

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Trawl catch and discard data from the Ministry of Fisheries Observer Programme and commercial catch-effort data for the period 1990–91 to 2001–02 were used to estimate bycatch and discard levels in the target trawl fisheries for southern blue whiting and oreos. From these, estimates of non-target catch were derived. Estimates were made for several categories of catch including the target species, commercial species, non-commercial species, and commonly caught individual species.

Two ratio estimators were formed from the observer data, one which measured bycatch or discards in relation to tow duration and the other to the level of target species catch. Bootstrapping techniques were used to test which was the better of the two ratio estimators. Several subsets of the observer data were tested and in almost every case the tow duration based estimator produced an estimate with a smaller c.v. (coefficient of variation), and therefore this version of the estimator was used for all subsequent calculations. A value of this estimator was calculated for logical subsets (strata) of each fishery and for each species category and used to scale up observed discard and bycatch rates to the total target fishery. Bootstrapping methods were used to provide confidence limits for the final bycatch and discard estimates.

Regression analyses were used to identify critical factors affecting bycatch and discard quantities in order to split each fishery into logical strata. For discards in particular, but also for bycatch, the factor with the greatest influences in the regressions was the categorical variable *vessel*. The variables *area* and *fishing year* were also frequently selected in the models. Because observer data were not available from all vessels, the fishery could not be split by this factor to scale up ratio estimates and so ratio estimators were calculated for combinations of *area* and *fishing year*, with the requirement that data were available from at least 3 vessels and at least 50 tows in each stratum.

Total bycatch estimates for the southern blue whiting fishery varied widely between years, ranging from about 60 to 1500 t, although in most years they were less than 400 t. This is small compared to the total estimated catch of the target species in the target fishery of 17 500–76 000 t. Most of this bycatch consisted of commercial species (mainly hoki, hake, and ling), which were generally retained. The target species accounted for more than 85% of the discards in this fishery and total annual discard estimates ranged from about 140 to 1200 t. Annual non-target catch (total bycatch plus discards of the target species) in the southern blue whiting fishery ranged from 300 to 2500 t.

Total bycatch estimates in the oreo fishery were also variable between years, ranging from about 450 to 2600 t per year (compared to the total estimated target species catch in the target fishery of 9500–17 700 t). Bycatch was evenly split between commercial species (mainly orange roughy, hoki, and pale ghost shark) and non-commercial species. Total annual discard estimates ranged from about 230 t to 1900 t and, for the 12 years combined, comprised about 60% non-commercial species and 40% oreo species. Annual non-target catch in the oreo fishery ranged from 470 to 2900 t.

1. INTRODUCTION

Information on the level of non-target fish catch and discards in commercial fisheries is important for fisheries management. Stock assessments will be more accurate if they are able to use the estimates of the true catch and mortality of fish species, rather than rely solely on reported landings. Such information is important for both target and non-target species, whether the latter are commercial species or non-commercial species, as there is an increasing emphasis in New Zealand and internationally towards ecosystem management of fisheries, whereby the full effects of a fishery on the associated environment are taken into consideration when making management decisions.

The Ministry of Fisheries has the responsibility for determining the effects of fishing on species that are physically associated with, or biologically dependent on, the target species. This can include target species that are discarded as well as non-target species taken as bycatch during normal fishing operations. The work undertaken here expands on an earlier study by NIWA, which measured discards in the southern blue whiting (*Micromesistius australis*) and oreo fisheries (as well as the orange roughy (*Hoplostethus atlanticus*) and hoki (*Macruronus novaezelandiae*) fisheries) for the 1994–95 and 1995–96 (1 October–30 September) fishing years (Clark et al. 2000). That study found that while discards were low in the southern blue whiting fishery, they comprised mostly the target species, and that discards in the oreo fishery were mostly non-commercial species. The present study also complements recent investigations into both bycatch and discards in other New Zealand trawl fisheries: e.g., the orange roughy and hoki fisheries (Anderson et al. 2001), and the arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.), and scampi (*Metanephrops challengeri*) fisheries (Anderson et al. 2000, Anderson 2004). This research is improving our understanding of the ecosystem effects of commercial fisheries in New Zealand and will assist in detecting trends over time in the level of bycatch and discards in these fisheries.

The single objective of this project requires estimates to be made of "the catch rates, quantity and discards of non-target fish catches and the discards of target fish catches in trawl fisheries for southern blue whiting and oreos, using data from observers and commercial fishing returns for the 1990–91 to 2001–02 fishing years". These are major New Zealand fisheries, with total reported catches in 2001–02 of 32 500 t for southern blue whiting and 18 721 t for oreos. These were, respectively, the third and seventh largest trawl fisheries by weight of landings in that year (Annala et al. 2003). Fisheries of this scale have considerable potential to catch and discard large quantities of non-target species with no commercial value. In addition, there is potential to discard target species and other commercial species if they cannot be processed due to damage (crushing in codend or factory line, contamination from being dropped, deterioration of flesh quality from processing delays) or because they are of unwanted size. Discarding of processed fish can also occur due to, e.g., chemical contamination or the breakdown of a freezer. Fish can also be discarded without ever reaching the deck of the boat, when dead or dying fish escape from the net due to gear damage caused by contact with the seabed, or as a result of a mechanical or other failure during gear retrieval.

Southern blue whiting are restricted mainly to the waters of the sub-Antarctic (Anderson et al. 1998). Spread around the Campbell Plateau and Bounty Plateau, they aggregate to spawn in August and September in several discrete areas, which are assumed to constitute four separate stocks for stock assessment. The fishery operates almost exclusively during these months, and most of the catch is taken from depths of 250–600 m by chartered Japanese and Soviet trawlers using a mixture of bottom and midwater trawling (Annala et al. 2003). The main bycatch species identified by Clark et al. (2000) were ling (*Genypterus blacodes*), hake (*Merluccius australis*), and hoki, with porbeagle shark (*Lamna nasus*), silverside (*Argentina elongata*), and dark ghost shark (*Hydrolagus novaezelandiae*) also frequently caught.

The oreo fishery comprises two main species, smooth oreo, (*Pseudocyttus maculatus*) and black oreo (*Allocyttus niger*), as well as spiky oreo (*Neocyttus rhomboidalis*), a species caught in much smaller quantities. The fishery occurs mostly on the south Chatham Rise, along the east coast of the South Island, around the northern fringes of the Campbell Plateau and the Bounty Plateau, and the northern end of the Macquarie Ridge (Annala et al. 2003). This fishery strongly overlaps with the orange roughy fishery, and trips frequently target and catch a mixture of these species. Other important bycatch species are hoki, silverside, deepwater dogfishes, especially Baxter's dogfish (*Etmopterus baxteri*), and rattails (Macrouridae) (Clark et al. 2000).

2. METHODS

2.1 Definition of terms

Non-target catch is the sum of the *incidental catch* (the retained catch of non-target species) plus the *discarded* catch of both target and non-target species. This is similar to *bycatch*, which is all fish caught that were not the stated target species for that tow, whether or not they were discarded. *Discarded catch* (or *discards*) are "all the fish, both target and non-target species, which are returned to the sea whole as a result of economic, legal, or personal considerations" (after McCaughran 1992). *Discarded catch* in this report includes estimates of any fish lost from the net at the surface. Estimates of *non-target catch* were not estimated directly, as it was more practical to separate the analyses strictly by target species/non-target species, but these figures can be obtained by adding target species *discards* to total *bycatch*.

2.2 Observer data

Collection of catch and processing data is one of the core duties of the Ministry of Fisheries observers, and these data are generally recorded for every tow on each trip. The allocation of observers to vessel trips takes into account a number of data collection requirements and compliance issues for multiple fisheries. For this reason, and because of the logistics involved in placing observers on vessels at short notice and in accommodating observers on smaller vessels, it is difficult for the Ministry of Fisheries to achieve an even or random spread of observer effort in each fishery. Observer coverage in the southern blue whiting and oreo fisheries, however, has generally been maintained at a high level during the period examined, due to the relative size and importance of these fisheries, and therefore a considerable amount of data is available for this study.

Two datasets were prepared from observer data for each fishery, one comprising discard data, and the other bycatch data. Observer records of catch and discards were extracted from the Ministry of Fisheries database '*obs*' (Mackay 1995) for the fishing years being examined. All records with target species codes SBW (southern blue whiting), or OEO, SSO, BOE, SOR (oreo), were extracted. The Ministry of Fisheries has been unable to make available any discard data collected by observers in the 1997–98 fishing year. As a result, discard estimates made here for this fishing year are based on discard ratios calculated using data from all other years.

For all records, the tow duration was calculated from the difference between the start and finish times, less the period (recorded by observers) between the start and finish times when the net was not fishing (e.g., when the net was brought to the surface during turning or the net remained in the water due to equipment malfunction). Errors resulting from confusion between the 12 and 24 h clock systems were identified and rectified where these were obvious. Where tow duration thus derived was suspiciously long (over 12 hours) it was replaced with a value calculated from the recorded fishing speed and tow distance (calculated from start and finish positions) if the difference between these two values for duration was greater than 50% of the value calculated from start and finish times. The speed times distance method of calculating duration was only used in these cases as, especially in the southern blue whiting fishery, tows were frequently not straight and it was possible for a long tow to finish near to the start position, resulting in an underestimate of the tow duration. Less than half (43%) of the 3606 observed southern blue whiting target tows were straight, with a mixture of "u-bend' (45%), "along depth contour" (6%) and "zigzag" (4.5%) tows. In contrast, over 95% of oreo tows were straight and so tow distances, calculated from start and finish positions, are likely to be accurate in most cases.

When fish were lost from the net before it was brought aboard, observers estimated the amount lost by recorded values for "total greenweight on surface" and "total greenweight on board". These losses were recorded much more frequently in the southern blue whiting fishery and came about mostly through rips in the net and burst windows or escape panels, either below the sea surface or at the surface or on the stern ramp of the vessel. A number of errors were found in the records of these data and corrected where possible. For example, where the recorded value for "total greenweight on board" was greater than "total greenweight on surface" the weight of fish lost was set to "NULL" unless an obvious typographical error could be uncovered and corrected by comparing greenweight totals from species by species tallies with the two total greenweight figures. The amount of fish lost was added proportionately to the discards for that tow or processing group, for each species category, according to the relative amounts of those categories actually landed on that tow.

Each record was assigned to a fishing year. This was straightforward for the oreo fishery but the southern blue whiting fishery changed from a 1 September–30 October to a 1 April–31 March fishing year starting with 2000–01. The transition between the two incorporated an 18-month (1998–2000) fishing year running from 1 Oct 1998 to 31 Mar 2000.

For southern blue whiting, where fishing is a mixture of bottom and midwater trawling, "towtype" was assigned as "mid" if a midwater trawl was used, the net was off the bottom throughout the tow, and the headline height was greater than 20 m. Tows were assigned "bot" if a bottom trawl was used, the net was on the bottom throughout the tow, and the headline height was less than 20 m. Many tows met neither criteria, however, so two other variables were formed. The variable "gear type" was set to "mid" if a midwater trawl was used and "bot" if a bottom trawl was used, without regard to how the trawl was used (i.e., on or off the bottom). The variable "towtype2" was set to "mid" if the net was off the bottom throughout the tow and "bot" if the net was on the bottom throughout the tow.

In the oreo fishery virtually all fishing used bottom trawls, but as observers recorded whether the tow was on a hill or not, a variable "terrain" was created and tows were assigned "hill" or "flat".

Each record was assigned to an area (see Figures 1 and 3). Areas were based on a combination of: 1, the areas used in the previous report (Clark et al. 2000); 2, known stock divisions or management areas; 3, the geographical distribution of observer sampling.

To create the discard dataset, the amount retained and discarded of each species was obtained from the Ministry of Fisheries observer database, which records these data at the level of the "processing group". The processing group is the finest level at which discard information is recorded, and although usually representing a single tow, the discards from two or more tows were frequently combined into one processing group. In order to examine how discard levels varied with fishing depth, area, fishing method, season, etc., it was necessary to summarise these data over all tows within a processing group. Hence catch and discards, and tow lengths and durations, were summed within each processing group. Usually, fishing year, area, season, and vessel nationality were constant between tows within a processing group, but occasionally there was a mixture of gear type (mid-water or bottom trawls) and a range of tow depths. For this reason depth of tow was assigned to each processing group as a categorical variable. Processing groups made up of tows which were all shallower than the average tow depth (408 m for southern blue whiting, 979 m for oreo) were assigned "shallow", those deeper than the average tow depth were assigned "deep", and those with a mixture of tow depths were assigned "NULL". The depth of each tow was calculated as the average of the depth of the groundline at the start and end of the tow.

The extraction of bycatch data was more straightforward because observers estimated or measured the weight of all species caught in each trawl. Bycatch could therefore be estimated and related to tow parameter data for each tow.

From these datasets the weights of fish caught and fish discarded were calculated for the following species categories:

- the target species (southern blue whiting (SBW)/oreo (OEO, SSO, BOE, SOR))
- other main commercial species combined (COM)
- all other species combined (OTH)
- individual bycatch species caught in significant quantities

Summaries by species of the overall observed catch and percentage discarded are tabulated for each fishery in Appendices 1 and 2.

Commercial species were defined as those which represented 0.1% or more of the total observed catch and either were quota species or 75% or more of the catch was retained. In the southern blue whiting fishery they comprised hoki (HOK), ling (LIN), and hake (HAK) and in the oreo fishery orange roughy (ORH), hoki, and pale ghost shark (*Hydrolagus* sp. B2) (GSP). The bycatch and discards of these species were assessed as a group (COM) as well as separately.

A total of 3705 tows and 2105 processing groups targeting southern blue whiting, and 3660 tows and 2293 processing groups targeting oreos, were used in the analysis.

2.3 Commercial fishing return data

Catch records from commercial fishing returns were obtained from Ministry of Fisheries databases for each fishery. This included all fishing recorded on Trawl, Catch, Effort and Processing Returns (TCEPRs), High Seas Trawl, Catch, and Effort Returns (HSTCERs), High Seas Catch, Effort and Landing Returns (HSCELRs), and Catch, Effort and Landing Returns (CELRs). The recorded target species was used to define each fishery, in the same way as described for the observer data above.

Data were error checked. Duration was derived from the difference in time between the start and finish of the tow. Any tow duration thus derived that was greater than 20 hours was assumed to have been caused by a transposition of the start and finish times and was corrected accordingly. Following this, any tow durations in the oreo fishery of more than 15 hours were assumed to be erroneous and were replaced by the mean duration of the remaining tows. Long tows were more common in the southern blue whiting fishery and those up to 20 hours duration were accepted as correct. Records were assigned to the areas defined in Figures 1 and 3. Catch weights were checked for unusual values. Missing or unusual start positions (e.g., those in very deep water or suspected to be the result of errors in the recording of the hemisphere) were substituted with the finish position to identify the area of the tow. A few positional errors will have remained but, with the broad area divisions used in the analyses, few of these are likely to have been assigned to the wrong area. A few records in the TCEPR data from each fishery showed a larger target species catch than the total catch from a tow. In these cases the total catch was set to equal the target species catch.

