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EXECUTIVE SUMMARY

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Trawl catch and discard data from the Ministry of Fisheries Observer Programme covering the period 1998–99 to 2000–01 (jack mackerel and arrow squid) and 1990–91 to 2000–01 (scampi) were used, along with commercial catch data, to estimate fish bycatch and discard levels in the target trawl fisheries for these species, from which 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.

Bootstrapping techniques were used to choose the better of two ratio estimators, one based on tow duration and the other on target species catch, to be used for scaling up observed discard and bycatch rates to the total target fishery. Several subsets of the observer data were tested and all showed the tow duration estimator to have a slightly smaller coefficient of variation (c.v.), and so this estimator was used in all subsequent calculations.

Regression analyses were used to determine which factors had the most influence on bycatch and discard quantities, in order to select the best stratification for calculation of these values. In all but the bycatch in the jack mackerel fishery, the underlying factor in the regressions was the categorical variable *vessel*. Bycatch in the jack mackerel fishery was influenced most by the variable *month*. The variables *area* and *fishing year* were also frequently selected in the models. Because observer data were not available from all vessels, *vessel* could not be used to scale up ratio estimates and so *area*, *month*, and *fishing year*, or combinations of these, were used.

Most of the bycatch in the jack mackerel fishery consisted of commercial species. Total annual bycatch estimates ranged from about 11 600 to 15 500 t (compared to the total estimated target species catch of 13 000–22 000 t) and almost 95% of this was made up of quota species or species which were usually retained. The main bycatch species were barracouta, redbait, and arrow squid. Total annual discard estimates ranged from about 1550 to 2600 t.

Total bycatch in the arrow squid fishery ranged from about 10 900 to 18 800 t per year (compared to the total estimated target species catch of 17 000–31 000 t). About 80% of this consisted of commercial species. Barracouta make up more than half of the commercial species catch, with silver warehou and jack mackerel accounting for most of the remainder. Total annual discard estimates ranged from about 2200 to 4300 t.

In the target scampi fishery, bycatch accounted for a much greater proportion of the total catch over the 11 years examined. Total annual bycatch estimates ranged from about 3200 to 6800 t, compared to annual estimated scampi catches of 800–1000 t. The main bycatch species in the scampi fishery were ling, hoki, and sea perch. Total annual discard estimates ranged from about 1400 to 5300 t.

The coverage required for optimising estimates of discards and bycatch in both the jack mackerel and arrow squid fisheries is highly dependent on the level of precision required and the measure of precision used. In the jack mackerel fishery, the best approach is to spread observer coverage with a monthly pattern, and in the arrow squid fishery observer coverage should be allocated by area. With this strategy annual bycatch in the jack mackerel fishery can be estimated to within 1000 t and, likewise, discards can be estimated to within 200 t. In the arrow squid fishery, optimised observer coverage could enable bycatch to be estimated to within 500 t, and discard estimates to within 400 t, with an increase of observer coverage of less than 50%.

1. INTRODUCTION

Some level of non-target species catch and discarding is common to virtually every commercial fishery. Target and non-target marketable species are retained for sale, and species for which there is no market, or which cannot economically be brought to market, are discarded, *i.e., thrown back into* the sea. Discards in commercial fisheries have become an increasingly important issue in fisheries management over the last decade or two as the world fishery harvest approaches theoretical maximum sustainable yields (Pascoe 1997), and studies on levels of discarding have revealed the magnitude of the problem. The issues have been most emphasised in the widely publicised shrimp trawl and drift-net fisheries (Clucas & James 1996), but the same problems exist with finfish trawling and lining. There is an extensive literature, which was summarised by Alverson et al. (1994), and a number of scientific workshops in recent years which focussed on bycatch and discard issues, e.g., the Technical Consultation on Reduction of Wastage in Fisheries in Japan (Clucas & James 1996).

On a global scale, annual discards are in the millions of metric tonnes. The most recent summary indicated annual discards in commercial fisheries in 1988–90 of 27 million tonnes, and a bycatch of non-target species amounting to about 29 million tonnes, out of a total harvest of about 80 million tonnes (Alverson et al. 1994). More recently Alverson (1998) admitted this may have been an overestimate, without providing a revised figure, and suggested that a significant reduction in global discards occurred in the early 1990s, due mostly to the actions of fishery managers and to better use of bycatch. Most discards were attributed to shrimp fisheries. Bottom trawls (together with longline and pot fisheries) ranked second, then drift-net and seine fisheries, with pelagic trawls and targeted purse-seine having the lowest ratios of discard to target catch.

Information on the level of non-target fish catch and discards in commercial fisheries is potentially important for fisheries management. Successful stock assessment requires good data on the true catch and mortality of fish species. This applies to both target and non-target species, where the latter comprise other commercial species, or non-commercial ones. Such data can also contribute to an improved understanding of fish communities, and the possible impact of fishing on the long-term sustainability of exploited ecosystems.

In New Zealand, the Ministry of Fisheries has the responsibility for determining impacts of fishing on associated or dependent species, which includes both target species that are discarded and non-target species taken during normal fishing operations. The work undertaken here follows on from a recent study carried out by NIWA to estimate the level of discards in the squid and jack mackerel trawl fisheries for the previous eight fishing years (1990–91 to 1997–98) (Anderson et al. 2000). It also complements other recent studies investigating bycatch and discards in New Zealand trawl fisheries: e.g., discards in the southern blue whiting, orange roughy, hoki, and oreo fisheries (Clark et al. 2000), and discards and non-target catch in the orange roughy and hoki fisheries (Anderson et al. 2001). This research is helping to increase our understanding of the more general effects of commercial fisheries on fish species and the aquatic environment in New Zealand.

Non-target fish catch and discards in selected New Zealand fisheries

The specific objectives of this project require estimates to be made of the catch of non-target fish species, and the discards of target and non-target fish species in three important New Zealand trawl fisheries:

- arrow squid (*Nototodarus sloani & N. gouldi*)
- jack mackerel (*Trachurus declivis, T. novaezelandiae, & T. symmetricus murphyi*)
- scampi (*Metanephrops challengeri*)

Total reported catches in 1998–99 were about 37 000 t for jack mackerel, 27 500 t for arrow squid, and 972 t for scampi (Annala et al. 2000). Fisheries of this scale have considerable potential to catch large amounts of non-target species, or of the target species that are of unwanted size, or are damaged.

Jack mackerel fisheries occur around much of New Zealand (Figure 1). There is a major purse-seine fishery in the Bay of Plenty and off the northeast coast of the North Island, and trawl fisheries in areas of the Chatham Rise, Southland/Subantarctic, and off the west coast of the North Island around Taranaki. The fishery catches three species: two New Zealand species, *T. declivis* and *T. novaezelandiae*, and from the mid 1990s the Peruvian jack mackerel *T. s. murphyi*. The trawl fisheries occur down to about 300 m, and catches can be quite mixed, catching arrow squid, barracouta (*Thyrsites atun*), blue mackerel (*Scomber australasicus*), spiny dogfish (*Squalus acanthias*), tarakihi (*Nemadactylus macropterus*), frostfish (*Lepidopus caudatus*), Ray's bream (*Brama brama*), and redbait (*Emmelichthys nitidus*) depending on the type of trawl (bottom or midwater) and the area of the fishery (Jones 1990, Horn 1991, Anderson et al. 2000).

Squid fisheries are based on two species: *Nototodarus sloani* in or south of the Subtropical Convergence, and *N. gouldi* occurring north of the convergence zone (Smith et al. 1987). The depth range is from 80 to 300 m, with most trawling effort about 200 m (Gibson 1995). The trawl fishery accounts most of the squid catch in most years. The main areas of trawling are in the southern Taranaki Bight, Puysegur Bank-Snares shelf, off the Auckland Islands, and near Banks Peninsula (Figure 2). Frostfish, slender tuna (*Allothunnus fallai*), and Ray's bream are amongst the bycatch taken by the midwater trawl fishery, and a wide range of middle depth species including barracouta, jack mackerel, common warehou (*Seriolella brama*), silver warehou (*S. punctata*), and spiny dogfish are caught in the bottom trawl fishery (Anderson et al. 2000).

The main fisheries for scampi are in the Bay of Plenty, off the Wairarapa coast, around the Chatham Rise, and in the Sub-Antarctic (Figure 3). Some fishing has been recorded on the Challenger Plateau, especially outside the Exclusive Economic Zone (EEZ) (Annala et al. 2002). Vessels trawl using multiple nets with low headline heights in depths of 300–450 m (Annala et al. 2000). The major commercial bycatch species include hoki (*Macruronus novaezelandiae*), ling (*Genypterus blacodes*), giant stargazer (*Kathetostoma giganteum*), and gemfish (*Rexea solandri*) (Cryer et al. 1999).

There has been regular observer coverage in each of these fisheries for more than 10 years. In most years, between 10 and 20% of the target fishery catch has been observed in these fisheries. Observers record the catch and discards from each trawl or group of trawls, as well as details of the fishing gear used, location and depth, and various other incidental information. Fishers themselves are required to record catch and effort from all commercial fishing for these species. Details of fishing activity, including total catch and target species catch (per tow or per day), are recorded on Trawl, Catch, Effort, and Processing Returns (TCEPRs) and Catch, Effort and Landing Returns (CELRs) and provided to the Ministry of Fisheries.

Previous research on bycatch and discards in jack mackerel and arrow squid estimated total annual discards for the years 1990–91 to 1997–98 at about 1000–2000 t for both fisheries (Anderson et al. 2000). The main factors influencing discards appeared to be tow-type (midwater or bottom) and area for jack mackerel and vessel nationality and area for arrow squid.

There has been no detailed study of discards in the New Zealand scampi fishery, but fisheries for the related *Nephrops* spp. in the North Sea have shown very high discard rates, equivalent to 0.88 kg discarded for every 1 kg landed, using similar fishing methods (Evans et al. 1994). Cryer & Coburn (2000) investigated finfish bycatch in the New Zealand scampi fishery, using observer data from 1990 to 1998. Although quantities of bycatch were not estimated, they found evidence that the species composition of the bycatch varied with geographical area, but not over time. There is a possibility that bycatch and discard levels have changed over time in this fishery, however, as fishing practices and changes in trawl gear have developed in an attempt to reduce the bycatch of non-commercial species and undersized commercial species.

Although not an objective in this project, an examination of the influence of various factors on the levels of discards and bycatch is made. This is necessary for stratification of data to estimate bycatch and discards, and also for addressing the third objective of the study – to recommend levels of coverage to ensure future observer effort is matched to the commercial fleet in a way that can enable robust estimates of catch and discard levels.

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

Two datasets were prepared 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 JMA, JMM, JMN, JMD (jack mackerel), SQU, ASQ, NOS, NOG (arrow squid), or SCI (scampi) 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 scampi for the 1997–98 fishing year are based on discard information from all other years.

For all records, the tow distance was calculated from start and finish positions, and duration of tow was calculated from start and finish times. These values were compared with each other to identify tows recorded with short length and long duration (and vice versa) that may contain errors. Where there was a large discrepancy between duration and distance, with no obvious errors in recording of position or time, distances were re-estimated from fishing speed and duration. Similarly, any suspiciously short or long duration was re-estimated from fishing speed and distance.

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 (midwater or bottom trawls) and a range of tow depths. 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 (120 m for jack mackerel, 160 m for arrow squid, 450 m for scampi) 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 extraction of bycatch data was more straightforward, as observers estimate or measure the weight of all species caught in each trawl. Bycatch can therefore be estimated and related to tow parameter data for each tow.

A season variable was assigned to each processing group and tow, based on the main fishing season for the target species. The high season was defined as November–April for jack mackerel, December–April for arrow squid, and September–February for scampi. Each fishery was divided into a number of areas based on natural breaks in the fishery or known stock divisions and tows were assigned to one of these areas (see Figures 1–3). For jack mackerel and arrow squid these areas were the same as those used by Anderson et al. (2000).

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

- the target species (jack mackerel (JMA)/arrow squid (SQU)/ scampi (SCI))
- other main commercial species combined (COM)
- all other species combined (OTH)
- individual bycatch species caught in significant quantities (about 2% of total catch)

Summaries by species of the overall observed catch and percentage discarded are tabulated for each fishery in Appendices 1–3. Species included in COM were defined as those non-target species that constituted at least 0.1% of the total observed catch over the period examined and were either a quota species or species of which more than 75% by weight was retained (Table 1).

Table 1: Commercial species included in the COM category for estimation of discards and bycatch in the jack mackerel, arrow squid, and scampi fisheries.

Fishery	Commercial species (ordered by decreasing percentage of total catch)
Jack mackerel	barracouta, blue mackerel, redbait, common warehou, arrow squid, hoki, silver warehou, frostfish, slender tuna, Ray's bream, hake (*Merluccius australis*).
Arrow squid	barracouta, jack mackerel, silver warehou, common warehou, red cod (*Pseudophycis bachus*), hoki, ling, ghost shark (*Hydrolagus novaezealandiae*), slender tuna, smooth skate (*Dipturus innominatus*).
Scampi	ling, hoki, sea perch (*Helicolenus* spp.), stargazer, red cod, silver warehou, ghost shark, hake, gemfish, white warehou (*Seriolella caerulea*), arrow squid, bluenose (*Hyperoglyphe antarctica*), southern blue whiting (*Micromesistius australis*), hapuku and bass (*Polyprion oxygeneios & P. americanus*), alfonsino (*Beryx splendens*), school shark (*Galeorhinus galeus*), ribaldo.

When fish were lost from the net at the surface, observers estimated the amount lost. These estimates can only be made by eye and therefore the error associated with them is unknown. This amount was added proportionately to the total bycatch and discards for that tow or processing group, for each species category, according to the relative amounts of those categories actually landed on that tow. A total of 1492 tows and 1280 processing groups targeting jack mackerel, 4864 tows and 4370 processing groups targeting arrow squid, and 4609 tows and 2996 processing groups targeting scampi 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. These included all fishing recorded on TCEPR and CELR forms. 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 calculated from the difference in time between the start and finish of the tow. Where this was zero or greater than 10 hours (less than 0.5% of all records), it was replaced by a value estimated from the tow distance (calculated from start and finish positions) and the recorded tow speed. Where large discrepancies remained, the median tow duration was assigned to the record. Records were assigned to the areas defined in Figures 1–3. Catch weights were checked for unusual values. 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 for the purpose of identifying 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. For CELR data, missing tow durations were assigned the median of all other tow durations. A few records in the TCEPR data from each fishery showed a larger target species catch than the total catch from a tow. These were assumed to be errors of transposition, and were corrected accordingly.

2.4 Examination of factors influencing discards and bycatch

A number of regression analyses were carried out to select appropriate factors for stratification of discard and bycatch calculations. Each species group was examined separately in each fishery and the analyses were approached in two ways: (1) a combined linear/binomial regression for species groups where a large fraction of the tows/processing groups had no catch/discards. This enabled an examination of factors influencing both the *probability* and the *level* of a bycatch/discard; and (2) a linear regression only 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 "1" if no bycatch/discard was recorded and "0" otherwise. The response variable for the linear regressions was determined from the outcome of the process described in Section 2.5 below, and a log transformation was made to provide an approximately normal distribution. 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 variables tested in the models are shown in Table 2. Because tows were combined within processing groups for discards analysis, the influence of variables such as *headline height* and vessel *speed* could not be tested. Variables were added to the model if they produced at least a 0.5% decrease in the residual deviance. Regressions were run in turn for discards of the target species (for JMA and SQU), bycatch and discards of other commercial species (COM), non-commercial species (OTH), and frequently caught individual species. Each of the variables selected as significant by the model process was examined closely using model predictions. Only variables with a strong influence in the model and for which the models made sensible predictions were used to stratify data for bycatch and discard calculations.

Table 2: Summary of variables tested in the models (b, bycatch; d, discard models).

Variable	Type	Description
Year (b,d)	categorical	fishing year
Vessel (b,d)	categorical	vessel callsign
Nation (b,d)	categorical	country of registration
Company (b,d)	categorical	company owning or chartering vessel
Area (b,d)	categorical	area in which tow(s) occurred
Latitude (b)	continuous	latitude (decimal degrees) at start of tow
Longitude (b)	continuous	longitude (decimal degrees) at start of tow
Month (b,d)	categorical	month of tow(s)
Season (b,d)	categorical	high or low
Depth (d)	categorical	depth of tow (deep or shallow, see text)
Depth (b)	continuous	depth of tow (m)
Duration (b,d)	continuous	duration of tow(s) (minutes)
Distance (b,d)	continuous	distance of tow(s) (n.miles)
Speed (b)	continuous	recorded speed of tow (knots)
Headline height (b)	continuous	recorded headline height of tow (m)
Towtype (b,d) (not scampi)	categorical	bottom or midwater gear

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 any 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 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 subset 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 were sampled with equal probability. These assumptions 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 areas covered. Therefore the assumptions may be reasonably approximated.

Once the best estimator was chosen, estimates of $\hat{DR}$ were derived for each stratum in each fishery and variances were derived by bootstrapping. The discard ratio calculated for each stratum was then multiplied by the total estimated catch of the target species (or the total tow duration, depending on the outcome of the comparison of estimators) in the stratum, from commercial catch records, to estimate total discards $\hat{D}$:

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

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

Bycatch estimates were calculated in a similar manner to discards except that, 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 "New S" (Becker et al. 1988).

2.6 Calculation of observer sample sizes required for specified levels of precision in the jack mackerel and arrow squid fisheries

The variance of the mean discard ratio was estimated by resampling from the observer records of discards from processing groups, within appropriate strata. The ratio of discards to target catch was used, with the tow duration alternative estimator not considered. The variance of the mean varies in proportion to $1/n$, where n is the number of processing groups. Hence, the sample size that would achieve the target precision was estimated by choosing an appropriate value for n.

The variance of the discards was typically very high for these fisheries. Hence, it was necessary to take as large a dataset as possible to achieve a good estimate of it for each fishery. Resampling was carried out using all available discard data from the three years being examined, and for all species categories combined, to obtain variance estimates for each stratum.

Three alternative approaches to precision were adopted. The precision targets were specified values for: (1) the coefficient of variation (c.v.) of the estimated discard ratio; (2) the standard error (s.e.) of the estimated discard ratio; and (3) the s.e. of the estimated discard quantity.

Let $\hat{s}$ be the estimated standard error of the estimated mean discard ratio $\hat{r}$,
let n be the sample size,
let T be the total annual target catch,
let t_1, t_2, and t_3 be the alternative target precisions.

Then the estimated sample size, n^*, to achieve a c.v. of the estimated discard ratio equal to t_1 is given by

$$t_1 = \frac{\hat{s}}{\hat{r}}\sqrt{\frac{n}{n^*}}$$

$$\therefore n^* = n\left(\frac{\hat{s}}{t_1\hat{r}}\right)^2$$

Values for t_1 of 0.1, 0.2, 0.3, and 0.4 were used. A drawback with this approach is that as much effort may be expended achieving the target for a fishery with a mean discard ratio of 0.5% as for one with a mean discard ratio of 15%, when the discards in the latter were 30 times greater.

The estimated sample size, n^*, to achieve a s.e. of the estimated discard ratio equal to t_2 is given by

$$t_2 = \hat{s}\sqrt{\frac{n}{n^*}}$$

$$\therefore n^* = n\left(\frac{\hat{s}}{t_2}\right)^2$$

This approach sets the level of uncertainty as a proportion of the target catch. An estimate of discards is sought that has a fair chance of being within 2%, say, of the target fishery catch, irrespective of whether the discard ratio is high or low. Values for t_2 of 0.02, 0.04, and 0.06 were used. A drawback with this approach is that as much effort may be expended achieving the target for a fishery with total discards of 20 t as for one with total discards of 1000 t even though the discards in the latter were 50 times greater.

The estimated sample size, n^*, to achieve a s.e. of the estimated discard quantity equal to t_3 is given by

$$t_3 = \hat{s}T\sqrt{\frac{n}{n^*}}$$

$$\therefore n^* = n\left(\frac{\hat{s}T}{t_3}\right)^2$$

This approach sets the level of uncertainty as an absolute quantity of discards. An estimate of discards is sought that has a fair chance of being within 100 t, say, of the actual discards. Values for t_3 of 100 t, 200 t, and 300 t were used. This is the preferred approach as it achieves the most precise estimates of total discard quantity. Small fisheries and fisheries with very low discard ratios would tend to be sampled lightly, whereas large fisheries and those with high discard ratios would tend to be sampled intensively.

These three approaches (with the same set of precision targets) were also applied to bycatch data to calculate the coverage required (this time in terms of number of tows) to optimise precision in each stratum.

3. RESULTS

3.1 Distribution of observer data

3.1.1 Jack mackerel

The positions of all observed tows in the target jack mackerel fishery are shown along with those of all commercial target tows (from TCEPR records) from 1998–99 to 2000–01 in Figure 1. There was a good spread of observer coverage over most of the geographical range of this fishery. In area WEST, observed tows covered the entire length of the west coast South Island fishery and the central portion of the Taranaki Bight fishery, but Tasman Bay, the inner Taranaki Bight, and the northern extent of the fishery north of Cape Egmont were less well covered. Almost half (49%) of the observer effort over the three years was spent in the WEST strata. All parts of the southern Stewart-Snares shelf fishery (SNAR) were covered (45% of observer effort), and the smaller Chatham Rise fishery (CHAT) was also well covered (6% of observer effort). 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 OTHR area category. The distribution of observer coverage in this fishery is influenced to a certain extent by the patterns of fishing in the hoki fishery. An undetermined number of observed trawls targeting jack mackerel were made on trips primarily targeting hoki in the Cook Strait and west coast South Island fisheries, outside of the main jack mackerel grounds, when the opportunity arose.

