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EXECUTIVE SUMMARY

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Trawl catch and discard data from the Ministry of Fisheries Observer Programme and commercial catch-effort data for the 1999–2000 to 2002–03 fishing years were used to examine rates of fish bycatch and discards, and to estimate annual totals, in the hoki trawl fishery. Estimates were made for several categories of catch including hoki, other commercial species combined, non-commercial species combined, and separately for the three most commonly caught individual species; hake, ling, and silver warehou.

A ratio estimator, measuring bycatch and discards in terms of tow duration, was used to calculate bycatch and discard rates for logical subsets (strata) of the fishery and for each species category. These ratios were used to scale up the observed discard and bycatch to make estimates for the total target fishery, using commercial catch-effort data. Multi-step bootstrapping methods, taking into account the effect of correlation between tows in the same trip and stratum, were applied to the ratios for each tow or group of tows to provide confidence limits for annual bycatch and discard estimates.

Regression analyses were used to identify critical factors affecting bycatch and discard quantities in order to split the fishery into logical strata. Variables used in the analyses were limited to the few which could potentially be used to partition commercial catch-effort data. The number of levels in the area and time of year variables, and their arrangement, were determined using regression tree methods which seek to maximise the explanatory power of variables while at the same time minimising the number of splits. These two factors in most cases explained more of the variability in the regressions than the other factors and were used to stratify the calculations of annual totals. Bycatch rates tended to be greater for both commercial and non-commercial species in the west coast South Island fishery than in other areas, and the split of the fishing year into three or four periods helped to explain much of the variability in ling and silver warehou bycatch rates. Vessel processing type (especially the presence or not of meal plants on factory vessels) was a critical factor influencing rates of discarding of commercial species, and the use of midwater nets tended to reduce the level of non-commercial species discards.

Total annual bycatch estimates ranged from about 51 000 to 60 000 t, which compares with estimated target species catches of 175 000–230 000 t per year during the same period. This bycatch contained slightly more commercial species than non-commercial species in the first two years and was a more even mixture of the two species groups in the last two years. Bycatch was higher during this four-year period than estimated in previous research for the preceding nine years and higher also for repeated estimates for three of those years. Repeated estimates were considerably higher than the original estimates, although revised confidence interval methods indicated that there is much more uncertainty in the estimates than initially calculated.

Non-commercial species accounted for about 90% of the discards in this fishery, with total annual discard estimates ranging from about 11 000 to 14 000 t. Hoki accounted for much of the remaining discards (600–2100 t per year), with very little discarding of other commercial species. Hoki discards were at lower levels than estimated for the nine previous years and total discards were at a similar level. The repeat estimates for 1990–91, 1994–95, and 1998–99 were at a similar level to the original estimates for both hoki and total discards.

1. INTRODUCTION

The Ministry of Fisheries (MFish) has an obligation under international treaties to determine the impacts of fishing on any stock, area, and the aquatic environment. This obligation includes the principle that associated or dependent species should be maintained above a level that ensures their long-term viability. The hoki trawl fishery is New Zealand's largest fishery, with between 20 000 and 30 000 trawls made within the Exclusive Economic Zone (EEZ) each year, stretching from the Bay of Plenty in the north to the southern slopes of the Campbell Plateau in the south. A fishery of this size has enormous potential for catching and discarding non-target species with no commercial value. These may be species for which there is no economic market or they may be marketable species which cannot be processed due to damage (crushing in codend or factory line, contamination from being dropped, deterioration of flesh quality from processing delays) or because they are of unwanted size. Discarding of processed fish can also occur due to, for example, chemical contamination or the breakdown of a freezer. Fish can also be discarded without ever reaching the deck of the boat, when dead or dying fish escape from the net due to gear damage caused by contact with the seabed, or as a result of a mechanical or other failure during gear retrieval.

Information on the level of non-target fish catch and discards in commercial fisheries is important for fisheries management, even though this information is frequently overlooked. Accurate estimates of the catch history of the stock are perhaps the single most important input to any stock assessment, yet this aspect often receives little attention. Official landing records are often assumed to accurately reflect total mortality with an arbitrary amount (percentage) added for catch overruns caused by such things as illegal fishing, incorrect conversion factors, and unreported discarding. Estimates of these additional mortalities are also required for non-target species, regardless of their commercial value, as there is an increasing emphasis in international fisheries management on considering the full effects of a fishery on the associated environment when making management decisions. The analysis undertaken here provides some quantitative measurements of target species discards which could be used to more accurately estimate fishing mortality, and provides quantitative and qualitative information on the effects of the hoki fishery on other fish species. In addition, some of the factors contributing to high levels of non commercial species bycatch and all species discards are identified as part of the process of calculating annual estimates.

The work undertaken here extends an earlier study which examined discards in this fishery (along with the orange roughy (*Hoplostethus atlanticus*) fishery) for the 1990–91 to 1998–99 (1 October–30 September) fishing years (Anderson et al. 2001). That study found that bycatch in the hoki fishery comprised mainly the commercial species hake (*Merluccius australis*), ling (*Genypterus blacodes*), silver warehou (*Seriolella punctata*), and frostfish (*Lepidopus caudatus*) and the non-commercial spiny dogfish (*Squalus acanthias*) and rattails (Macrouridae). Discards comprised mostly non-commercial species (about 2000–7000 t per year) and hoki (about 2000–6000 t per year), with very little discarding of other commercial species (about 350–750 t per year). Both bycatch and discard levels were influenced mainly by differences between vessels, and these differences were not adequately explained by vessel size, crew nationality, or fishing company, the associated variables available at the time. Fishing year and area also influenced bycatch and discards, and these variables were used to stratify the fishery to calculate annual estimates.

This study also complements recent studies on bycatch and discards in other New Zealand trawl fisheries: e.g., the orange roughy fishery (Anderson et al. 2001), the southern blue whiting (*Micromesistius australis*) and oreo (*Pseudocyttus maculatus, Neocyttus rhomboidalis, Allocyttus niger*) fisheries (Anderson 2004a), and the arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.), and scampi (*Metanephrops challengeri*) fisheries (Anderson 2004b). With this ongoing programme of research, the effects of trawl fishing on associated fish species is now being monitored in virtually all the main trawl fisheries in New Zealand waters, enabling the rapid detection of any trends or sudden changes in the level of bycatch and discards.

This report was prepared as an output from the MFish project ENV2003/01 "Estimation of non-target catches in the hoki fishery" and addresses the following objectives.

1. To estimate the catch rates, quantity, and discards of non-target fish catches and the discards of target fish catches in trawl fisheries for hoki, using data from the Observer Programme and commercial fishing returns for the 1999/00 to 2002/03 fishing years.

2. To compare and contrast the estimates from the four years of data in Objective 1 with the 1990/91 through 1998/99 series previously reported.

MFish observers have been collecting bycatch and discard information from the hoki fishery since the early 1990s, in most years covering between 10% and 20% of the fishery (by hoki catch). Observers record the catch and discards from each trawl or group of trawls, as well as details of the location, depth, tow duration, fishing gear used, and various other incidental information. This study calculated bycatch and discards for the entire target fishery by scaling up estimates determined from the observer fraction, using effort data collected by the fishing industry. The process was fine-tuned by a process of stratification, and precision was estimated using multi-step bootstrap procedures which take into account vessel to vessel differences and variability in the total amount of fishing effort per trip.

2. METHODS

2.1 Definition of terms

For the purposes of this study we have interpreted "*non-target fish catch*" to mean non-target *species* fish catch, which is equivalent to *bycatch*, all fish caught that were not the stated target species for that tow, whether or not they were discarded (McCaughran 1992). He further defines *non-target catch* as the sum of the *incidental catch* (the retained catch of non-target species) plus the *discarded* catch of both target and non-target species, and *discarded catch* (or *discards*) as "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". *Discarded catch* in this report includes estimates of any fish lost from the net at the surface. Estimates of *non-target catch*, if required, can be obtained from this report by adding target species *discards* to total *bycatch*.

2.2 Observer data

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

Two datasets were prepared from observer data, one comprising discard data, and the other bycatch data. Observer records of catch and discards were extracted from the Ministry of Fisheries *obs* database for the fishing years being examined. All records with hoki recorded as the target species were extracted.

For all records, the tow duration was derived from the difference between the start and finish times, less the period (recorded by observers) between those times when the net was not fishing (e.g., when the net was brought to the surface during turning or the net remained in the water due to equipment malfunction). Errors resulting from confusion between the 12 and 24 h clock systems were identified and rectified where these were obvious. The top 1% of these derived tow durations were compared with the duration calculated from towing speed and calculated distance and substituted by the latter value where the absolute difference between the two was greater than 50% of the speed and distance derived value. This resulted in 130 corrections. This method was used only in these extreme cases as tows were frequently not straight and it was possible for a long tow to finish near to the start position, resulting in an underestimate of the tow duration. Only 63% of the observed tows were straight, with the remainder a mixture of "u-bend' (17%), "along depth contour" (10%), and "zigzag" (10%) tows. Tow durations of zero were substituted with an arbitrary value of 1 minute.