2.4 Examination of factors influencing discards and bycatch

In order to select appropriate factors for stratification of discard and bycatch calculations, a series of regression analyses were performed. Each species group was examined separately in each fishery and a combination of linear and binomial regressions applied. Both linear and binomial regressions were used for species groups for which no catch/discards were recorded for a large fraction of the tows/processing groups. This enabled an examination of factors influencing both the *probability* and the *level* of a bycatch/discard. Linear regressions only were used for species groups where most tows/processing groups recorded a catch/discard. The binomial regression uses a response variable which is a binomial vector of discards in two categories. For each record this variable was assigned "0" if no bycatch/discard was recorded and "1" otherwise. The response variable for the linear regressions was determined from the outcome of the process described in Section 2.5 (below), and in all cases a log transformation was used to provide an approximately normal distribution of values. The log transformation was found to be the most appropriate in each case, after visual examination of histograms and normal probability plots of untransformed and transformed data. The analyses focussed on variables which could practically be used to stratify commercial catch effort data and other variables for which values were available for most records. Because tows were combined within processing groups for discards analysis, the influence of some variables, e.g., *headline height* and vessel *speed*, could not be tested. Regressions were run in turn for discards of the target species, bycatch and discards of other commercial species (COM), non-commercial species (OTH), and frequently caught individual species. A detailed examination of the influence of the main factors identified is beyond the scope of this project, and so summaries were made only of the order of variable selection in each model. Variables used to stratify data for bycatch and discard calculations were chosen from these summaries.

2.5 Calculation of discard and bycatch ratios

Observer data were combined so that discards and catch by species, and tow duration, were summed within each fishery, species category, and strata determined from the regression analyses. From this the "Discard ratio", $\hat{DR}$, was derived. Initially two versions of the ratio were calculated for several subsets of the data, one based on the total catch of the target species, the other on the total trawl duration. The estimators had the following form,

$$\hat{DR}_1 = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} l_i} \quad \text{and} \quad \hat{DR}_2 = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} t_i}$$

where m processing groups were sampled from a stratum; d_i is the weight of discarded catch from the ith processing group sampled; l_i is the weight of the target species caught in the ith processing group sampled; and t_i is the total towing time for the processing group i. Variances of these estimates were calculated using bootstrap techniques. This involved sampling at random (with replacement) 1000 sets of pairs of ratio values from each data subset. Each of the sets were the same length as the number of records in each subset. This resulted in 1000 estimates of $\hat{DR}$ from which, provided they were approximately normally distributed, variances and confidence intervals were calculated. A comparison was made, between the two estimators, of the ratio variances derived from each of the initial subsets tested and the estimator with lower variance overall was used for all subsequent calculations.

The assumption was made that all trips and all tows within a trip, in each of the strata, were sampled with equal probability. This assumption may not always hold true, but the spread of observed tow positions compared with all recorded tow positions from each fishery (see below) showed that there has been fairly representative coverage of the spatial extent of each fishery, with the main fishing grounds covered. In addition, the calculations ignored any measurement error associated with catch and discard estimates. These errors will be greatest for observer estimates of fish lost from the net, which are difficult to judge by eye.

Once the best estimator was chosen, estimates of $\widehat{DR}$ were derived for each stratum in each fishery and variances were derived by bootstrapping. Separate ratios were calculated only for strata with 50 records or more, and overall ratios (e.g., for all areas or all fishing years) were substituted for strata with fewer than 50 records. The discard ratio calculated for each stratum was then multiplied by the total estimated catch of the target species (or the total tow duration) in the stratum, from commercial catch records, to estimate total discards $\hat{D}$:

$$(1) \qquad \hat{D} = \hat{D}R \times L \text{ (or } T\text{)}$$

where L is the total catch of the target species in the stratum and T is the total tow duration in the stratum.

The 2.5% and 97.5% quantiles of the distribution of $\widehat{DR}$ values were used to calculate 95% confidence intervals around the estimate of discards in each stratum. Because a significant fraction of the fishery was observed, the samples were treated as having been taken from a "finite population" for statistical purposes. That is, for the fraction of the fishery that was observed, the level of discards is exactly known and the error associated with $\widehat{DR}$ should apply only to the unobserved portion. Hence the, e.g., 2.5% confidence limit was calculated from equation (1) by adding the $\widehat{DR}$ multiplied by the observed catch (or duration) to the 2.5% quantile value of $\widehat{DR}$ multiplied by the remaining catch (or duration).

Bycatch estimates were calculated in a similar manner to discards but, as discard data were not required, it was possible to use tow-by-tow data and hence a different (and slightly larger) set of records for comparing estimators and calculating ratios. Bootstrapping was carried out using procedures in "S-PLUS" (Venables & Ripley 1999).

3. RESULTS

3.1 Distribution of observer data

3.1.1 Southern blue whiting

The positions of all observed tows in the target southern blue whiting fishery between 1 October 1990 and 30 September 2002 are shown along with those of all commercial target tows recorded on TCEPR forms from the same period in Figure 1. There is an excellent spread of observer coverage over the geographical range of this fishery. The main fishery for southern blue whiting, on the Campbell Rise, has had observer coverage over virtually its entire range, as have the smaller fisheries on the Bounty Plateau, Pukaki Rise, and east of the Auckland Islands. The few tows recorded in areas outside those defined by the boxes in Figure 1 (including outliers with probable position errors) were combined into a single OTHER area category. The good spread of coverage in this fishery is aided by all vessels being large (over 58 m) and able to accommodate observers, and the fishery being predictable in its timing and restricted in its distribution, which simplifies the placement of observers on vessels.

The annual number of observed tows ranged from 144 to 723 and the number of vessels observed from 4 to 12 (Table 1). The percentage of the fishery observed (in terms of the total southern blue whiting catch) was greater than 10% in all but the first year (1990–91), was 20% or more in all other years, and was 80% or more in 3 of the 11 years (including the last two years). A total of 35 different vessels were observed during this period.

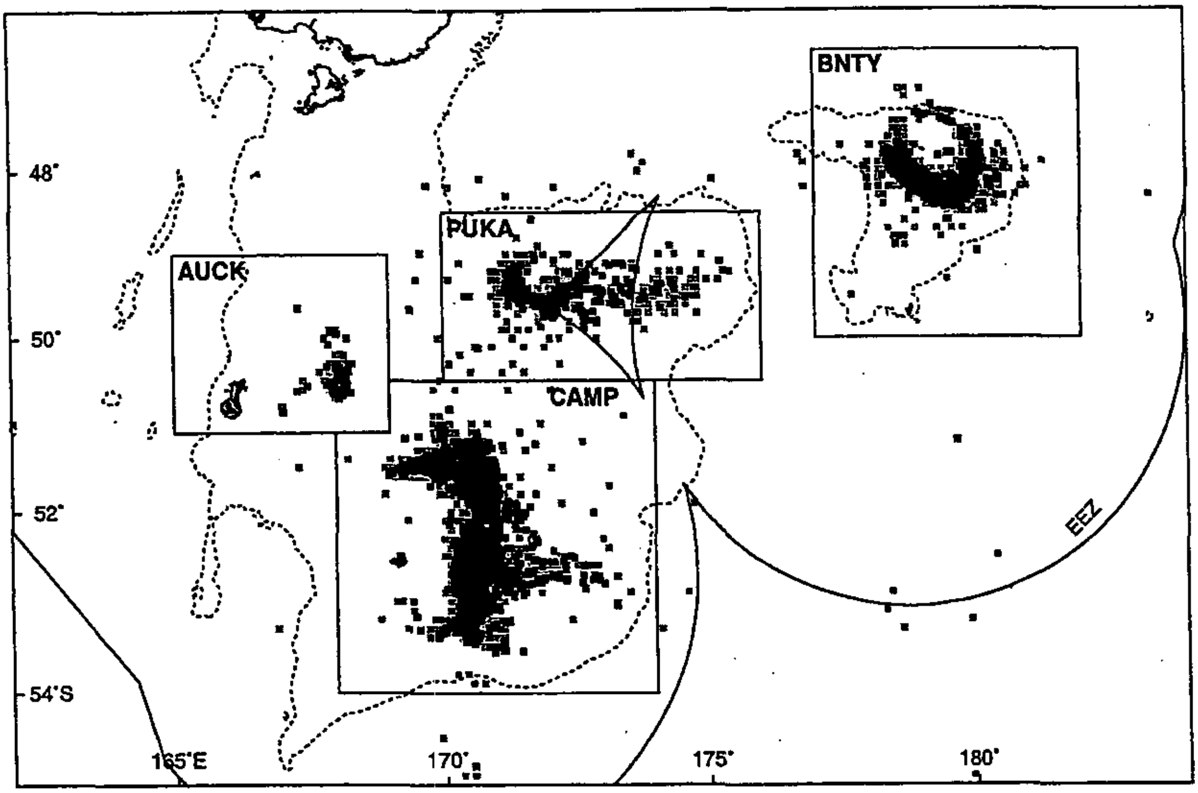

Figure 1: Distribution of tows recorded by observers on vessels targeting southern blue whiting between 1 October 1990 and 31 March 2002 (black dots), and all commercial tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.

Table 1: Number of tows and fraction of catch observed in the southern blue whiting target fishery, by fishing year.

Fishing year	Number of tows observed	Number of vessels observed	Number of trips	Observed catch (% of target fishery catch)	Total fishery effort (h)
1990–91	189	4	4	9.5	7 413
1991–92	723	12	12	20.3	14 964
1992–93	411	7	8	48.9	4 722
1993–94	226	5	7	58.6	2 578
1994–95	240	5	7	87.6	2 228
1995–96	144	4	4	38.1	2 310
1996–97	249	6	9	54.1	2 801
1997–98	418	9	13	66.3	4 065
1998–00*	376	11	14	45.2	4 962
2000–01	288	10	10	79.9	2 382
2001–02	441	10	11	80.3	3 899

* 18 month period due to transition between Oct–Sep and Apr–Mar fishing year

The spread of observer effort over the range of vessel sizes was examined and compared to the spread of vessel sizes over the entire target fishery (Figure 2). These histograms, which are formed from the vessel length associated with each tow over the 12-year period, show that although the full range of vessel sizes in the southern blue whiting fishery received some observer coverage, the proportion of tows made by each vessel length class was not well matched by the observer effort. The fishery was dominated by vessels in the 80–90 m and 100–110 m ranges with very few tows by vessels less than 60 m. The observed effort was spread more evenly among the range of vessel sizes, with the result that the largest length group, the 100–110 m vessels, were underrepresented and the smaller, 60–80 m, vessels were overrepresented by observer coverage.

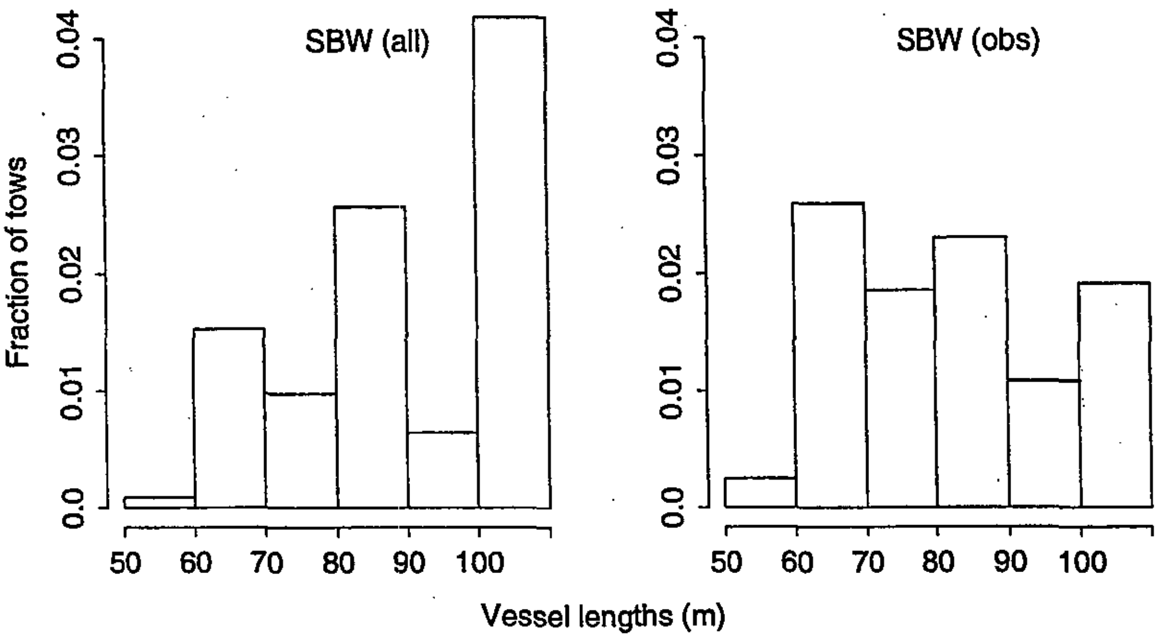

Figure 2: Distribution of vessels sizes for all tows in the target southern blue whiting fishery (left) and for all tows in the observed fraction (right) for the period 1990–91 to 2001–02.

3.1.2 Oreos

The positions of all observed trawls in the target oreo fishery between 1 October 1990 and 30 September 2002 are shown in comparison with those of all target commercial trawls recorded on TCEPR forms from the same period in Figure 3. The geographic spread of coverage is good over most of the main fishery grounds, particularly along the south Chatham Rise (areas SWCR and SECR), off Otago (OTAG), along the Macquarie Ridge (MACQ), and around the Bounty Plateau and Pukaki Rise (BNTY). In some inshore regions, especially off Kaikoura and the east coast of the North Island, coverage was very low, but annual landings of oreos from these areas are relatively low. The distribution of observer effort is strongly linked to the distribution of the orange roughy fishery as there is a considerable overlap of the fishing grounds and many trips target both oreos and orange roughy. Tows recorded in areas outside the six defined by the boxes in Figure 3 (including outliers with probable position errors) were combined into a single OTHER area category.