The annual number of observed tows was highest in the first year (Table 3) and decreased by a third by 2000–01. In terms of the total estimated target fishery catch, however, that portion covered by observers has been consistently high, between 19 and 23%. Twenty vessels were observed during this period.

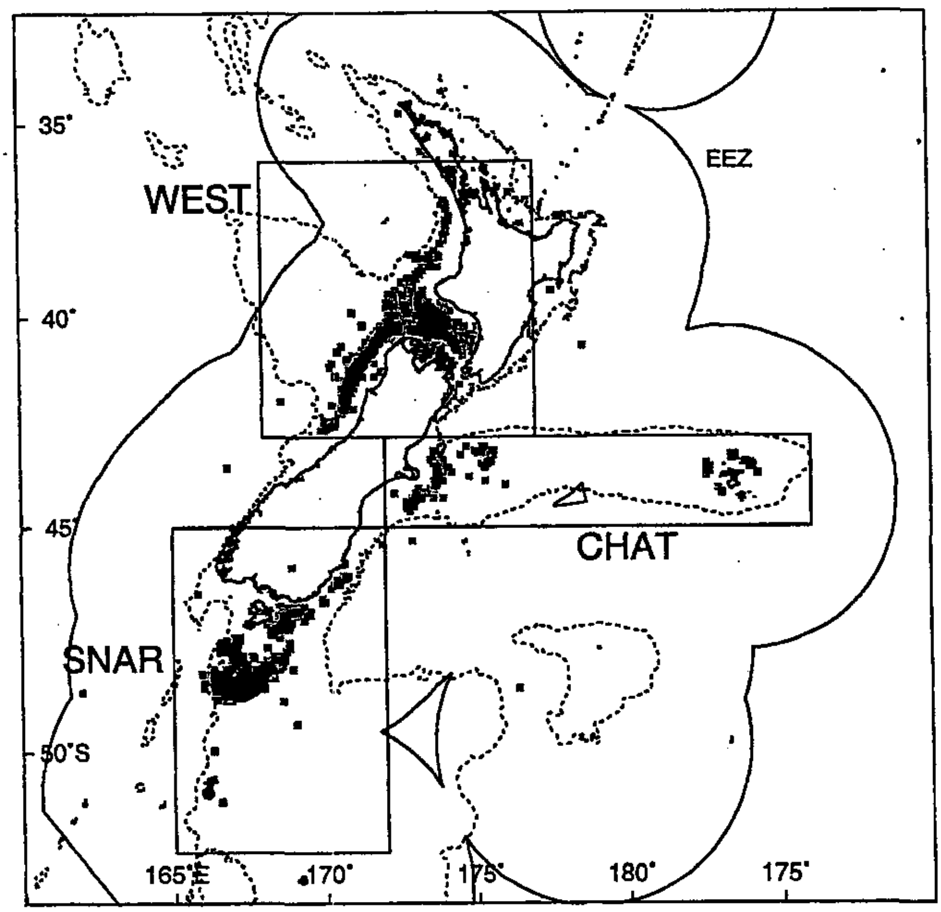

Figure 1: Distribution of tows recorded by observers on vessels targeting jack mackerel between 1 October 1998 and 30 September 2001 (black dots), and all commercial tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.

Table 3: Number of tows and fraction of catch observed in the jack mackerel target trawl fishery, by year.

Fishing year	Tows observed	Number of vessels observed	Observed catch (% of target fishery catch)
1998–99	597	10	21.0
1999–00	497	12	22.7
2000–01	398	14	18.7

3.1.2 Arrow squid

The positions of all observed tows in the target arrow squid fishery, from 1998–99 to 2000–01, are shown in comparison with those of all target commercial tows (from TCEPR records) from the same period, in Figure 2.

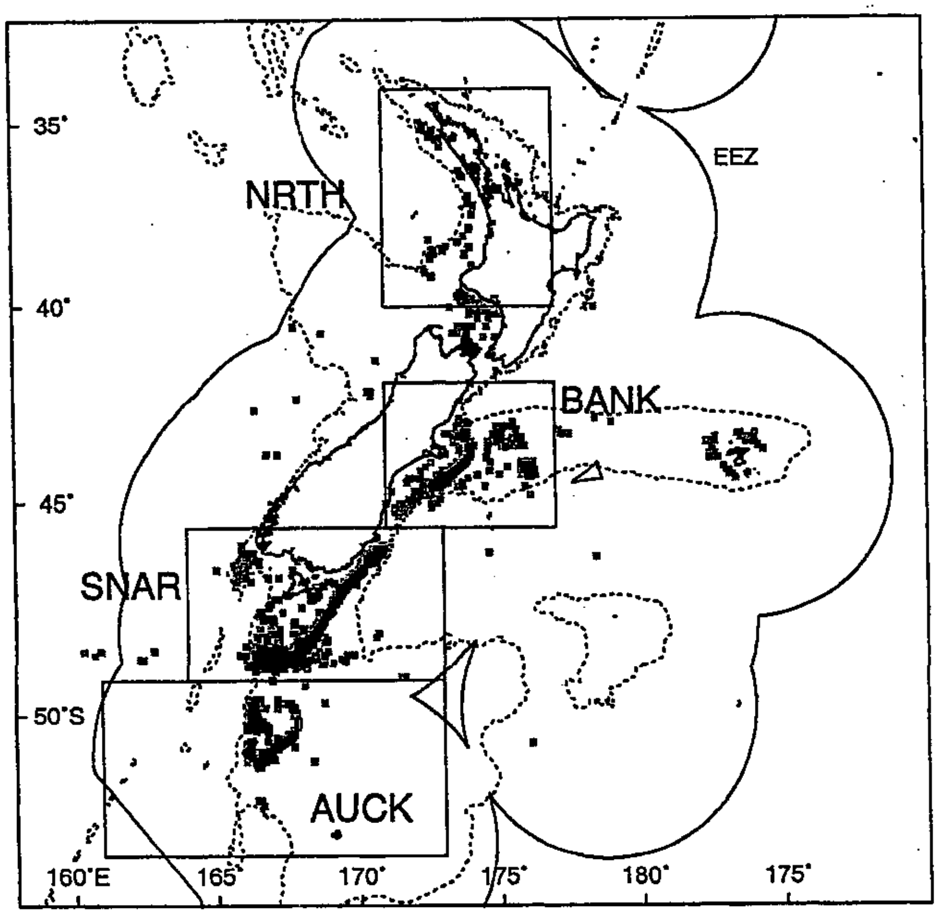

Figure 2: Distribution of tows recorded by observers on vessels targeting arrow squid between 1 October 1998 and 30 September 2001 (black dots), and all commercial tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.

The Auckland Islands fishery (AUCK) has very high observer coverage due to management measures imposed for the protection of Hooker's Sealions (*Phocarctos hookeri*). Fishing for arrow squid in that area was confined to the summer and autumn months and observers recorded catch and discards from 40% of all target tows in 1998–99, 36% in 1999–2000, and 100% in 2000–01. The Stewart-Snares shelf region (SNAR) was also well covered apart from the area in the vicinity of the Puysegur Banks. In the east coast South Island and western Chatham Rise (BANK) area coverage is restricted to a few locations, and the small Chatham Islands fishery was not covered. The sporadic fishing along the west coast of the North Island between Cape Egmont and North Cape was well covered. The central fishery off the Taranaki Bight, identified by commercial tow positions in Figure 2, may be due to incorrect recording of the target species. Catches of arrow squid in this area represented less than 4% of the total catch during the three years. Tows recorded in this area and in other areas outside the four defined by boxes in Figure 2 (including outliers with probable position errors) were combined into a single OTHR area category.

The annual number of observed tows has been high during the period, particularly in the most recent year when the 2999 tows observed accounted for over 50% of the target fishery catch in that year (Table 4). In the other two years the percentage coverage was well above the nominal 10% usually considered sufficient to be representative of the fishery. Thirty-two vessels were observed during this period.

Table 4: Number of tows and fraction of catch observed in the arrow squid target trawl fishery, by year.

Fishing year	Tows observed	Number of vessels observed	Observed catch (% of target fishery catch)
1998–99	997	16	15.4
1999–00	868	12	20.0
2000–01	2 999	26	53.6

3.1.3 Scampi

The positions of all observed tows in the target scampi fishery, from 1990–91 to 2000–01, are shown in comparison with those of all target commercial tows (from TCEPR forms) from the same period, in Figure 3. The main fisheries for scampi off the east coast of the North Island, on the Chatham Rise, and in the sub-Antarctic, were well covered by observers during this time. The small fishery around the EEZ boundary on the Challenger Plateau was less well covered. The tows recorded on the west coast of the South Island are in conflict with recorded landings from that area, which are negligible (see Annala et al. 2002), and may be the result of incorrect recording of the target species. Tows recorded in this area and in other areas outside those separated out in Figure 3 (including outliers with probable position errors) were combined into a single OTHR area category.

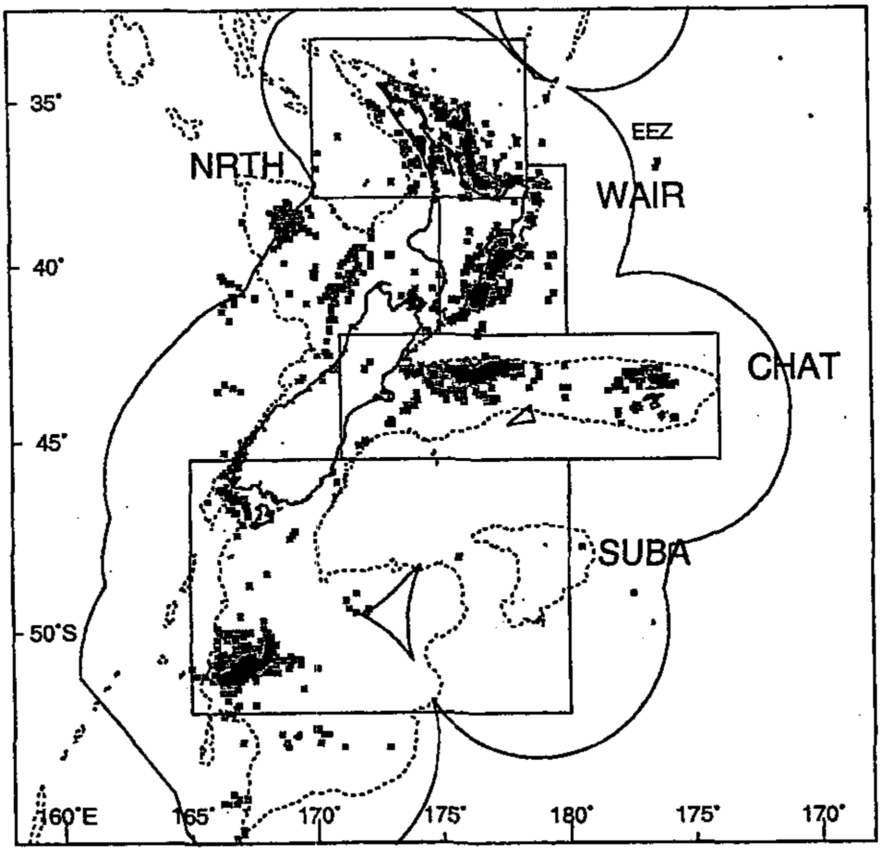

Figure 3: *Distribution of tows recorded by observers on vessels targeting scampi between 1 October 1990 and 30 September 2001 (black dots), and all commercial tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.*

This fishery has had observers present for several hundred tows per year in all years covered by this analysis (Table 5). Coverage has ranged from a low of 266 tows (5% of the target fishery catch) in 2000–01 to a high of 807 tows (14.3% of the target fishery catch) in 1990–91. Less than 10% of the target fishery catch was observed in 5 of the 11 years, but over the entire period the total coverage was more than 11%. Fourteen vessels were observed during this period.

Table 5: Number of tows and fraction of catch observed in the scampi target trawl fishery, by year.

Fishing year	Tows observed	Number of vessels observed	Observed catch (% of target fishery catch)
1990–91	353	6	7.4
1991–92	555	7	17.1
1992–93	410	5	10.5
1993–94	807	7	14.3
1994–95	402	6	16.7
1995–96	279	3	7.6
1996–97	323	5	9.5
1997–98	297	6	9.5
1998–99	498	6	13.6
1999–00	419	6	10.7
2000–01	266	5	5.3

3.2 Comparison of estimators

Two alternative forms of the bycatch and discard ratio estimators were considered and compared. Overall ratios (observer data from all fishing years combined) and bootstrap estimates of c.v.s were calculated for bycatch and discards of COM and OTH species categories in each of the three fisheries, using the target species estimated catch and the tow duration as alternative denominators in the ratios. The two c.v.s calculated for each species category were compared, with the intention of using the estimator which consistently produced the lowest c.v.. The results of these comparisons are shown in Tables 6 and 7. In all 12 comparisons the c.v. associated with the tow duration-based estimator is lower than the c.v. associated with the target species catch-based estimator. The differences are in all cases slight, however, ranging from 0.03% to 1.40%, and are least for bycatch in the scampi fishery and greatest for bycatch in the jack mackerel fishery. The ratio c.v.s are smaller for discards than for bycatch in the jack mackerel and arrow squid fisheries, but the reverse is true in the scampi fishery. It is difficult to know whether commercial catch-effort records of target species catch are recorded with more accuracy than records of tow duration. Although it is easier to measure tow duration than estimate catch weights, target species catch is of more interest and is recorded more frequently than tow duration. Without this knowledge the estimator chosen must be the one that is most likely to provide the highest precision in the estimates. Therefore, the tow duration-based estimator was selected for all bycatch and discard calculations.

Table 6: Comparison of bycatch estimators. Bycatch ratios and their c.v.s for the two estimators in each category of bycatch in the jack mackerel, arrow squid, and scampi fisheries. Ratios were derived from observer data from all three fishing years combined and c.v.s were calculated by bootstrapping.

Fishery	Species category	Estimator	Bycatch ratio	c.v. (%)
Jack mackerel	COM	JMA catch	0.653	4.96
	COM	Tow duration	1801	3.56
	OTH	JMA catch	0.044	11.54
	OTH	Tow duration	121	10.40
Arrow squid	COM	SQU catch	0.364	3.80
	COM	Tow duration	468	3.20
	OTH	SQU catch	0.082	5.96
	OTH	Tow duration	106	5.52
Scampi	COM	SCI catch	2.047	1.44
	COM	Tow duration	85.2	1.41
	OTH	SCI catch	2.976	1.71
	OTH	Tow duration	123.5	1.63

Table 7: Comparison of discard estimators. Discard ratios and their c.v.s for each of the two alternative estimators in the COM and OTH categories of discards in the jack mackerel, arrow squid, and scampi fisheries. Ratios were derived from observer data from all three fishing years combined and c.v.s were calculated by bootstrapping.

Fishery	Species category	Estimator	Discard ratio	c.v. (%)
Jack mackerel	COM	JMA catch	0.017	27.32
	COM	Tow duration	46.6	26.70
	OTH	JMA catch	0.029	14.05
	OTH	Tow duration	80.78	13.11
Arrow squid	COM	SQU catch	0.018	37.55
	COM	Tow duration	22.84	37.33
	OTH	SQU catch	0.053	8.40
	OTH	Tow duration	69.61	8.16
Scampi	COM	SCI catch	0.298	4.22
	COM	Tow duration	11.95	4.06
	OTH	SCI catch	2.85	2.92
	OTH	Tow duration	114.04	2.77

3.3 Factors influencing bycatch in the jack mackerel fishery

3.3.1 Overview of raw bycatch data

Bycatch data were initially examined by plotting total bycatch in each tow against variables recorded by observers to get an initial impression of what factors may be important (Figure 4). There is an indication of increased bycatch with tow duration up to about 6 hours, a between area difference with catches slightly lower in area WEST, and lower catches from NZPOL vessels compared with vessels of other nations. The recorded nationality refers to the country of registration except where a combined code, such as NZPOL or NZRUS, 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 a, e.g., Russian or Polish vessel. Total bycatch in 1998–99 was on average less than in the following two years. There were some differences between companies, with medians for the five companies shown ranging from about 2 to 8 t, although the interquartile ranges were all overlapped. There was also a moderate monthly pattern, with an indication of increasing bycatch between January and August in each year, followed by a decrease in the following months.

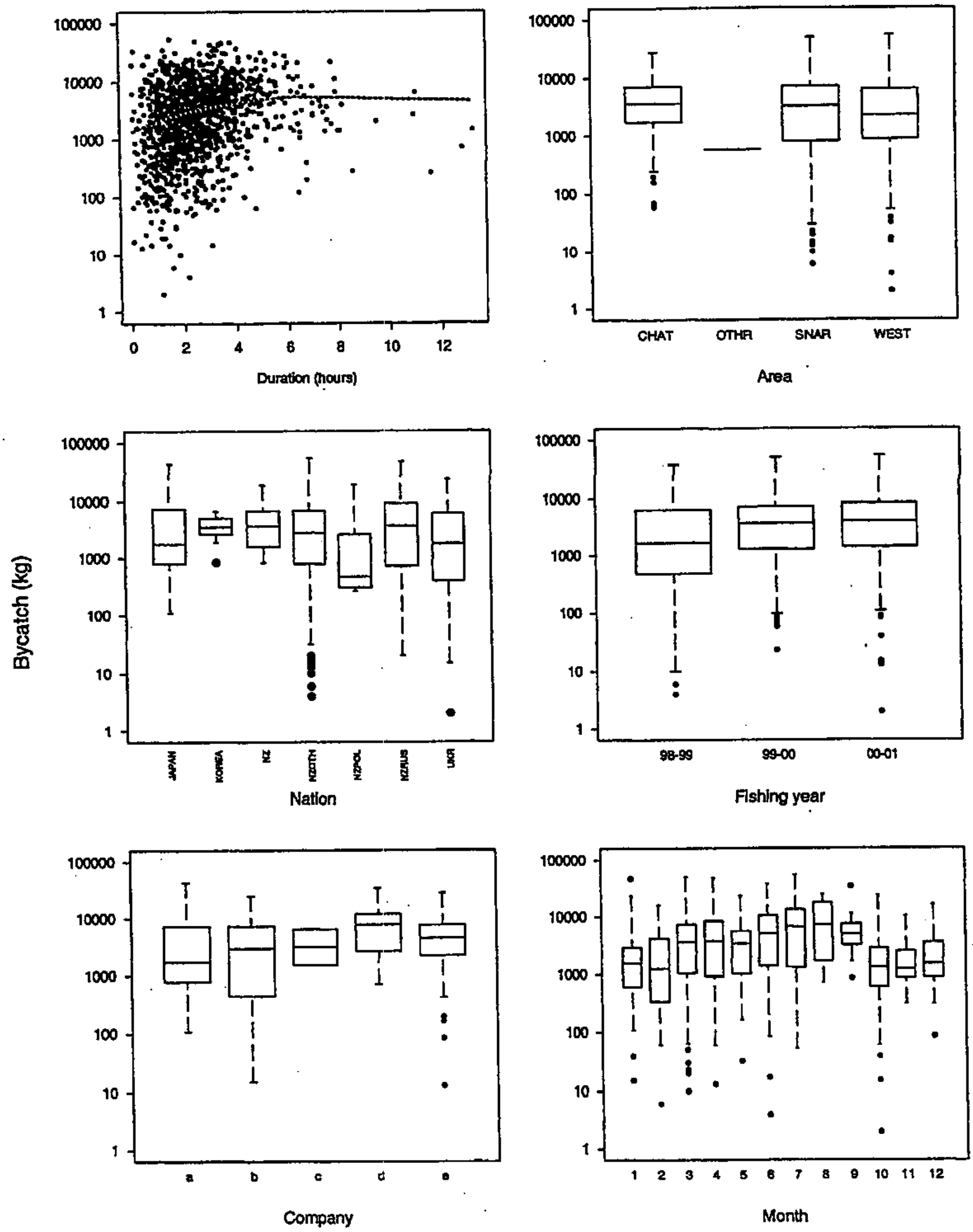

Figure 4: Jack mackerel fishery, observer catch data for fishing years 1998–99 to 2000–01. Total bycatch per tow plotted against some of the available variables. Bycatch and duration are plotted on a log scale. The dashed line in the top left panel represents a mean fit to the data. The box and whisker 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.

3.3.2 Regression modelling and stratification of bycatch data

The unit of interest in this analysis is the bycatch ratio, catch/hour. If this ratio differs between areas, nationalities, months, etc., for a bycatch species category then a ratio that is specific to the level of that factor should be applied. Only 2% of all tows did not have some level of bycatch of COM species, and 24% of tows did not record any bycatch of OTH species. The equivalent percentages for the main individual bycatch species were barracouta (BAR), 6%; blue mackerel (EMA), 66%; redbait (RBT), 60%; arrow squid (SQU), 63%. Linear models or a combination of linear and binomial models were run in a forward stepwise manner to identify the most influential factors in each case. For species categories where linear models only were run, a nominal 0.1 $kg.h^{-1}$ was added to records with no bycatch. Variables given in Table 2 were tested in the models.

The variables *month* and *vessel* were consistently selected in each model, indicating a strong seasonal effect on bycatch not only for commercial species and non-commercial species overall, but also for the four commercial species examined separately (Table 8). The *fishing year* was also important in several of the models but fishery *area* had only a small influence in less than half of the models. There was insufficient spread of data to allow stratification of bycatch ratio estimates by more than one or two factors. In addition, some factors, e.g., *vessel*, *headline height*, and *towtype* cannot easily be used to group commercial catch effort data due to incomplete observer coverage of the fleet and missing data in some fields. Appropriate strata were determined from the model results for each species group, and separate estimates of ratios made where more than 50 records and at least three vessels were available in each stratum.