When fish were lost from the net before it was brought aboard, observers estimated the amount lost by recording "total greenweight on surface" and "total greenweight on board". These losses came about through a mixture of burst codends, burst windows/escape panels, and rips in the belly of the net, either below the sea surface or at the surface or on the stern ramp of the vessel. A number of errors and unlikely values were found in these records and these were corrected where possible. For example, where the recorded value for "total greenweight on board" was greater than "total greenweight on surface" the weight of fish lost was set to "NULL" unless an obvious typographical error could be uncovered and corrected by comparing greenweight totals from species by species tallies with the two total greenweight figures. In addition, differences in the recorded values for "total greenweight on surface" and "total greenweight on board" were accepted as valid fish losses only if they were accompanied by a code identifying the cause of the loss. This proviso eliminated several large values of lost fish, and the frequency of occurrence of validated fish losses was calculated to be 1 in 100 tows. The estimate of fish lost was added proportionately to the discards for that tow or processing group, for each species category, according to the relative amounts of those categories actually landed on that tow:

Each record was assigned to a fishing year (1 October to 30 September) and to a processing type; FR, fresher/ice boat; PR, processing/factory vessel (no meal plant); MP, processing/factory vessel with meal plant. The processing type was determined from notes made in the observer trip reports and the processing records on the *obs* database. Crew nationality was also assigned to tows, again determined from notes made in trip reports. Where there was a mixture of nationalities on a vessel (and this was frequently the case) the main nationality of the captain and other officers was assigned.

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

Each record was assigned to an area (Figure 1). Areas were the same as those used in the previous report (Anderson et al. 2001) and are based on known stock divisions or management areas and the geographical distribution of observer sampling. The number of tows observed in each area over the four years is shown in Table 1.

Observer data were available from 71 vessels operated by 20 companies. No vessel or company is identified in this report, and alphanumeric codes are presented where necessary.

Table 1: Number of observed tows targeting hoki by area (see Figure 1) and year.

Fishing year							Area
	WCSI	CHAT	SUBA	COOK	PUYS	OTHR	All areas
1999–00	1 163	772	1 140	165	32	8	3 280
2000–01	1 078	1 375	704	265	108	2	3 532
2001–02	1 337	972	761	145	50	3	3 268
2002–03	928	877	580	134	54	9	2 582
All years	4 506	3 996	3 185	709	244	22	12 662

To create the dataset used to estimate discards, the amount of each species retained and discarded in each "processing group" was obtained from the Ministry of Fisheries observer database. The processing group is the level at which observers record discard information, and although usually represented by a single tow, the discards from two or more tows are frequently combined into one processing group. This grouping of processing data stems from the difficulty of keeping track of the catch from individual tows in the factory of a vessel. 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. For this reason depth of tow was assigned to each processing group as a categorical variable. Examination of individual tow data showed a bimodal distribution of depths (taken as the average of the depth of the groundline at the start and end of the tow) with the mid-point between the modes at about 630 m. Therefore processing groups made up of tows which were all shallower than this depth were assigned "shallow", those made up of tows all deeper than this depth assigned "deep", and those with a mixture of tow depths set to "NULL".

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

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

- the target species, hoki (HOK)
- other main commercial species combined (COM)
- all other species combined (OTH)
- individual bycatch species caught in substantial quantities

The abbreviations in parentheses above are used throughout the remainder of this report to refer to these species categories. Summaries by individual species of the overall observed catch and percentage retained are tabulated in Appendix 1.

Commercial species were defined as those which represented 0.1% or more of the total observed catch and either were quota species or 75% or more of the catch was retained. They comprised the following 15 species/species groups: hake, ling, silver warehou, frostfish, pale ghost shark (*Hydrolagus bemisi*), southern blue whiting, ribaldo (*Mora moro*), sea perch (*Helicolenus* spp.), barracouta (*Thyrsites atun*), white warehou (*Seriolella caerulea*), lookdown dory (*Cyttus traversi*), arrow squid (*Nototodarus* spp.), oreos, Ray's bream (*Brama brama*), and stargazer (*Kathetostoma giganteum*). The bycatch and discards of these species were assessed as a group (COM) and those of hake, ling, and silver warehou (which made up 8% of the total catch in the target fishery) were assessed separately.

A total of 12 662 tows and 9127 processing groups targeting hoki were used in the analysis.

2.3 Commercial fishing return data

Catch records from commercial fishing returns were obtained from Ministry of Fisheries catch-effort databases for all hoki target fishing. This included all fishing recorded on Trawl, Catch, Effort and Processing Returns (TCEPRs) and Catch, Effort and Landing Returns (CELRs). Data were groomed for errors using routines developed for hoki catch per unit effort (cpue) analyses (see Dunn & Livingston (2004) for details). In addition, tow duration was derived from the difference in time between the start and finish of the tow and corrections made using the protocols described for the observer data in Section 2.2.

Records were assigned to the areas defined in Figure 1.

2.4 Examination of factors influencing discards and bycatch

Regression analyses were performed on the observer data to identify the factors with the most influence on the level of bycatch and discards. These factors were then used for stratification. A large number of variables are available for each observed tow, but only a few are useful for stratifying commercial data. For example the individual vessel code is available, and previous analyses of hoki observer data has shown this factor to be highly influential in the level of bycatch and discards; however, only a fraction of vessels are observed and therefore a ratio could not be calculated for those that were not. Other variables were not considered as preliminary plots showed them to have little influence. Six variables were considered in the regressions for each species category; fishing year, processing type, fishing period, fishing area, net type, and vessel length. Processing type was set up as a factor with two levels, fresher and factory trawler, with two categories of factory trawler, based on the presence of a meal plant.

The number of fishing periods per year and their start and finish points ("day of the fishing year" for bycatch, month for discards) was determined using recursive partitioning and regression tree analysis. This procedure determines the optimal number of splits in explanatory variables (either numeric or categorical) by repeatedly splitting the data into mutually exclusive groups, each of which is as homogeneous as possible, and then pruning back the number of branches by a process of cross-validation (see, e.g., De'Ath & Fabricius (2000) for details of the procedure). The same regression tree approach was used to find the best combination of fishery areas, so that areas with sufficiently similar patterns of bycatch or discards could be combined to reduce model complexity.

Each species group was examined separately and a combination of linear and binomial regressions applied. Both linear and binomial regressions were used for species groups for which no catch/discards were recorded for a large fraction of the tows/processing groups. This enabled an examination of factors influencing both the *probability* and the *level* of a bycatch/discard. Linear regressions only were used for species groups where most tows/processing groups recorded a catch/discard. The response variable in the binomial regression comprised a binomial vector assigned "0" if no bycatch/discard was recorded and "1" otherwise. The response variable in the linear regressions was determined from the outcome of the process described in Section 2.5, and in all cases a log transformation was used to provide an approximately normal distribution of values. The log transformation was found to be the most appropriate in each case, after visual examination of histograms and normal probability plots of untransformed and transformed data.

Regressions were run in turn for discards of the target species (HOK), bycatch and discards of other commercial species (COM), non-commercial species (OTH), and frequently caught individual species. A detailed examination of the influence of the main factors identified is beyond the scope of this project, and there is no intention of trying to predict bycatch and discard rates from these regressions, so summaries were made only of the order of variable selection in each model. Variables used to stratify data for bycatch and discard calculations were determined from these summaries.

2.5 Calculation of discard and bycatch ratios

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

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

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

The standard bootstrap assumes that all tows were sampled with equal probability. This assumption about the assignment of observers to tows is not true, but the spread of observed tow positions compared with all recorded tow positions from each fishery (see below) showed that there was fairly representative coverage of the spatial extent of each fishery, with the main fishing grounds covered.

Once the best estimator was chosen, estimates of $\hat{DR}$ were derived for each stratum in each fishing year and variances were derived by a more sophisticated bootstrapping procedure that allowed for correlation of discards between sample units, in this case processing groups, within an observed trip. Separate ratios were calculated only for strata with 50 records or more, and overall ratios (e.g., for all areas or all periods within a year) were substituted for strata with fewer than 50 records. The discard ratio calculated for each stratum was then multiplied by either the total estimated catch of hoki or the total tow duration in the stratum (depending on the version of the estimator chosen), from commercial catch records, to estimate total discards $\hat{D}$:

$$(1) \quad \hat{D} = \sum_j \hat{DR}_j \times L_j \text{ (or } T_j \text{)}$$

where L_j is the total catch of hoki in stratum j and T_j is the total tow duration in the stratum.