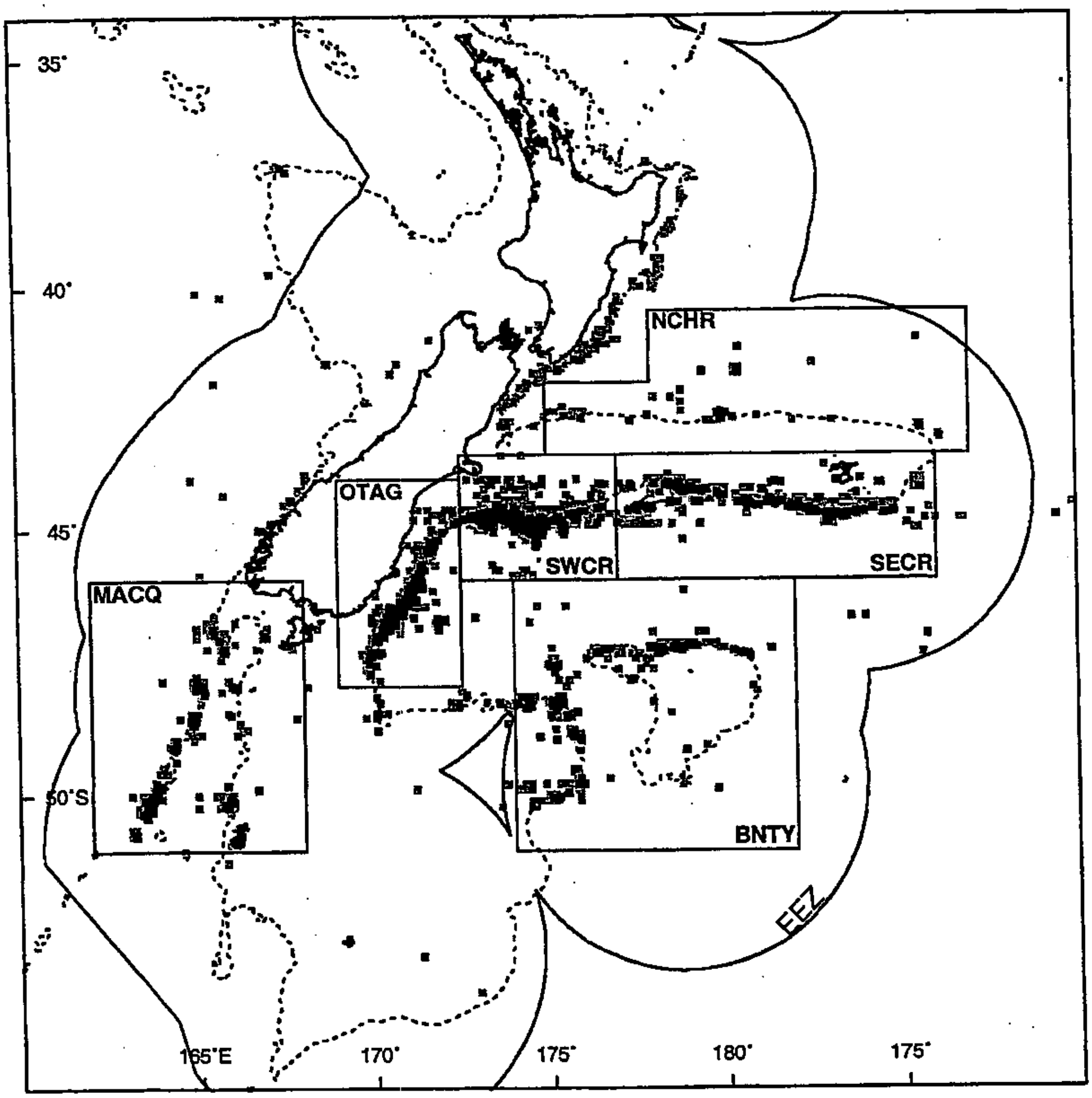

Figure 3: Distribution of tows recorded by observers on vessels targeting oreo between 1 October 1990 and 30 September 2002 (black dots), and all commercial target tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.

The annual number of observed tows, and the fraction of the fishery observed, has fluctuated considerably during the 12 years (Table 2). For the first four years examined, the fraction of the total annual catch which was observed was less than 7% and was only 1.7% in 1993–94. Coverage improved from 1994–95 onwards and in the last four years has ranged from 10% to 23% of the annual target catch. The number of vessels observed has also increased over time from 2–7 vessels per year in the first 6 years to 6–12 vessels in the last 6 years. A total of 35 vessels were observed during this period.

Table 2: Number of tows and fraction of catch observed in the oreo target fishery, by year.

Fishing year	Tows observed	Number of vessels observed	Number of trips	Observed catch (% of target fishery catch)	Total fishery effort (h)
1990–91	321	7	7	6.8	2 540
1991–92	32	2	2	3.5	1 559
1992–93	54	2	2	3.7	2 078
1993–94	51	5	7	1.7	2 520
1994–95	221	6	8	11.0	1 892
1995–96	111	3	4	6.0	2 820
1996–97	161	6	7	6.6	3 605
1997–98	277	8	10	8.4	2 374
1998–99	328	7	9	10.2	3 845
1999–00	991	12	18	22.9	4 244
2000–01	574	7	13	15.7	2 664
2001–02	539	11	14	18.1	2 338

The spread of observer effort over the range of vessel sizes was examined and compared to the spread of vessel sizes over the entire target fishery (Figure 4). These histograms show that not only was the range of vessels in the oreo fishery well covered, but also the proportion of tows made by each vessel length class was well matched by the observer effort. Most vessels in this fishery were in the 40–50 and 60–70 m range and this is the range most covered by observers. Only the very smallest and very largest vessels in the fleet, less than 20 m or over 80 m, and vessels in the 50–60 m range were poorly covered by observers, but these vessels contributed only a small fraction to the total effort in this fishery.

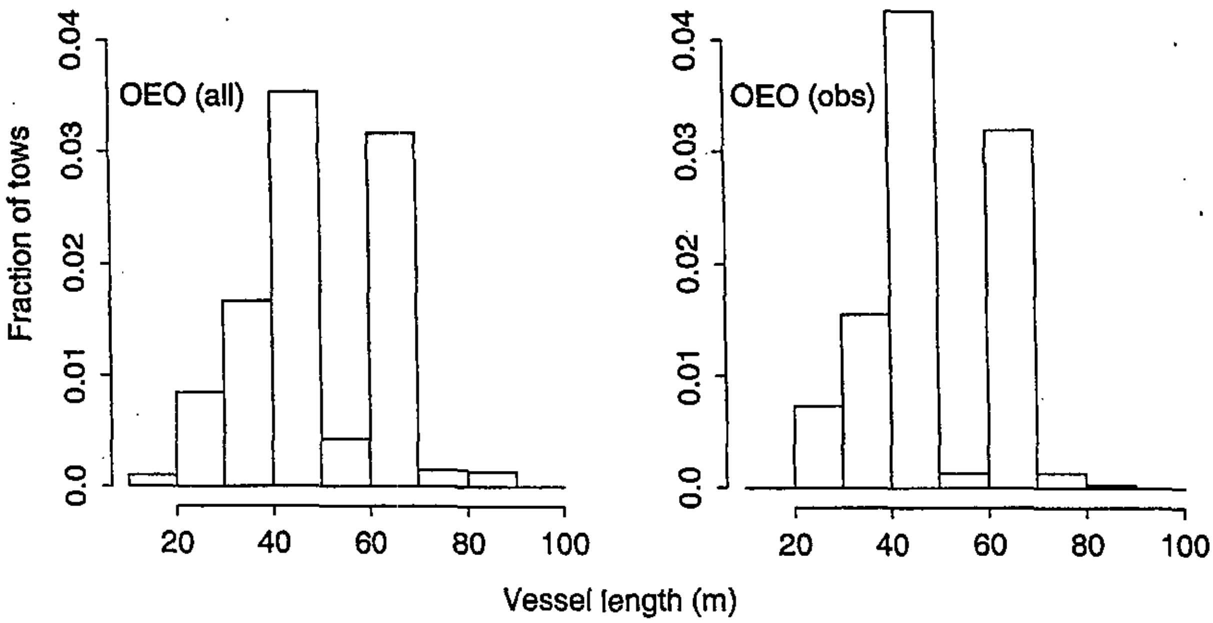

Figure 4: Distribution of vessels sizes for all tows (TCEPR and CELR) in the target oreo fishery (left) and for all tows in the observed fraction (right) for the period 1990–91 to 2001–02.

3.2 Comparison of estimators

The two forms of the bycatch and discard ratio estimators were examined and compared. This was done by combining observer data from all fishing years and making bootstrap estimates of c.v.s for bycatch and discards of the COM and OTH species categories in each fishery for each of the estimators (one based on target species estimated catch and the other on tow duration). The two c.v.s calculated in each case were compared in order to identify the estimator which consistently produced the lowest c.v.. The results of these comparisons are shown in Tables 3 and 4. Although the differences were small (range 0.03% to 2.06%), in six out of the eight comparisons the tow duration-based estimator provided a lower c.v. than the target species catch-based estimator. The two cases in which the target species catch-based estimator was lowest were not linked, one associated with bycatch in the oreo fishery and the other with discards in the southern blue whiting fishery. The ratio c.v.s were generally smaller for bycatch than for discards (especially in the southern blue whiting fishery and for COM species in both fisheries) and were particularly high for COM species discards in both fisheries. It is uncertain whether commercial catch-effort records of target species catch are more reliable than records of tow duration. Although it is easier to measure tow duration than to estimate catch weights, two entries are required (start and finish times) both of which need to be correct, and target species catch is of more interest. These comparisons provide a way of choosing between the two alternatives and so, although there was very little between them, the tow duration-based estimator was selected for all bycatch and discard calculations.

Table 3: Comparison of bycatch estimators

Fishery	Species category	Estimator	Bycatch ratio	c.v.
Southern blue whiting	COM	SBW catch	0.0051	4.97
	COM	Tow duration	56.6	4.75
	OTH	SBW catch	0.0024	5.74
	OTH	Tow duration	26.5	5.52
Oreo	COM	OEO catch	0.035	10.19
	COM	Tow duration	231.4	10.39
	OTH	OEO catch	0.037	6.65
	OTH	Tow duration	241.8	6.51

Table 4: Comparison of discard estimators

Fishery	Species category	Estimator	Discard ratio	c.v.
Southern blue whiting	COM	SBW catch	3.2e-05	26.81
	COM	Tow duration	0.336	27.14
	OTH	SBW catch	0.001	9.65
	OTH	Tow duration	14.37	9.62
Oreo	COM	OEO catch	0.0002	35.65
	COM	Tow duration	1.37	33.59
	OTH	OEO catch	0.029	6.93
	OTH	Tow duration	179.66	6.47

3.3 Bycatch in the southern blue whiting fishery

3.3.1 Overview of raw bycatch data

Exploratory plots were prepared to examine total bycatch per tow (plotted on a log scale) with respect to the available variables (Figure 5). Although total bycatch per tow was highly variable in each of these plots, there is an indication of increased bycatch with tow duration throughout the range of tow durations recorded. There were some between-area differences with catches higher in AUCK and PUKA than in BNTY and CAMP. There were some differences in bycatch rates between nations, with higher catches from Norwegian vessels compared with vessels of other nations. Vessels from Russia, Ukraine, and Poland had similar, relatively low, bycatch levels at about 80 $kg.tow^{-1}$. The recorded nationality refers to the country of registration except where a combined code, such as NZJAP, is used. These codes can be interpreted as meaning there are two nationalities involved in the vessel, usually the presence of New Zealand personnel on, for example, a Japanese vessel. There is no trend in the relatively small between-year fluctuations of bycatch, with the highest levels in 1993–94 and 1994–95 and the lowest levels in the preceding and following years. The level of variation in bycatch levels between companies is similar to that between years, although company 'k' stands out as having much greater bycatch levels than other companies. The median bycatch differs very little among the main three months of the fishery, but fishing outside of the main season in May results in greater levels of bycatch. There is considerable variation in bycatch levels among the 31 vessels plotted, from less than 50 $kg.tow^{-1}$ to more than 2.5 $t.tow^{-1}$. There is also a clear difference in bycatch between the two tow-types, with midwater tows catching much smaller amounts of non-target species.

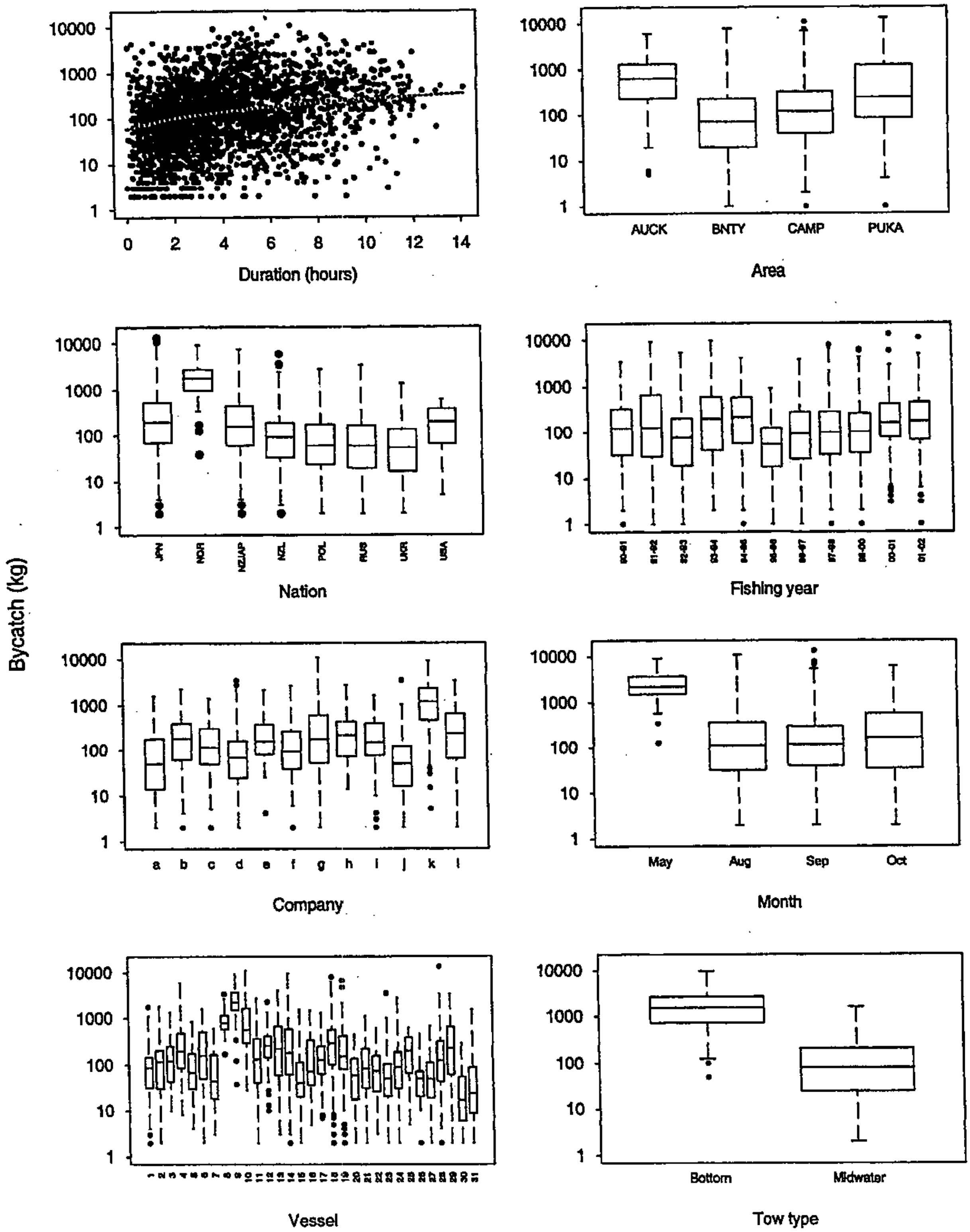

Figure 5: Southern blue whiting. Total bycatch per tow plotted against some of the available variables. Bycatch is plotted on a log scale. The dashed line in the top left panel represents a mean fit to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. Nations, companies, months, and vessels with fewer than 40 records were not plotted. See Figure 1 for area codes; JPN, Japan; NOR, Norway; NZJAP, New Zealand crew on Japanese vessel; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine; USA, United States of America.