Table 8: Summary of regression modelling for bycatch in the jack mackerel fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses; –, not selected. Figures in bold type indicate variables used in stratification of bycatch data. *fyr*, fishing year; *head-ht*, headline height.

Species category	Model type	*month*	*vessel*	*fyr*	*area*	*head-ht*	*latitude*	*nation*	*depth*	Variable *speed*
COM	Linear	2(09.85)	1(05.60)	3(15.72)	4(16.39)	–	–	–	–	–
OTH	Logistic	3(18.90)	2(16.84)	1(10.82)	–	4(20.99)	–	5(21.86)	–	6(22.51)
OTH	Linear	1(14.33)	2(18.48)	3(19.15)	–	–	–	–	–	–
BAR	Linear	1(17.86)	3(30.19)	2(25.30)	5(36.16)	4(35.40)	–	–	–	–
EMA	Logistic	1(69.96)	2(74.78)	–	3(77.30)	–	–	–	–	–
EMA	Linear	1(39.10)	2(44.39)	–	3(45.09)	–	–	–		–
RBT	Logistic	1(08.51)	3(17.33)	2(14.11)	–	–	–	–	4(20.51)	–
RBT	Linear	2(16.31)	1(13.50)	–	–	–	3(18.60)	–	–	–
SQU	Logistic	2(17.36)	3(21.65)	4(22.45)	–	1(10.62)	–	–	–	–
SQU	Linear	1(40.92)	2(45.92)	3(49.07)	–	–	5(52.15)	4(50.88)	–	–

(a) COM (non-target commercial species)

Less than 2% of tows did not record any bycatch of COM species and therefore linear models only were run. The variable *vessel* had the most influence in the model, followed by *month*, *fishing year*, and *area*. These four variables explained 16.4% of the variance in the data. Model predictions for bycatch of COM by month show three groupings of similar months: a) May, October, and November (less than 70 $kg.h^{-1}$); b) January–April, December (200–500 $kg.h^{-1}$); and c) June–September (750–1700 $kg.h^{-1}$). Ratios were estimated separately for these groupings of months and for each fishing year, where data were sufficient.

(b) OTH (*non-target non-commercial species*)

A quarter of the tows recorded no catch of OTH species and so a binomial model was constructed in addition to a linear model. A total of 1271 records were used in the binomial regression. The most critical factors were *fishing year*, *vessel*, and *month*. The reduction in residual deviance, termed 'R^2', was 22.5%.

For the linear model, only records recording a bycatch of OTH species, a total of 921, were used. The variable *month* had a strong influence in this model with *vessel* and *fishing year* also selected. The model R^2 was 19.2%.

Linear model predictions showed an erratic pattern of bycatch of OTH from month to month, and there were no clear groupings of months with similar catch rates. Predictions from the logistic model revealed one month (May) with a low probability of a not target catch of OTH relative to all other months, which were similar. There were too little data to stratify by *month*, and no clear groupings of like months, so in this case stratification was limited to *fishing year* only.

(c) BAR (barracouta)

With a relatively small fraction of records having no bycatch of BAR, a linear model only was run. The *month* variable had the most influence in this model, followed by *fishing year* and *vessel*. The model R^2 was 36.2%. Linear modelling predictions show a monthly pattern of bycatch of BAR and these were used to break up the year into four quarters for calculation of ratios. From January to March (coded "a") levels were moderate (about 200–300 $kg.h^{-1}$), were low from April to June ("b", under 100 $kg.h^{-1}$), high from July to September ("c", 175–500 $kg.h^{-1}$), and low from October to December ("d", under 125 $kg.h^{-1}$).

(d) EMA (blue mackerel)

Two-thirds of jack mackerel tows recorded no catch of EMA and so both binomial and linear models were run. The same three variables were selected in both models, and in the same order; *month*, *vessel*, and *area*. *Month* had a very strong influence in both models, contributing 70% to the R^2 in the binomial model and 39% in the linear model. The other two variables were of minor importance in comparison.

Blue mackerel have a more northern distribution in New Zealand waters, and are uncommon on the Chatham Rise and south (Anderson et al. 1998). Logistic model predictions agree, with a 50% chance of a bycatch of EMA in area WEST and close to zero chance in CHAT and SNAR. There were conflicting patterns of EMA catch by month predicted from linear and logistic models, with a high probability of an EMA catch predicted for August and September, but high catch rates predicted for June and July. Because of this, stratification was limited to *area*.

(e) RBT (redbait)

A large fraction of tows recorded no catch of RBT and so here, too, both binomial and linear models were run. In the logistic model, *month* was the most critical factor, followed by *fishing year* and *vessel*. In the linear model, *vessel* had the most influence on the catch of RBT, followed by *month*. The logistic model R^2 was 21% and the linear model R^2 was 19%.

Model predictions for bycatch of redbait show a month effect which is driven largely by a few catches of this species in one month (August) with few records, so that stratification by *month* would not be appropriate. The linear model predicts lower bycatch of RBT in 1999–2000 than in the other years, and so stratification was by *fishing year* only.

(d) SQU (arrow squid)

Both binomial and linear models were run for SQU bycatch also. The binomial model showed that *headline height* was the most influential factor in determining the probability of a SQU catch, followed by *month, vessel,* and *fishing year*. In the linear model, *headline height* was not selected but *month* again had a strong influence, followed by *fishing year* and *vessel*. The logistic model R^2 was 22% and the linear model R^2 was 52%.

Model predictions for arrow squid catch by month show strong variation in probability of catch and in level of catch, but there is little pattern and a lack of agreement between the two models. On the other hand, the year effect in each model predicts a lower probability of a SQU catch as well as a lower catch level for the 1998–99 year. Bycatch ratios were therefore calculated separately for each year.

3.4 Factors influencing discards in the jack mackerel fishery

3.4.1 Overview of raw discard data

Raw discard data were initially examined by plotting total discards in each processing group against the available variables to get a first impression of what factors may be important (Figure 5). A general relationship is evident from the plot between discards and total tow duration, with an increasing weight of discards with increasing tow duration. Discard levels were even across the three defined areas, with less variation in discard levels in CHAT than other in areas. There was some variation between nations also, but only for NZOTH and NZRUS were there more than 20 records available and there was little difference between these two categories. Although there was only limited company information, with this variable missing for many records, there appears to be some variation between the five companies plotted. Discards varied with month also, with peaks in discard in autumn and spring. Discard levels were similar in each of the three fishing years, with median discards of about 100 kg per processing group.

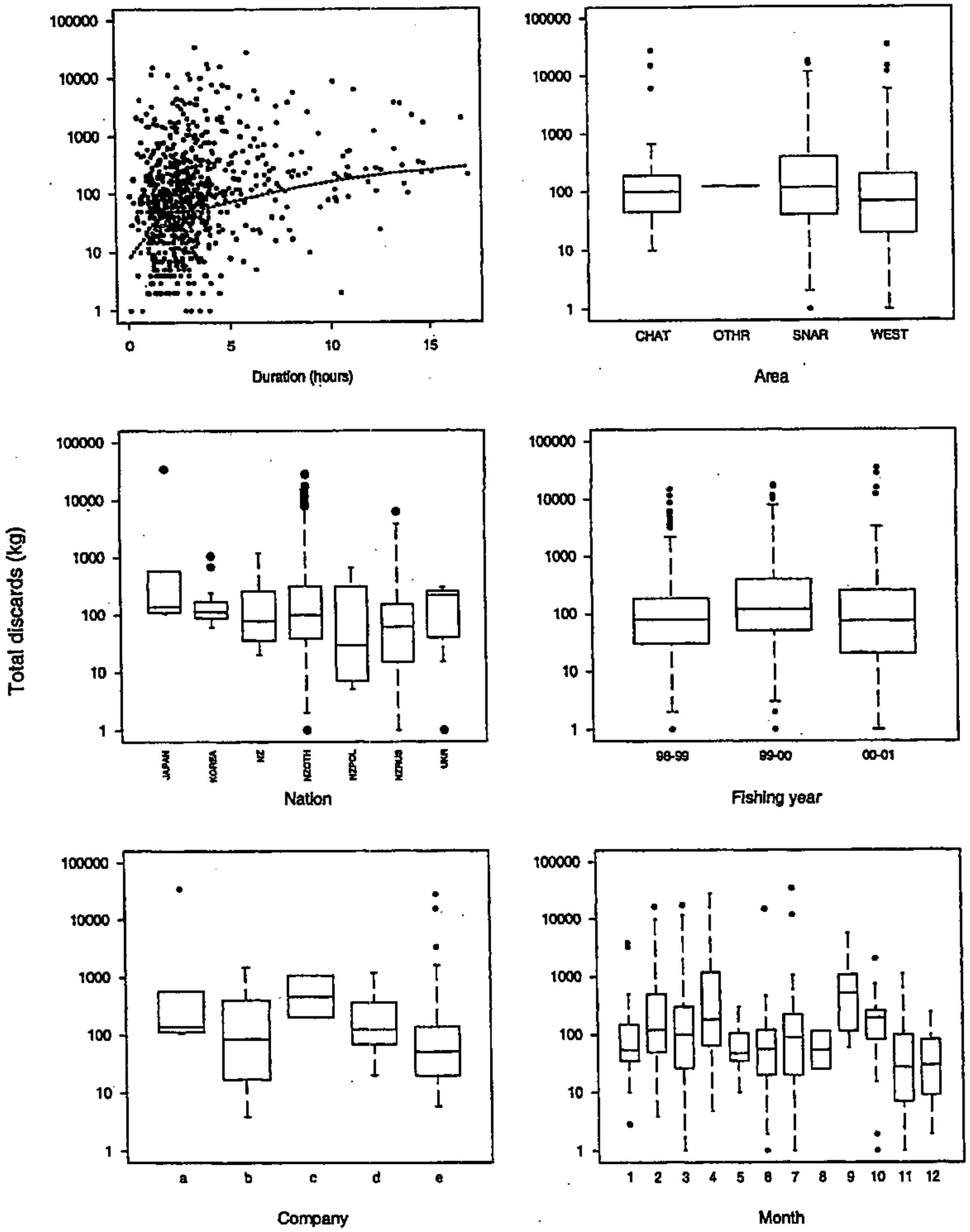

Figure 5: Jack mackerel fishery, observer discard data for fishing years 1998–99 to 2000–01. Total discards per processing group plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers.

3.4.2 Regression modelling and stratification of discard data

The dependant variable in these regressions was the discard ratio, discards per hour, for JMA, COM, and OTH species categories. Of the 1280 individual records available for this analysis only 53 (4%) recorded any discard of JMA, while 102 (8%) recorded a discard of COM and 811 (63%) recorded a discard of OTH. Discards of individual non-target species were too low to examine separately. Regressions were weighted by 1/n.tows to put less weight on the relatively few records with more than one tow per processing group, to account for the fact that those records tended to have greater discards than those representing a single tow. A combination of log-linear and logistic models were run.

Of the variables available to test, three were consistently selected in models describing discards in the jack mackerel fishery. These were, in order of importance, *vessel*, *month*, and *fishing year* (Table 9). *Depth* and *nation* were each selected once in the models tested, but explained only a small amount of the variability in the data. Factors considered for stratification of discard ratio calculations were *fishing year* and *month* (*vessel* cannot be used to scale up ratios to landings as only a fraction of the vessels in the fleet were observed). Discard ratios were calculated for strata only where more than 50 records were available and, in consideration of the importance of *vessel* in discards, where data were derived from at least three vessels. Where these criteria were not met for a particular stratum, a ratio based on all data was calculated.

Table 9: Summary of regression modelling for discards in the jack mackerel fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses. Figures in bold type indicate variables used in stratification of discard data. –, not selected; *fyr*, fishing year.

Species category	Model type	Variable				
		vessel	*month*	*fyr*	*depth*	*nation*
JMA	Linear	1(25.99)	4(46.48)	3(38.03)	2(33.10)	–
JMA	Logistic	1(36.64)	2(38.78)	–	–	–
COM	Linear	1(30.53)	2(41.53)	3(42.11)	–	–
COM	Logistic	1(32.56)	2(36.61)	3(37.95)	–	–
OTH	Linear	2(14.20)	1(09.26)	3(15.74)	–	4(16.54)
OTH	Logistic	1(10.58)	2(15.27)	3(16.71)	–	–

(a) JMA (target species)

The variable *vessel* contributed 26% to the R^2 in the linear model, and was followed in importance by tow *depth*, *fishing year*, and *month*. The model R^2 was 46%. Only two variables had any influence in the binomial model, *vessel* (36% of total R^2) and *month*. The model R^2 was 39%. *Month* was the only usable term selected in the logistic model, and this term also featured in the linear model. The models showed little difference in the likelihood of a discard between months (although for several months there were no discards recorded at all), that discard levels were inversely related to fishing depth, and that discards were much greater in 2000–01 than in the two preceding years. These predictions are unreliable, however, as discards of JMA were infrequent and generally small, and so a single ratio was calculated with no stratification.

(b) COM (non-target commercial species)

The same three variables, in the same order, were selected for both the binomial and linear model. The variable *vessel* was the most important factor determining both the chance and level of a discard of COM, contributing more than 30% to the R^2 in both models. The factors *month* and *fishing year* were the other two selected. The binomial model R^2 was 38% and the linear model R^2 was 42%. Due to the small number of discard events, several of which were over 10 tonnes, the pattern of predicted monthly discard probabilities and levels was highly variable. These patterns were probably influenced as much by chance as by real effects. The same may be true for variation in model predictions between years. In 2000–01, for example, there were only 11 records out of 193 with discards of COM. For these reasons a single ratio was calculated for COM discards, as was with JMA.

(c) OTH (non commercial species)

Both models describing the pattern of OTH discards had little explanatory power, with R^2 values of about 16–17%. The predictors *month* and *vessel* had the most influence in the binomial model and also, in the reverse order, in the linear model. *Fishing year* was the third variable selected in each model. The models predicted a high probability of a discard of OTH in the early months of the calendar year, as well as August, and also high levels of discards in the early part of the year. Discards of OTH were much more frequent and despite low R^2 values in both models the predictions are more plausible than those in the JMA and COM models. Ratios were therefore stratified by *month*.

3.5 Factors influencing bycatch in the arrow squid fishery

3.5.1 Overview of raw bycatch data

Raw bycatch data were initially examined by plotting total bycatch in each tow against the available variables (Figure 6).

There was a positive relationship between tow duration and total bycatch in this fishery, with catch increasing with duration for tow durations of up to and over 10 hours. Most of the tows were between 2 and 5 hours long, but ranged from a few minutes to over 12 hours. Bycatch was considerably lower overall in area AUCK (median 150 kg per tow) than in the other areas (800–1700 kg per tow). Bycatch was low for nation NZRUS (median 370 kg per tow) and similar for the other nation categories (450–650 kg per tow). There was little difference in median values between the three fishing years, but there is an indication of some variation between companies and also months, with higher bycatch levels in September and December.

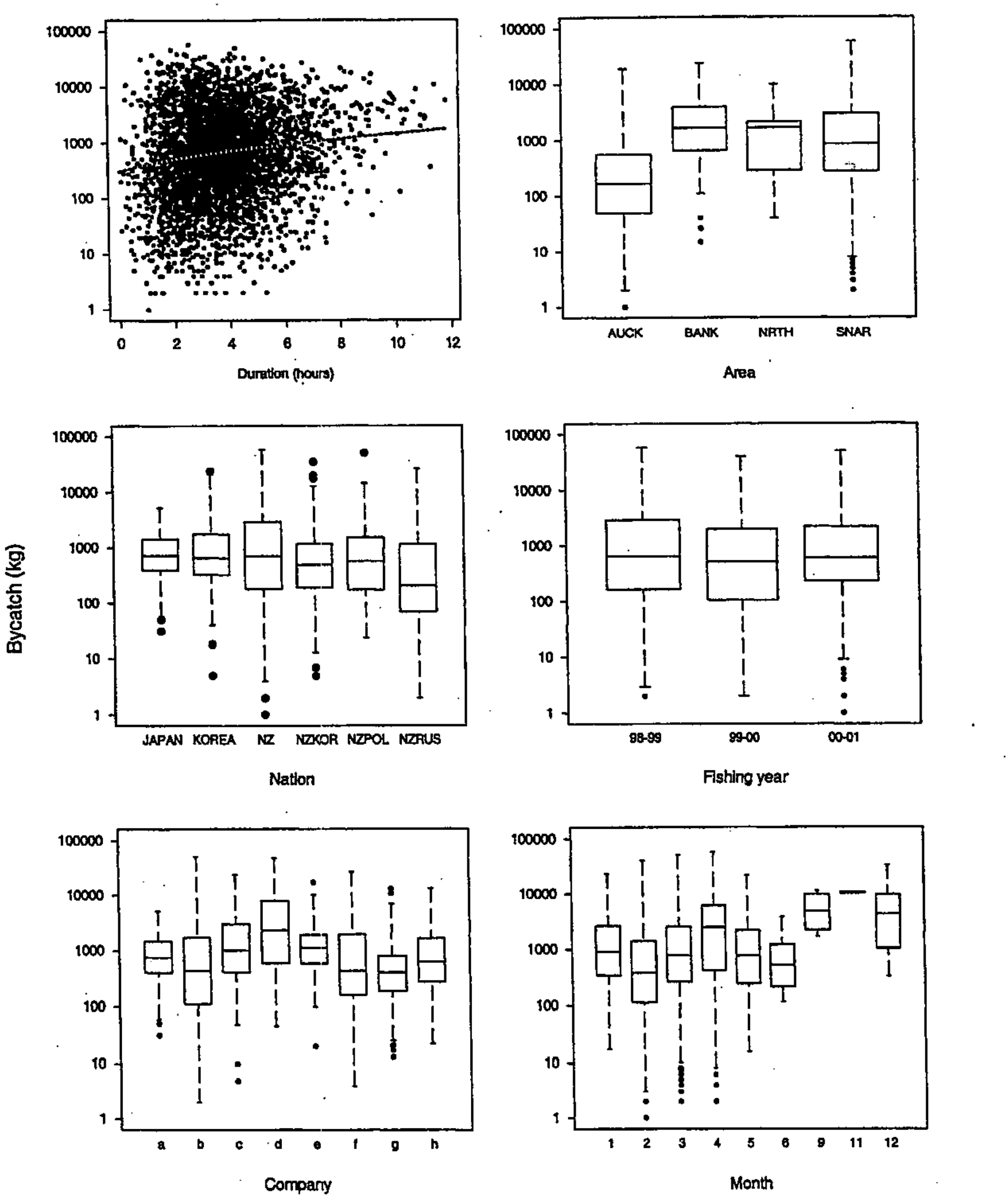

Figure 6: Arrow squid fishery, observer catch data for fishing years 1998–99 to 2000–01. Total bycatch per tow plotted against some of the available variables. Bycatch is plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers.

3.5.2 Regression modelling and stratification of bycatch data

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 individual species frequently caught, i.e., barracouta (BAR), jack mackerel (JMA), and silver warehou (SWA). Only 7% of all tows did not have some level of bycatch of COM species, while 15% of tows did not record any bycatch of OTH species. The equivalent values for individual species groups examined were: BAR 19%; JMA 62%; SWA 37%. Linear models or a combination of linear and binomial models were used to identify the most influential factors.

The *vessel* variable was consistently the most influential in determining the probability and level of bycatch in the arrow squid fishery, entering all models in the first or second position (Table 10). *Area* was nearly as influential and is more useful in this analysis as the commercial catch data are easily grouped into areas. *Month* was also selected in all models and is a useful variable for the same reason. *Fishing year* and tow *depth* also had some influence, but always less than *area* and *month*, and so these were the only factors used for stratification of catch ratio estimates.

Table 10: Summary of regression modelling for bycatch in the arrow squid fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses. Figures in bold type indicate variables used in stratification of bycatch data. –, not selected; *fyr*, fishing year.

Species category	Model type	Variable				
		vessel	*area*	*month*	*fyr*	*depth*
COM	Linear	1(17.25)	**2(26.86)**	**3(30.10)**	4(31.30)	–
OTH	Linear	1(25.46)	**2(30.25)**	**3(33.20)**	–	–
BAR	Linear	1(15.25)	**2(21.36)**	**3(25.37)**	5(28.71)	4(28.14)
JMA	Logistic	2(28.58)	**1(15.64)**	**4(34.42)**	–	3(32.22)
JMA	Linear	1(16.27)	**3(23.93)**	**4(25.83)**	–	2(21.01)
SWA	Logistic	2(17.61)	**1(09.16)**	**3(21.48)**	4(23.14)	–
SWA	Linear	1(13.07)	**2(17.80)**	**3(20.12)**	4(20.76)	–

(a) COM (non-target commercial species)

A nominal 0.1 $kg.h^{-1}$ was added to records with no bycatch of COM species and linear models only were run. The variables with the most influence on levels of COM bycatch were *vessel*, followed by *area* and *month*. The model R^2 was 31%. Model predictions for bycatch of COM by *month* show that the influence of this factor was due to the contrast in catch between February and March, when most of the data were collected. Catch rates in March were three times those of February. Similarly, bycatch of COM in the two areas with most data, AUCK and SNAR, showed a clear difference in the model predictions. The catch rates of COM in *area* SNAR were nearly eight times those in AUCK. Ratios were therefore calculated separately for February and March and for AUCK and SNAR and overall ratios calculated to apply to other months and areas.