To obtain a 95% confidence interval for the total discards that allows for correlation between sampling units within a trip, 1000 bootstrap samples were generated from the sampling units within each stratum using a three-step sequential sampling procedure. First a trip was chosen at random, then a bootstrap sample of the processing groups that were from that trip in the stratum. These steps were repeated until the effective number of discard groups was approximately equal to the effective number of observed discard groups for the stratum. At step 3 the effective number of trips in the bootstrap sample was calculated. If this was within 5% of the effective number of observed trips in the stratum then the bootstrap sample was accepted. Otherwise a new bootstrap sample was drawn until 1000 samples in all had been accepted. The effective number of discard groups and the effective number of trips was calculated from the effort (either catch or duration) and reflected the contributions to the variance of the discard rate $\hat{DR}$ from the variance of the discards and the covariance between pairs of discards within the same trip and stratum. Matching a bootstrap sample to the stratum on these criteria ensured that the variation in the bootstrap sample estimate matched the sampling variation of $\hat{D}$. An empirical distribution for the total discards was obtained by totalling the bootstrap estimates across the strata, and the 95% confidence interval was obtained from the 2.5% and 97.5% quantiles.

Bycatch estimates were calculated in a similar manner to discards but, as discard data were not required, it was possible to use tow-by-tow data and hence a different (and slightly larger) set of records for comparing estimators and calculating ratios. Bootstrapping was carried out using the statistical software package R (Ihaka & Gentleman 1996).

3. RESULTS

3.1 Distribution and representativeness of observer data

The positions of all observed tows in the target hoki fishery between 1 October 1999 and 30 September 2003 are shown, along with those of all commercial hoki target tows recorded on TCEPR forms from the same period, in Figure 1. Observer coverage was well spread over the geographical range of this fishery, and concentrated on the west coast South Island, western and central Chatham Rise, the Stewart-Snares Shelf, the Auckland Islands Rise, and the southern and western flanks of the Campbell Rise. The grey coloured areas in Figure 1, which indicate fished but unsampled areas, are restricted mainly to lightly fished locations at the limits of the depth range of hoki and don't reveal any major grounds that were overlooked. Examination of density plots (Figure 2) confirms this, with the distribution of observed tows through the latitudinal and longitudinal range of the fishery almost identical to that of the wider fishery, in each of the four years. These plots also show that most fishing took place between 40° and 45° S, with strong peaks at 170° and 175° E, a pattern that has stayed very constant over time. The few tows recorded in areas outside those defined by the boxes in Figure 1 (mostly in the Bay of Plenty and the east coast of the North Island, and including outliers with probable position errors) were combined into a single OTHER area category.

The annual number of observed tows ranged from 2582 to 3532 and the number of vessels observed from 32 to 43 (Table 2). The percentage of the fishery observed (in terms of the estimated annual target fishery catch) ranged from 10.7% to 14.8%, above the 10%. A total of 71 different vessels were observed during this 4-year period. Total target fishery effort remained fairly constant during the period, ranging from 101 000 to 114 000 hours per year.

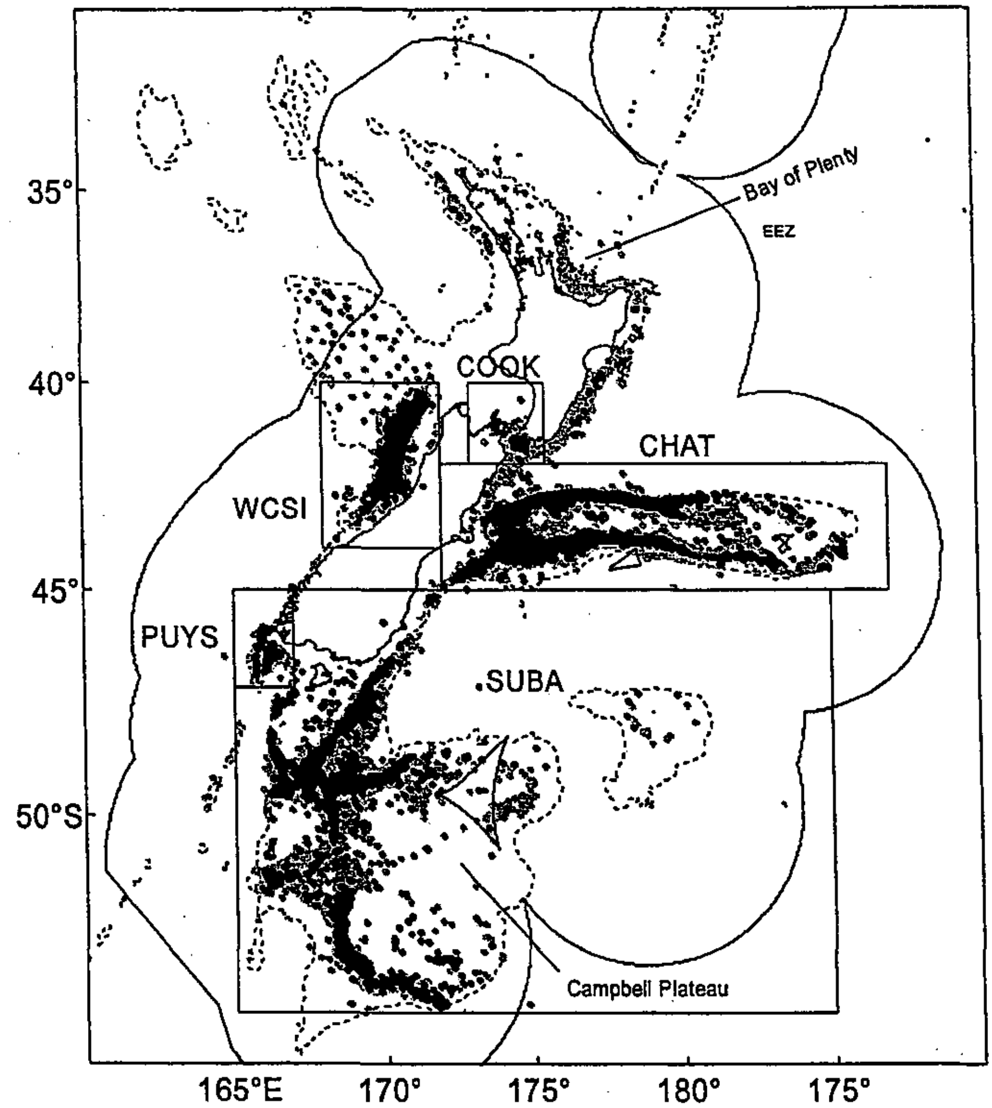

Figure 1: Distribution of tows recorded by observers on vessels targeting hoki between 1 October 1999 and 30 September 2003, and all commercial tows with recorded position from the same period (grey dots). Area divisions are those used in the analyses.