3.3.2 Regression modelling and stratification of bycatch data

The unit of interest in this analysis was the bycatch ratio, catch/hour, which was log-transformed. Some 34% of observed tows did not record any bycatch of COM species, and 35% of tows did not record any bycatch of OTH species. The equivalent percentages for the main individual bycatch species were hoki (HOK), 61%; hake (HAK), 66%; ling (LIN), 50%. Because of the high fraction of tows in each species category with no bycatch, a combination of linear and binomial models was run in each case. Variables tested were *vessel*, *fishing year*, *area*, *month*, *vessel nationality*, and *net type*. Other variables, such as *depth category* and vessel *company*, were available but were not considered because they could not practically be used to stratify commercial catch effort data or because preliminary plots showed that they had little influence.

The variable *vessel* was most consistently selected first into each model, with either *area* or *fishing year* the next variable selected in most of the models (Table 5). There was a strong area effect in the bycatch of COM species, especially HOK and to a lesser extent HAK, but *fishing year* had a much greater influence on the bycatch of OTH species. The variables *month* and *fishing year* were the next most important, after vessel, in the models for LIN. There was insufficient spread of observer data to allow stratification of bycatch ratio estimates by more than one or two factors, and factors such as *vessel* and *net-type* could not easily be used to group commercial catch effort data. Appropriate strata were determined from the model results for each species group and, because of the importance of vessel in the regressions, separate ratios were calculated only where at least three vessels were represented in each stratum. The strata selected for each species group are shown in Table 5.

Table 5: Summary of regression modelling for bycatch in the southern blue whiting fishery. The numbers denote the order in which the variable entered the model; –, not selected. Figures in bold type indicate variables used in stratification of bycatch data. *fyr*, fishing year.

Species category	Model type						Variable
		vessel	*area*	*fyr*	*month*	*net-type*	*nation*
COM	Linear	1	**2**	5	6	3	4
COM	Binomial	1	**2**	3	4	6	5
OTH	Linear	1	6	**2**	5	3	4
OTH	Binomial	1	3	**2**	4	6	5
HOK	Linear	1	**2**	4	3	5	–
HOK	Binomial	2	**1**	5	3	–	4
HAK	Linear	1	**4**	**3**	2	5	6
HAK	Binomial	2	**1**	**3**	4	5	6
LIN	Linear	1	**–**	**5**	2	3	4
LIN	Binomial	1	**5**	**2**	4	3	6

3.4 Discards in the southern blue whiting fishery

3.4.1 Overview of raw discard data

Exploratory plots were prepared to examine total discards per processing group (plotted on a log scale) with respect to the available variables (Figure 6). There was a correlation between discards and total tow duration (r = 0.26), with discards increasing with tow duration. Most tows (97%) were less than 10 hours long, but the combined duration of several tows within a processing group was as much as 50 hours. There was little variation in total discards between areas, depth categories, and between the three main months of the fishery, August–October. There was no trend in discard levels over time, although the lowest median value was in the first fishing year in the series and, of the vessel nationalities, those of Japan and Norway had the highest median discards and those of Poland and Russia the lowest. There is a high level of variation in discards between companies and vessels.

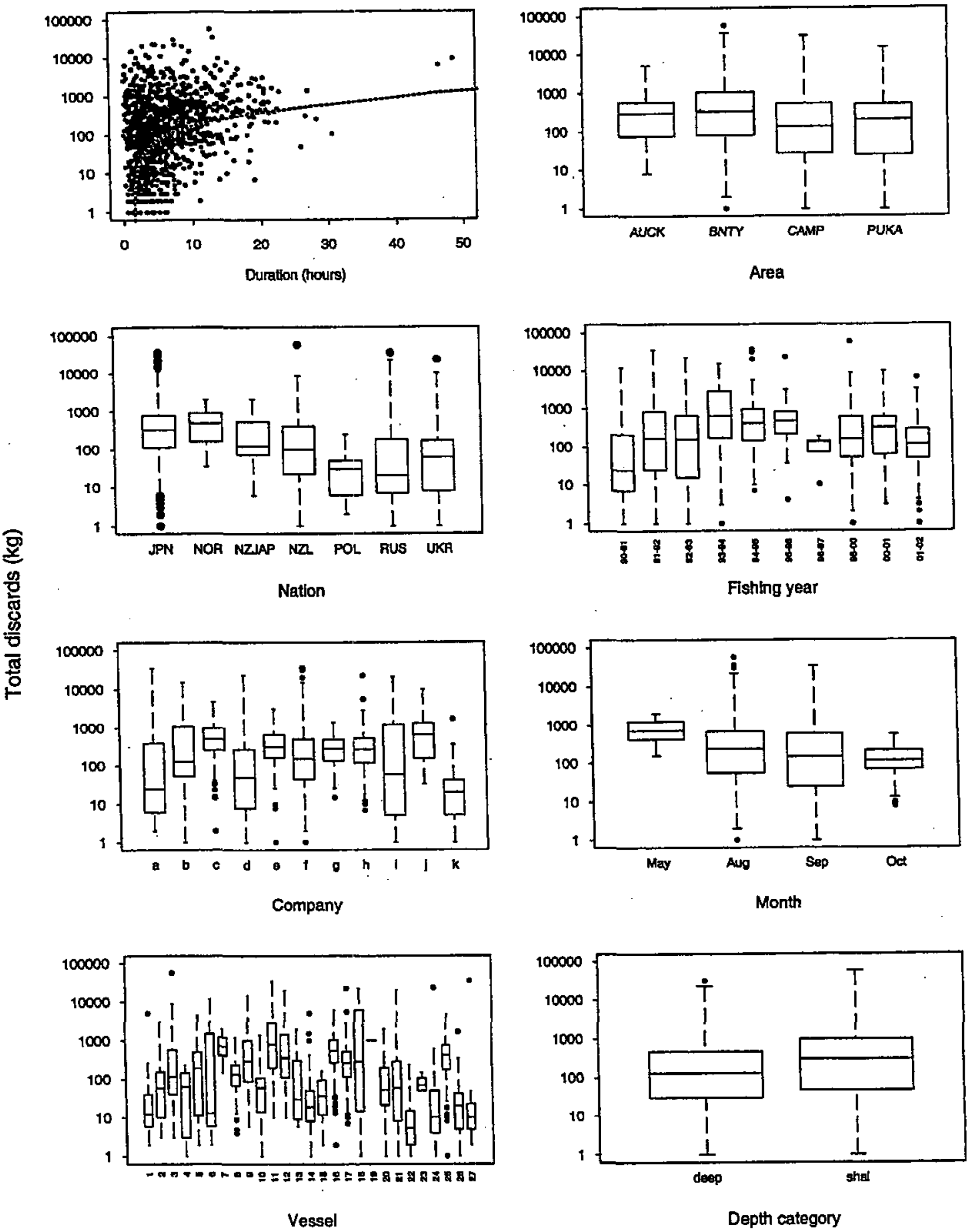

Figure 6: Southern blue whiting. Total discards per processing group plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. Months, nations, companies, and vessels with fewer than 20 records were not plotted. See Figure 1 for area codes; JPN, Japan; NOR, Norway; NZJAP, New Zealand crew on Japanese vessel; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine.

3.4.2 Regression modelling and stratification of discard data

The dependent variable in these regressions was the log of the discard ratio, discards/hour. Of the 2105 records available for this analysis 69% did not show any discard of SBW, while 95% did not show any discard of COM and 54% did not show a discard of OTH. More than 95% of records for each of the commercial species examined separately, HOK, HAK, and LIN, did not show a discard. Because of the low level of discarding of commercial species, regressions were not performed for those species categories and no stratification was used in the subsequent calculation of total discards. For the remaining two categories, SBW and OTH, a combination of log-linear and logistic models was run.

In each of the four regressions run, the variable *vessel* was selected first, with *fishing year* in the second position in three out of four models (Table 6). In the linear model for OTH, *net-type* was selected second into the model, the result of catching more unwanted species by midwater fishing than by bottom fishing. The number of tows in each processing group (*ntows*) was also tested in the models, but as the value of this variable was mostly "1", it had little influence in the models. The variable *area* was selected into only one model, having some influence on the probability of a discard of OTH species. The strata chosen for the ratio calculations for each species group are shown in Table 6. Because of the importance of vessel in the regressions, separate ratios were calculated only where at least three vessels were represented in each stratum.

Table 6: Summary of regression modelling for discards in the southern blue whiting fishery. The numbers denote the order in which the variable entered the model; –, not selected. Figures in bold type indicate variables used in stratification of discard data. *fyr*, fishing year; *ntows*, number of tows in the processing group.

Species category	Model type	Variable						
		vessel	*month*	*fyr*	*net type*	*nation*	*ntows*	*area*
SBW	Linear	1	3	**2**	–	4	–	–
SBW	Binomial	1	5	**2**	–	3	4	–
OTH	Linear	1	6	**5**	2	4	3	–
OTH	Binomial	1	7	**2**	5	4	6	3

3.5 Bycatch in the oreo fishery

3.5.1 Overview of raw bycatch data

Exploratory plots were prepared to examine total bycatch per tow (plotted on a log scale) with respect to the available variables (Figure 7). There was a positive relationship between tow *duration* and total bycatch, with catch increasing with duration throughout the range of tow durations. Bycatch levels varied with *area*, with the highest median levels in the north Chatham Rise (570 kg.tow^{-1}) and the lowest in the Louisville Ridge (22 kg.tow^{-1}) and South Tasman Rise fisheries (27 kg.tow^{-1}). There was less variation in median bycatch levels between *fishing years* (range 60–160 kg.tow^{-1}) and between *months* (range 50–230 kg.tow^{-1}), and no apparent temporal trends within or between years. The *company* coded 'b' had lower median bycatch levels (40 kg.tow^{-1}) than the other five companies plotted (range 90–145 kg.tow^{-1}). Most vessels were New Zealand registered and crewed with some data from Faroese registered vessels, and the median bycatch did not vary between these nations. The median bycatch was only slightly greater for flat tows than for hill tows, but there was considerable variation between *vessels* with medians ranging from 40 kg.tow^{-1} to 265 kg.tow^{-1}.

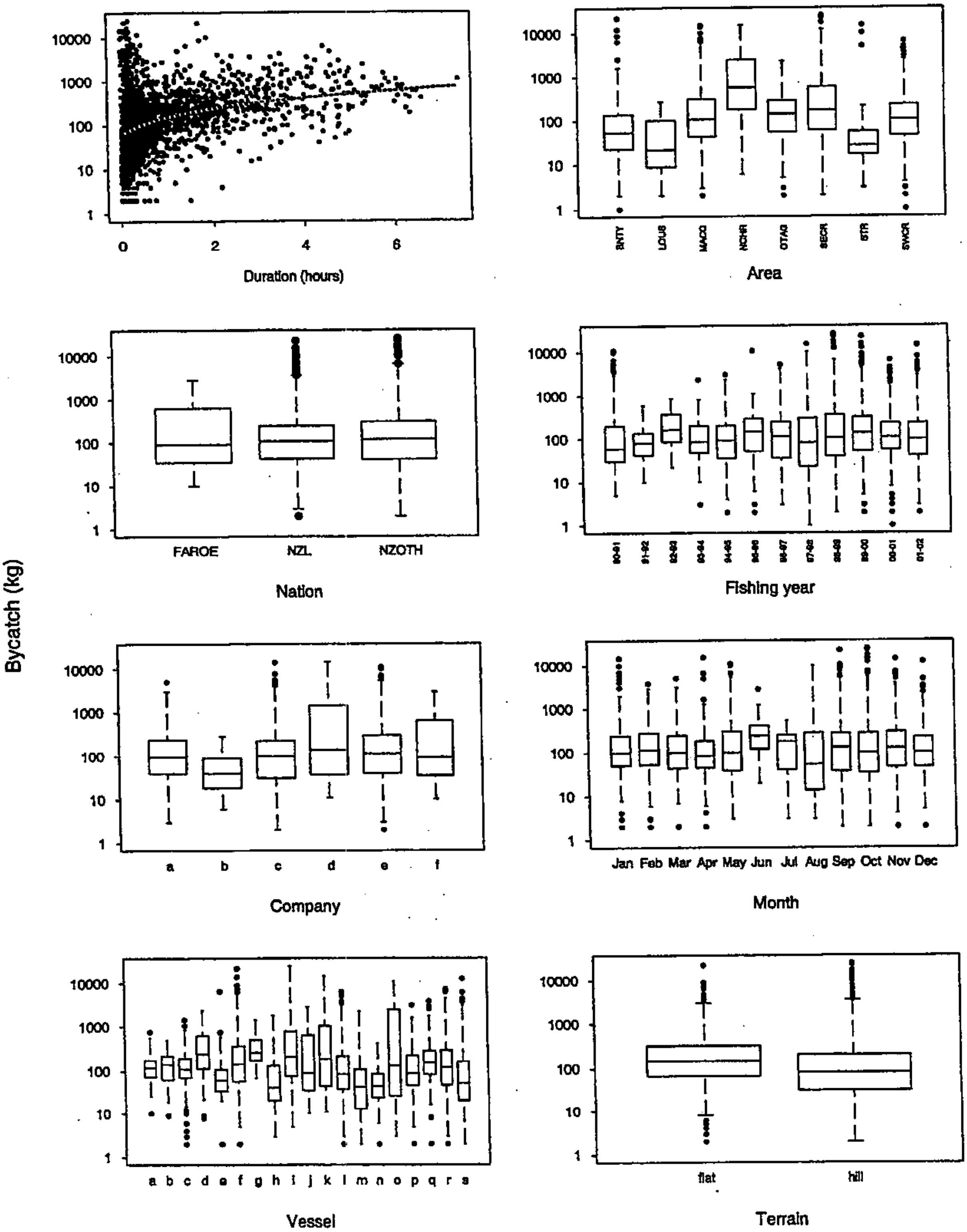

Figure 7: Oreo. Total bycatch per tow plotted against some of the available variables. Bycatch is plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. Nations, companies, and vessels with fewer than 25 records were not plotted. See Figure 3 for area codes; FAROE, Faroe Islands; NZL, New Zealand; NZOTH, mixture of New Zealand and other nationalities.

3.5.2 Regression modelling and stratification of bycatch data

The unit of interest in this analysis was the log of the bycatch ratio, catch/hour. Regression models were run to examine the influence of various factors on the catch rates of the combined COM and OTH species categories as well as for orange roughy (ORH), hoki (HOK), and pale ghost shark (GSP) separately. Of the 3660 observed tows, 59% did not record any bycatch of COM species, while only 18% of tows did not record any bycatch of OTH species. The equivalent values for individual species examined were; ORH, 72%; HOK, 81%; GSP, 89%. A combination of linear and binomial models was run for each category.

The *vessel* variable was consistently the most influential in determining the probability and level of bycatch in the oreo fishery, entering 6 of the 10 models in the first position (Table 7). The variable *area* was nearly as influential, however, being selected in the first or second position in most models and *fishing year* was generally selected third or fourth. The strata chosen for the ratio calculations for each species group are shown in Table 7. Because of the importance of vessel in the regressions, separate ratios were calculated only where at least three vessels were represented in each stratum.