(b) OTH (non-target non-commercial species)

For this model a nominal 0.1 $kg.h^{-1}$ was added to records with no bycatch of OTH species and linear models only were run. The same three variables selected first into the COM model were also selected for this model, and in the same order. *Vessel* contributed 25% of the R^2, with *area* and *month* bringing the total R^2 to 33%. Predicted catch rates of OTH by *month* showed similar values for the months with the most data, February and March, with the extreme values in months with few data points. In contrast, the linear model predicted catch rates in *area* SNAR to be more than three times those in *area* AUCK, the two areas with most data. Bycatch ratios were therefore estimated separately for these two areas and an overall ratio calculated for other areas.

(c) BAR (barracouta)

A nominal 0.1 kg.h^{-1} was added to records with no bycatch of BAR and linear models only were run. *Vessel*, *area*, and *month* were the most influential variables, with *depth* and *fishing year* also having a small influence. For bycatch of BAR there were sufficient differences in predictions between February and March and between AUCK and SNAR, and sufficient data, to justify calculating separate ratios for combinations of these months and areas, and overall ratios for the remaining months and areas. The bycatch rate of BAR in March was three times that of February, and predicted catch rates in SNAR were several times greater than for AUCK.

(d) JMA (jack mackerel)

Both binomial and linear models were used for examination of JMA bycatch, as a large fraction of tows did not catch these species. The same four variables were selected in both models, but in a different order. In the binomial model *area* was the most important predictor, followed by *vessel*, *depth*, and *month*. The model R^2 was 34%. In the linear model *vessel* was selected first, followed by *depth*, *area*, and *month*, with a model R^2 of 26%. There were large differences in the probability and level of catch between areas and with depth. At 100 m the probability of a catch of JMA was about 0.8 and the predicted catch level was about 40 kg. Bycatch dropped off steadily with depth to a probability of less than 0.1 and a level of less than 5 kg at depths of more than 250 m. The AUCK *area* stood out with a very low probability of a catch of JMA compared with the other areas, and the BANK and SNAR areas showed both a similar probability and a similar predicted level of JMA catch. Although *depth* had an influence on JMA catch, this is a difficult factor by which to stratify commercial catch data. Ratios were therefore calculated by *area* only, for AUCK, BANK, and SNAR separately, and for NRTH and OTHR combined.

(e) SWA (silver warehou)

Just over a third of all tows did not record any catch of SWA and so both model types were used. In both models *area* and *vessel* had the most influence, in that order in the binomial model, and in the reverse order in the linear model. The variables *month* and *fishing year* also had a small influence in both models. The models had similar, moderate explanatory power, with R^2 values of 21–23%. *Area* was the most influential usable factor in both models. The probability of a SWA catch was predicted to be about 20% in AUCK compared to about 75–85 % in BANK and SNAR. Similarly, when catches of SWA were made, the level in AUCK was about a quarter of that in SNAR and BANK. *Month* was also important in both models, but each showed a different pattern of catches and probabilities over the year. Stratification in this case was by *area* only.

3.6 Factors influencing discards in the arrow squid fishery

3.6.1 Overview of raw discard data

Exploratory plots were prepared to examine total discards per processing group with respect to the available variables (Figure 7). These show a strong relationship between tow duration and total discards, with total tow duration generally under 5 hours. Discard levels in AUCK were an order of magnitude less than in BANK. Discard levels in *area* SNAR were in between those of these two areas, while there were relatively few records from the other two areas shown.

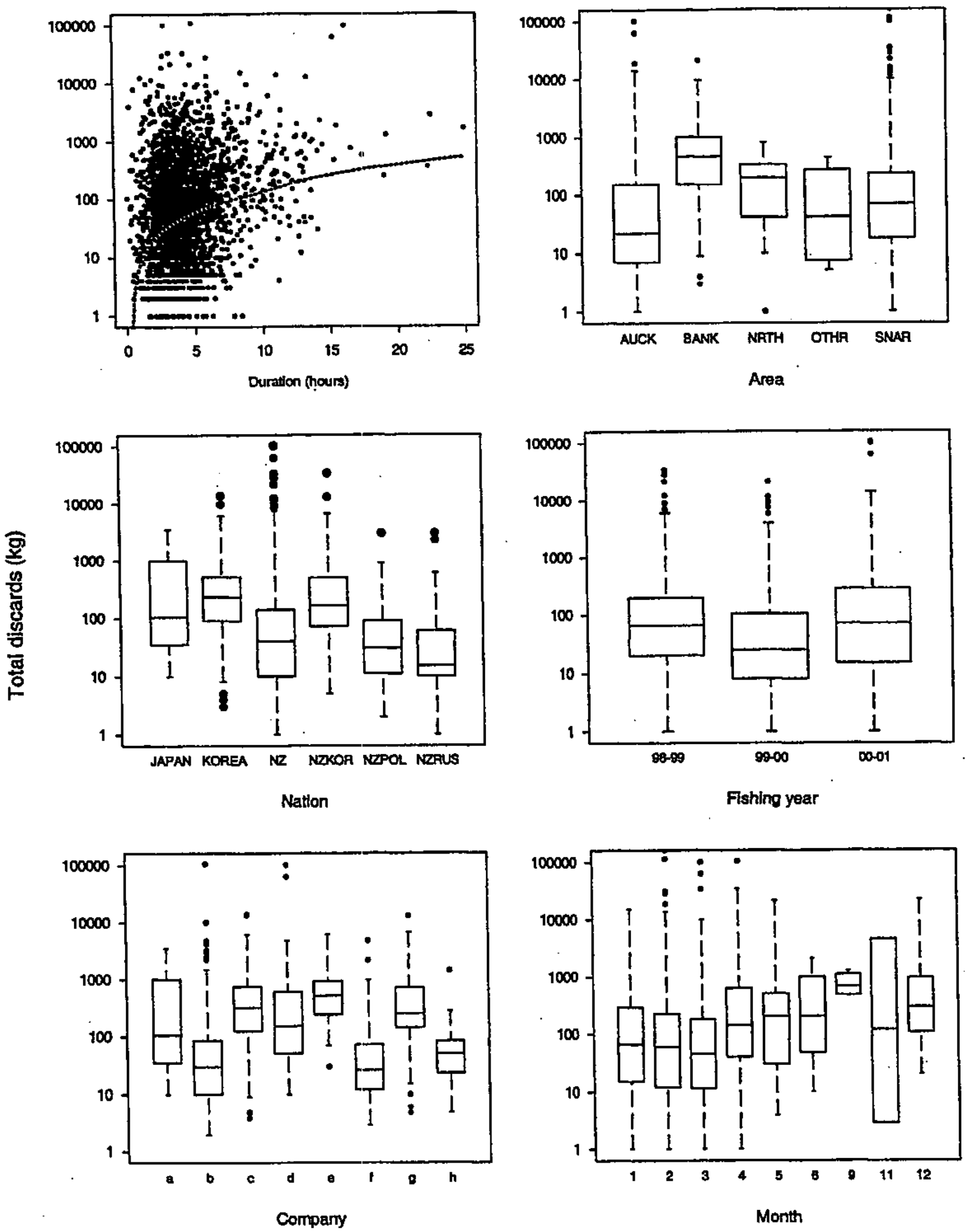

Figure 7: Arrow squid fishery, observer discard data for fishing years 1998–99 to 2000–01. Total discards per processing group plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers.

There were considerable differences in discard levels among vessel nationalities, with higher discard on vessels of nations KOR and NZKOR, and lower discards from vessels of nations NZPOL and NZRUS. Total discards were lower in 1999–2000 than in the other two years. There were considerable differences between fishing companies, too, with medians ranging from 30–40 kg to 500–600 kg per processing group. There is evidence of a monthly pattern in discards, with increasing levels between March and September, and fluctuating levels subsequently, although there were few records from outside the January–April period.

3.6.2 Regression modelling and stratification of discard data

The dependant variable in these regressions was discards per hour. Of the 4358 processing groups available for this analysis, only 345 (8%) recorded any discard of SQU, while 636 (15%) recorded a discard of COM, 3110 (71%) recorded a discard of OTH, and 377 (9%) recorded a discard of SWA. Regressions were weighted by 1/n.tows, as for the jack mackerel regressions.

Modelling of factors affecting discard probabilities and levels showed that, as in the jack mackerel fishery, *vessel* was the most critical factor overall in all species groups (Table 11). After this, *month*, *nation*, and *area* were the terms most commonly selected into the models. Discard ratios were calculated for strata only where more than 50 records and at least three vessels were available. Where these criteria were not met for a particular stratum, a ratio based on all data was calculated.

Table 11: Summary of regression modelling for discards in the arrow squid fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses. Figures in bold type indicate variables used in stratification of discard data. –, not selected, *fyr*, fishing year.

Species category	Model type	Variable					
		vessel	*month*	*nation*	*area*	*fyr*	*depth*
SQU	Linear	1(28.62)	2(33.96)	4(37.98)	3(36.88)	–	–
SQU	Logistic	1(29.13)	3(32.98)	2(31.91)	–	–	–
COM	Linear	1(20.62)	–	2(27.98)	–	3(29.98)	–
COM	Logistic	1(25.58)	–	2(26.59)	3(27.61)	–	–
OTH	Linear	127.18)	2(32.41)	–	–	–	3(33.43)
OTH	Logistic	1(09.75)	2(11.36)	–	3(12.36)	–	–
SWA	Linear	2(23.27)	1(12.31)	4(34.31)	5(37.62)	3(30.88)	–
SWA	Logistic	1(36.50)	3(45.40)	4(46.69)	2(42.01)	–	–

(a) SQU (target species)

Both binomial and linear models were used in this case and the variable *vessel* came out as the most influential in both, contributing a similar fraction of the total R^2 (28–29%). In the linear regression, *month* was the next most important factor, followed by *area* and *nation*. The total R^2 was 38%. In the binomial model *nation* was selected after *vessel*, followed by *month*. The two additional explanatory variables added little to the total power of the model, increasing the R^2 only marginally to 33%.

Despite the infrequency of SQU discards, there were sufficient for model predictions to indicate a clear difference in the level of discards between February and March, with discards in the latter month twice those of the former. Ratios were initially estimated separately for these two months, with an overall ratio for all other months. The distribution of the bootstrapped ratios for both months showed a distinctly non-normal distribution, however, and reliable estimates with reasonable c.v.s could not be obtained. As a consequence, no stratification was used and a single ratio was calculated.

(b) COM (non-target commercial species)

Both binomial and linear models were used in this case and three variables were selected into each model. The first two variables selected were the same in each model, *vessel* and *nation*. In the linear model, *fishing year* was also selected and the total R^2 was 30%. In the binomial model *area* was selected as the third factor, for a total R^2 of 28%. New Zealand vessels stood out in the model predictions of both model types, having a higher probability of discarding COM species, but lower total discard weights than other nations. This factor was not very useful for stratifying discard ratios as data were spread unevenly over the nations represented and the interpretation of nationality was likely to be different between observer records (which take into account crew nationality as well as the vessel's nation of registration) and commercial catch effort records. The available data were well spread over the three fishing years, however, and the model predicts much greater COM discards in 2000–01 than in the other two years. Stratification by *fishing year* was therefore applied.

(c) OTH (non commercial species)

The linear model selected *vessel* first, contributing over 27% to the R^2 value. *Month* was selected next, followed by tow *depth*, bringing the total R^2 to 33%. A similar three-variable model resulted from the binomial regression with the same first two variables, *vessel* and *month*, as in the linear model. *Area* was selected in the third position. The explanatory power of this model is weak, however, with a total R^2 of only 12%. *Month* was the obvious choice for stratification of data for ratio estimates. Most of the data came from the first four months of the calendar year, and although the probability of a discard varied little between these months (and was more than 80% in all months) there was more variation in the level of discards between these months. In particular, discard levels were low in February and high in April. Ratios were therefore calculated by *month* for January, February, March, and April and an overall ratio was used for the other months.

(d) SWA (silver warehou)

Both model types were used in this case, with 9% of records showing a discard of this species. In the linear model *month* was the most critical factor, followed by *vessel* and *fishing year*. This R^2 for this model was 38%. In the binomial model *vessel* had the most influence on the probability of a discard of SWA, contributing 37% to the R^2. *Area,* followed by *month* and *nation* were also selected. The total fraction of the variance in the data explained by these factors was 47%. There was little consistency between the two models in the predicted pattern of discards with *month,* the best candidate for stratification, and discards of SWA were too infrequent to enable very much grouping of the data in any case, and so a single overall ratio was produced.

3.7 Factors influencing bycatch in the scampi fishery

3.7.1 Overview of raw bycatch data

Raw bycatch data were initially examined by plotting total bycatch in each tow against the available variables (Figure 8). There was a positive relationship between tow duration and total bycatch. Catch increased with duration for tow durations of up to about 5 hours, but for tows longer than this mean bycatch remained steady at about 1000 kg per tow. Most tows were about 4 to 8 hours long. Bycatch was greater in *area* CHAT than in SUBA and WAIR (there are few data in the OTHR category) with a median of about 1600 kg per tow compared to 700–800 kg per tow.

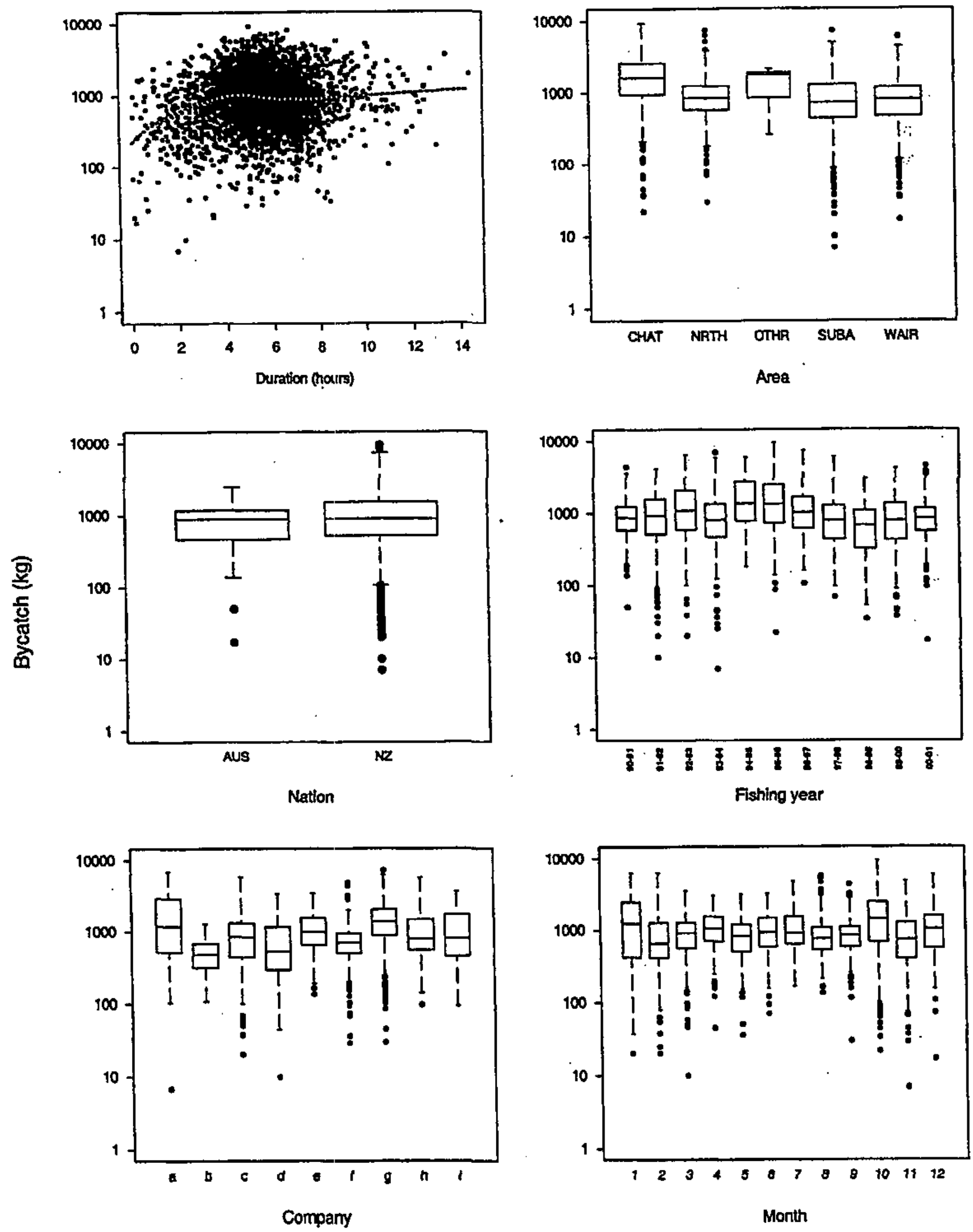

Figure 8: Scampi fishery, observer catch data for fishing years 1990–91 to 2000–01. Total bycatch per tow plotted against some of the available variables. Bycatch is plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers.

Most data came from New Zealand vessels, but some were recorded against Australian registered vessels. The plots indicate little difference in total bycatch between vessels of these two countries. Annual median bycatch values fluctuated between about 650 and 1350 kg per tow during the 11 years examined and showed a decreasing trend over the last 6 years. There was considerable variation in median bycatch levels between companies and a moderate amount between months, although there is no evidence of any seasonal pattern.

3.7.2 Regression modelling and stratification of bycatch data

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 individual species frequently caught, i.e., ling (LIN), hoki (HOK), sea perch (SPE), red cod (RCO), and stargazer (STA). The top 50 species observed caught in the scampi fishery are listed in Appendix 3, along with discard fractions. It is unfortunate that more of the observed catch was assigned the code MIX (mixed fish) than any other code in this fishery, as this disguised much of the bycatch species composition information. Only 1% of all tows did not have some level of bycatch of COM species, and 3% of tows did not record any bycatch of OTH species. The equivalent values for the individual species examined separately were LIN, 6%; HOK, 10%; SPE, 38%; RCO, 35%; STA, 32%. Linear models or a combination of linear and binomial models were run in a forward stepwise manner to identify the most influential factors.

As in the regression models for jack mackerel and arrow squid, the variables *vessel*, *area*, *month*, and *fishing year* were those most consistently selected in the models of bycatch in the scampi fishery (Table 12). There was insufficient spread of data to allow stratification of bycatch ratio estimates by more than one or two factors and the most critical factor, *vessel*, could not be used to group catch effort data as only a small fraction of the fishing fleet has been observed. *Area* had the strongest influence of the variables useful for stratification in both of the grouped categories and also in individual species categories with different patterns of abundance to scampi. The variables *depth* and *headline height* were selected once or twice in the models, but had little influence in general on the level of bycatch. Appropriate strata were determined from the model results for each species group, and separate estimates of ratios made where more than 50 records and at least three vessels were available in each stratum.

Table 12: Summary of regression modelling for bycatch in the scampi fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses. Figures in bold type indicate variables used in stratification of bycatch data. –, not selected; *fyr*, fishing year; *head-ht*, headline height.

Species category	Model type	Variable					
		vessel	*area*	*month*	*fyr*	*depth*	*head-ht*
COM	Linear	1(16.89)	**2**(28.76)	4(34.63)	3(33.56)	–	–
OTH	Linear	1(10.91)	**2**(13.79)	4(17.32)	3(16.21)	–	–
LIN	Linear	1(12.71)	**2**(20.07)	3(23.11)	4(25.05)	–	–
HOK	Linear	1(20.37)	4(32.16)	3(30.64)	**2**(27.15)	–	–
SPE	Linear	1(24.12)	4(43.33)	2(34.16)	3(40.55)	–	–
SPE	Logistic	2(66.15)	**1**(63.15)	3(68.97)	4(71.10)	–	–
RCO	Linear	3(29.37)	4(33.01)	1(14.83)	**2**(19.95)	5(35.30)	–
RCO	Logistic	1(06.24)	4(19.82)	3(19.02)	**2**(13.71)	–	–
STA	Linear	2(36.43)	**1**(24.96)	4(44.20)	3(40.99)	–	5(45.95)
STA	Logistic	3(25.67)	**2**(21.64)	4(27.50)	1(12.44)	–	–

(a) COM (non-target commercial species)

As most tows recorded some catch of COM species, a nominal 0.1 $kg.h^{-1}$ was added to records of tows that did not, and a linear model only was run. The variable *vessel* had the most explanatory power in the model (R^2 = 16.9%), followed by *area, fishing year*, and *month*. The model R^2 was 35%. Model predictions for bycatch of COM showed considerable differences in catches between areas. Predicted catches of COM in SUBA were less than a third of those in CHAT and catches in NRTH and WAIR were similar. The model also predicted different catches between years, although the range of annual catches was small and the data were stretched too thinly over the 11 years examined to enable stratification by this factor. Ratios were estimated separately for each *area*, where data were sufficient.

(b) OTH (non-commercial species)

Again, most tows recorded some catch of species in this category and so a linear model only was run. The same four variables were selected, in the same order, as in the COM model above. The model had less explanatory power, however, with the model R^2 only 17%. The pattern of catches identified for COM species between areas was also shown for OTH species, and the level of catches was also similar between the two species groups. The linear model predicted almost twice the catch of OTH in CHAT than in SUBA with similar catches in WAIR and NRTH. *Fishing year* was again the next most important factor, although there was no trend in catch levels over time, and data were stretched thinly over the years. Stratification for ratio calculation was again restricted to *area*.

(c) LIN (ling)

With catches of ling recorded in almost 95% of tows targeting scampi, again a linear model only was run. A very similar model to that created for COM and OTH species groups was formed, selecting first *vessel*, followed by *area*, *month*, and *fishing year* for a total R^2 of 25%. Variation in catch levels of LIN were strongly linked to *area*, and the highest bycatch levels of this species were in CHAT. The three other fishery areas showed similar, lower levels of LIN catch. *Month* was the next most important factor in the model, but there was no clear pattern in catches over the year and data were too thinly spread to justify calculating ratios by this factor as well as by *area*. Stratification was therefore limited to *area*.