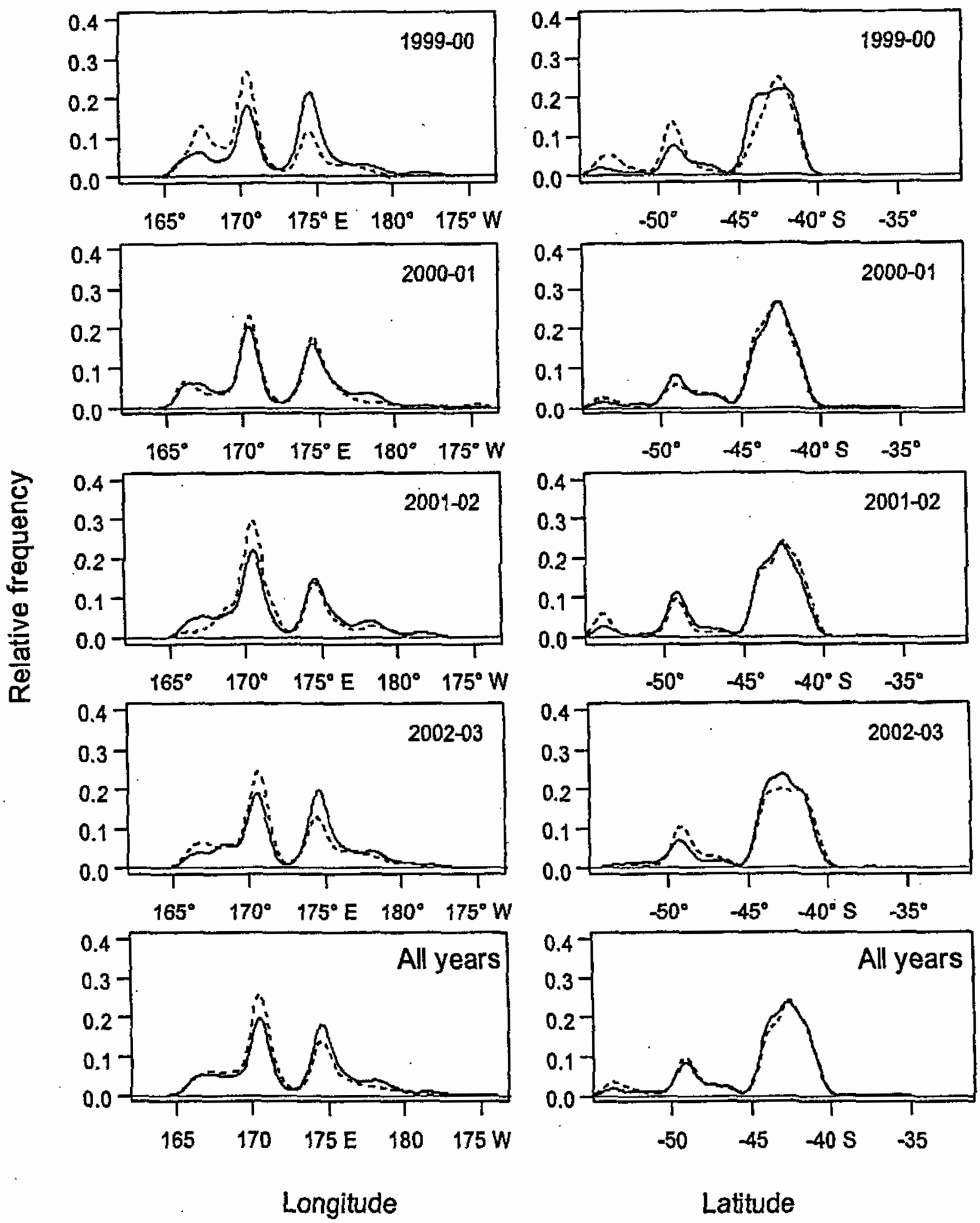

Figure 2: Comparison of position (latitude and longitude) of observed trawls (dashed lines) versus all trawls captured on TCEPR forms (solid line) for each fishing year from 1999–2000 to 2002–03, and for all four fishing years combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Table 2: Number of tows, vessels, and trips observed and the fraction of the target fishery catch and effort observed in the hoki fishery, by fishing year.

Fishing year	Total tows observed	Total vessels observed	Total no. trips	Observed catch (% of target fishery catch)	Total fishery effort (h)
1999–00	3 280	37	43	13.7	111 922
2000–01	3 532	43	74	14.4	113 950
2001–02	3 268	36	47	14.8	100 770
2002–03	2 582	32	42	10.7	106 511

The spread of observer effort over the range of vessel sizes was compared to the spread of vessel sizes over the entire target fishery using density plots (Figure 3). These plots show that not only was the full range of vessel sizes covered by observers in each year, but the coverage was also in proportion to the overall participation of each class of vessel size in the fishery. The fishery was attended by vessels of a wide range of sizes during this period, from 25 to 105 m, although half of all tows were made by vessels between 58 and 68 m. The observed effort showed a similar focus on this size range, although the largest and smallest vessels were slightly overrepresented and underrepresented respectively in one or two years.

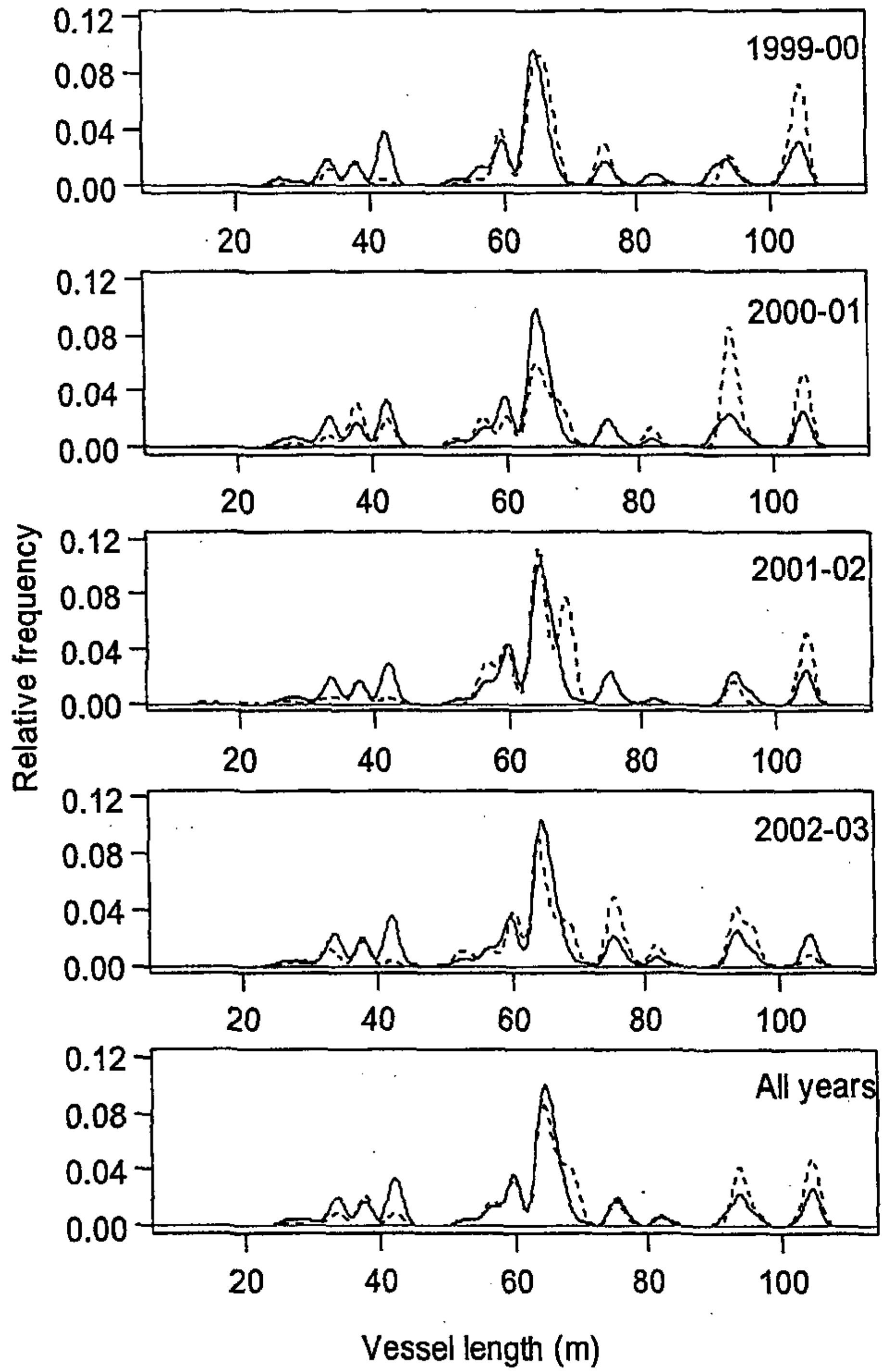

Figure 3: Comparison of vessel sizes in observed trawls (dashed lines) versus all trawls captured on TCEPR forms (solid line) for each fishing year from 1999–2000 to 2002–03, and for all four fishing years combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

The spread of observer effort over the fishing year was examined and compared to the spread of effort in the wider fishery, using a density function on numbers of trawls per day (Figure 4). These plots show that there was a very even spread of target fishing for hoki throughout each year, although there has consistently been an increase in effort during the spawning period in July and August. In contrast, observer effort was more variable, with February and March not well covered in 2001–02 and 2002-03 and smaller gaps at other times of the year in both these and the two earlier years. Observer coverage during the spawning period was high in each year, however, and coverage for the four years overall showed a reasonable match for all but the early months of the calendar year.