Table 7: Summary of regression modelling for bycatch in the oreo fishery. The numbers denote the order in which the variable entered the model; –, not selected. Figures in bold type indicate variables used in stratification of bycatch data. *fyr*, fishing year; *depthcat*, depth category (shallow/deep).

Species category	Model type							Variable
		vessel	*area*	*fyr*	*depthcat*	*month*	*nation*	*target*
COM	Linear	1	**2**	**3**	4	5	6	7
COM	Binomial	1	**2**	**4**	3	5	6	7
OTH	Linear	2	**1**	**3**	4	5	6	–
OTH	Binomial	1	**4**	**3**	6	2	–	5
ORH	Linear	2	**1**	**3**	–	–	4	–
ORH	Binomial	2	**1**	**4**	3	5	6	7
HOK	Linear	1	**2**	**3**	4	5	–	–
HOK	Binomial	1	**3**	**4**	2	5	7	6
GSP	Linear	–	–	**2**	–	1	–	–
GSP	Binomial	1	**2**	**4**	5	3	7	6

3.6 Discards in the oreo fishery

3.6.1 Overview of raw discard data

Exploratory plots were prepared to examine total discards per processing group (plotted on a log scale) with respect to the available variables (Figure 8). These show a positive relationship between tow duration and total discards, with total tow duration per processing group mostly under 8 hours. There is little evidence of a difference in total discards between fishery areas, with medians all at a similar level. Most data are from New Zealand vessels and there is little apparent difference in discard levels between these vessels and those recorded as being Faroese. The first fishing year of the series, 1990–91, stands out as having somewhat higher discards than in the other years, but the medians are at a broadly similar level in subsequent years. Discard levels were low in July compared to other months and there was no discernible difference due to depth of fishing. There is a high level of variability in discard levels between vessels in this fishery, as was shown for the southern blue whiting fishery above.

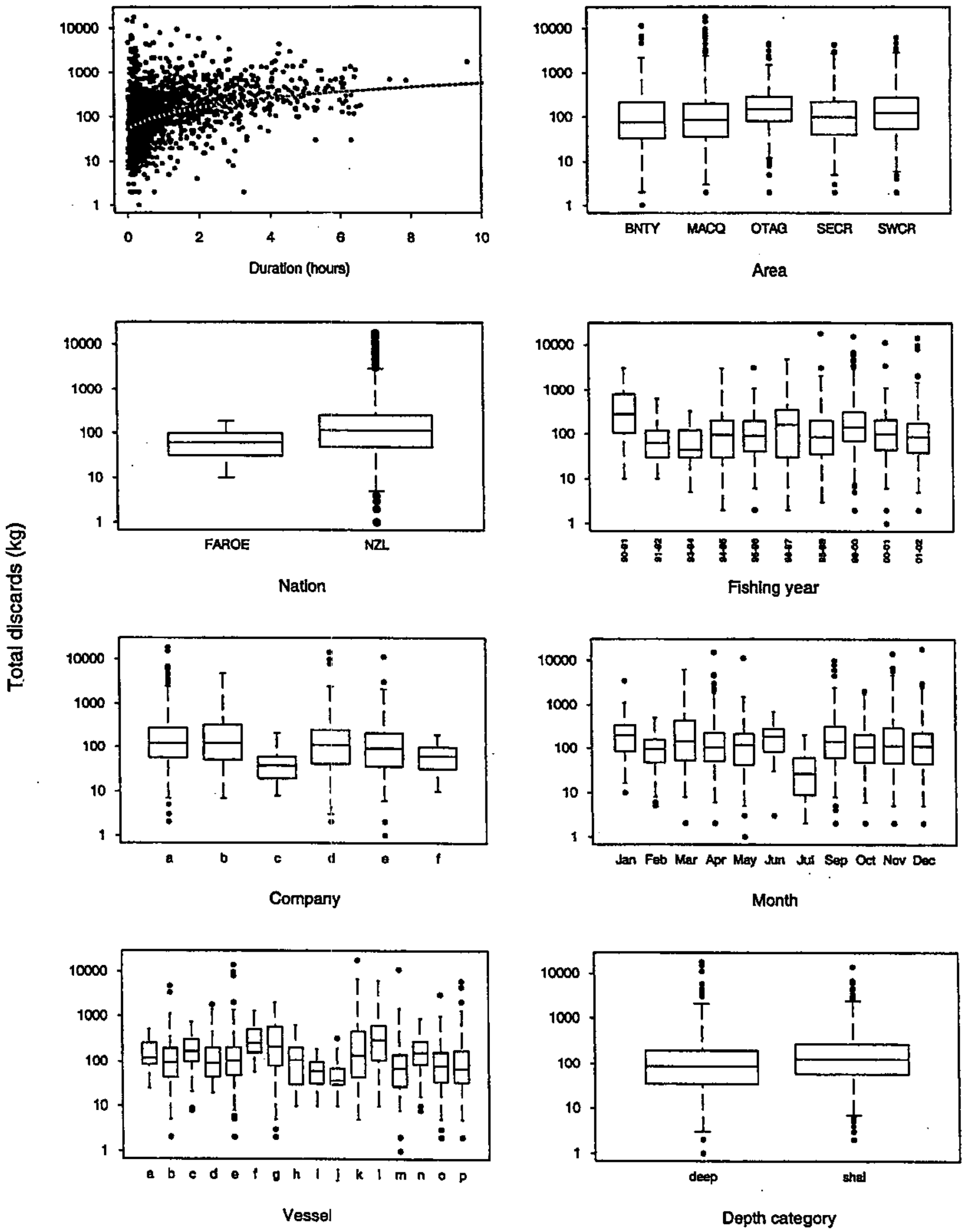

Figure 8: Oreo. Total discards per processing group plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. Areas, nations, fishing years, companies, months, and vessels with fewer than 20 records were not plotted. See Figure 3 for area codes; FAROE, Faroe Islands; NZL, New Zealand; NZOTH, mixture of New Zealand and other nationalities.

3.6.2 Regression modelling and stratification of discard data

The dependent variable in these regressions was the log of the discard ratio, discards per hour. A log transformation was made to this variable in each case, resulting in an approximately normal distribution of values. Of the 2293 processing groups available for this analysis, 85% did not record any discard of OEO, 95% did not record a discard of COM, and 12% did not record a discard of OTH. The equivalent values for the individual species examined were; ORH, 99%; HOK, 98%; GSP, 97%. Because of the low level of discarding of commercial species, regressions were not performed for those species categories and no stratification was used in the subsequent calculation of total discards. For the remaining two categories, OEO and OTH, a combination of log-linear and logistic models was run.

Regression modelling revealed that, as in the southern blue whiting fishery, *vessel* was the most critical factor overall (Table 8). After this, *month, area,* and *fishing year* were the terms most frequently selected, with area being especially influential in discard levels of OTH species. The strata chosen for the ratio calculations for each species group are shown in Table 8. Because of the importance of vessel in the regressions, separate ratios were calculated only where at least three vessels were represented in each stratum.

Table 8: Summary of regression modelling for discards in the oreo fishery. The numbers denote the order in which the variable entered the model; –, not selected. Figures in bold type indicate variables used in stratification of discard data. *fyr*, fishing year; *depthcat*, depth category (shallow/deep); *ntows*, number of tows in the processing group.

Species category	Model type	Variable						
		vessel	*fyr*	*area*	*month*	*depthcat*	*nation*	*ntows*
OEO	Linear	1	**4**	3	2	5	–	–
OEO	Binomial	1	**2**	5	3	4	–	–
OTH	Linear	2	**4**	**1**	3	–	–	–
OTH	Binomial	1	**2**	**3**	4	–	–	–

3.7 Calculation of bycatch

3.7.1 Southern blue whiting

Bycatch ratios for COM species were calculated separately for each area and year. Where sufficient records were available, and bootstrapping produced a normal or near-normal distribution of ratio estimates, ratios were calculated for combinations of areas and months. This was possible for all years in CAMP (the area with the most data) and for a few years in PUKA and BNTY. A summary of the calculated ratios, by year and area, are shown in Table 9. Bycatch of COM species ranged from about 23 $kg.h^{-1}$ in BNTY to about 160 $kg.h^{-1}$ in AUCK, with an overall catch rate of 56.5 $kg.h^{-1}$. Bycatch ratios of OTH species, calculated by fishing year alone, fluctuated over time and ranged from about 8 $kg.h^{-1}$ in 1992–93 and 1995–96, to 61 $kg.h^{-1}$ in 1993–94. The high rate of COM catches in AUCK and PUKA are due largely to high catch rates of hoki (HOK), which were also highest in these areas, and to a lesser extent hake (HAK). These two species were virtually absent from records in area BNTY. Hake, in particular, is known not to be present around the Bounty Plateau (Anderson et al. 1998). The catch rate of ling (LIN) also fluctuated between years, from a low of 5.7 $kg.km^{-1}$ in 1996–97 to about 30 $kg.km^{-1}$ in 1991–92 and 1993–94. The calculated c.v.s for each ratio were generally less than 20% and those larger than this were mostly associated with catch ratios derived from fewer records. An unusually large catch of a less common species also tends to inflate the c.v..

Table 9: Summary of sample sizes, bycatch ratios (kg.h^{-1}) and associated c.v.s used to calculate total bycatch in the southern blue whiting fishery. Only values for the primary stratum (as identified from regression analysis) are shown; n, number of tows (number of vessels in parentheses); $\hat{R}$, bycatch ratio.

Species category	Area	Fishing year	n	$\hat{R}$	c.v. (%)
COM	All	All	3665(35)	56.5	4.7
COM	AUCK	All	65(9)	161.9	19.5
COM	BNTY	All	893(23)	23.3	11.4
COM	CAMP	All	2228(34)	44.3	5.3
COM	PUKA	All	473(23)	156.8	8.5
OTH	All	All	3665(35)	10.3	5.5
OTH	All	1990–91	188(4)	10.3	15.5
OTH	All	1991–92	721(12)	26.5	9.2
OTH	All	1992–93	406(7)	7.8	16.6
OTH	All	1993–94	222(5)	61.0	22.4
OTH	All	1994–95	238(5)	12.9	14.8
OTH	All	1995–96	141(4)	7.6	20.2
OTH	All	1996–97	248(6)	15.4	13.0
OTH	All	1997–98	407(9)	32.6	21.3
OTH	All	1998–00	370(11)	22.8	16.4
OTH	All	2000–01	285(10)	55.0	12.5
OTH	All	2001–02	439(10)	29.4	8.6
HOK	All	All	3665(35)	23.1	7.8
HOK	AUCK	All	65(9)	90.2	29.3
HOK	CAMP	All	2228(34)	12.2	7.9
HOK	PUKA	All	473(23)	106.1	10.3
HOK	BNTY	All	893(23)	0.0025	40.2
HAK	All	All	3665(35)	12.6	6.6
HAK	AUCK	All	65(9)	53.0	30.5
HAK	CAMP	All	2228(34)	15.6	7.4
HAK	PUKA	All	473(23)	11.9	12.1
HAK	BNTY	All	893(23)	0.0	0.0
LIN	All	All	3665(35)	11.7	5.2
LIN	All	1990–91	188(4)	11.7	17.9
LIN	All	1991–92	721(12)	31.0	7.3
LIN	All	1992–93	406(7)	10.3	21.8
LIN	All	1993–94	222(5)	30.2	16.4
LIN	All	1994–95	238(5)	24.4	11.1
LIN	All	1995–96	141(4)	10.1	24.1
LIN	All	1996–97	248(6)	5.7	15.6
LIN	All	1997–98	407(9)	21.5	15.8
LIN	All	1998–00	370(11)	16.3	26.9
LIN	All	2000–01	285(10)	17.4	15.0
LIN	All	2001–02	439(10)	25.2	15.9

Annual bycatch was estimated by applying the ratios in Table 9 to the target fishery tow duration totals for the equivalent strata, as described in Section 2.5 (Table 10 and Figure 9). The estimates of bycatch of COM species in the target southern blue whiting fishery show a wide range (45–1082 t per year) due mostly to annual fluctuations in fishing effort (see Table 1). The three main commercial bycatch species in this fishery, hoki, hake, and ling, were caught in similar amounts overall, with each species being the main bycatch species in at least one year. Catches of OTH species were generally less than COM species, ranging between 14% and 59% of the total annual bycatch. Total annual bycatch estimates ranged from 63 to 1479 t.

Table 10: Estimates of bycatch (t) in the target southern blue whiting trawl fishery by fishing year, species category, and overall, with 95% confidence intervals in parentheses.

												Species category
	COM		OTH		HOK		HAK		LIN		Total	
1990–91	457	(355–570)	76	(56–98)	136	(73–223)	225	(163–291)	101	(46–101)	533	(412–668)
1991–92	1 082	(928–1 252)	397	(343–460)	606	(513–704)	99	(78–123)	454	(314–454)	1 479	(1 271–1 712)
1992–93	169	(120–235)	37	(29–47)	76	(47–121)	41	(29–57)	75	(32–75)	206	(150–282)
1993–94	225	(182–278)	157	(116–205)	53	(40–70)	89	(70–113)	109	(60–109)	382	(298–483)
1994–95	149	(131–170)	29	(25–34)	50	(42–59)	49	(41–58)	57	(42–57)	178	(157–204)
1995–96	45	(35–56)	17	(12–23)	16	(11–23)	5	(4–7)	21	(10–21)	63	(48–79)
1996–97	160	(132–191)	43	(36–51)	104	(82–131)	22	(17–29)	21	(13–21)	203	(168–242)
1997–98	163	(135–196)	132	(101–176)	55	(41–76)	28	(22–35)	97	(61–97)	296	(236–372)
1998–00	170	(134–216)	113	(92–140)	67	(47–92)	35	(24–50)	78	(40–78)	283	(226–356)
2000–01	92	(80–107)	131	(116–151)	38	(32–44)	11	(10–14)	42	(27–42)	223	(195–258)
2001–02	249	(219–290)	115	(106–125)	66	(56–80)	81	(66–100)	120	(88–120)	364	(325–415)

3.7.2 Oreos

Bycatch ratios for all species categories were calculated separately for each area and fishing year where the number of records was sufficient (Table 11). Because of the particularly low observer coverage from 1991–92 to 1993–94, ratios based on all years were substituted for all combinations of areas with these years. Similar substitutions were made for other strata where data were insufficient or where bootstrapped distributions of ratios were too irregular. Bycatch rates for COM species were lowest in STR (5.3 kg.h^{-1}) and highest in MACQ and SECR (550 kg.h^{-1} and 616 kg.h^{-1}, respectively) where ORH catch rates were high. Surprisingly, for an orange roughy fishery, catch rates of ORH in area STR were very low. As only observer records showed any targeting at all of oreos in this area (i.e., no targeting of oreos was recorded on commercial catch effort forms) this situation is likely to be the result of a discrepancy between the observer and skipper in the recording of target species. The observer trawl catch effort logbook instructions (Sanders & Mackay 2002) state "If the vessel does not identify a target species, enter the species you believe is being targeted." The overall catch ratio for OTH species is very similar to that for COM species, with differences only in the annual levels. In particular, OTH bycatch ratios in area STR were very high and this can be attributed to the high level of coral species bycatch in deepwater fisheries in that area (Anderson & Clark, 2003). Of the three commercial bycatch species, ORH was of much greater importance, with overall HOK bycatch ratios only about one quarter, and GSP less than 2%, of ORH bycatch ratios. The c.v.s associated with these ratios were generally less than 20% and ranged from 3.7% to 59%.