(d) HOK (hoki)

Bycatch of hoki was also a very regular occurrence in this fishery, and hence a linear model only was run. The same four variables were selected for this model as for the LIN model, but in the order *vessel, fishing year*, *month*, and *area*. The *vessel* variable had a strong influence (R^2 = 20%) and the explanatory power of the model overall was greater, with a total R^2 of 32%. The level of bycatch of HOK was also influenced strongly by *fishing year*, which showed generally decreasing catches of HOK over the 11 years examined. The variable *month* was also important, but there was no discernable annual pattern and insufficient data to use this in addition to year for stratification of ratio calculations.

(e) SPE (sea perch)

A sufficient fraction of tows did not catch any SPE to warrant an examination of factors influencing the probability of a catch as well as the level, so both binomial and linear models were formed. *Area* had a powerful influence on the probability of a SPE catch, with this variable accounting for 63% of the total R^2. Also included in the binomial model were *vessel, month,* and *fishing year*, for a total R^2 of 71%. In the linear regression, which examined only those records with some SPE catch, the same variables were selected, but *area* was shifted to the fourth position. The resulting model had strong explanatory power, due mainly to the influence of *vessel* and *month*, with a total R^2 of 43%. The importance of *area* in the binomial model was due to SPE only rarely being caught in the SUBA *area*, much of which is south of this species' normal range (see Anderson et al. 1998). Catch levels of SPE in the other areas were very similar to each other. Although *month* also had some influence in the linear model, there was no pattern, with the highest catches in December and February and the lowest in January. As a result, ratio calculations were stratified by *area* only.

(f) RCO (red cod)

Both binomial and linear models were run for bycatch of RCO. After *vessel, fishing year* was the most influential factor, and *month* also had some influence. The explanatory power of the model was weak, however, with the R^2 less than 20%. In the linear model, *month* was selected first, followed by *fishing year* and *vessel* in the third position. The model R^2 was 35%. The level of RCO catches was strongly influenced by *month*, with this being the first term selected in the linear model and contributing almost 15% of the R^2. There was some pattern in the predicted monthly catches, with catches increasing through autumn to reach a maximum in June and July, and dropping again in spring, although this was inconsistent with the known seasonality of the RCO fishery. The *fishing year* was next most important and was also the most important term in the binomial model (after *vessel*). Recruitment is known to be highly variable in this species and annual catches vary greatly (Annala et al. 2002). Bycatch ratio calculations were therefore stratified by *fishing year* only.

(f) STA (stargazer)

Both model types were also run for bycatch of STA, a species caught in about two-thirds of the tows observed during the period. *Fishing year* and *area* were the most critical factors influencing the likelihood of a bycatch of STA, followed by *vessel* and *month*. The model had only moderate power, with an R^2 of 28%. In the linear model *area* was selected first and this factor had a very strong influence on the catch levels of STA contributing 25% to the R^2. *Vessel* was selected next, followed by *fishing year*. The final model had reasonable power, with an R^2 of 46%. Model predictions showed that catch levels of STA in CHAT were more than four times those in NRTH and SUBA and the probability of a catch of STA was also greatest in CHAT. Although the probability of a catch of STA was high in SUBA, the predicted catch level was relatively low. Ratio calculations were made separately for each *area* only.

3.8 Factors influencing discards in the scampi fishery

3.8.1 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 9). There was a positive relationship between total discard weight and total tow duration, with discards of about 200 kg per processing group for combined tow durations of an hour or two, up to over 1000 kg for durations of 20 hours. There were differences in median discard levels between areas, with as much as 1100 kg per processing group (CHAT) and as little as 400 kg per processing group (WAIR). Data were mostly from New Zealand registered vessels, but the data from the few recorded as Australian suggest there was no difference between nations in median discard levels.

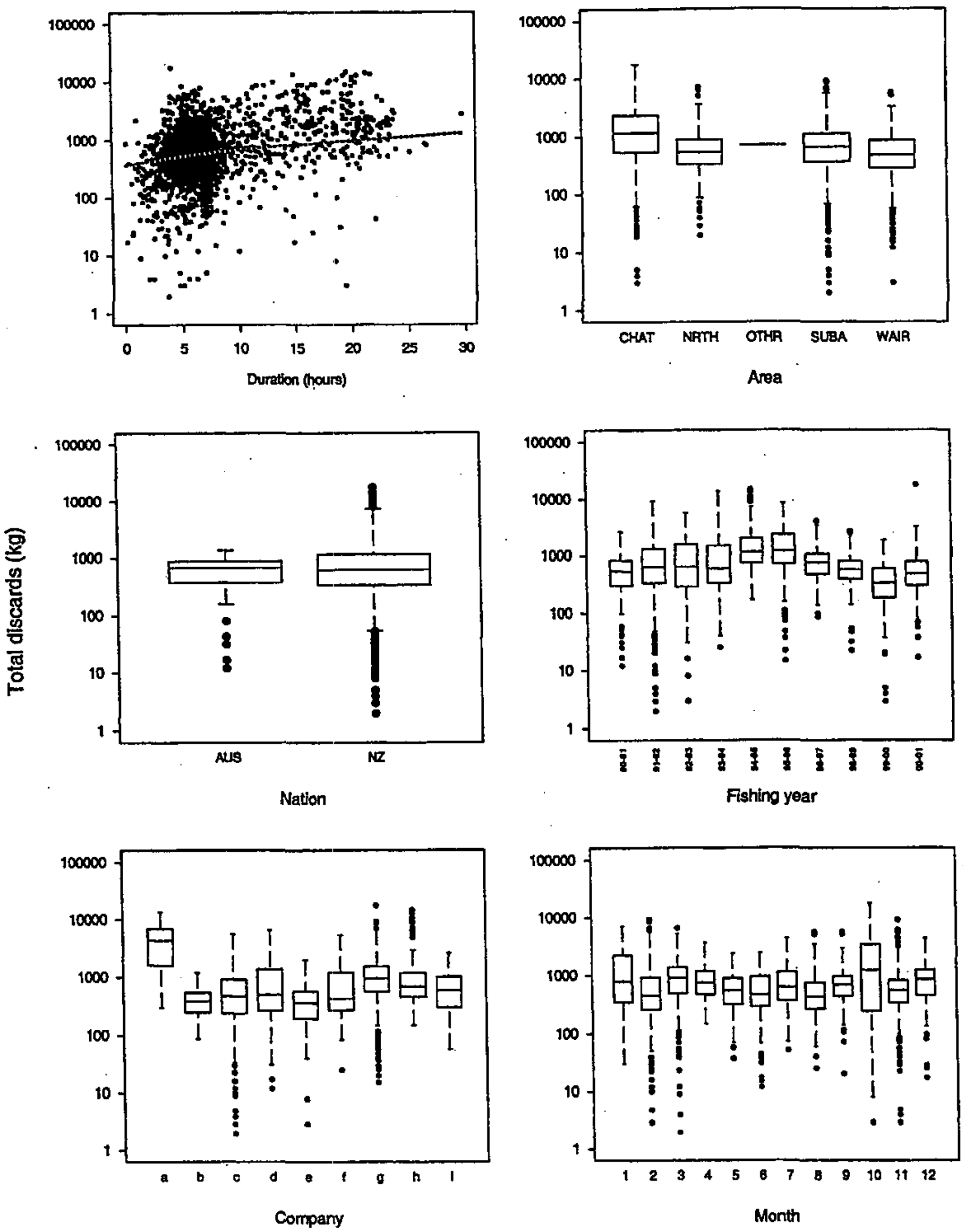

Figure 9: Scampi fishery, observer discard data for fishing years 1990–91 to 2000–01. Total discards per processing group plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers.

An increase in observed discards in the mid 1990s was followed by a decrease over the last four years. The variation between companies in discard levels was slight, except for one company with a comparatively high median value. Closer examination of the data showed that there were few records from this company and all were from the same vessel. There was some fluctuation in discard levels from month to month with records well spread over all months, but there was no obvious annual pattern. Discards were greater and more variable in October.

3.8.2 Regression modelling and stratification of discard data

Regression models were constructed using the methods described for the two other fisheries. Of the 2996 processing groups available for this analysis, 1721 (57%) recorded a discard of COM, while 2613 (87%) recorded a discard of OTH. The equivalent values for the species examined individually were, LIN, 431 (14%); HOK, 480 (16%); SPE, 999 (33%); RCO, 491 (16%).

Modelling of factors affecting discard probabilities and levels showed that *vessel* was the critical factor for most species/species groups, but *fishing year* was almost as important overall, and, in several of the models, explained more of the variability in discards (Table 13). There was no trend in the predicted discard levels over time that was repeated in each species group and there was little similarity between models in the patterns of discards over time. The terms *month* and *area* were also selected into most of the models, and *company* was selected in half.

Following the criteria used in the jack mackerel and arrow squid fisheries above, discard ratios were calculated for strata only where data were available for more than 50 records and at least three vessels. Where these criteria were not met for a particular stratum, a ratio based on all data was calculated.

Table 13: Summary of regression modelling for discards in the scampi fishery. The numbers denote the order in which the variable entered the model, with the cumulative R^2 value at each step in parentheses. Figures in bold type indicate variables used in stratification of discard data. –, not selected; *fyr*, fishing year.

Species category	Model type					Variable
		vessel	*fyr*	*month*	*area*	*company*	*depth*
COM	Linear	2(32.49)	1(19.12)	4(44.97)	3(41.10)	5(45.70)	–
COM	Logistic	2(34.91)	1(21.35)	3(41.02)	4(43.37)	5(44.92)	–
OTH	Linear	1(25.41)	3(46.58)	2(37.45)	5(49.11)	4(47.83)	–
OTH	Logistic	1(29.30)	2(56.87)	3(64.23)	4(68.07)	–	–
LIN	Linear	–	1(25.52)	4(42.09)	2(32.73)	3(34.94)	–
LIN	Logistic	1(30.94)	2(43.29)	3(50.63)	4(52.01)	–	–
HOK	Linear	1(47.07)	3(62.42)	2(57.10)	–	4(83.38)	–
HOK	Logistic	1(24.25)	3(55.54)	2(41.13)	4(58.66)	5(59.84)	–
SPE	Linear	1(36.96)	4(44.53)	2(41.94)	3(43.22)	–	–
SPE	Logistic	3(72.00)	1(32.27)	4(80.20)	2(61.07)	–	–
RCO	Linear	2(53.90)	1(38.76)	3(59.58)	–	–	4(64.21)
RCO	Logistic	1(13.21)	3(34.92)	2(26.04)	5(40.67)	4(38.97)	–

(a) COM (non-target commercial species)

Discards of COM species were recorded in a little more than half of the processing groups and so both binomial and linear models were run. In both models *fishing year* was the first variable selected and in both models contributed about 20% to the R^2. *Vessel* was selected next in both models followed by *area, month,* and *company* in the linear model and by *month, area,* and *company* in the binomial model. Both models had strong explanatory power, with R^2 values of 45–46%. Although *fishing year* was the obvious choice for stratification, it was not used. A combination of low observer coverage and a low number of processing groups recording COM discards in some years meant that ratios would be based on too few data. Instead, *area* was used for stratification, as this variable was important in both models and also in models of LIN and SPE discards (see below).

(b) OTH (non commercial species)

Discarding of OTH species was more common than COM species, occurring in 87% of observed processing groups, and both model types were run. In the linear model, *vessel* was the most critical factor, followed by *month* and *fishing year*. The model R^2 was 49%. In the binomial model, *vessel* was again the variable first selected, but *fishing year* also had a strong influence, increasing the R^2 by 28%. *Month* and *area* were also selected, and the final model had high explanatory power, with an R^2 of 68%. Model predictions showed that the probability of a discard of OTH was less than 35% in 1990–91 and 1992–93 and greater than 80% in all other years. They also showed that discard levels were lowest in 1992–93 and highest in 1995–96. There was considerable variation in discard levels between months, and although either *month* or *fishing year* could have been used to stratify ratio calculations, *fishing year* was selected, to be consistent with COM.

(c) LIN (ling)

Discarding of LIN was uncommon, recorded in only 14% of the records, and so both model forms were run. In the linear model, *fishing year* had the greatest influence on discards of LIN, followed by *area, company,* and *month*. Significantly, as this factor had a strong influence in a number of other discard models, *vessel* was not included in the model. The model is relatively powerful, with an R^2 of 42%. In contrast with the linear model, the binomial model showed that *vessel* had a large influence on the likelihood of a LIN discard. *Fishing year* also was very influential in the model, adding 12% to the R^2, and this model is also powerful, with an R^2 of 52%. Discard levels of LIN were heavily influenced by *fishing year* and also by *area*. Although *fishing year* had a stronger influence in the linear model, there were very few discards recorded in some years and low discard estimates for these years would be based on a small number of records. In contrast, records were well spread over four of the defined areas and there appeared to be a more genuine difference in discards of LIN between these areas. Therefore, ratios were stratified by *area*.

(d) HOK (hoki)

Discarding of HOK was also uncommon, being recorded in only 16% of the records, so both model forms were run. The first three variables selected were the same for both models: *vessel, month,* and *fishing year*. *Vessel* accounted for almost half of the variability in the data in the linear model, and a quarter in the binomial model. *Month* had a strong influence in both models also, increasing the R^2 by 10% in the linear model and by 17% in the binomial model. Both models produced large R^2 values, 63% for the linear model, and 60% for the binomial model. *Month* was the obvious choice for stratification in this case, but there were 20 or fewer discards of HOK recorded in six of the months and the between month differences may not be very reliable. For this reason no stratification was applied and a single overall ratio was calculated.

(e) SPE (sea perch)

Discarding of SPE was twice as common as discarding of HOK, being recorded in 33% of processing groups. Both model types were run. *Vessel* had a very powerful influence on the level of SPE discards, contributing 37% of the R^2. This was followed by *month*, and *area*, and the total R^2 was 45%. In the binomial model *fishing year* was selected first, contributing 32% of the R^2. *Area* had a similar level of influence, adding 29% to the R^2 value. *Vessel* and *month* were also useful and together these variables explained most of the variability in the data (80%). The most appropriate factor for stratifying SPE ratio calculations was *area*. This factor was significant in both models, predicting both a low probability and a low level of SPE discards in the WAIR *area* compared with CHAT and NRTH. No discards were recorded in SUBA where this species is seldom caught (Anderson et al. 1998). Therefore it is critical to take area into account, when estimating discards over the whole range of the scampi fishery.

(f) RCO (red cod)

Discards of RCO were recorded in 16% of observed processing groups, a similar level to discards of HOK. Both model types were run. In the linear model *fishing year* had the strongest influence, adding 39% to the R^2. This was followed by *vessel* and *month*, and the final model R^2 was 64%. In the binomial model *vessel* entered the model first, but *month* had a similar explanatory power, adding 13% to the R^2, and *fishing year* was also influential. The model R^2 was 41%. Model predictions showed that the probability and level of RCO discards was particularly high in 1993–94, but there was no general trend in the pattern of discarding over time, and also no strong monthly pattern of discards. With generally low numbers of discards of RCO overall, no stratification was applied in this case.

3.9 Calculation of bycatch

3.9.1 Jack mackerel

Bycatch ratios for COM species were calculated separately for six out of the nine year/month strata defined (Table 14). Because of a lack of data, ratios for the remaining three strata were set to a default value based on all records. The ratios calculated showed bycatch rates ranging from about 900–4300 $kg.h^{-1}$. Annual bycatch rates of OTH species showed an increase over the three years, from 74 $kg.h^{-1}$ in 1998–99 to 181 $kg.h^{-1}$ in 2000–01. Bycatch ratios of BAR were calculated separately for 8 of the 12 year/month strata defined. These ranged between about 230 $kg.h^{-1}$ and 1600 $kg.h^{-1}$. Bycatch of EMA was close to zero in the SNAR *area*, and 660 $kg.h^{-1}$ in WEST. The bootstrap distribution of EMA catch ratios calculated for CHAT showed a strong departure from normal, due to one or two large catches, so the ratio was based on data from all areas combined. Annual RBT catch rates were about 120–240 $kg.h^{-1}$ and annual SQU catch rates were between about 6 and 100 $kg.h^{-1}$. Estimated c.v.s were low overall, usually less than 20% and often less than 10%, but were occasionally higher, particularly for species which were less frequently caught.

Table 14: Summary of sample sizes, bycatch ratios (kg.h^{-1}) and associated c.v.s used to calculate total bycatch in the JMA fishery; *n*, number of tows (number of vessels in parentheses); $\hat{R}$, bycatch ratio. Month codes: a=May, Oct, Nov; b=Jan–Apr, Dec; c=Jun–Sep.

Species category	Fishing year	Month/area	*n*	$\hat{R}$	c.v. (%)
COM	1998–99	a	*2(1)	1693	6.0
COM	1998–99	b	324(9)	903	9.6
COM	1998–99	c	270(4)	2538	7.3
COM	1999–00	a	*100(2)	1786	6.0
COM	1999–00	b	383(9)	2133	6.3
COM	1999–00	c	*14(3)	1786	6.0
COM	2000–01	a	100(5)	1021	13.4
COM	2000–01	b	248(9)	1818	7.4
COM	2000–01	c	50(5)	4272	15.5
OTH	1998–99	–	596(10)	74	19.1
OTH	1999–00	–	497(12)	124	13.1
OTH	2000–01	–	398(14)	181	22.6
BAR	1998–99	a	229(7)	546.6	11.4
BAR	1998–99	b	250(6)	316.9	17.6
BAR	1998–99	c	92(4)	227.0	16.5
BAR	1998–99	d	*25(1)	387.3	8.9
BAR	1999–00	a	317(9)	1168.2	5.1
BAR	1999–00	b	66(3)	1158.7	10.8
BAR	1999–00	c	*14(3)	951.7	5.0
BAR	1999–00	d	*100(2)	951.7	5.0
BAR	2000–01	a	170(9)	1619.8	8.9
BAR	2000–01	b	*44(3)	1219.7	6.4
BAR	2000–01	c	50(5)	1291.1	21.0
BAR	2000–01	d	134(5)	686.4	10.2
EMA	All	WEST	661(13)	1073.5	7.9
EMA	All	CHAT**	76(7)	464.0	8.3
EMA	All	SNAR	753(13)	0.00369	51.2
RBT	1998–99	–	596(10)	117.1	23.8
RBT	1999–00	–	497(12)	288	18.9
RBT	2000–01	–	398(14)	237.6	27.4
SQU	1998–99	–	596(10)	5.9	31.5
SQU	1999–00	–	497(12)	37.1	12.5
SQU	2000–01	–	398(14)	97.6	30.2

* Denotes area/month combinations with fewer than 50 records and/or fewer than 3 vessels. In these cases ratios were based on data from all months. ** Bootstrap distributions of ratios non-normal, ratio based on data from all areas.

Total bycatch estimates for each year were calculated by applying the ratios in Table 14 to the target fishery tow duration totals for the equivalent strata (as described in Section 2.1). The best estimates of bycatch of COM species in the target jack mackerel fishery range from about 11 000 to 14 700 t per year, and those of OTH species range from 750 to 670 t per year (Table 15 and Figure 10). Most of the COM catch was made up of three species, BAR, RBT, and SQU, accounting for 76 to 92% in the three years. The estimated bycatch of SQU increased nearly eightfold between 1998–99 and 2000–01. Total annual bycatch estimates ranged from about 11 600 to 15 500 t.

Table 15: Estimates of bycatch (t) in the target JMA trawl fishery by fishing year, species category, and overall, with 95% confidence intervals in parentheses.

Species category	Fishing year					
	1998–99		1999–00		2000–01	
COM	14 739	(12 600–17 068)	10 973	(9 744–12 396)	11 668	(9 103–14 738)
OTH	750	(520–1 059)	671	(501–857)	867	(531–1 306)
BAR	3 828	(2 882–4 896)	5 910	(5 168–6 679)	5 154	(4 297–6 119)
EMA	6 252	(5 358–7 250)	2 584	(2 212–2 998)	4 476	(3 840–5 189)
RBT	1 186	(717–1 825)	1 558	(1 028–2 147)	1 138	(597–1 847)
SQU	60	(28–101)	201	(155–254)	467	(230–766)
Total	15 489	(13 120–18 127)	11 644	(10 245–13 253)	12 535	(9 634–16 044)

An estimate of total bycatch can be made directly from commercial catch records (TCEPR and CELR forms) by subtracting the total catch recorded for each tow (or each day) from the catch of the target species, jack mackerel. These values are recorded generally as 'eyeball' estimates and are unlikely to record the smaller quantities of bycatch species with much accuracy. However, it was simple to make these calculations and useful as a rough check on the scale of bycatch estimated from observer data. These alternative estimates were, as might be expected, much smaller than those shown in Table 15, particularly in 2000–01 (Table 16). The fraction of the observer-based estimate of bycatch calculated from the commercial catch records decreased from 70% in 1998–99 to 52% in 2000–01.

Table 16: Alternative estimates of annual bycatch (t) in the target JMA trawl fishery, based on TCEPR and CELR records alone. Total bycatch = total catch (all species) minus total catch (JMA).