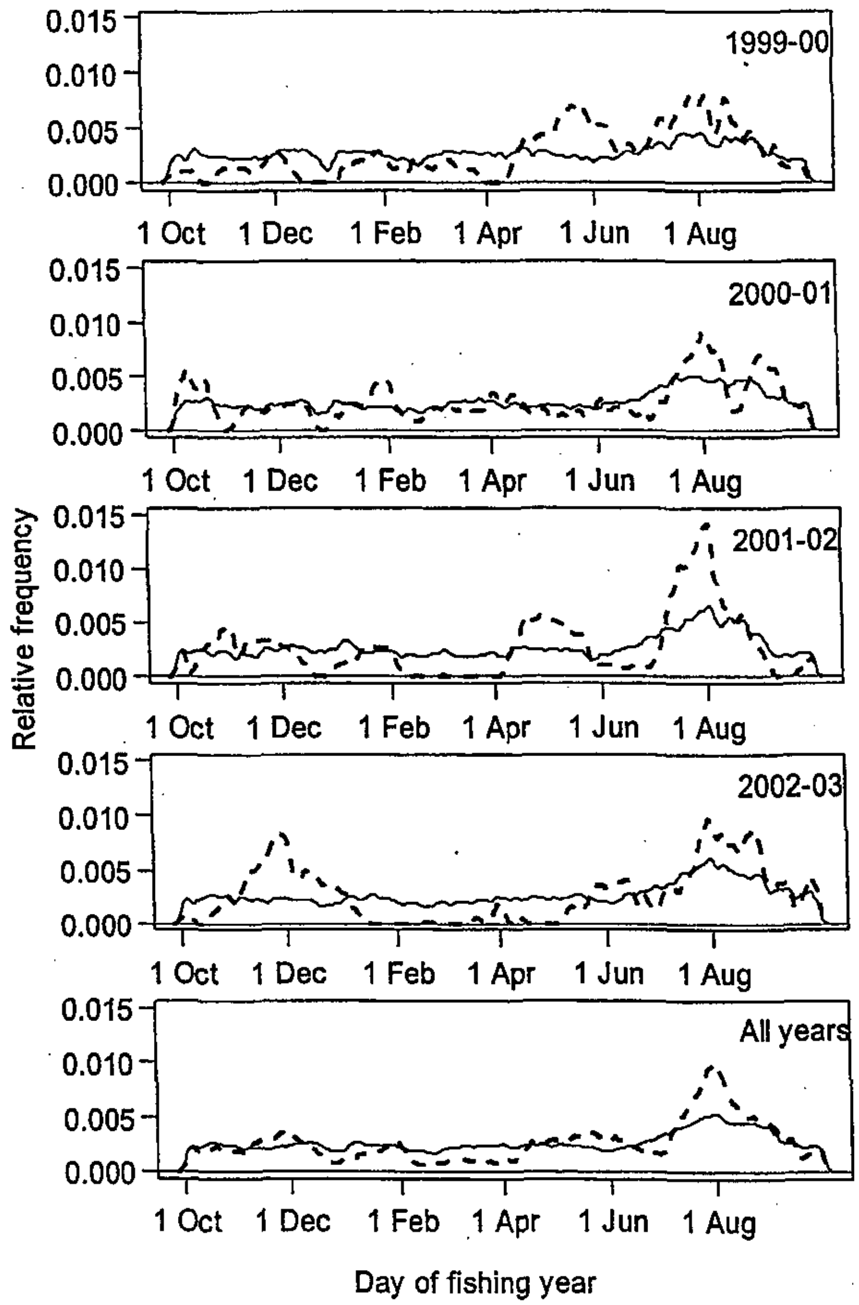

Figure 4: Comparison of the temporal spread of observed trawls (dashed lines) with all trawls recorded on TCEPR forms (solid line) for each fishing year from 1999–2000 to 2002–03, and for all four fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Comparison of estimators

Using observer data, the *hoki-estimated-catch-weight-based* and *tow-duration-based forms* of the bycatch and discard ratio estimators were examined and compared with the aim of selecting and using the one which would provide ratios with the least amount of associated error. For each of the two forms in turn, ratios were calculated for the bycatch and discards in the COM and OTH species categories, without any stratification, and c.v.s estimated by bootstrapping. Individual species categories (including discards of hoki) were not considered as they were represented by far fewer non-zero value observations, and would carry less weight. The results of these comparisons are shown in Table 3. The estimated c.v.s were smaller for bycatch than for discards and smaller for OTH species than for COM species. Coefficients of variation were very small for bycatch of both species categories and for discards of OTH species, for both forms of the estimator (range 1.6% to 3.0%), and much greater for discards of COM species (26.8% for both forms of the estimator). Differences in c.v.s between the two forms were small (range 0.04% to 0.39%), but in three out of the four comparisons the tow-duration-based estimator provided a lower c.v. than the hoki-estimated-catch-based estimator, and in the fourth comparison the difference between the two forms was insignificant.

On the basis of these comparisons, although there was very little difference between the two forms, the tow-duration-based estimator was selected for all bycatch and discard calculations. A similar exercise was carried out by Anderson (2004a, 2004b) for bycatch and discards of southern blue whiting and oreos, with similar results, and also led to the use of a tow duration-based estimator.

Table 3: *Comparison of estimators.*

Bycatch/discards	Species category	Estimator	Bycatch ratio	c.v. (%)
Bycatch	COM	HOK catch	0.127	2.02
	COM	Tow duration	306.4	1.63
	OTH	HOK catch	0.073	1.94
	OTH	Tow duration	175.9	1.59
Discards	COM	HOK catch	0.002	26.76
	COM	Tow duration	4.8	26.80
	OTH	HOK catch	0.038	3.02
	OTH	Tow duration	90.6	2.77

3.3 Observer bycatch data

3.3.1 Overview of raw bycatch data

Hoki accounted for 83% of the total estimated catch from all observed trawls targeting hoki between 1 October 1999 and 30 September 2003. The remaining 17% mostly comprised quota species, especially hake (3.5%), ling (2.7%), and silver warehou (1.7%). About 300 species or species groups were identified by observers, with rattails (2.9% of the catch), especially javelinfish (*Lepidorhynchus denticulatus*) heading the list of non-commercial species caught. Large quantities of chondrichthyans, especially spiny dogfish (1.0%) and other squalids such as shovelnose spiny dogfish (*Deanea calcea*) and seal sharks (*Dalatias licha*), skates (Batoidei), chimaeras (Holocephali), and squids (Teuthida) were also recorded (see Appendix 1 for a list of the top 50 bycatch species).

Exploratory plots were prepared to examine total bycatch per tow (plotted on a log scale) with respect to the available variables (Figure 5). Total bycatch was extremely variable between tows, ranging from none to 78 t, and tended to increase with increasing tow duration. Median bycatch varied among areas, from about 200 $kg.tow^{-1}$ in COOK to about 900–1400 $kg.tow^{-1}$ in the other four areas. There was also variation between nations with the median bycatch lowest for vessels crewed by the European nations Poland, Russia, and Ukraine (650–950 $kg.tow^{-1}$), and highest for Japanese crewed vessels (about 2000 $kg.tow^{-1}$). Bycatch on ice boats was low (median 260 $kg.tow^{-1}$) compared with factory vessels and factory vessels with meal plants recorded less bycatch (1100 $kg.tow^{-1}$) than those without (1700 $kg.tow^{-1}$). There is considerable variability in bycatch among the 15 companies and 50 vessels for which there were more than 20 records. The range of median values among vessels is especially high, from 100 to 3500 $kg.tow^{-1}$. Bycatch levels vary relatively little from month to month although lower medians and wider inter-quartile ranges are shown for August, September, and October compared to other months. Low bycatch may be expected in the hoki spawning season when large aggregations are often targeted, but this doesn't explain the pattern continuing into September and October. There is also a clear difference in bycatch between the two tow-types, with midwater tows tending to catch less non-target species. Median bycatch levels remained very constant from year to year (not shown), ranging from 1000 to 1300 $kg.tow^{-1}$.