Table 11: Summary of sample sizes, bycatch ratios (kg.h^{-1}) and associated c.v.s used to calculate bycatch in the oreo fishery. Only values for the primary stratum (as identified from regression analysis) are shown; n, number of tows (number of vessels in parentheses); $\hat{R}$, bycatch ratio.

Species category	Area	Fishing year	n	$\hat{R}$	c.v. (%)
COM	All	All	3 660(35)	231.4	10.4
COM	BNTY	All	395(9)	213.5	47.5
COM	LOUS	All*	43(1)	231.4	10.4
COM	MACQ	All	725(11)	550.9	22.0
COM	NCHR	All*	43(6)	231.4	10.4
COM	OTAG	All	443(18)	43.0	15.0
COM	OTHR	All*	22(10)	231.4	10.4
COM	SECR	All	430(14)	616.0	20.2
COM	STR	All	65(4)	5.3	51.6
COM	SWCR	All	1 494(19)	91.1	12.6
OTH	All	All	3 660(35)	241.8	6.5
OTH	BNTY	All*	395(9)	241.8	6.5
OTH	LOUS	All*	43(1)	241.8	6.5
OTH	MACQ	All	725(11)	1 295.3	13.9
OTH	NCHR	All*	43(6)	241.8	6.5
OTH	OTAG	All	443(18)	106.8	4.5
OTH	OTHR	All*	22(10)	241.8	6.5
OTH	SECR	All	430(14)	151.5	7.7
OTH	STR	All	65(4)	3 572.3	53.4
OTH	SWCR	All	1 494(19)	163.0	3.7
ORH	All	All	3 660(35)	182.5	13.1
ORH	BNTY	All	395(9)	212.8	48.8
ORH	LOUS	All*	43(1)	182.5	13.1
ORH	MACQ	All	725(11)	522.1	23.0
ORH	NCHR	All*	43(6)	182.5	13.1
ORH	OTAG	All	443(18)	3.8	15.6
ORH	OTHR	All*	22(10)	182.5	13.1
ORH	SECR	All	430(14)	568.0	20.6
ORH	STR	All	65(4)	5.3	50.3
ORH	SWCR	All	1 494(19)	21.8	25.6
HOK	All	All	3 660(35)	46.5	13.8
HOK	BNTY	All	395(9)	0.6	51.4
HOK	LOUS	All*	43(1)	46.5	13.8
HOK	MACQ	All	725(11)	28.4	21.3
HOK	NCHR	All*	43(6)	46.5	13.8
HOK	OTAG	All	443(18)	34.0	18.4
HOK	OTHR	All*	22(10)	46.5	13.8
HOK	SECR	All*	430(14)	46.5	13.8
HOK	STR	All	65(4)	0.0	–
HOK	SWCR	All	1 494(19)	66.9	14.7
GSP	All	All	3 660(35)	2.5	9.2
GSP	BNTY	All	395(9)	0.1	50.5
GSP	LOUS	All*	43(1)	2.5	9.2
GSP	MACQ	All	725(11)	0.5	59.1
GSP	NCHR	All*	43(6)	2.5	9.2
GSP	OTAG	All	443(18)	5.3	13.5
GSP	OTHR	All*	22(10)	2.5	9.2
GSP	SECR	All	430(14)	0.6	34.4
GSP	STR	All	65(4)	0.0	–
GSP	SWCR	All	1 494(19)	2.4	12.2

* Strata with fewer than 50 records, fewer than 3 vessels, or non-normal bootstrap distribution of ratios. For these strata the ratio shown for all years and all areas was substituted.

The best estimates of annual bycatch of COM species in the target oreo fishery ranged from about 200 to 1700 t, and bycatch of OTH species was at a similar level ranging from about 240 to 1000 t per year (Table 12). Most of the COM catch in each year comprised orange roughy (ORH) with more than 1500 t of this species caught as bycatch in the oreo fishery in 1998–99. Hoki (HOK) was also frequently caught in this fishery, although much less so than orange roughy, and pale ghost shark contributed only a small amount to commercial species bycatch, with less than 10 t caught in most years. Total annual bycatch estimates ranged from 450 to 2600 t.

Table 12: Estimates of bycatch (t) in the target oreo trawl fishery by fishing year, species category, and overall, with 95% confidence intervals in parentheses.

Fishing year	Species category					
	COM	OTH	ORH	HOK	GSP	Total
1990–91	442 (220–783)	515 (398–638)	380 (201–678)	96 (36–174)	6 (5–7)	957 (618–1 422)
1991–92	207 (149–275)	242 (219–268)	121 (79–172)	81 (59–107)	5 (4–7)	449 (368–543)
1992–93	357 (254–481)	533 (456–622)	240 (154–344)	112 (82–148)	5 (4–7)	890 (710–1 103)
1993–94	281 (208–366)	460 (416–508)	122 (75–183)	153 (113–198)	7 (5–8)	741 (624–874)
1994–95	370 (227–562)	532 (436–652)	336 (192–523)	32 (24–42)	4 (3–5)	902 (663–1 213)
1995–96	401 (281–551)	589 (517–670)	244 (150–370)	150 (110–196)	7 (6–9)	990 (798–1 221)
1996–97	624 (423–875)	791 (686–912)	437 (266–660)	176 (129–232)	10 (7–12)	1 415 (1 109–1787)
1997–98	434 (284–637)	1 067 (604–1 805)	396 (248–599)	105 (79–136)	5 (4–6)	1 502 (888–2 442)
1998–99	1 721 (914–3 112)	880 (750–1 028)	1 560 (782–2 819)	153 (109–206)	9 (7–12)	2 601 (1 664–4 140)
1999–00	672 (447–971)	821 (726–933)	647 (366–1 040)	87 (62–119)	11 (9–14)	1 493 (1 174–1 903)
2000–01	572 (418–765)	620 (520–734)	336 (220–477)	229 (176–287)	6 (4–7)	1 192 (938–1 499)
2001–02	334 (202–487)	481 (394–587)	175 (117–244)	158 (70–254)	7 (5–8)	815 (597–1 073)

3.8 Calculation of discards

3.8.1 Southern blue whiting

Discard ratios were calculated for each year for SBW and OTH species categories, but for commercial species (COM, HOK, HAK, LIN) discards were too infrequent to apply any stratification and so ratios were calculated based on data from all years (Table 13). Discard ratios of SBW ranged from 67 $kg.h^{-1}$ to 171 $kg.h^{-1}$ over the eight years for which ratios were calculated. This is a high rate for a target species and reflects in part the more frequent and greater losses of fish from the net before landing in this fishery. Discarding of COM species was at a very low rate, less than 1 $kg.h^{-1}$, reflecting the generally low catch of commercial species other than SBW. Within the COM category, discard rates for HOK and LIN were identical and twice that for HAK. Discarding of OTH species was low but relatively frequent compared to other categories and as a result the ratios generally have low c.v.s associated with them.

Table 13: Summary of sample sizes, discard ratios (kg.h^{-1}) and associated c.v.s used to calculate total discards in the southern blue whiting fishery; n, number of tows (number of vessels in parentheses); $\hat{D}$, discard ratio.

Species category	Fishing year	n	$\hat{D}$	c.v. (%)
SBW	All	2 088(33)	81.8	11.3
SBW	1990–91	179(4)	97.5	31.3
SBW	1991–92	338(12)	67.5	28.7
SBW	1992–93	301(7)	109.8	28.1
SBW	1993–94	141(5)	141.6	22.7
SBW	1994–95	136(5)	129.0	28.9
SBW	1995–96	83(4)	171.2	39.3
SBW	1996–97*	13(3)	81.8	11.3
SBW	1997–98*	0(0)	81.8	11.3
SBW	1998–00*	248(9)	81.8	11.3
SBW	2000–01	253(10)	34.0	22.0
SBW	2001–02	396(10)	24.3	16.1
COM	All	2 088(33)	0.3	28.1
OTH	All	2 088(33)	14.4	9.1
OTH	1990–91	179(4)	2.8	17.3
OTH	1991–92	338(12)	13.6	13.8
OTH	1992–93	301(7)	3.6	22.9
OTH	1993–94	141(5)	45.5	30.5
OTH	1994–95	136(5)	6.4	19.2
OTH	1995–96	83(4)	4.2	31.8
OTH	1996–97*	13(3)	14.4	9.1
OTH	1997–98*	0(0)	14.4	9.1
OTH	1998–00	248(9)	12.8	17.9
OTH	2000–01	253(10)	23.1	25.7
OTH	2001–02	396(10)	16.2	8.5
HOK	All	2 088(33)	0.14	43.1
HAK	All	2 088(33)	0.06	29.4
LIN	All	2 088(33)	0.14	36.7

* Strata with fewer than 50 records, fewer than 3 vessels, or non-normal bootstrap distribution of ratios. For these strata the ratio shown for all years was substituted.

Estimates of discards of SBW ranged from about 80 t to over 1000 t per year, although in most years discards were 200–500 t (Table 14 and Figure 9). Discards of COM species were negligible, with a maximum of 5 t estimated for 1991–92. Discards of OTH species fluctuated widely over the first four years in the series, ranging from 17 to 203 t, but subsequently were more consistent, ranging from 10 to 63 t between 1994–95 and 2001–01. There was a general decline over time in the level of total discards, and discards of southern blue whiting, with the highest three values in the first three years and the lowest two values in the last two years of the series. The estimates of discards in the main three categories for 1994–95 and 1995–96 were generally similar to those made in an earlier study (Clark et al. 2000), and estimates for SBW discards and total discards from that study fall well within the confidence intervals calculated in this study. The main differences in methodology, apart from data grooming details and a smaller set of COM species in this study, were in the stratification used for SBW and OTH and the form of the ratio estimator, which in the earlier study used the target species catch version (see Section 2.5). Estimates of individual commercial species discards were very low with a maximum of 2 t estimated for both HOK and LIN in 1991–92 (Table 15). Total annual discard estimates ranged from about 140 to 1200 t.

Table 14: Estimates of discards (t) in the target southern blue whiting trawl fishery by year, for the species categories SBW, COM, OTH, and overall, with 95% confidence intervals in parentheses.

	Species category			
Fishing year	SBW	COM	OTH	All
1990–91	723 (354–1 177)	2.5 (1.4–3.9)	21 (15–28)	746 (370–1 209)
1991–92	1 010 (616–1 502)	5.0 (3.0–7.5)	203 (159–251)	1 218 (778–1 761)
1992–93	518 (330–745)	1.6 (1.0–2.3)	17 (12–23)	537 (343–769)
1993–94	365 (267–492)	0.9 (0.6–1.2)	117 (74–170)	483 (342–663)
1994–95	287 (213–367)	0.7 (0.6–1.0)	14 (12–17)	303 (226–385)
1995–96	396 (210–685)	0.8 (0.5–1.1)	10 (6–16)	406 (217–702)
1996–97	229 (199–267)	0.9 (0.6–1.3)	40 (36–45)	270 (236–313)
1997–98	332 (289–388)	1.4 (0.9–1.9)	58 (52–66)	392 (342–455)
1998–00	406 (349–478)	1.7 (1.1–2.4)	63 (49–81)	471 (399–561)
2000–01	81 (65–102)	0.8 (0.6–1.1)	55 (44–73)	137 (109–176)
2001–02	95 (81–109)	1.3 (1.0–1.7)	63 (58–69)	159 (140–179)
Estimates from Clark et al. 2000				
1994–95	271	2	5	278
1995–96	345	2	7	354

Table 15: Estimates of discards (t) in the target southern blue whiting trawl fishery by year, for HAK, HOK, and LIN, with 95% confidence intervals in parentheses.

	Species		
Fishing year	HAK	HOK	LIN
1990–91	0.5 (0.3–0.7)	1.0 (0.4–1.9)	1.0 (0.5–1.7)
1991–92	1.0 (0.6–1.5)	2.0 (1.0–3.6)	2.0 (1.1–3.4)
1992–93	0.3 (0.2–0.4)	0.6 (0.3–1.1)	0.6 (0.4–1.0)
1993–94	0.2 (0.1–0.2)	0.3 (0.2–0.6)	0.4 (0.2–0.5)
1994–95	0.1 (0.1–0.2)	0.3 (0.2–0.4)	0.3 (0.2–0.4)
1995–96	0.1 (0.1–0.2)	0.3 (0.2–0.5)	0.3 (0.2–0.5)
1996–97	0.2 (0.1–0.3)	0.4 (0.2–0.6)	0.4 (0.2–0.6)
1997–98	0.3 (0.2–0.4)	0.5 (0.3–0.9)	0.6 (0.3–0.8)
1998–00	0.3 (0.2–0.5)	0.7 (0.4–1.1)	0.7 (0.4–1.1)
2000–01	0.2 (0.1–0.2)	0.3 (0.2–0.5)	0.3 (0.2–0.5)
2001–02	0.3 (0.2–0.3)	0.5 (0.4–0.8)	0.5 (0.4–0.7)

A major, and under-utilised, bycatch species identified by observers was porbeagle shark. This species, which has supported target fishery in the North Atlantic since the early 1960s (Campana et al. 2002), was caught in about 4% of observed tows. A total of 54 t were observed caught from 350 (mostly midwater) tows making it the fifth most caught species by weight. On a few of the observed trips they were finned, but generally (78% by weight) they were discarded. The other group adversely affected by this fishery were several species of mostly unidentified rattails (Macrouridae) which were the sixth most caught species or species group observed and were mostly discarded.

Estimated catches from the southern blue whiting target trawl fishery represented more than 95% of the total landings of this species in all but the last 2 of the 11 years examined (Table 16). The low figures for 2000–01 and 2001–02 indicate either that catch-effort data may be incomplete for these years or that southern blue whiting have begun to be caught more frequently in the target fisheries for other species, most likely hoki, which overlap the southern blue whiting fishery in parts of the sub-Antarctic.

Table 16: Estimated catch totals of southern blue whiting from the target trawl fishery, and all reported landings from the trawl fishery from the QMS, by year. Landings data from Annala et al. (2003).

Fishing year	Target fishery estimated catch (t)	Total fishery reported catch (t)	Target/total (%)
1990–91	37 933	36 870	103
1991–92	76 369	76 255	100
1992–93	27 833	27 708	100
1993–94	17 918	18 560	97
1994–95	18 199	17 477	104
1995–96	21 094	22 279	95
1996–97	21 233	20 147	105
1997–98	33 886	31 165	109
1998–00	40 792	40 926	100
2000–01	20 729	24 929	83
2001–02	27 433	32 500	84

3.8.2 Oreo

In comparison to the southern blue whiting fishery, target species discards in the oreo fishery were small and infrequent. Discard ratios for OEO were calculated for each year where possible. Because of a lack of observer coverage from 1991–92 to 1993–94, data from these years were combined to produce a single ratio. This ratio was the lowest for the period at 14.6 kg.h^{-1}, with the ratios for the remaining years in the range 70–90 kg.h^{-1} (Table 17). Because few tows recorded a discard of COM species, a single ratio was calculated from all years of data. This applied also to the individual commercial species. In contrast, discards of OTH species were frequent and ratios were calculated for combinations of area and fishing year where possible. Overall area ratios only are shown in Table 17 and these range from 99 kg.h^{-1} in OTAG to 869 kg.h^{-1} in MACQ.