	Fishing year		
	1998–99	1999–2000	2000–01
Total catch (t)	33 145	20 393	22 122
JMA catch (t)	22 187	13 117	15 660
Total bycatch (t)	10 958	7 276	6 462

3.9.2 Arrow squid

Bycatch ratios for COM species were calculated separately for four area/month strata, for all areas in February and March, and for all months in AUCK and SNAR (Table 17). These ratios showed bycatch rates for COM ranged from about 74 to 770 $kg.h^{-1}$. Annual bycatch rates of OTH species showed a clear difference between the two areas, based on a large number of records, with the rate in AUCK less than half that in SNAR. Bycatch ratios of BAR were calculated separately for 8 of the 12 year/month strata defined. These ranged between about 230 $kg.h^{-1}$ and 1600 $kg.h^{-1}$. Bycatch of BAR was estimated for the same strata as for COM species, and again a wide range of values are shown, from about 41 $kg.h^{-1}$ in AUCK in February, to about 485 $kg.h^{-1}$ in SNAR in March. Bycatch rates of JMA and SWA were at a similar level to each other and were comparatively small (53 and 67 $kg.h^{-1}$ overall, respectively).

Table 17: Summary of sample sizes, bycatch ratios (kg.h^{-1}) and associated c.v.s used to calculate total bycatch in the SQU fishery; *n*, number of tows (number of vessels in parentheses); $\hat{R}$, bycatch ratio.

Species category	Area	Month	*n*	$\hat{R}$	c.v. (%)
COM	AUCK	February	696(25)	73.9	9.0
COM	SNAR	February	1 569(29)	309.1	5.7
COM	ALL*	February	2 302(29)	252.9	5.5
COM	AUCK	March	348(18)	162.5	10.1
COM	SNAR	March	1 167(26)	768.6	5.4
COM	ALL*	March	1 560(27)	646.8	5.1
COM	AUCK	All months	1 169(27)	107.4	8.0
COM	SNAR	All months	3 493(30)	567.2	3.6
COM	ALL*	All months	4 851(32)	467.9	3.3
OTH	AUCK	–	1 169(27)	53.9	12.1
OTH	SNAR	–	3 493(30)	111.3	6.8
OTH	ALL*	–	4 851(32)	105.7	5.9
BAR	AUCK	February	696(25)	40.7	10.3
BAR	SNAR	February	1 569(29)	178.9	7.0
BAR	ALL*	February	2 302(29)	147.0	6.6
BAR	AUCK	March	348(18)	126.0	9.6
BAR	SNAR	March	1 167(26)	484.7	6.2
BAR	ALL*	March	1 560(27)	411.6	5.7
BAR	AUCK	All months	1 169(27)	65.8	7.6
BAR	SNAR	All months	3 493(30)	348.2	4.0
BAR	ALL*	All months	4 851(32)	285.0	3.6
JMA	AUCK	–	1 169(27)	0.074	24.3
JMA	BANK	–	171(16)	14.6	27.7
JMA	SNAR	–	3 493(30)	69.8	7.8
JMA	ALL*	–	4 851(32)	53.2	7.6
SWA	AUCK	–	1 169(27)	14.3	19.0
SWA	BANK	–	171(16)	91.0	13.8
SWA	SNAR	–	3 493(30)	80.2	7.1
SWA	ALL*	–	4 851(32)	66.5	6.5

* For areas BANK and OTHR, where there were too few records, ratios were based on data from all areas.

Total bycatch estimates for each year were calculated by applying the ratios in Table 17 to the target fishery tow duration totals for the equivalent strata. For area AUCK in 2000–01, however, there was 100% observer coverage, and recorded catch totals were used in place of estimates for the affected strata. The best estimates of bycatch of COM species in the target arrow squid fishery ranged from about 9000 to 15 300 t per year, and bycatch of OTH species was about 20% of this at about 2000–3400 t per year (Table 18, and Figure 10). More than half of the COM catch was made up of BAR, with SWA and JMA accounting for most of the remainder. These three species accounted for about 85% of the COM bycatch in each year. Total annual bycatch estimates ranged from about 10 900 to 18 800 t.

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

Species category	Fishing year		
	1998–99	1999–2000	2000–01
COM	15 530 (14 231–16 876)	8 954 (8 205–9 730)	15 263 (14 048–16 515)
OTH	3 310 (2 887–3 781)	1 995 (1 742–2 291)	3 365 (2 987–3 809)
BAR	9 539 (8 661–10 489)	5 517 (5 010–6 063)	9 430 (8 610–10 324)
JMA	1 737 (1 460–2 058)	695 (557–859)	1 303 (1 050–1 603)
SWA	2 432 (2 049–2 871)	1 438 (1 155–1 767)	2 507 (2 035–3 051)
Total	18 840 (17 118–20 657)	10 949 (9 947–12 021)	18 628 (17 035–20 324)

Alternative estimates of total annual bycatch in the arrow squid fishery were made from commercial catch records in the same way as for jack mackerel above (Table 19). These alternative estimates were again smaller than those calculated from observer data, but less so than shown for jack mackerel, ranging from 60 to 92% of the observer-based estimates of bycatch shown in Table 18.

Table 19: Alternative estimates of annual bycatch (t) in the target SQU trawl fishery, based on TCEPR and CELR records alone. Total bycatch = total catch (all species) minus total catch (SQU).

	Fishing year		
	1998–99	1999–2000	2000–01
Total catch (t)	32 787	27 410	44 735
SQU catch (t)	21 611	17 345	31 015
Total bycatch (t)	11 176	10 064	13 719

3.9.3 Scampi

Byatch ratios for COM species were calculated separately for four *area* strata, and a value based on data from all areas for area OTHR (Table 20). Bycatch rates for COM varied between areas from 72 $kg.h^{-1}$ in NRTH to about 150 $kg.h^{-1}$ in CHAT. Bycatch rates for OTH and LIN were also estimated by area. In contrast to the jack mackerel and arrow squid fisheries, bycatch rates of OTH species were generally greater than bycatch rates of COM species. Although the values were similar in WAIR, OTH bycatch rates were about 40% greater in NRTH and nearly twice as great in SUBA. Bycatch rates of LIN were comparatively low and varied less between areas, ranging from 14 to 40 $kg.h^{-1}$. Bycatch rates for HOK, estimated separately for each fishing year, were at a similar overall level to those for LIN, ranging from 6.8 $kg.h^{-1}$ in 1997–98 to 34 $kg.h^{-1}$ in 1992–93. Bycatch rates of SPE, estimated by area, were close to zero in SUBA and up to 43 $kg.h^{-1}$ in CHAT. Bycatch rates of RCO, estimated by fishing year, were consistently low, ranging between 1.3 and 9.7 $kg.h^{-1}$. Bycatch rates of STA were estimated by area and were again low, particularly in NRTH.

Table 20: Summary of sample sizes, byratios (kg.h^{-1}) and associated c.v.s used to calculate total bycatch in the SCI fishery; *n*, number of tows (number of vessels in parentheses); $\hat{R}$, bycatch ratio.

Species category	Area/Year	*n*	$\hat{R}$	c.v. (%)
COM	CHAT	1 115(12)	152.4	2.1
COM	NRTH	561(9)	71.7	3.1
COM	SUBA	1 404(10)	55.8	3.2
COM	WAIR	1 502(9)	74.5	1.9
COM	OTHR (ALL)*	4 587(14)	85.2	1.4
OTH	CHAT	1 115(12)	229.0	2.9
OTH	NRTH	561(9)	101.8	4.2
OTH	SUBA	1 404(10)	107.2	2.3
OTH	WAIR	1 502(9)	78.6	2.4
OTH	OTHR (ALL)*	4 587(14)	123.5	1.7
LIN	CHAT	1 115(12)	40.6	2.9
LIN	NRTH	561(9)	14.1	4.3
LIN	SUBA	1 404(10)	20.1	4.5
LIN	WAIR	1 502(9)	16.4	3.0
LIN	OTHR (ALL)*	4 587(14)	22.6	2.1
HOK	1990–91	353(6)	19.5	5.6
HOK	1991–92	554(7)	21.9	4.8
HOK	1992–93	406(5)	34.1	6.1
HOK	1993–94	807(7)	14.3	3.9
HOK	1994–95	402(6)	23.9	5.6
HOK	1995–96	278(3)	15.2	6.2
HOK	1996–97	323(5)	18.7	7.0
HOK	1997–98	297(6)	6.8	6.8
HOK	1998–99	492(6)	8.7	5.1
HOK	1999–00	409(6)	10.5	5.5
HOK	2000–01	266(5)	18.5	5.5
SPE	CHAT	1 115(12)	43.1	3.4
SPE	NRTH	561(9)	27.4	5.7
SPE	SUBA	1 404(10)	0.019	32.2
SPE	WAIR	1 502(9)	16.7	3.5
SPE	OTHR (ALL)*	4 587(14)	18.5	2.5
RCO	1990–91	353(6)	1.5	11.7
RCO	1991–92	554(7)	9.7	8.2
RCO	1992–93	406(5)	4.8	9.2
RCO	1993–94	807(7)	8.8	6.1
RCO	1994–95	402(6)	6.6	7.1
RCO	1995–96	278(3)	4.2	11.7
RCO	1996–97	323(5)	2.2	9.4
RCO	1997–98	297(6)	2.1	11.3
RCO	1998–99	492(6)	2.6	8.1
RCO	1999–00	409(6)	1.3	9.9
RCO	2000–01	266(5)	3.4	14.6
STA	CHAT	1 115(12)	14.2	3.0
STA	NRTH	561(9)	0.646	12.4
STA	SUBA	1 404(10)	3.8	3.8
STA	WAIR	1 502(9)	3.8	3.7
STA	OTHR (ALL)*	4 587(14)	5.6	2.3

* For area OTHR there were too few records and so ratios were based on data from all areas.

Annual bycatch estimates for each species category were calculated by applying the ratios in Table 20 to the target fishery tow duration totals for the equivalent strata. The best estimates of bycatch of COM species in the target scampi fishery ranged from about 1400 to 2800 t per year, and the bycatch of OTH species was slightly greater at about 1750–4000 t per year (Table 21 and Figure 10). The COM bycatch in the scampi fishery was not dominated by any one species, with LIN, HOK, and BAR contributing similar amounts to the total in most years, and RCO and STA accounting for a significant fraction of it, particularly in the early 1990s (Table 22). Total annual bycatch estimates ranged from about 3200 to 6800 t.

Table 21: Estimates of bycatch (t) in the target SCI trawl fishery by fishing year, for the COM and OTH species categories, and overall, with 95% confidence intervals in parentheses.

Fishing year			Species category
	COM	OTH	Total
1990–91	1 433 (1 368–1 502)	1 764 (1 658–1 878)	3 197 (3 025–3 379)
1991–92	2 792 (2 668–2 918)	3 998 (3 773–4 237)	6 790 (6 440–7 155)
1992–93	2 620 (2 505–2 735)	3 808 (3 598–4 030)	6 428 (6 103–6 765)
1993–94	2 539 (2 426–2 654)	3 716 (3 516–3 928)	6 256 (5 942–6 581)
1994–95	1 846 (1 761–1 932)	2 776 (2 629–2 932)	4 622 (4 389–4 864)
1995–96	1 651 (1 574–1 730)	2 474 (2 345–2 611)	4 125 (3 919–4 341)
1996–97	1 605 (1 530–1 682)	2 395 (2 271–2 527)	4 001 (3 801–4 209)
1997–98	1 693 (1 613–1 774)	2 507 (2 376–2 646)	4 200 (3 990–4 421)
1998–99	2 097 (1 999–2 197)	3 065 (2 909–3 230)	5 162 (4 908–5 427)
1999–00	2 399 (2 287–2 515)	3 470 (3 283–3 668)	5 870 (5 570–6 183)
2000–01	2 450 (2 334–2 571)	3 503 (3 314–3 704)	5 953 (5 648–6 274)

Table 22: Estimates of bycatch (t) in the target SCI trawl fishery by fishing year, for the main bycatch species, with 95% confidence intervals in parentheses.

Fishing year					Species category
	LIN	HOK	SPE	RCO	STA
1990–91	310 (290–332)	364 (327–405)	409 (375–447)	28 (21–34)	58 (53–62)
1991–92	711 (666–757)	628 (574–691)	721 (668–779)	278 (238–328)	192 (179–204)
1992–93	682 (640–726)	885 (784–987)	657 (611–708)	125 (102–146)	192 (180–204)
1993–94	674 (631–719)	385 (356–414)	587 (546–632)	237 (211–265)	184 (172–195)
1994–95	503 (470–538)	498 (443–555)	395 (367–426)	137 (118–158)	131 (122–139)
1995–96	453 (423–485)	300 (265–336)	331 (308–357)	83 (65–102)	114 (106–121)
1996–97	440 (410–472)	370 (323–422)	313 (290–337)	44 (37–53)	108 (100–115)
1997–98	459 (428–492)	143 (126–163)	338 (313–365)	44 (36–56)	110 (102–117)
1998–99	570 (531–611)	234 (212–258)	396 (368–427)	70 (61–83)	135 (125–144)
1999–00	630 (587–675)	312 (280–348)	518 (479–561)	39 (33–48)	148 (137–158)
2000–01	637 (593–683)	587 (526–650)	522 (481–566)	108 (78–140)	141 (131–151)

Alternative estimates of total annual bycatch in the scampi fishery were made from commercial catch records in the same way as for jack mackerel and arrow squid above (Table 23). These alternative estimates are only a fraction of those calculated from observer data (range 12–25%), and in this case offer little support to those estimates.

Table 23: Alternative estimates of annual bycatch (t) in the target SCI trawl fishery, based on TCEPR and CELR records alone. Total bycatch = total catch (all species) minus total catch (SCI)

Fishing year	Total catch (t)	SCI catch (t)	Total bycatch (t)
1990–91	1 119	463	656
1991–92	2 159	898	1 261
1992–93	2 222	891	1 331
1993–94	2 018	922	1 096
1994–95	1 726	858	868
1995–96	1 536	875	661
1996–97	1 565	912	653
1997–98	1 454	943	511
1998–99	1 902	991	911
1999–00	2 125	938	1 187
2000–01	2 388	913	1 475

3.10 Calculation of discards

3.10.1 Jack mackerel

Because of the infrequency of target species discards, a single ratio based on all available data was estimated, producing a value of 7 $kg.h^{-1}$ with a high c.v. (35%) (Table 24). Discarding of COM species was too variable for stratifying calculations and an overall value of 46.6 $kg.h^{-1}$ was calculated. Discarding of OTH species was more frequent and separate estimates were made for six months where data were sufficient, and an overall value was calculated for the other six months. Discard rates of OTH species were greatest in April (240 $kg.h^{-1}$) and least in July (18 $kg.h^{-1}$). Estimated c.v.s were greater in those months with individual estimates, due to smaller sample sizes, than in the overall estimate applied to the other months.

Table 24: Summary of sample sizes, discard ratios ($kg.h^{-1}$) and associated c.v.s used to calculate total discards in the JMA fishery; *n*, number of tows (number of vessels in parentheses); $\hat{D}$, discard ratio.

Species category	Month	*n*	$\hat{D}$	c.v. (%)
JMA	ALL	1 279(20)	7.0	35.2
COM	ALL	1 279(20)	46.6	26.1
OTH	Jan	51(8)	19.3	32.9
OTH	Feb	112(10)	130.4	29.3
OTH	Mar	460(12)	91.4	19.8
OTH	Apr	137(9)	241.0	30.2
OTH	May	*22(2)	80.8	13.3
OTH	Jun	*172(2)	80.8	13.3
OTH	Jul	104(8)	18.2	18.8
OTH	Aug	*2(2)	80.8	13.3
OTH	Sep	*30(4)	80.8	13.3
OTH	Oct	53(4)	21.1	26.1
OTH	Nov	*57(2)	80.8	13.3
OTH	Dec	*79(2)	80.8	13.3

* Denotes months with fewer than 50 records and/or fewer than 3 vessels. In these cases ratios were based on data from all months.

Total discard estimates for each year were calculated by applying the ratios in Table 24 to the target fishery tow duration totals for the equivalent strata. The best estimates of discards of the target species in the jack mackerel fishery ranged from 34 to 71 t per year, with the upper 95% confidence limit no more than 126 t in any year (Table 25 and Figure 10). Discards of COM species were six to seven times greater, ranging from about 223 t to 472 t per year. OTH species discard levels were about twice COM levels in each year and decreased by almost two thirds between 1998–99 and 2000–01. Total annual discard estimates ranged from about 600 to 1500 t.

Table 25: Estimates of discards (t) in the target JMA trawl fishery by year, species category, and overall, with 95% confidence intervals in parentheses.

Species category						Fishing year
		1998–99		1999–00		2000–01
JMA	71	(28–126)	38	(15–68)	34	(13–60)
COM	472	(256–743)	252	(137–397)	223	(121–351)
OTH	995	(633–1 512)	494	(309–757)	362	(264–491)
TOT	1 538	(917–2 381)	784	(461–1 221)	619	(399–902)

The jack mackerel target trawl fishery represented about 60% of the total landings of these species in each of the three years (Table 26). Although the bycatch and discards associated with a large fraction (40%) of annual catches of jack mackerel appear to be unaccounted for, about half of that fraction is landed by purse-seiners operating in the Bay of Plenty and on the east Northland coast, a portion of the fishery not covered by this report. Much of the remainder is incorporated in recent analyses of other fisheries where jack mackerel is a major bycatch species, e.g., the arrow squid fishery (examined here and by Anderson et al. 2000) and the hoki fishery (Clark et al. 2000, Anderson et al. 2001).

Table 26: Estimated catch totals of jack mackerel from the target trawl fishery, and all reported landings from the trawl fishery from the QMS, by year. Landings data from Annala et al. (2002).

Fishing year	Target fishery estimated catch (t)	Total fishery reported catch (t)
1998–99	22 188	37 439
1999–00	13 117	21 061
2000–01	15 660	26 806

3.10.2 Arrow squid

As in the jack mackerel fishery, target species discards were rarely recorded in the arrow squid fishery, and a single ratio based on all available data was estimated to give an overall discard rate of 25 $kg.h^{-1}$ (Table 27). This estimate also has a high c.v. (47%). Discarding of COM species was also rare, but there was a strong indication of differences between the three years, so ratios were estimated separately for each year. The discard rate was estimated to be five times greater in 2000–01 than in 1998–99. Discarding of OTH species was more frequent and separate estimates were made for four months where data were sufficient, and an overall value was calculated for the remaining months. Catch rates of OTH species were greatest in April (142 $kg.h^{-1}$), as was also seen in the jack mackerel fishery, and least in March (42 $kg.h^{-1}$). An overall estimate was also made for discards of SWA. This produced a low value (6.9 $kg.h^{-1}$).

Table 27: Summary of sample sizes, discard ratios (kg.h^{-1}) and associated c.v.s used to calculate total discards in the SQU fishery; *n*, number of tows (number of vessels in parentheses); $\hat{D}$, discard ratio.

Species category	Year/month	*n*	$\hat{D}$	c.v. (%)
SQU	ALL	4 358(31)	25.3	47.2
COM	1998–99	870(12)	6.4	30.4
COM	1999–00	822(25)	7.5	43.7
COM	2000–01	2 666(16)	33.4	41.2
OTH	Jan	411(19)	65.6	19.5
OTH	Feb	2 075(29)	66.4	14.3
OTH	Mar	1 361(27)	42.2	15.2
OTH	Apr	410(14)	142.6	17.2
OTH	ALL	4 358(31)	69.7	8.4
SWA	ALL	4 358(31)	6.9	19.4

Total discard estimates for each year were calculated by applying the ratios in Table 27 to the target fishery tow duration totals for the equivalent strata. The best estimates of discards of the target species in the arrow squid fishery ranged from about 500 to 800 t per year, but there were broad confidence limits around these estimates and arrow squid discards could have been as much as 1000 to 1600 t per year (Table 28 and Figure 10). Discards of COM species were more variable, estimated at much less than target species discards in the first two years but at a higher level in 2000–01. Most discarding related to fish in the OTH species category, with discard levels between 1500 and 2400 t per year. Total annual discard estimates ranged from about 2200 to 4300 t.

Table 28: Estimates of discards (t) in the target SQU trawl fishery by year, species category, and overall, with 95% confidence intervals in parentheses.

Species category					Fishing year	
	1998–99		1999–2000		2000–01	
SQU	779	(199–1 555)	519	(133–1 038)	803	(206–1 605)
COM	197	(99–327)	153	(47–312)	1 060	(353–1 991)
OTH	2 167	(1 613–2 882)	1 501	(1 123–1 996)	2 417	(1 826–3 196)
SWA	213	(141–304)	142	(94–203)	220	(146–313)
Total	3 142	(1 911–4 764)	2 174	(1 302–3 346)	4 280	(2 385–6 791)

The target arrow squid trawl fishery represented about 90% of the total landings by trawl method of these species in each of the three years (Table 29). A portion of the bycatch and discards associated with the remainder of the annual catch of arrow squid will have been accounted for in recent analyses of other fisheries where arrow squid is a significant bycatch species, e.g. the jack mackerel fishery (examined here and by Anderson et al. 2000) and the hoki fishery (Clark et al. 2000, Anderson et al. 2001).

Table 29: Estimated catch totals of arrow squid from the target trawl fishery, and all reported landings from the trawl fishery from the QMS, by year. Landings data from Annala et al. (2002).

Fishing year	Target fishery estimated catch (t)	Total trawl fishery reported catch (t)
1998–99	21 611	24 312
1999–00	17 345	19 290
2000–01	31 015	34 551

3.10.3 Scampi

Discard rates for COM species, calculated by area, were lowest in SUBA (5.3 $kg.h^{-1}$) and highest in CHAT (24.8 $kg.h^{-1}$) (Table 30). For 10 of the 11 years examined, discards of OTH species were estimated using observer data from only the year concerned. Because of problems with data management in 1997–98, observer discard data were not available and discard estimates for that year were based on an average discard rate from all other years. Discard ratios for OTH species ranged from 57 $kg.h^{-1}$ in 1999–00 to 245 $kg.h^{-1}$ in 1995–96. Discard ratios were estimated by area for LIN and SPE, and with no stratification for HOK and RCO. Discard rates were generally low for these species, 1 $kg.h^{-1}$ or less for LIN, HOK, and RCO, and 0–15 $kg.h^{-1}$ for SPE.