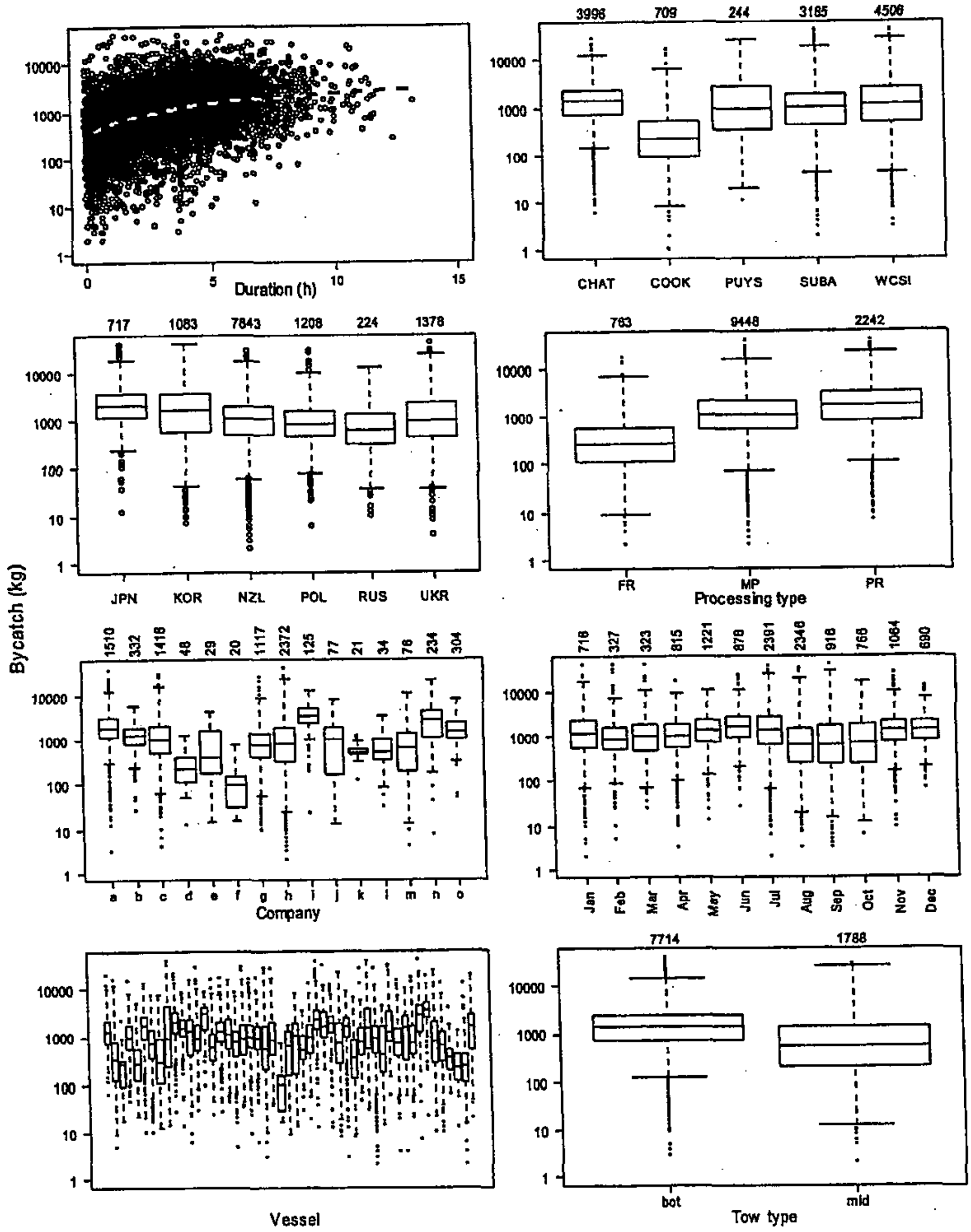

Figure 5: Total bycatch per tow plotted against some of the available variables. Bycatch is plotted on a log scale. The dashed line in the top left panel represents a mean fit to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. The numbers above each plot indicate the number of records associated with that level of the variable: those represented by fewer than 20 records were not plotted. See Figure 1 for area codes; JPN, Japan; KOR, Korea; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine; FR, fresher; PR, factory vessel; MP, factory vessel with meal plant.

3.3.2 Regression modelling and stratification of bycatch data

Regression tree analysis, using the log of the bycatch ratio as the predictand and examining each predictor in turn, indicated that for bycatch of each species group the most parsimonious split of the fishing year resulted in it being partitioned into three or four periods (Table 4). The splitting process included the constraint that there must be a minimum of 20 observations in a branch for a split to be attempted. In practice no accepted split resulted in a stratum with less than 357 observations. The same process combined the six areas to produce "super-areas"; three for COM, four for OTH, and two each for the three individual species examined. These super-areas tended to group adjacent areas (e.g., PUYS with SUBA or WCSI in each case) and group OTHR (mostly northern locations) with COOK (Table 4).

Table 4: Results of regression tree analyses on the optimal stratification of fishing day and area variables for describing rates of bycatch. Split points are "day of the fishing year" where 1 = 1 October and 365 = 30 September.

Species category	N.periods(split points)	N.areas(groupings)
COM	3(0–248–305–365)	3(COOK+OTHR, CHAT+PUYS+SUBA, WCSI)
OTH	3(0–16–288–365)	4(COOK, OTHR+CHAT, PUYS+WCSI, SUBA)
HAK	3(0–266–306–365)	2(COOK+OTHR+CHAT+PUYS+SUBA, WCSI)
LIN	3(0–54–308–365)	2(COOK+SUBA+PUYS, CHAT+OTHR+WCSI)
SWA	4(0–35–233–320–365)	2(COOK+OTHR+CHAT+SUBA, PUYS+WCSI)

The unit of interest in the regression analyses was the bycatch ratio, expressed as the log of catch (kg) per hour. Of the 12 662 observed tows examined, about 4.2% did not record any bycatch of COM species, and 4.0% did not record any bycatch of OTH species. The equivalent percentages for the individual bycatch species were hake (HAK), 25%; ling (LIN), 16.8%; silver warehou (SWA), 57%. In those cases, because of the higher fraction of tows with no bycatch, a combination of linear and binomial models was run.

The variable *area* had the most influence on bycatch of the two main species categories, COM and OTH, followed by *net-type,* whereas *period* was more influential in the bycatch rates of the individual species (Table 5). Because of the uneven spread of observer data and the erratic distribution of bycatch levels, stratification of ratios to use for total bycatch estimates was restricted to a single factor. Stratification was based on the results of these regressions and the factors used in each category are shown in Table 5. Although the individual *vessel* cannot be used for stratification, as explained above, to acknowledge the influence that this factor has on rates of bycatch, separate ratios were calculated only where at least three vessels were represented in each stratum.

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

Species category	Model type	Model R^2 (%)	Variable					
			area	*period*	*proctype*	*v_length*	*net-type*	*fyr*
COM	Linear	14.1	**1**	3	6	5	2	4
OTH	Linear	28.1	**1**	5	3	6	2	4
HAK	Linear	26.1	1	**2**	4	6	5	3
HAK	Binomial	16.9	4	**2**	1	5	3	6
LIN	Linear	8.3	3	**1**	2	5	6	4
LIN	Binomial	11.1	5	**1**	4	3	2	–
SWA	Linear	14.1	4	**1**	5	6	3	2
SWA	Binomial	17.1	1	**3**	2	6	5	4

3.4 Observer discard data

3.4.1 Overview of raw discard data

The associated species most affected by discarding in this fishery was the spiny dogfish (*Squalus acanthias*). Although rattails were caught at nearly three times the rate of spiny dogfish, they comprised a number of mostly unidentified species and 35–40% of them were retained. Of the more than 1300 t of spiny dogfish observed caught in the four years, more than 90% (about 1200 t) was discarded. Most of the other frequently caught species which were usually discarded were shark species too. Many of these were unidentified by observers but they included large quantities of shovelnose spiny dogfish and seal sharks. Other than sharks and rattails, discards comprised mostly small quantities of non commercial fish and squid species (see Appendix 1 for details).

Fish lost from the net during landing accounted for only a small fraction of the total discards in each year, with the great majority of discarding due to the intentional return to the sea of unwanted fish. For the seven years examined, the percentage of total discarding due to lost fish was: 1990–91, 8.7%; 1994–95, 4.1%; 1998–99, 4.4%; 1999–2000, 3.2%; 2000–01, 7.2%; 2001–02, 0.9%; 2002–03, 0.0%.

Exploratory plots were prepared to examine the variability in the total level of discards per processing group with respect to some of the available factors (Figure 6). As for bycatch, the level of discards tended to increase with increasing tow duration. Most tows (97%) were less than 7 hours long, but the combined duration of several tows (max. 74) within a processing group was as much as 300 hours. There was some variation in total discards between areas, with the lowest median level in PUYS (75 $kg.group^{-1}$) and the highest in CHAT (360 $kg.group^{-1}$). Polish and Ukrainian crewed vessels discarded the least (40 $kg.group^{-1}$) and Japanese crewed vessels the most (about 600 $kg.group^{-1}$). Discards were least on vessels with meal plants, but the median value for those vessels was only about 70 $kg.group^{-1}$ less than that for ice boats, and factory vessels without meal plants recorded the highest levels of discards. There is no evidence in these plots of a trend in discard levels over time, with annual median discard levels remaining constant at about 150–250 $kg.group^{-1}$. As was the case for bycatch above, the factors showing the most variability were company and vessel, for which median discard levels ranged from 90–420 $kg.group^{-1}$ and 30–1200 $kg.group^{-1}$, respectively. Monthly median discard levels were high in May and decreased in each of the following four months to a low in September of about 80 $kg.group^{-1}$, after which monthly levels were variable through to April. The highest median discard level, in January, was 420 $kg.group^{-1}$.