Table 17: Summary of sample sizes, discard ratios (kg.h^{-1}) and associated c.v.s used to calculate total discards in the oreo fishery. Only values for the primary stratum (as identified from regression analysis) are shown; *n*, number of tows (number of vessels in parentheses); $\hat{D}$, discard ratio.

Species category	Fishing year	Area	*n*	$\hat{D}$	c.v. (%)
OEO	All	All	2 293(34)	77.4	15.4
OEO	90-91	All	100(6)	74.5	19.5
OEO	91-92#	All	29(2)	14.6	69.8
OEO	92-93#	All	9(2)	14.6	69.8
OEO	93-94#	All	24(5)	14.6	69.8
OEO	94-95	All	128(6)	156.6	29.4
OEO	95-96*	All	85(3)	77.4	15.4
OEO	96-97	All	106(6)	366.2	25.4
OEO	97-98*	All	0(0)	77.4	15.4
OEO	98-99*	All	198(5)	77.4	15.4
OEO	99-00	All	746(12)	87.8	20.0
OEO	00-01*	All	450(7)	77.4	15.4
OEO	01-02*	All	416(11)	77.4	15.4
COM	All	All	2 293(34)	1.4	33.6
OTH	All	All	2 279(34)	180.6	6.8
OTH	All	BNTY	235(8)	125.7	10.1
OTH	All	LOUS**	13(1)	–	–
OTH	All	MACQ	513(11)	868.9	15.0
OTH	All	NCHR**	10(4)	–	–
OTH	All	OTAG	318(16)	99.1	6.3
OTH	All	OTHR**	16(8)	–	–
OTH	All	SECR	262(14)	134.8	9.8
OTH	All	STR**	14(2)	–	–
OTH	All	SWCR	898(19)	134.8	4.0
ORH	All	All	2 293(34)	0.1	44.3
HOK	All	All	2 293(34)	1.1	43.4
GSP	All	All	2 293(34)	0.2	16.9

Data for these 3 years combined due to low observer coverage

* Strata with fewer than 50 records, fewer than 3 vessels, or non-normal bootstrap distribution of ratios. For these strata the ratio shown for all years was substituted.

** Insufficient data available for these areas, ratios calculated for each year, based on all areas.

Annual estimates of discards of the three target species in the oreo fishery varied widely, from a low of 23 t in 1991–92 to a high of 1320 t in 1996–97 (Table 18 and Figure 9). For 8 of the 12 years, however, discards of oreo species were within a comparatively narrow range of 180–370 t per year. The very high value for 1996–97 was due to a combination of a high discard ratio for that year and one of the highest annual tow duration totals for the period. In contrast, discards of COM species were consistently low in each year, ranging from 2 to 6 t, and comprised almost entirely hoki and pale ghost shark. Overall, annual discards of OTH species were at a similar level to OEO species, ranging from about 200 to 700 t, but the year to year fluctuations for the two species categories show quite different patterns. Annual discards of all species combined ranged from about 200 to 1900 t per year, with the four highest values coming from the six most recent years. The estimates of discards in the main three categories for 1994–95 and 1995–96 were, as for southern blue whiting, generally similar to those made by Clark et al. (2000), and estimates for OEO discards and total discards from that study fall within the confidence intervals calculated in this study. The estimate of OTH discards for 1994–95 from Clark et al. (2000) was the only estimate outside the 95% confidence interval limit, but the two figures are not strictly comparable as a slightly different set of COM species was defined for the previous study.

Table 18: Estimates of discards (t) in the target oreo trawl fishery by year, species category, and overall, with 95% confidence intervals in parentheses.

	Species category													
Fishing year	OEO		COM		OTH		ORH		HOK		GSP		All	
1990–91	189	(131–266)	3	(2–6)	473	(384–569)	0	(0–0)	3	(1–5)	1	(0–1)	666	(517–842)
1991–92	23	(2–63)	2	(1–4)	204	(179–235)	0	(0–0)	2	(1–3)	0	(0–0)	229	(182–302)
1992–93	30	(3–85)	3	(1–5)	410	(329–510)	0	(0–0)	2	(1–4)	0	(0–1)	443	(333–599)
1993–94	37	(4–101)	3	(2–6)	372	(323–430)	0	(0–0)	3	(1–5)	1	(0–1)	412	(329–537)
1994–95	296	(162–488)	3	(1–5)	210	(151–293)	0	(0–0)	2	(1–4)	0	(0–1)	509	(314–785)
1995–96	218	(160–289)	4	(2–7)	448	(384–526)	0	(0–1)	3	(1–6)	1	(0–1)	670	(546–821)
1996–97	1 320	(771–2 054)	5	(2–9)	604	(512–713)	0	(0–1)	4	(1–7)	1	(0–1)	1 929	(1 285–2 776)
1997–98	184	(137–241)	3	(2–6)	388	(336–448)	0	(0–0)	3	(1–5)	0	(0–1)	575	(475–695)
1998–99	297	(220–392)	5	(3–9)	691	(576–832)	0	(0–1)	4	(1–8)	1	(1–1)	994	(798–1 233)
1999–00	373	(266–497)	6	(3–10)	645	(555–753)	0	(0–1)	5	(2–8)	1	(1–1)	1 024	(824–1 260)
2000–01	206	(160–262)	4	(2–6)	502	(419–602)	0	(0–0)	3	(1–5)	1	(0–1)	712	(581–870)
2001–02	181	(141–230)	3	(2–5)	336	(268–424)	0	(0–0)	3	(1–4)	0	(0–1)	521	(410–660)
Estimates from Clark et al. 2000														
1994–95	207		1		309								517	
1995–96	270		1		402								693	

Deepwater sharks (mostly unidentified, but including seal sharks (*Dalatias licha* and *Etmopterus* species), and rattails were the species groups most affected by discarding. Combined, deepwater sharks accounted for more than 1% of the total observed catch and these were mostly (about 90%) discarded. The catch of rattails was about half that of deepwater sharks but close to 100% were discarded.

Species identification by observers was poor for rattails, deepwater sharks, and for less common fish species in general, in both fisheries. The generic codes RAT (any rattail), DWD (deepwater dogfishes), OSD (other sharks and dogfishes), and MIX (mixed fish) were frequently used (see Appendices 1 and 2).

The target oreo trawl fishery represented between 42 and 79% of the total annual landings of these species over the period 1990–91 to 2001–02 (Table 19). Much of the remainder of the reported catch will have come from bycatch in the target orange roughy fishery, which overlaps the oreo fishery in many areas. The bycatch and discards associated with the catch of oreos in the orange roughy fishery, for all but the three most recent years, has been accounted for in a recent analysis of these aspects of the orange roughy fishery (Anderson et al. 2001).

Table 19: Estimated catch totals of oreo from the target trawl fishery, and all reported landings from the trawl fishery from the QMS, by year. Landings data from Annala et al. (2003).

Fishing year	Target fishery estimated catch (t)	Total fishery reported catch (t)	Target/total (%)
1990–91	13 763	21 614	64
1991–92	10 863	21 718	50
1992–93	12 342	23 820	52
1993–94	9 748	23 318	42
1994–95	9 563	18 291	52
1995–96	14 811	23 810	62
1996–97	14 442	24 779	58
1997–98	14 192	21 249	67
1998–99	16 750	22 083	76
1999–00	17 743	22 518	79
2000–01	17 364	22 719	76
2001–02	14 478	18 721	77

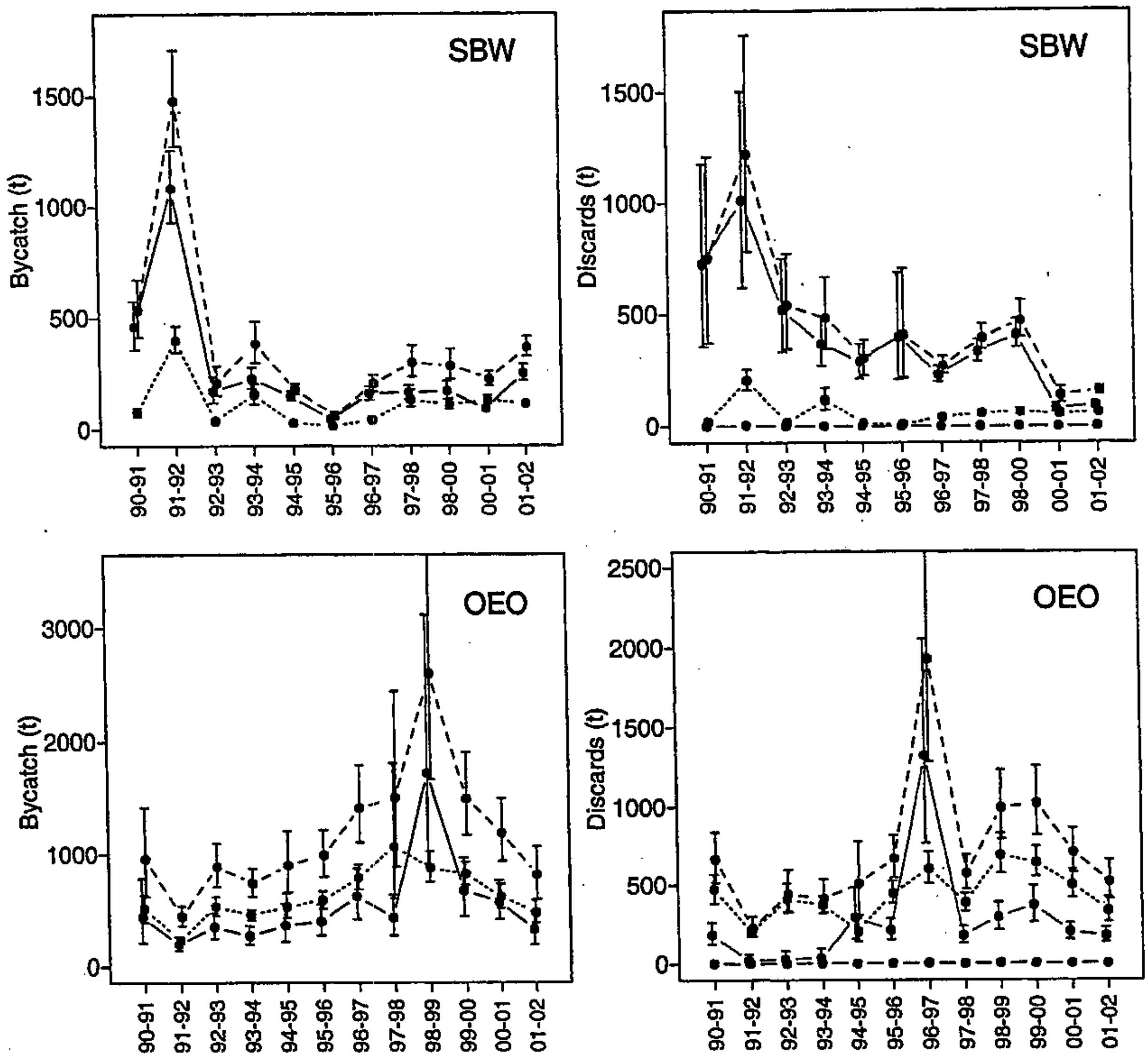

Figure 9: Annual bycatch (left) and discard (right) estimates for the southern blue whiting (SBW) (top), and oreo (OEO) (bottom) trawl fisheries. Grey lines, target species; solid lines, commercial species (COM); dotted lines, non-commercial species (OTH); dashed lines, all species. Error bars represent 95% confidence intervals.

3.9 Summary of annual non-target catch

Because non-target catch, by definition, incorporates not only bycatch but also target species discards (see Section 2.1 for definitions), it is not appropriate to use the term non-target catch when addressing an individual bycatch species or group of bycatch species. It was useful in this report to consider non-target-species catch for individual bycatch species and species groups, and so bycatch (which doesn't incorporate target species discards) was calculated rather than non-target catch. In fisheries where discards of the target species are low, e.g., the scampi and jack mackerel fisheries (Anderson 2004), there is usually little difference between total bycatch and total non-target catch. This is not the case for the southern blue whiting fishery, in which the target species accounted for 60–97% of total annual discards (see Table 14) and 20–85% of annual non-target catch. Annual non-target catch in the southern blue whiting fishery showed a decrease from a range of 720 to 2500 t in the early 1990s to 300–690 t since 1994–95 (Table 20).

Discards of the target species also contributed a considerable amount to total annual discards in the oreo fishery (7–68%), and also to annual non-target catch (3–48%). Annual non-target catch in the oreo fishery comprised mainly bycatch species and ranged between 470 and 2900 t during the period of study (Table 21).

Table 20: Annual non-target catch (t) in the southern blue whiting fishery for the fishing years 1990–91 to 2001–02, with 95% confidence intervals in parentheses.

Fishing year	Non-target catch (t)
1990–91	1 256 (766–1 845)
1991–92	2 489 (1 887–3 214)
1992–93	724 (480–1 027)
1993–94	747 (565–975)
1994–95	465 (370–571)
1995–96	459 (258–764)
1996–97	432 (367–509)
1997–98	628 (525–760)
1998–00	689 (575–834)
2000–01	304 (260–360)
2001–02	459 (406–524)

Table 21: Annual non-target catch (t) in the oreo fishery for the fishing years 1990–91 to 2001–02, with 95% confidence intervals in parentheses.

Fishing year	Non-target catch (t)
1990–91	1 146 (749–1 688)
1991–92	472 (370–606)
1992–93	920 (713–1 188)
1993–94	778 (628–975)
1994–95	1 198 (825–1 701)
1995–96	1 208 (958–1 510)
1996–97	2 735 (1 880–3 841)
1997–98	1 686 (1 025–2 683)
1998–99	2 898 (1 884–4 532)
1999–00	1 866 (1 440–2 400)
2000–01	1 398 (1 098–1 761)
2001–02	996 (738–1 303)

4. DISCUSSION

The level of observer coverage in these two fisheries varied, both over time and between fisheries. Coverage was consistently very high in the southern blue whiting fishery, with observers witnessing more than half the target fishery catch in 6 of the 11 years. Despite a relative lack of coverage of the very largest vessels in the fleet, this should be sufficient to allow a high level of confidence in the estimates of bycatch and discards produced. On the other hand, coverage in the oreo fleet was poor in some years; with observers witnessing less than 10% of the target fishery catch in 7 of the 12 years. The good spread of observer effort over the range of vessel sizes and over the geographical range of the fishery will have at least helped to minimise bias, but the low coverage has contributed to higher levels of uncertainty associated with bycatch estimates than in the southern blue whiting fishery. The higher level of uncertainty around estimates of discards in the southern blue whiting fishery compared to the oreo fishery, in some years, was largely due to the influence of more frequent instances of catch being lost due to net damage. These events were unpredictable and often involved large quantities of fish, widening the range of possible discard ratios produced by the bootstrap process.