Table 30: Summary of sample sizes, discard ratios ($kg.h^{-1}$) and associated c.v.s used to calculate total discards in the SCI fishery; *n*, number of tows (number of vessels in parentheses) ; $\hat{D}$, discard ratio.

Species category	Year/area	*n*	$\hat{D}$	c.v. (%)
COM	CHAT	633(12)	24.8	5.7
COM	NRTH	512(9)	9.3	14.2
COM	OTHR	***1(1)	12.0	4.1
COM	SUBA	838(9)	5.3	8.4
COM	WAIR	994(8)	11.1	6.1
OTH	1990–91	260(6)	72.6	7.4
OTH	1991–92	340(7)	127.7	7.3
OTH	1992–93	208(5)	65.7	10.8
OTH	1993–94	475(7)	101.6	6.1
OTH	1994–95	256(6)	184.8	8.7
OTH	1995–96	236(3)	245.0	7.7
OTH	1996–97	310(4)	123.9	4.2
OTH	1997–98	*—	114.0	2.7
OTH	1998–99	223(4)	96.6	4.5
OTH	1999–00	408(6)	57.5	4.9
OTH	2000–01	265(5)	96.9	12.1
LIN	CHAT	633(12)	0.5	14.2
LIN	NRTH	**512(9)	0.7	11.2
LIN	OTHR	***1(1)	0.7	11.2
LIN	SUBA	838(9)	1.3	13.5
LIN	WAIR	994(8)	0.4	12.5
HOK	ALL	2981(14)	1.1	10.8
SPE	CHAT	633(12)	15.7	7.5
SPE	NRTH	512(9)	8.0	15.9
SPE	OTHR	***1(1)	7.2	5.4
SPE	SUBA	838(9)	0.0	0
SPE	WAIR	994(8)	8.3	7.0
RCO	ALL	2981(14)	0.7	9.3

* Due to problems with data availability calculations for this year are based on data from all other years. ** Bootstrap distribution non-normal, ratio based on records from all areas. *** Too few data, ratio based on records from all areas.

Total discard estimates for each year were calculated by applying the ratios in Table 30 to the target fishery tow duration totals for the equivalent strata. The best estimates of discards of COM species in the scampi fishery ranged from 200 to 400 t per year, with comparatively tight confidence limits around these estimates (Table 31). Discards of OTH species were much greater, ranging from a low of 1350 t in 1990–91 to a high of 4800 in 1995–96. Estimates of discards of LIN, HOK, and RCO were similar and varied little between years, ranging between 10 and 34 t per year (Table 32). Discards of SPE were about ten times greater, ranging from about 120 to 270 t per year. Total annual discard estimates ranged from about 1500 to 5000 t. There was no indication of increasing or decreasing discard levels during the 11-year period for any species group (Figure 10).

Table 31: Estimates of discards (t) in the target SCI trawl fishery by year, species category, and overall, with 95% confidence intervals in parentheses.

Fishing year	Species category		
	COM	OTH	TOT
1990–91	207 (174–244)	1 353 (1 166–1 553)	1 561 (1 340–1 797)
1991–92	414 (358–474)	3 664 (3 146–4 178)	4 078 (3 504–4 652)
1992–93	391 (341–445)	1 705 (1 373–2 071)	2 096 (1 714–2 516)
1993–94	370 (322–421)	2 739 (2 421–3 069)	3 109 (2 743–3 490)
1994–95	261 (226–297)	3 848 (3 232–4 524)	4 109 (3 458–4 821)
1995–96	229 (198–261)	4 828 (4 130–5 625)	5 057 (4 328–5 886)
1996–97	220 (190–252)	2 454 (2 256–2 660)	2 674 (2 446–2 912)
1997–98	232 (200–266)	2 403 (2 283–2 532)	2 634 (2 483–2 798)
1998–99	285 (247–326)	2 600 (2 374–2 840)	2 885 (2 621–3 166)
1999–00	332 (285–383)	1 706 (1 541–1 877)	2 038 (1 826–2 260)
2000–01	334 (286–387)	3 076 (2 515–3 958)	3 410 (2 801–4 345)

Table 32: Estimates of discards (t) in the target SCI trawl fishery by year, for significant individual species, with 95% confidence intervals in parentheses.

Fishing year	Species category			
	LIN	HOK	SPE	RCO
1990–91	10 (8–13)	20 (16–24)	159 (129–194)	14 (11–16)
1991–92	19 (14–24)	30 (25–37)	269 (225–318)	21 (17–25)
1992–93	17 (13–22)	28 (22–34)	246 (208–289)	19 (16–22)
1993–94	20 (15–25)	29 (23–35)	225 (190–263)	20 (16–23)
1994–95	17 (13–21)	22 (18–27)	150 (127–176)	15 (12–18)
1995–96	16 (12–21)	21 (17–26)	129 (109–151)	14 (12–17)
1996–97	17 (13–21)	21 (17–26)	123 (104–144)	14 (12–17)
1997–98	17 (13–22)	22 (18–27)	132 (111–156)	15 (13–18)
1998–99	22 (17–28)	29 (23–35)	161 (136–189)	20 (16–23)
1999–00	23 (18–29)	31 (26–38)	201 (167–238)	22 (18–26)
2000–01	25 (19–31)	34 (27–41)	204 (169–244)	23 (19–27)

The target trawl fishery represented between 91 and 100% of the total landings of scampi in each of the 11 years (Table 33). Incomplete records and errors in estimated catches probably account for higher estimated catches than estimated landings in 1996–97 and 1997–98, and it is likely that target trawling for scampi accounted for close to 100% of the landings in each year.

Table 33: Estimated catch totals of scampi from the target trawl fishery, and all reported landings from the QMS, by year. Landings data from Annala et al. (2002).

Fishing year	Target fishery estimated catch (t)	Total trawl fishery reported catch (t)
1990–91	463	508
1991–92	898	909
1992–93	891	916
1993–94	922	989
1994–95	858	873
1995–96	875	924
1996–97	912	911
1997–98	943	906
1998–99	991	1 020
1999–00	938	1 000
2000–01	913	870

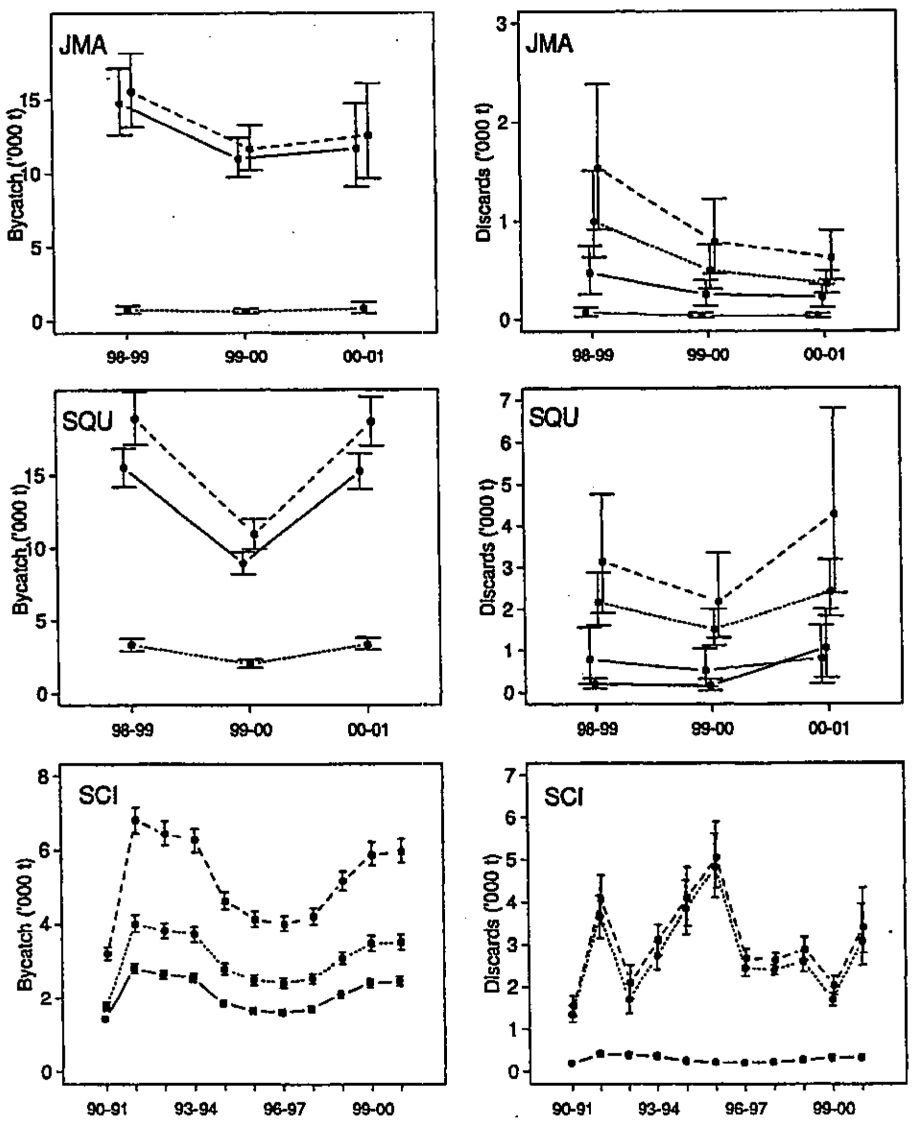

Figure 10: Annual bycatch and discard estimates for the jack mackerel (JMA) (top), arrow squid (SQU) (middle), and scampi (SCI) (bottom) trawl fisheries. Grey lines, target species; solid lines, commercial species (COM); dotted lines, non-commercial species (OTH); dashed lines, all species. Error bars represent 95% confidence intervals.

3.11 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), non-target catch cannot be calculated for each bycatch species or group of bycatch species. It was useful in this report to consider non-target-species catch for separate species groups, commercial (COM) and non-commercial (OTH), and so bycatch (which doesn't incorporate target species discards) was calculated rather than non-target catch. Although there is usually little difference between total bycatch and total non-target catch, for completeness Table 34 presents total non-target catch for each fishery. Because target species discards in the scampi fishery were not calculated (they are presumed to be negligible) the non-target catch figures for scampi in Table 34 are identical to those in Table 21. Jack mackerel discards in the jack mackerel fishery were in the tens of tonnes per year hence non-target catch figures differ by less than 1% from the total bycatch figures in Table 15. The largest difference between total bycatch and non-target catch was in the arrow squid fishery, where discards of arrow squid were 500–800 t per year (see Table 28), and non-target catch was 4–5% greater than total bycatch (see Table 18).

Table 34: Annual non-target catch (t) in the jack mackerel, arrow squid, and scampi fisheries for the fishing years examined in this study, with 95% confidence intervals in parentheses.

Fishing year						Fishery
		Jack mackerel		Arrow squid		Scampi
1990–91		–		–	3 197	(3 025–3 379)
1991–92		–		–	6 790	(6 440–7 155)
1992–93		–		–	6 428	(6 103–6 765)
1993–94		–		–	6 256	(5 942–6 581)
1994–95		–		–	4 622	(4 389–4 864)
1995–96		–		–	4 125	(3 919–4 341)
1996–97		–		–	4 001	(3 801–4 209)
1997–98		–		–	4 200	(3 990–4 421)
1998–99	15 560	(13 148–18 253)	19 619	(17 317–22 212)	5 162	(4 908–5 427)
1999–00	11 682	(10 260–13 321)	11 468	(10 080–13 059)	5 870	(5 570–6 183)
2000–01	12 569	(9 647–16 104)	19 431	(17 241–21 929)	5 953	(5 648–6 274)

3.12 Calculation of observer sample sizes required for specified precision levels

The regression analyses described above were used to identify factors showing the most variation in bycatch and discards of various species categories in the jack mackerel and arrow squid fisheries. The initial exploratory plots (see Figures 4–7) were also examined as they described patterns of total bycatch and total discards. Bootstrap estimates of the variance of discard and bycatch ratios, using methods described in Section 2.6, were used to determine the best spread of observer effort among the strata of the factors identified, in order to achieve various precision targets.

In the jack mackerel fishery, *month* was the factor that had the greatest influence on most categories of bycatch, closely followed by *vessel*. These two factors also had the greatest influence on discards in all species categories, but in the reverse order. It is not possible to estimate optimum coverage by *vessel*, as data would be required from all vessels in the fleets, so estimates were made of the optimum observer coverage by month, in terms of number of tows or number of processing groups. Over the last several years, the observer practice of combining processing information from two or more tows into a single 'processing group' has become less and less common. In the three years of observer data used in the current study, only 14% of jack mackerel target tows and 10% of arrow squid target tows were combined in this way, and this percentage is likely to become smaller in future years as observers are being encouraged not to combine data from tows. This means that the sample sizes in terms of processing groups, shown below, can effectively be considered in terms of number of tows.

The number of observed tows by month required for specified precision targets for estimation of bycatch in the jack mackerel fishery are summarised in Table 35. The analysis predicts that a precision of 10% or less in the annual bycatch ratio c.v. could be achieved with current levels of observer coverage, but to achieve this precision in each month would require a large increase in coverage. To achieve a precision which would be likely to estimate bycatch to within 200 t of the actual amount in each month would require similar or less coverage than at present in most months, but in June and July the required coverage to achieve this target is unrealistically high. This is most likely due to the influence on the standard deviation (s.d.) of the observations of a few large non-target species catches in these months. These large catches also have an effect on the all months estimate of required coverage to achieve this target, which is also well beyond current levels. These relatively rare, large events mean that at the current level of observer coverage bycatch can be estimated only to within 1000 t. A s.e. of the estimated bycatch ratio of 0.06 is achievable at the current level of coverage, but a s.e. of 0.04 would require a doubling of observer effort. To achieve ratio s.e.s of 0.04–0.06 in each month would again require unrealistically high coverage in some months.

Table 35: Number of observed tows required by month to achieve specified precision of bycatch estimates in the jack mackerel fishery, based on mean total bycatch ratios and their variance, from bootstrapping of observed catch data. N.tows (n.vessels), number of tows and vessels calculations were based on; 200 t, precision of within 200 t of actual bycatch. See text for more details.

Month	Jan	Feb	Mar	Apr	May*	Jun	Jul	Aug*	Sep*	Oct	Nov	Dec	All
N.tows (n.vessels)	51(8)	137(10)	529(12)	160(9)	22(2)	178(2)	121(8)	4(2)	31(4)	119(4)	61(2)	79(2)	1492(20)
Bootstrap sample size	51	137	529	160	1492	178	121	1492	1492	119	61	79	1492
Mean bycatch ratio	0.254	0.303	0.861	0.832	0.698	2.370	2.353	0.698	0.698	0.285	0.132	0.165	0.698
s.e. mean of ratios	0.077	0.048	0.057	0.117	0.034	0.337	0.550	0.034	0.034	0.037	0.019	0.023	0.034
s.d. of ratios	0.550	0.557	1.300	1.478	1.304	4.496	6.055	1.304	1.304	0.401	0.146	0.205	1.304
c.v. of ratios	2.163	1.837	1.510	1.777	1.867	1.897	2.573	1.867	1.867	1.407	1.1	1.2	1.867
c.v. 10%	468	337	228	316	349	360	662	349	349	198	121	154	349
c.v. 20%	117	84	57	79	87	90	166	87	87	50	30	39	87
c.v. 30%	52	37	25	35	39	40	74	39	39	22	13	17	39
c.v. 40%	29	21	14	20	22	22	41	22	22	12	8	10	22
Avg. landings (3 yr) (t)	2104	1277	1823	1736	1354	2877	1052	222	224	1012	608	2700	16988
200 t	33	13	140	165	78	4182	1014	2	2	4	1	8	12261
4% precision	189	194	1056	1365	1062	12632	22914	1062	1062	100	13	26	1062
6% precision	84	86	470	607	472	5614	10184	472	472	45	6	12	472
Mean coverage (3 yr)	17	46	176	53	7	59	40	1	10	40	20	26	497

* There were insufficient data to analyse these months separately. Estimates are based on data from all months.

A similar pattern is shown for the coverage required to achieve precision targets of discard levels in this fishery, with current observer coverage sufficient to enable an annual discard ratio c.v. of 20–30%, but insufficient to achieve this precision in every month (Table 36). Estimates of discards to within 100 t can be achieved in most months with current levels of coverage or less, but to obtain annual estimates within 100 t of the actual amount would require an increase of 3 to 4 times in the number of samples. However, the analysis shows that, with the current level of coverage, annual estimates of total discards could be predicted to within 200 t.

Table 36: Number of observed processing groups required by month to achieve specified precision of discard estimates in the jack mackerel fishery, based on mean total discard ratios and their variance, from *bootstrapping of observed discard data*. N.pgs (n.vessels), number of processing groups and vessels calculations were based on; 100 t, precision of within 100 t of actual discards. See text for more details.

Month	Jan	Feb	Mar	Apr	May*	Jun	Jul	Aug*	Sep*	Oct	Nov	Dec	All
N.pgs (n.vessels)	51(8)	112(10)	461(12)	137(9)	22(2)	172(2)	104(8)	2(2)	30(4)	53(4)	57(2)	79(2)	1279(20)
Bootstrap sample size	51	112	461	137	1279	172	104	1279	1279	53	57	79	1279
Mean discard ratio	0.013	0.065	0.053	0.113	0.048	0.045	0.122	0.048	0.048	0.008	0.007	0.002	0.048
s.e. mean of ratios	0.008	0.021	0.010	0.032	0.007	0.031	0.085	0.007	0.007	0.002	0.002	0.000	0.007
s.d. of ratios	0.055	0.226	0.210	0.372	0.234	0.413	0.864	0.234	0.234	0.017	0.013	0.004	0.234
c.v. of ratios	4.146	3.483	3.924	3.299	4.826	9.108	7.097	4.826	4.826	2.014	2.030	1.704	4.826
c.v. 10%	1719	1213	1540	1088	2329	8296	5037	2329	2329	406	412	290	2329
c.v. 20%	430	303	385	272	582	2074	1259	582	582	101	103	73	582
c.v. 30%	191	135	171	121	259	922	560	259	259	45	46	32	259
c.v. 40%	107	76	96	68	146	519	315	146	146	25	26	18	146
Avg. landings (3 yr) (t)	2104	1277	1823	1736	1354	2877	1052	222	224	1012	608	2700	16988
100 t	1	8	15	42	10	141	83	1	1	1	1	1	1577
2% precision	8	128	110	346	137	426	1865	137	137	1	0.44	0.04	137
4% precision	2	32	28	87	34	106	466	34	34	0	0.11	0.01	34
Mean coverage (3 yr)	17	37	154	46	7	57	35	1	10	18	19	26	427

* There were insufficient data to analyse these months separately. Estimates are based on data from all months.

Regression analyses identified vessel as the single most important factor influencing both bycatch and discards in the arrow squid fishery. This result alone gives a clear indication of how observer effort should be spread over the fishery, i.e., over as wide a range of vessels as possible. The analyses also identified fishery *area* as an important factor, particularly in patterns of bycatch, and for this reason and because of its practicality, this factor was chosen for calculation of optimal spread of coverage.

The analysis predicts that to achieve a precision where the bycatch ratio c.v. for all areas is 10% or less overall would require only one-third of the observer coverage of current levels, and even separate estimates of ratios for each area with a c.v. of 10% would be possible at current levels of coverage (Table 37). This level of precision would require a shift of some of the effort from SNAR into BANK and AUCK. The other two areas contribute little to the fishery and warrant only a low level of coverage. To achieve a precision which would be likely to estimate bycatch to within 200 t of the actual amount in each area would be easily achievable in AUCK with current levels of coverage, but would require a substantial increase in effort in BANK and SNAR. A few large non-target species catches in these areas are likely to be responsible for this result and such events may not be restricted to these two areas. An estimate of bycatch for all areas combined which is within 200 t of the actual level is also out of reach with current levels of coverage, but an estimate within 500 t would be possible with an increase in coverage of about 50%. An s.e. of the estimated bycatch ratio of 0.02–0.04 is achievable at the current level of coverage, especially with a shift in the spread of effort from SNAR into BANK. To achieve a ratio s.e. of better than 0.02 overall would require about a 70% increase in effort.

Table 37: Number of observed tows required by area to achieve specified precision of bycatch estimates in the arrow squid fishery, based on mean total bycatch ratios and their variance, from bootstrapping of observed catch data. N.tows (n.vessels), number of tows and vessels calculations were based on; 100 t, precision of within 100 t of actual bycatch. See text for more details.

Area	AUCK	BANK	NRTH*	OTHR*	SNAR	ALL
N.tows (n.vessels)	1 170(27)	171(16)	18(1)	2(1)	3 503(30)	4 864(32)
Bootstrap sample size	1 170	171	4 864	4 864	3 503	4 864
Mean bycatch ratio	0.106	0.747	0.446	0.446	0.550	0.446
s.e. mean of ratios	0.008	0.107	0.015	0.015	0.020	0.015
s.d. of ratios	0.287	1.401	1.060	1.060	1.196	1.060
c.v. of ratios	2.718	1.875	2.375	2.375	2.175	2.375
c.v. 10%	739	352	564	564	473	564
c.v. 20%	185	88	141	141	118	141
c.v. 30%	82	39	63	63	53	63
c.v. 40%	46	22	35	35	30	35
Avg. landings (3 yr) (t)	3 364	5 871	8	74	14 020	23 336
Within 100 t	93	6 770	1	1	28 095	61 132
Within 200 t	23	1 692	1	1	7 024	15 283
2% precision	206	4 910	2 806	2 806	3 573	2 806
4% precision	52	1 227	702	702	893	702
6% precision	23	546	312	312	397	312
Mean coverage (3 yr)	390	57	6	1	1 168	1 621

* There were insufficient data to analyse these areas separately. Estimates are based on data from all areas.