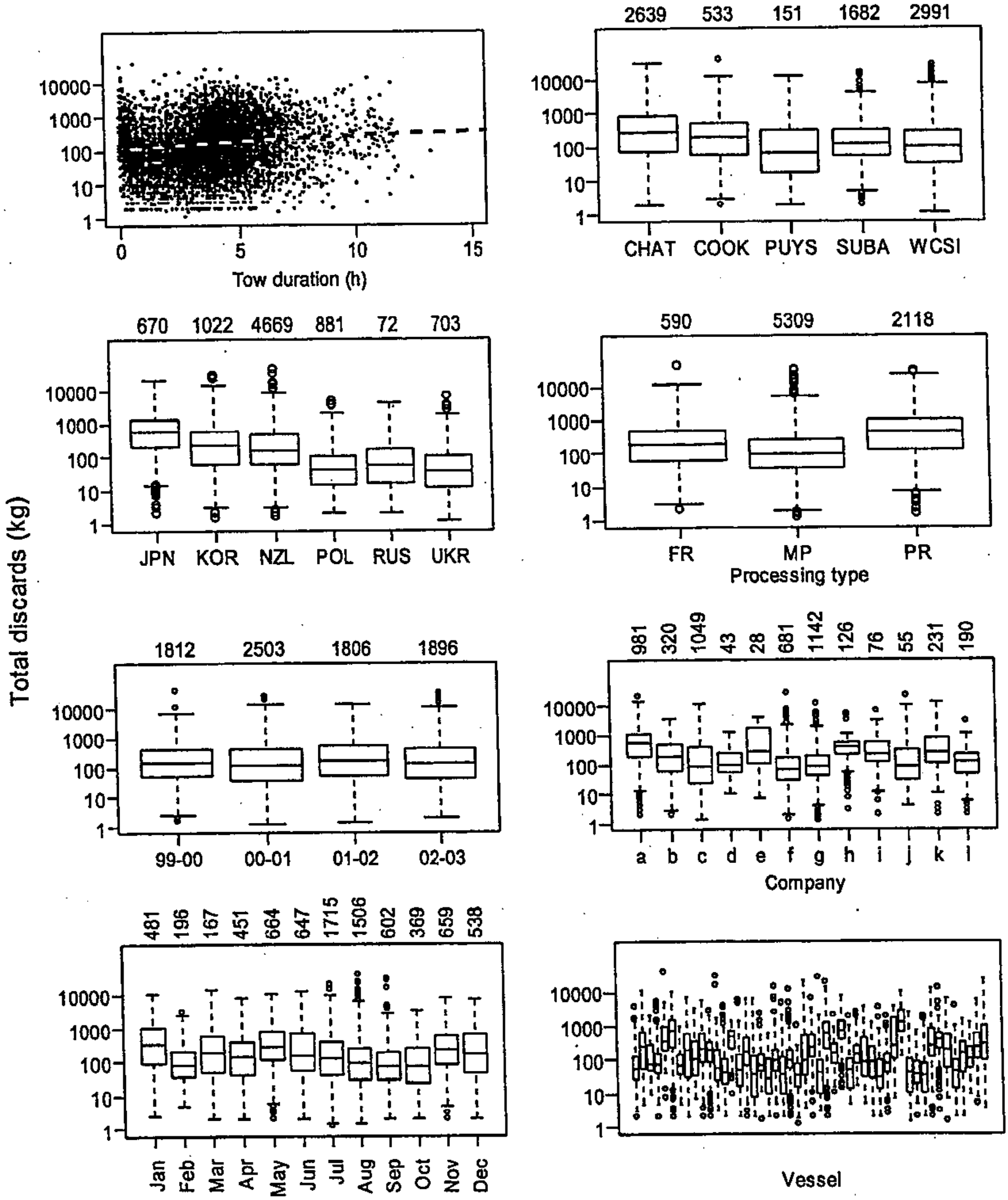

Figure 6: Total discards per tow (total discards per processing group divided by the number of tows in the group) plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The dashed line in the top left panel represents a mean fit to the 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. Levels of variables represented by fewer than 20 records were not plotted. See Figure 1 for area codes; JPN, Japan; KOR, Korea; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine; FR, fresher; PR, factory vessel; MP, factory vessel with meal plant. Company codes do not match those in Figure 5 above.

3.4.2 Regression modelling and stratification of discard data

Regression tree analysis, using the log of the discard ratio as the predictand, indicated that four periods should be used for HOK discards regressions and three periods for COM regressions (Table 6). Month was used instead of fishing day as processing groups often ran for two or more days. Insufficient improvement in error statistics was achieved to allow any sensible split of the fishing year for OTH discards. The number of areas was reduced from six to two or three by this process, which grouped PUYS with the adjacent WCSI in each case.

Table 6: Results of regression tree analyses on the optimal stratification of fishing day and area variables for describing rates of discards.

Species category	N.periods(groupings)	N.areas(groupings)
HOK	4(Apr–Jun, Jul–Aug, Sep–Dec, Jan–Mar)	3(CHAT+SUBA, PUYS+WCSI, COOK)*
COM	3(Apr–Jun+Sep–Oct, Jan, Feb–Mar+Jul–Aug+Nov–Dec	2(CHAT+OTHR,COOK+PUYS+SUBA +WCSI)
OTH	–	3(OTHR+PUYS+WCSI,SUBA+CHAT +COOK)

* Area OTHR not considered as only 22 observations in this area.

The unit of interest in the regression analyses was the discard ratio, expressed as the log of discards (kg) per hour. Of the 9127 observed processing groups examined, only about 8.1% showed a discard of HOK, 12.3% showed a discard of COM, but 87.8% showed a discard of OTH species. The equivalent percentages for the individual species examined were hake (HAK), 2.3%; ling (LIN), 2.3%; silver warehou (SWA), 1.1%. Both linear and binomial regressions were run for HOK, COM, and OTH categories, but the individual species were not examined as no appropriate stratification could be determined from such small numbers of observed discard events.

Fishery area and vessel processing type were the variables with the most influence overall in these regressions. Area was most influential in the rate of HOK and OTH discards, and proctype was most influential in the rate of COM discards and in the probability of HOK and COM discards (Table 7). The influence of processing type is linked to the lower rates of discarding on vessels with meal plants, as indicated in Figure 6. Although proctype has no influence on the level of HOK discards, this factor does influence the probability of a HOK discard, as vessels with meal plants tend to be less likely to discard small amounts of hoki. Net type is important in discards of OTH species. Tows using midwater trawls tended to discard less, and were also less likely to discard, unwanted species than tows using bottom trawls.

Stratification of discard calculations was based on the results of these regressions and the strata used in each category are shown in Table 7. As in the bycatch calculations above, separate ratios were calculated only where at least three vessels were represented in each stratum.

Table 7: Summary of regression modelling for discards in the hoki fishery. The numbers denote the order in which the variable entered the model; –, not selected. Figures in bold type indicate variables used in stratification of discard data.

Species category	Model type	Model R^2 (%)	Variable					
			area	*period*	*fyr*	*net type*	*proctype*	*depcat*
HOK	Linear	20.2	1	2	–	–	–	3
HOK	Binomial	19.8	4	2	3	5	1	–
COM	Linear	4.1	4	3	2	–	1	–
COM	Binomial	25.3	4	2	3	5	1	6
OTH	Linear	33.7	1	5	4	2	3	–
OTH	Binomial	22.1	–	2	5	1	3	4

3.5 Calculation of bycatch

3.5.1 Bycatch rates

Bycatch ratios for COM species were calculated from the observer data separately for each of the three super-areas (COOK+OTHR, CHAT+PUYS+SUBA, and WCSI) and four fishing years. The same stratification was used to calculate ratios for three earlier years (1990–91, 1994–95, and 1998–99) in order to compare estimates using these methods with those used by Anderson et al. (2001). Insufficient records were available from area COOK+OTHR in the first two of these earlier years to enable ratios to be estimated for this stratum and so an overall ratio (representing all areas for the year) was substituted in the total bycatch calculations. The variance in these bycatch rates was calculated using the bootstrap methods described above.

These ratios not only provide the basis from which total bycatch can be determined from target fishery effort totals, but they also provide a guide to the rate at which bycatch species are caught during trawling and allow an examination of how bycatch rates vary among the areas and time periods used for stratification. Bycatch rates of COM species were higher in area WCSI than in the other two areas in each year (ranging from 300 to 600 $kg.h^{-1}$) and lower in COOK and OTHR in each year (around 100 $kg.h^{-1}$) (Figure 7). High bycatch rates of HAK (150–300 $kg.h^{-1}$) for the same area compared to all other areas show that this species may be mostly responsible for this pattern. Bycatch rates of OTH species were greatest in COOK, but were quite variable (range 450–1400 $kg.h^{-1}$). In other areas OTH bycatch rates were mostly less than 300 $kg.h^{-1}$, and in PUYS and WCSI were particularly low (under 100 $kg.h^{-1}$). Bycatch rates of LIN were higher in the November to August period than in the two spring periods when catch rates were more variable. SWA bycatch rates were generally greatest between May and August, and varied considerably from year to year during October. A summary of the bycatch rates, with standard deviations, is given in Appendix 2.