In years when observer coverage was high, confidence intervals around the estimates tended to be narrower, due to the adjustments made for the finite population effect on sampling assumptions. Estimates for the southern blue whiting fishery were most affected by this, particularly in 1994–95, 2000–01, and 2001–02, when observer coverage accounted for 70–80% of the target fishery catch. The effect was smaller for the oreo fishery in which coverage was less than 10% of the total target catch for most years before 1998–99. These confidence intervals can be misleading, however, as they don't take into account the uncertainty associated with the model assumptions, especially the assumption that observed tows were a random selection of all trips and tows within each stratum. This randomness would be difficult to achieve in reality and the departure from it in practice will contribute an unknown amount to the total uncertainty.

Regression modelling showed that the factor with the most influence on discards and bycatch in both of these fisheries was the fishing vessel. The influence of the fishing vessel is greater for discards than for bycatch and the same has been shown to be true for other fisheries examined recently, including jack mackerel and arrow squid (Anderson 2004), and orange roughy and hoki (Anderson et al. 2001). This emphasises the clear need to spread observer effort over as many vessels as possible in each fishery and also the requirement for data to be available from a minimum number of vessels in each stratum. Other factors with an important influence were area and fishing year on bycatch in both fisheries and discards in the oreo fishery, and fishing year and month on discards in the southern blue whiting fishery. In all cases strata used in the calculations were based on either fishing year, area, or both of these factors.

The southern blue whiting fishery during this period was characterised by very large, clean catches of the target species. TCEPR data showed that more than 12% of tows caught more than 50 t and observer data showed that southern blue whiting accounted for more than 99% of the total catch. In comparison, catch sizes in the oreo fishery were more mixed and much smaller. Less than 0.2% of tows caught more than 50 t of oreo species and oreos accounted for about 94% of the total catch. With this greater efficiency, it is not surprising to find that the southern blue whiting fishery was also cleaner in terms of discards than the oreo fishery (although there was a higher level of target species discarding, mostly associated with the logistics of dealing with very large catches). A simple calculation shows that, for the 12-year period examined, there were 0.015 kilograms of total discards per kilogram of southern blue whiting caught, the same figure as calculated previously for the 1994–95 to 1995–96 period (Clark et al. 2000). Similarly, for the same period in the oreo fishery, there were 0.052 kilograms of total discards per kilogram of oreos caught. Although low compared with most fisheries, this is almost twice the level reported by Clark et al. (2000) for 1994–95 to 1995–96. By this measure the southern blue whiting fishery is the least wasteful of the New Zealand trawl fisheries that have been examined, and wastage in the oreo fishery is similar to that in the orange roughy and hoki fisheries and less than that in the jack mackerel and arrow squid fisheries (see Anderson 2004). These discard rates also compare favourably with those reported for fisheries in other parts of the world. The fishery with the lowest reported discard rate is the northwest Atlantic hake fishery in which 0.11 kilograms are discarded per kilogram landed (Alverson 1996) and the global average discard rate for all fishery types was estimated to be 0.35 kilograms of discards per kilogram landed (Alverson et al. 1994).

The 1991–92 fishing year stands out in the southern blue whiting fishery, because the total catch for this year was almost 90% greater than for any other year in the history of the fishery, and effort was similarly high. There may be a link between this statistic and the introduction of the species into the QMS the following year. Similarly, bycatch and discards were higher in this year than in the other years in the series. In contrast to that year, in 1995–96 both bycatch and non-target species discards were especially low. The reasons for this are unclear, although effort and catch levels in this year were lower than average.

In the oreo fishery, the gradual increase in the level of total bycatch between 1990–91 and 1998–99 was due in part to increasing levels of effort. The strong peak of bycatch in 1998–99, associated with large catches of commercial species in some areas, especially in the southeast of the Chatham Rise (area SECR), was followed by a decline in both bycatch and total effort over the final three years. The pattern of discard levels over time is broadly similar to that of bycatch, although there is less of an upward trend in the first six years and the strong peak in total discards is in the previous year, 1996–97. This peak is due to a high level of target species discards in that year.

The non-target commercial species bycatch in each fishery was restricted mainly to three species, with only hoki common to both. Bycatch was greater in the oreo fishery, mainly because of its strong association and overlap with the orange roughy fishery in some areas, resulting in frequent large catches of orange roughy. The level of hoki bycatch was roughly similar in each fishery (averaging about 120 t per year), and was matched by the level of hake and ling bycatch in the southern blue whiting fishery.

The oreo discard results presented here can be considered alongside published figures for the orange roughy fishery to obtain estimates for the two fisheries combined, thereby accounting for virtually all discards associated with each fishery. This is a useful exercise, as in each fishery a portion of the total landings comes as bycatch from the other, and discards from that portion are unaccounted for in the estimates provided here, which are for the target fishery only. Bycatch of these species from other target fisheries is negligible. By adding the annual estimates from this study to those for orange roughy reported by Anderson et al. (2001), total discards in these two closely linked fisheries were calculated for the fishing years 1990–91 to 1998–99 (Table 22). Estimates of bycatch or a breakdown of these totals into commercial and non-commercial species was not possible, however, because separate estimates of oreo bycatch in the orange roughy fishery were not made by Anderson et al. (2001) and because of different combinations of species in those categories. Total discards in these fisheries ranged from about 1850 to 3300 t during these nine years and the figures show no trend of increasing or decreasing levels. In all fishing years except 1996–97, most discarding was associated with the larger orange roughy fishery. The fraction of the total discards associated with the oreo fishery was highly variable, 10–59%, and may reflect between-year inconsistencies in target species nomination, and changes in the relative catch limits, as well as real fluctuations in the relative discard rates between fisheries.

Table 22: Annual estimates of total discards (t) in the target oreo and orange roughy trawl fisheries, with 95% confidence intervals in parentheses.

Fishing year	Orange roughy		Oreo fishery		Total	
1990–91	1 382	(862–2 103)	666	(517–842)	2 048	(1 379–2 945)
1991–92	2 010	(1 262–3 003)	229	(182–302)	2 239	(1 444–3 305)
1992–93	2 015	(1 306–2 997)	443	(333–599)	2 458	(1 639–3 596)
1993–94	2 670	(864–5 307)	412	(329–537)	3 082	(1 193–5 844)
1994–95	1 469	(1 000–2 097)	509	(314–785)	1 978	(1 314–2 882)
1995–96	1 176	(691–1 877)	670	(546–821)	1 846	(1 237–2 698)
1996–97	1 349	(939–1 876)	1 929	(1 285–2 776)	3 278	(2 224–4 652)
1997–98	963	(656–1 385)	575	(475–695)	1 538	(1 131–2 080)
1998–99	2 317	(1 303–3 909)	994	(798–1 233)	3 311	(2 101–5 142)

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Appendix 1: Species codes, common and scientific names, estimated catch weight, percentage of the total catch, and overall percentage discarded (to the nearest percent), of the top 50 species by weight from all observer records for the target fishery for southern blue whiting from 1 Oct 1990 to 31 Mar 2002. Records are ordered by decreasing percentage of catch; codes in bold are those species combined in the COM category.

Species code	Common name	Scientific name	Estimated catch (t)	% of catch	% discarded
SBW	Southern blue whiting	*Micromesistius australis*	121828	99.2	1
HOK	Hoki	*Macruronus novaezelandiae*	295	0.2	<1
LIN	Ling	*Genypterus blacodes*	247	0.2	1
HAK	Hake	*Merluccius australis*	156	0.1	<1
POS	Porbeagle shark	*Lamna nasus*	54	<0.1	78
RAT	Rattails	Macrouridae	43	<0.1	62
MIX	Mixed fish		30	<0.1	88
WWA	White warehou	*Seriolella caerulea*	21	<0.1	1
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*	20	<0.1	67
GSH	Ghost shark	*Hydrolagus novaezealandiae*	16	<0.1	32
RBM	Ray's bream	*Brama brama*	15	<0.1	37
SSI	Silverside	*Argentina elongata*	14	<0.1	10
LDO	Lookdown dory	*Cyttus traversi*	11	<0.1	4
MOO	Moonfish	*Lampris guttatus*	10	<0.1	80
PAH	Opah	*Lampris immaculatus*	9	<0.1	34
SPD	Spiny dogfish	*Squalus acanthias*	7	<0.1	94
SBO	Southern boarfish	*Pseudopentaceros richardsoni*	6	<0.1	100
WSQ	Warty squid	*Moroteuthis* spp.	5	<0.1	87
SWA	Silver warehou	*Seriolella punctata*	4	<0.1	0
LCH	Longnose spookfish	*Harriotta raleighana*	3	<0.1	70
BRS	Bramble shark	*Echinorhinus brucus*	2	<0.1	100
ONG	Sponges	Porifera	2	<0.1	100
FUR	New Zealand fur seal	*Arctocephalus forsteri*	1	<0.1	90
SKA	Skate	Rajidae & Arhynchobatidae	1	<0.1	100
PIG	Pigfish	*Congiopodus leucopaecilus*	1	<0.1	8
MAN	Finless flounder	*Neoachiropsetta milfordi*	1	<0.1	4
BOA	Sowfish	*Paristiopterus labiosus*	1	<0.1	100
DSP	Deepsea pigfish	*Congiopodus coriaceus*	1	<0.1	97
RCO	Red cod	*Pseudophycis bachus*	1	<0.1	9
GSP	Pale ghost shark	*Hydrolagus* sp. B2	1	<0.1	21
DWD	Deepwater dogfish	Squalidae (unidentified)	<1	<0.1	100
ETB	Baxter's lantern dogfish	*Etmopterus baxteri*	<1	<0.1	100
BCO	Blue cod	*Parapercis colias*	<1	<0.1	83
BTH	Bluntnose/deepsea skates	*Notoraja* spp.	<1	<0.1	100
OSD	Sharks and dogfishes	Chondrichthyes (unidentified)	<1	<0.1	100
STU	Slender tuna	*Allothunnus fallai*	<1	<0.1	52
BBE	Banded bellowsfish	*Centriscops humerosus*	<1	<0.1	100
BAR	Barracouta	*Thyrsites atun*	<1	<0.1	0
SOP	Pacific sleeper shark	*Somniosus pacificus*	<1	<0.1	100
STA	Giant stargazer	*Kathetostoma giganteum*	<1	<0.1	5
SQX	Squids	Teuthoidea (unidentified)	<1	<0.1	41
TOA	Toadfish	*Neophrynichthys* spp.	<1	<0.1	88
RSK	Rough skate	*Dipturus nasutus*	<1	<0.1	100
OPH	Brittle stars	Ophiuroidea	<1	<0.1	100
OPA	Opalfish	*Hemerocoetes* spp.	<1	<0.1	0
SSK	Smooth skate	*Dipturus innominatus*	<1	<0.1	95
WIT	Witch	*Arnoglossus scapha*	<1	<0.1	81
BCD	Black cod	*Paranotothenia magellanica*	<1	<0.1	0
ANT	Anemones	Anthozoa	<1	<0.1	100
STN	Southern bluefin tuna	*Thunnus maccoyii*	<1	<0.1	0

Appendix 2: Species codes, common and scientific names, estimated catch weight, percentage of the total catch, and overall percentage discarded, of the top 50 species by weight from all observer records for the target fishery for oreos from 1 Oct 1990 to 30 Sep 2002. Records are ordered by decreasing percentage of catch, codes in bold are those species combined in the COM category.

Species code	Common name	Scientific name	Estimated catch (t)	% of catch	% discarded
SSO	Smooth oreo	*Pseudocyttus maculatus*	9945	61.0	1
BOE	Black oreo	*Allocyttus niger*	5398	33.1	2
SOR	Spiky oreo	*Neocyttus rhomboidalis*	1	<0.1	32
ORH	Orange roughy	*Hoplostethus atlanticus*	316	1.9	0
HOK	Hoki	*Macruronus novaezelandiae*	123	0.8	2
DWD	Deepwater dogfish	Squalidae (unidentified)	104	0.6	87
RAT	Rattails	Macrouridae	90	0.6	98
COU	Coral (unspecified)		63	0.4	100
BSH	Seal shark	*Dalatias licha*	52	0.3	94
	Etmopterus	*Etmopterus* spp.	51	0.3	84
GSP	Pale ghost shark	*Hydrolagus* sp B2.	20	0.1	2
MIX	Mixed fish		16	0.1	100
WOE	Warty oreo	*Allocyttus verrucosus*	14	0.1	100
SLK	Slickhead	Alepocephalidae	12	0.1	100
WSQ	Warty squid	*Moroteuthis* spp.	11	0.1	99
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*	9	0.1	2
HAK	Hake	*Merluccius australis*	7	<0.1	2
ECH	Echinodermata	Echinodermata	7	<0.1	99
GSH	Ghost shark	*Hydrolagus novaezealandiae*	6	<0.1	57
BEE	Basketwork eel	*Diastobranchus capensis*	6	<0.1	99
MOD	Morid cods	Moridae	5	<0.1	97
SSI	Silverside	*Argentina elongata*	5	<0.1	3
HJO	Johnson's cod	*Halargyreus johnsonii*	4	<0.1	99
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	3	<0.1	100
LCH	Longnose spookfish	*Harriotta raleighana*	3	<0.1	96
SND	Shovelnose spiny dogfish	*Deania calcea*	3	<0.1	100
SCC	Sea cucumbers	Holothuriidae	2	<0.1	100
UNI	Unidentified		2	<0.1	1
WWA	White warehou	*Seriolella caerulea*	2	<0.1	0
SPD	Spiny dogfish	*Squalus acanthias*	2	<0.1	100
PLS	Plunkets shark	*Centroscymnus plunketi*	1	<0.1	99
LIN	Ling	*Genypterus blacodes*	1	<0.1	1
SKA	Skates	Rajidae & Arhynchobatidae	1	<0.1	95
RIB	Ribaldo	*Mora moro*	1	<0.1	34
CHI	Chimaeras	*Chimaera* spp.	1	<0.1	86
SPI	Spider crab	Majidae	1	<0.1	95
VIT	Deepsea spider crab	*Vitjazmaia latidactyla*	1	<0.1	92
OCT	Octopus	*Pinnoctopus cordiformis*	1	<0.1	98
VCO	Violet cod	*Antimora rostrata*	1	<0.1	97
SAL	Salps	Thaliacea	1	<0.1	100
TOA	Toadfish	*Neophrynichthys* sp.	1	<0.1	99
ANT	Anemones	Anthozoa	1	<0.1	100
SMC	Small-headed cod	*Lepidion microcephalus*	<1	<0.1	92
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	<1	<0.1	99
AME	Sculpin	*Antipodocottus megalops*	<1	<0.1	100
SWA	Silver warehou	*Seriolella punctata*	<1	<0.1	2
CHG	Giant chimaera	*Chimaera phantasma*	<1	<0.1	95
CRB	Crab	Decapod	<1	<0.1	97
EPT	Deepsea cardinalfish	*Epigonus telescopus*	<1	<0.1	79
BSL	Black slickhead	*Xenodermichthys* spp.	<1	<0.1	100