Present levels of coverage are sufficient to enable discard ratio c.v.s of only 30–40% in each of the three main arrow squid fishery areas, but the spread of coverage over the past three years in these areas is close to optimum (Table 38). To achieve an 'all areas' c.v. of 20% would require an increase in the number of processing groups observed from 1457 to 2591, or nearly 80%. The analysis predicts that discards could be estimated to well within 200 t of their actual value with current levels of coverage in AUCK, and also in BANK if the AUCK level of coverage was applied. In SNAR, however, more than twice the effort would be necessary to achieve estimates within 300 t. To achieve estimates within 300 t over the whole fishery would require an unrealistic increase in effort, but estimates within 500 t could be achieved with only a 25% increase in effort. An s.e. of the estimated discard ratio of 0.02–0.04 is achievable at the current level of coverage. This mirrors the situation for bycatch and, again, this would be aided by a shift in the spread of effort from SNAR into BANK. To achieve a ratio s.e. of better than 0.02 overall would require about a 45% increase in effort.

Table 38: Number of observed processing groups required by area to achieve specified precision of discard estimates in the arrow squid fishery, based on mean total discard ratios and their variance, from bootstrapping of observed discard data. N.pgs (n.vessels), number of processing groups and vessels calculations were based on; 200 t, precision of within 200 t of actual discards. See text for more details.

Area	AUCK	BANK	NRTH*	OTHR*	SNAR	ALL
N.pgs (n.vessels)	1 060(26)	163(15)	18(1)	6(4)	3 123(29)	4 370(31)
Bootstrap sample size	1 060	163	4 370	4 370	3 123	4 370
Mean discard ratio	0.065	0.240	0.090	0.090	0.094	0.090
s.e. mean of ratios	0.022	0.044	0.014	0.014	0.018	0.014
s.d. of ratios	0.705	0.561	0.916	0.916	1.014	0.916
c.v. of ratios	10.887	2.338	10.180	10.180	10.784	10.180
c.v. 10%	11 852	546	10 363	10 363	11 629	10 363
c.v. 20%	2 963	137	2 591	2 591	2 907	2 591
c.v. 30%	1 317	61	1 151	1 151	1 292	1 151
c.v. 40%	741	34	648	648	727	648
Avg. landings (3 yr) (t)	3 364	5 871	8	74	14 020	23 336
Within 200 t	141	271	0	0	5 053	11 418
Within 300 t	63	120	0	0	2 246	5 075
2% precision	1 243	786	2 097	2 097	2 570	2 097
4% precision	311	197	524	524	643	524
6% precision	138	87	233	233	286	233
Mean coverage (3 yr)	353	54	6	2	1 041	1 457

* There were insufficient data to analyse these areas separately. Estimates are based on data from all areas.

4. DISCUSSION

Observer effort in these fisheries was variable both over time and between fisheries. About 20% of the jack mackerel target trawl fishery was observed in each year, a figure that compares favourably to the equivalent percentages in the previous eight years, which ranged from 9 to 22% (Anderson et al 2000). Observer coverage in the arrow squid fishery has seen a steady increase since 1994–95, from 6% to 54% of the target trawl fishery catch. Increasing concerns regarding incidental catch of Hooker's sealions around their breeding grounds on the Auckland Islands has been largely responsible for this increase, especially in 2000–01 when there was 100% observer coverage in that area. The high coverage in the three years examined here has enabled more precise estimates of bycatch and discards than was possible for the previous examination of this fishery (Anderson et al 2000). Observer coverage in the scampi fishery was more variable and generally lower than in the other two fisheries, ranging from 5.3% to 17.1% of the annual target fishery catch, but still sufficient overall to provide robust estimates of bycatch and discards. Observer coverage was also well spread over the main fishing areas in each fishery. Some smaller fisheries were not so well covered, such as the near shore and northern parts of area WEST (JMA 7) in the jack mackerel fishery, the arrow squid fisheries around the Puysegur Bank and Chatham Islands, and the scampi fishery on the Challenger Plateau (QMA 7).

Modelling of discards and bycatch showed that the most influential factor overall in these fisheries was the fishing *vessel* itself. The probability of occurrence and the amount of discards and bycatch in a tow were highly dependent on the vessel carrying out the tow. This result stresses the need to spread observer effort over as many vessels as possible in each fishery. Other important factors included *month* in the jack mackerel fishery (both bycatch and discards), *area* in bycatch in the arrow squid and scampi fisheries, *month* in discards in the arrow squid fishery, and *fishing year* in discards in the scampi fishery. The area effect could in some cases be directly related to the known distribution of a particular bycatch species, such as the northern distribution of sea perch and blue mackerel, and the scarcity of barracouta south of the Stewart-Snares shelf. Bycatch of all species groups was especially low in the Auckland Islands arrow squid fishery, and particularly high in the Chatham Rise scampi fishery.

Estimates of bycatch of commercial species in the jack mackerel fishery were high in each year, adding 1100–15 000 t (60–80%) to the target species catch. Barracouta and blue mackerel, in roughly equal proportions, account for most of the commercial species bycatch over the three years, and redbait contributes between 1000 and 1500 t. The total annual bycatch in the three years examined is at a similar level to that estimated for the previous year (12 299 t) but more than in each of the seven years between 1990–91 and 1996–97 (Anderson et al. 2000). Catches of non-commercial species were low in comparison to commercial species at between 670 and 870 t per year. Commercial species also represented a significant fraction of the total discards in this fishery, although there was twice as much discarding of non-commercial species, and only low levels of target species discards. Total discards in 1998–99 were at a similar level to those estimated for the 1991–92 to 1997–98 period (Anderson et al. 2000) but the estimates for 1999–2000 and 2000–01 were the lowest of any year since before 1990–91. An average of 0.06 kg of total discards per kilogram of jack mackerel caught was calculated for the three years examined in this study, similar to the value of 0.07 calculated by Anderson et al. (2000) for the previous eight years.

Total bycatch estimates for the arrow squid fishery were within the range estimated for the previous eight years (Anderson et al. 2000) and there is no indication of changing levels over the combined 11 years examined. Commercial species (mostly barracouta and silver warehou) accounted for about 80% of the total bycatch. The 2000–3000 t annual catch of non-commercial species were mostly discarded and this group accounted for 60–70% of all discards. More than 10 times as much of the target species were discarded each year as in the jack mackerel fishery, and levels of arrow squid discards were higher in each of the three years than in most of the previous eight years examined by Anderson et al. (2000). Overall, there was 0.14 kg of total discards per kilogram of arrow squid caught for the three years examined in this study. This is much higher than the 0.04 kg calculated by Anderson et al. (2000) for the previous eight years, and is the result of higher average levels of discards in each of the three species categories.

In contrast to the other two fisheries, bycatch in the scampi fishery was composed more of non-commercial than of commercial species, with the former accounting for between 55 and 60% of the total annual bycatch. Total annual bycatch was in the order of 3200 to 6700 t. Bycatch was made up of five main species, with similar annual catch levels for ling, hoki, and sea perch (150–900 t), and lesser, more variable, catches of red cod and stargazer. Discards of the target species were not estimated in this study, as they were expected to be minimal. Total discards were dominated by non-commercial species, although discards of ling, red cod, hoki, and sea perch were consistently recorded. Discards of sea perch were 8 to 10 times greater than those of the other three species, at between 120 and 270 t per year. An average of 3.5 kg of total discards per kilogram of scampi caught was calculated for the 11 years examined in this study, a far higher level than in the jack mackerel and arrow squid fisheries, and four times higher than in the North Sea scampi (*Nephrops* spp.) fishery (Evans et al. 1994). The equivalent values for other New Zealand fisheries are: orange roughy, 0.06 kg; hoki, 0.05 kg; and southern blue whiting 0.02 kg (Anderson et al. 2000, 2001).

The coverage required for optimising estimates of discards and bycatch in both the jack mackerel and arrow squid fisheries is highly dependent on the choice of the precision statistic and the level of precision required. Because discards and bycatch vary greatly by month in the jack mackerel fishery, the best approach would be to spread observer coverage throughout the year. The ratio c.v.s can be determined to within 20% with the same or slightly increased coverage, but this approach has the disadvantage that the absolute estimate of bycatch or discards in larger fisheries will be less precisely estimated. Estimates can be made of bycatch to within 6%, and of discards to within 2%, of the target catch with current levels, but this approach will tend to oversample sectors of the fishery with inherently low bycatch or discards and vice-versa. The best approach is probably that which optimises the precision of the absolute value of discards or bycatch. With this strategy, annual bycatch (11 000–12 000 t) could be estimated to within about 1000 t with current effort and more precisely if coverage was spread among months according to the proportions in Table 35. Likewise annual estimates of discards could, with the same approach, be estimated to within 200 t or less.

The best strategy for achieving improved estimates of bycatch and discards in the arrow squid fishery would be to spread observer coverage over the geographical range of the fishery. A bycatch ratio with a c.v. of less than 10% and a discard ratio with a c.v. of 20–30% could be estimated with present coverage. Bycatch and discard estimates with a precision of between 2 and 4% of the target catch would also be possible with present coverage. However, these approaches suffer from the same drawbacks as described for the jack mackerel fishery, in that smaller fisheries and those with lower bycatch/discards may be oversampled. By spreading observer coverage between areas in proportion to the values in Tables 37 and 38, bycatch could be estimated to within 500 t, and discard estimates to within 400 t, with an increase of observer coverage of less than 50%. Regardless of the approach taken, a good spread of effort over a range of vessels is important in each of these fisheries. This was the overriding factor in regression models for both fisheries, suggesting that fishing and processing practices vary widely between vessels. This must be taken into account when planning future observer placements.

5. ACKNOWLEDGMENTS

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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 jack mackerel target fishery from 1 Oct 1998 to 30 Sep 2001. 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
JMA	Jack mackerel	*Trachurus declivis, T. s. murphyi, T. novaezelandiae*	10 655	56.03	0
BAR	Barracouta	*Thyrsites atun*	3 381	17.78	0
EMA	Blue mackerel	*Scomber australasicus*	1 901	10.00	0
RBT	Redbait	*Emmelichthys nitidus*	802	4.22	19
WAR	Common warehou	*Seriolella brama*	724	3.81	0
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*	444	2.33	0
SPD	Spiny dogfish	*Squalus acanthias*	260	1.37	96
HOK	Hoki	*Macruronus novaezelandiae*	210	1.11	0
SWA	Silver warehou	*Seriolella punctata*	153	0.80	0
FRO	Frostfish	*Lepidopus caudatus*	129	0.68	1
STU	Slender tuna	*Allothunnus fallai*	61	0.32	5
RBM	Ray's bream	*Brama brama*	60	0.32	0
POS	Porbeagle shark	*Lamna nasus*	25	0.13	32
HAK	Hake	*Merluccius australis*	21	0.11	1
THR	Thresher shark	*Alopias vulpinus*	18	0.10	98
RAT	Rattails	Macrouridae	18	0.09	70
TAR	Tarakihi	*Nemadactylus macropterus*	15	0.08	0
SNI	Snipefish	*Macrorhamphosus scolopax*	15	0.08	0
SKI	Gemfish	*Rexea solandri*	12	0.06	0
KIN	Kingfish	*Seriola lalandi*	10	0.05	4
SCH	School shark	*Galeorhinus galeus*	10	0.05	8
RCO	Red cod	*Pseudophycis bachus*	9	0.05	0
STA	Giant stargazer	*Kathetostoma giganteum*	9	0.05	0
LIN	Ling	*Genypterus blacodes*	9	0.05	0
GUR	Gurnard	*Chelidonichthys kumu*	7	0.04	1
SDO	Silver dory	*Cyttus novaezealandiae*	7	0.04	77
HPB	Hapuku & bass	*Polyprion oxygeneios, P. americanus*	6	0.03	0
GSH	Ghost shark	*Hydrolagus novaezealandiae*	6	0.03	1
SSK	Smooth skate	*Dipturus innominatus*	4	0.02	9
JAV	Javelinfish	*Lepidorhynchus denticulatus*	3	0.02	0
BAT	Large headed slickhead	*Rouleina* sp.	3	0.02	0
LDO	Lookdown dory	*Cyttus traversi*	2	0.01	58
SWO	Broadbill swordfish	*Xiphias gladius*	2	0.01	44
PIF	Pilotfish	*Naucrates ductor*	2	0.01	100
JDO	John dory	*Zeus faber*	2	0.01	1
PIL	Pilchard	*Sardinops neopilchardus*	2	0.01	0
MAK	Mako shark	*Isurus oxyrinchus*	2	0.01	100
BWS	Blue shark	*Prionace glauca*	1	0.01	95
SUN	Sunfish	*Mola mola*	1	<0.01	100
FUR	New Zealand fur seal	*Arctocephalus forsteri*	1	<0.01	100
RIB	Ribaldo	*Mora moro*	1	<0.01	0
RDO	Rosy dory	*Cyttopsis roseus*	1	<0.01	79
STG	Stargazer	Uranoscopidae	1	<0.01	0
SNA	Snapper	*Pagrus auratus*	1	<0.01	0
WPS	White pointer shark	*Carcharodon carcharias*	1	<0.01	100
EPT	Deepsea cardinalfish	*Epigonus telescopus*	1	<0.01	0
MOO	Moonfish	*Lampris guttatus*	1	<0.01	30
POP	Porcupinefish	*Allomycterus jaculiferus*	1	<0.01	100
ELE	Elephantfish	*Callorhinchus milii*	<1	<0.01	1
POR	Porae	*Nemadactylus douglasi*	<1	<0.01	1

Appendix 2: 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 arrow squid target fishery from 1 Oct 1998 to 30 Sep 2001. 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
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*	23 196	66.79	0
BAR	Barracouta	*Thyrsites atun*	5 318	15.31	0
JMA	Jack mackerel	*Trachurus declivis, T. s. murphyi, T. novaezelandiae*	1 633	4.70	0
SWA	Silver warehou	*Seriolella punctata*	1 337	3.85	8
SPD	Spiny dogfish	*Squalus acanthias*	853	2.46	73
WAR	Common warehou	*Seriolella brama*	614	1.77	1
RBT	Redbait	*Emmelichthys nitidus*	402	1.16	27
RCO	Red cod	*Pseudophycis bachus*	253	0.73	8
HOK	Hoki	*Macruronus novaezelandiae*	182	0.52	3
LIN	Ling	*Genypterus blacodes*	114	0.33	0
CRB	Crab	Decapoda	94	0.27	98
RAT	Rattails	Macrouridae	93	0.27	79
RBM	Ray's bream	*Brama brama*	63	0.18	39
GSH	Ghost shark	*Hydrolagus novaezealandiae*	49	0.14	8
BSK	Basking shark	*Cetorhinus maximus*	45	0.13	68
STU	Slender tuna	*Allothunnus fallai*	42	0.12	0
SSK	Smooth skate	*Dipturus innominatus*	41	0.12	2
HPB	Hapuku & bass	*Polyprion oxygeneios, P. americanus*	34	0.10	1
WWA	White warehou	*Seriolella caerulea*	24	0.07	1
SWC	Swimming crab	Decapoda	24	0.07	94
SPE	Sea perch	*Helicolenus* spp.	23	0.07	4
MIX	Mixed fish		23	0.06	96
STA	Giant stargazer	*Kathetostoma giganteum*	22	0.06	2
SCH	School shark	*Galeorhinus galeus*	21	0.06	4
PAD	Paddle crab	*Ovalipes catharus*	21	0.06	91
POS	Porbeagle shark	*Lamna nasus*	20	0.06	75
JAV	Javelinfish	*Lepidorhynchus denticulatus*	16	0.05	98
CBE	Crested bellowsfish	*Notopogon lilliei*	15	0.04	95
HAK	Hake	*Merluccius australis*	12	0.04	2
SBW	Southern blue whiting	*Micromesistius australis*	12	0.04	100
SPI	Spider crab	Decapoda	12	0.04	100
MAK	Mako shark	*Isurus oxyrinchus*	12	0.03	89
GMU	Grey mullet	*Mugil cephalus*	9	0.03	100
BEL	Bellowsfish	*Centriscops* spp.	8	0.02	12
BCO	Blue cod	*Parapercis colias*	5	0.02	1
SDO	Silver dory	*Cyttus novaezealandiae*	5	0.01	91
TAR	Tarakihi	*Nemadactylus macropterus*	5	0.01	2
BWS	Blue shark	*Prionace glauca*	5	0.01	94
CAR	Carpet shark	*Cephaloscyllium isabellum*	4	0.01	100
THR	Thresher shark	*Alopias vulpinus*	4	0.01	99
FRO	Frostfish	*Lepidopus caudatus*	4	0.01	1
BBE	Banded bellowsfish	*Centriscops humerosus*	4	0.01	98
OCT	Octopus	*Octopus cordiformis*	4	0.01	6
LDO	Lookdown dory	*Cyttus traversi*	4	0.01	70
SUN	Sunfish	*Mola mola*	3	0.01	100
WIT	Witch	*Arnoglossus scapha*	2	0.01	79
SFI	Starfish	Asteroidea & Ophiuroidea	2	0.01	53
QSC	Queen scallop	*Chlamys delicatula*	2	0.01	97
POR	Porae	*Nemadactylus douglasi*	2	0.01	100
RDO	Rosy dory	*Cyttopsis roseus*	2	0.01	94

Appendix 3: 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 scampi target fishery from 1 Oct 1990 to 30 Sep 2001. 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
MIX	Mixed fish		1 091	20.83	100
SCI	Scampi	*Metanephrops challengeri*	907	17.33	1
LIN	Ling	*Genypterus blacodes*	528	10.08	3
RAT	Rattails	Macrouridae	502	9.58	100
JAV	Javelinfish	*Lepidorhynchus denticulatus*	453	8.64	100
HOK	Hoki	*Macruronus novaezelandiae*	422	8.06	6
SPE	Sea perch	*Helicolenus* spp.	239	4.56	68
STA	Giant stargazer	*Kathetostoma giganteum*	129	2.47	1
RCO	Red cod	*Pseudophycis bachus*	108	2.07	15
SWA	Silver warehou	*Seriolella punctata*	71	1.36	0
SSK	Smooth skate	*Dipturus innominatus*	53	1.00	97
GSH	Ghost shark	*Hydrolagus novaezealandiae*	50	0.96	60
FHD	Deepsea flathead	*Hoplichthys haswelli*	46	0.88	100
SFI	Starfish	Asteroidea & Ophiuroidea	42	0.80	99
CRB	Crab	Decapoda	41	0.78	100
SPD	Spiny dogfish	*Squalus acanthias*	40	0.77	100
HAK	Hake	*Merluccius australis*	40	0.77	0
SKI	Gemfish	*Rexea solandri*	38	0.72	1
RSK	Rough skate	*Dipturus nasutus*	36	0.68	96
BBE	Banded bellowsfish	*Centriscops humerosus*	27	0.52	100
WWA	White warehou	*Seriolella caerulea*	24	0.45	4
SQU	Arrow squid	*Nototodarus sloanii, N. gouldi*	23	0.45	2
TOA	Toadfish	*Neophrynichthys* sp.	22	0.43	100
SRH	Silver roughy	*Hoplostethus mediterraneus*	20	0.39	100
BNS	Bluenose	*Hyperoglyphe antarctica*	18	0.35	0
LDO	Lookdown dory	*Cyttus traverse*	18	0.34	47
ANT	Anemones	Anthozoa	14	0.26	99
SCC	Sea cucumber	*Stichopus mollis*	12	0.23	100
SSI	Silverside	*Argentina elongate*	11	0.21	100
SBW	Southern blue whiting	*Micromesistius australis*	11	0.21	99
HPB	Hapuku & bass	*Polyprion oxygeneios, P. americanus*	10	0.20	0
BYX	Alfonsino & long-finned beryx	*Beryx splendens, B. decadactylus*	10	0.19	12
SCH	School shark	*Galeorhinus galeus*	10	0.19	4
BEL	Bellowsfish	*Centriscops* spp.	9	0.17	100
HAG	Hagfish	*Eptatretus cirrhatus*	8	0.15	100
CDO	Capro dory	*Capromimus abbreviatus*	8	0.15	100
DSK	Deepwater spiny	*Amblyraja hyperborea*	7	0.14	100
COU	Coral (unspecified)		7	0.14	100
SDO	Silver dory	*Cyttus novaezealandiae*	7	0.13	94
PRK	Prawn killer	*Ibacus alticrenatus*	6	0.12	100
RIB	Ribaldo	*Mora moro*	6	0.11	77
PSK	Longnosed deepsea skate	*Bathyraja shuntovi*	5	0.10	100
CRU	Crustacea		5	0.10	79
CSH	Catshark	Scyliorhinidae	5	0.09	100
SPI	Spider crab	Decapoda	4	0.08	100
MDO	Mirror dory	*Zenopsis nebulosus*	4	0.08	93
WSQ	Warty squid	*Moroteuthis* spp.	4	0.08	100
FLA	Flats		4	0.07	99
EEL	Eels, marine		4	0.07	99
CON	Conger eel	*Conger* spp.	4	0.07	100