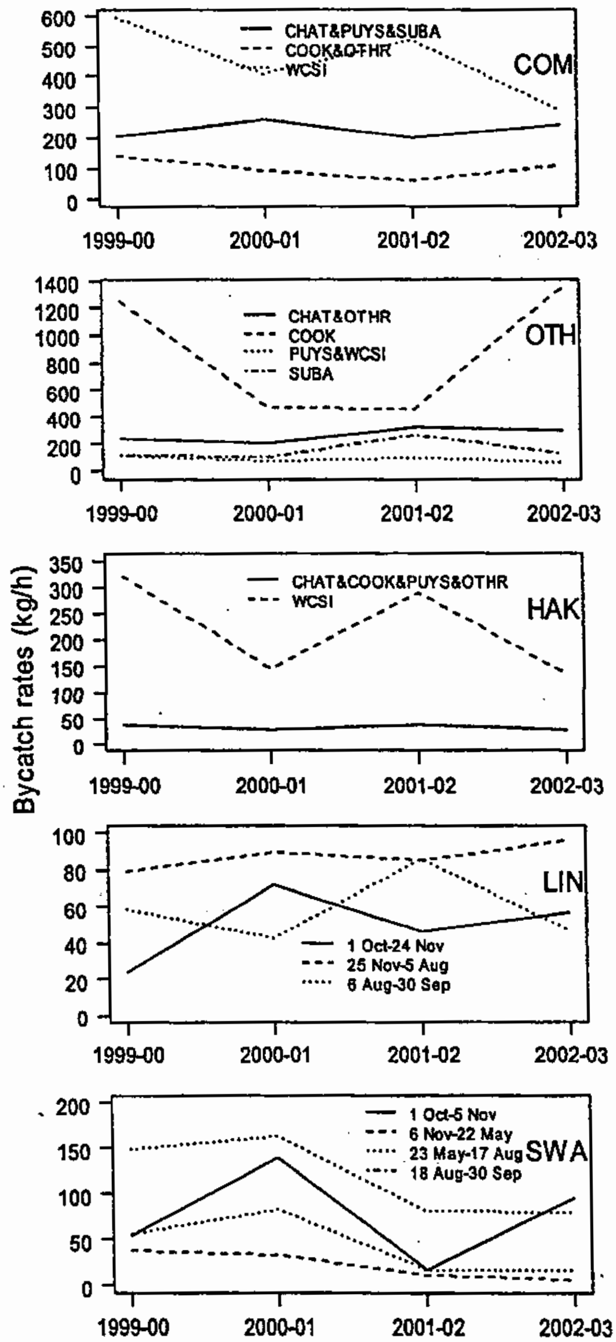

Figure 7: Annual bycatch rates by the areas or periods used for stratification for five species categories, in the hoki trawl fishery. Bycatch rates shown are the median of the bootstrap sample of 1000.

3.5.2 Annual bycatch levels

Annual bycatch was determined by multiplying the ratios calculated for each stratum by the target fishery tow duration totals for the equivalent stratum, as described in Section 2.5 (Table 8). Bycatch of COM species was about 33 000 t in 1999–2000 and 2000–01, and dropped slightly in the following two years to just over 26 000 t. The estimates of individual commercial species bycatch show that HAK, LIN, and SWA contribute a similar amount to the total commercial species bycatch, and together these species comprise 68–80% of the COM bycatch in each year (Table 9). Bycatch of OTH species was also similar between years, with a minimum of about 18 000 t in 2000–01, and was less than the bycatch of COM in each year, although by variable degrees (45% less in 2000–01 but only 3% less in 2002–03). Total bycatch was highest in 1999–2000 at 60 000 t and decreased to 51 000–54 000 t in the following three years. The 95% confidence intervals around the total bycatch (and also the COM species bycatch) strongly overlap between years (Figure 8) indicating that there were no significant changes during this time.

Annual bycatch of LIN remained at a comparatively constant level over the four years, between about 8000–9000 t. Annual bycatch of HAK and SWA were at a similar level to LIN (6 000–12 000 t and 2000–9000 t respectively), but were more variable from year to year (Table 9). The combined HAK, LIN, and SWA bycatch accounted for 35–49% of the total bycatch in each year. The raw observer data summarised in Appendix 1 serves as a rough check on this figure, showing that these three species made up 45% of the observed bycatch between 1999 and 2003. The confidence intervals varied widely between years for these individual species bycatch estimates (Figure 9). This is because the recorded bycatch weights had a more uneven distribution than the combined groups, and the estimated variance was affected more by a few large values.

Table 8: Estimates of bycatch (t) in the target hoki trawl fishery by fishing year and species categories COM, OTH, and overall (TOT), with 95% confidence intervals in parentheses. Rows in bold show results for the years for which estimates from Anderson et al. (2001) were repeated. Results from this study are rounded to the nearest 100 t.

						Species category
		COM		OTH		TOT
1990–91	–	–	–	–	**42 300**	**(31 700–51 300)**
1994–95	–	–	–	–	**37 000**	**(29 300–46 600)**
1998–99	–	–	–	–	**47 700**	**(40 500–55 300)**
1999–00	33 100	(28 000–38 700)	26 900	(22 200–32 100)	60 000	(50 200–70 800)
2000–01	33 200	(27 900–38 800)	18 100	(15 200–21 000)	51 300	(43 100–59 800)
2001–02	28 900	(24 800–32 900)	24 900	(20 400–29 800)	53 800	(45 200–62 700)
2002–03	26 300	(22 000–31 700)	25 600	(20 200–32 200)	51 900	(42 200–63 900)
Estimates from Anderson et al. (2001)						
1990–91	21 878	(19 331–24 898)	9 090	(8 035–10 249)	30 968	(27 366–35 147)
1991–92	15 748	(13 692–18 019)	8 401	(7 254–9 747)	24 148	(20 946–27 766)
1992–93	15 838	(12 475–20 254)	6 034	(5 046–7 219)	21 871	(17 521–27 474)
1993–94	10 184	(8 541–12 086)	5 011	(4 160–6 052)	15 196	(12 701–18 138)
1994–95	12 499	(9 927–15 668)	6 695	(5 654–7 915)	19 194	(15 580–23 583)
1995–96	19 322	(15 907–23 649)	9 247	(7 852–10 786)	28 569	(23 759–34 435)
1996–97	24 307	(18 978–30 946)	14 172	(11 862–17 115)	38 479	(30 840–48 061)
1997–98	25 271	(22 046–29 005)	17 443	(15 451–19 854)	42 714	(37 498–48 859)
1998–99	18 650	(16 524–20 998)	16 971	(15 439–18 695)	35 621	(31 963–39 693)

Table 9: Estimates of bycatch (rounded to the nearest 100 t) in the target hoki trawl fishery by fishing year for the species categories (hake (HAK), ling (LIN), and silver warehou (SWA)) examined separately, with 95% confidence intervals in parentheses.

						Species category
		HAK		LIN		SWA
1999–00	11 900	(8 800–15 400)	7 800	(6 300–9 100)	7 100	(4 000–11 700)
2000–01	6 700	(5 500–8 200)	9 100	(6 600–13 500)	9 300	(5 900–13 100)
2001–02	11 000	(8 200–14 500)	8 200	(6 900–9 400)	2 400	(1 500–3 500)
2002–03	6 200	(4 300–8 800)	8 900	(7 600–9 900)	3 000	(2 100–4 000)

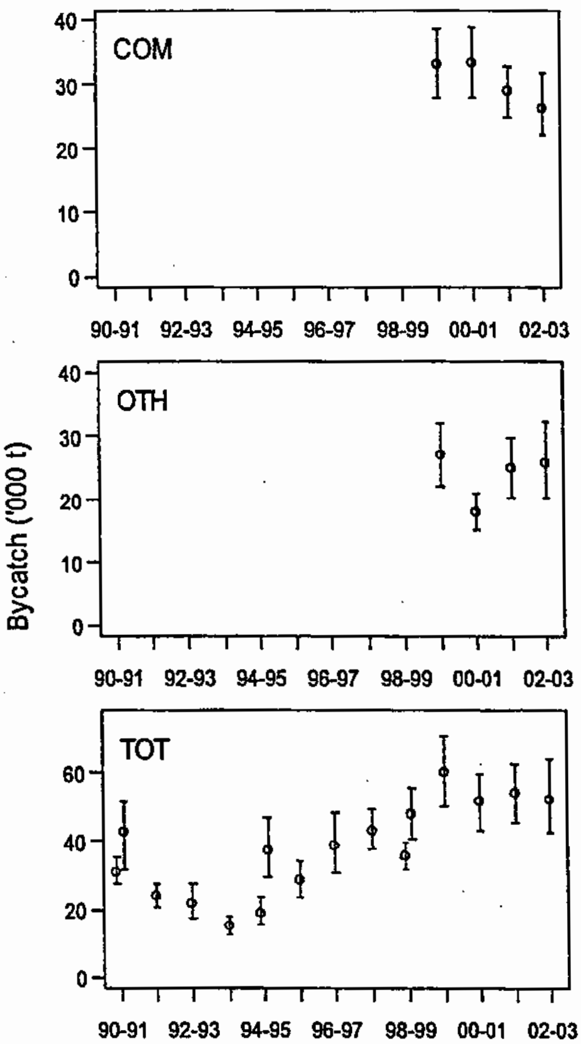

Figure 8: Annual estimates of fish bycatch in the target hoki trawl fishery, calculated for commercial species (COM), non-commercial species (OTH), and overall (TOT). Also shown (in grey) are estimates of overall bycatch calculated for the period 1990–91 to 1998–99 by Anderson et al. (2001), and re-estimates for three of those years made in this study (in black) using different stratification and revised variance calculation methods.

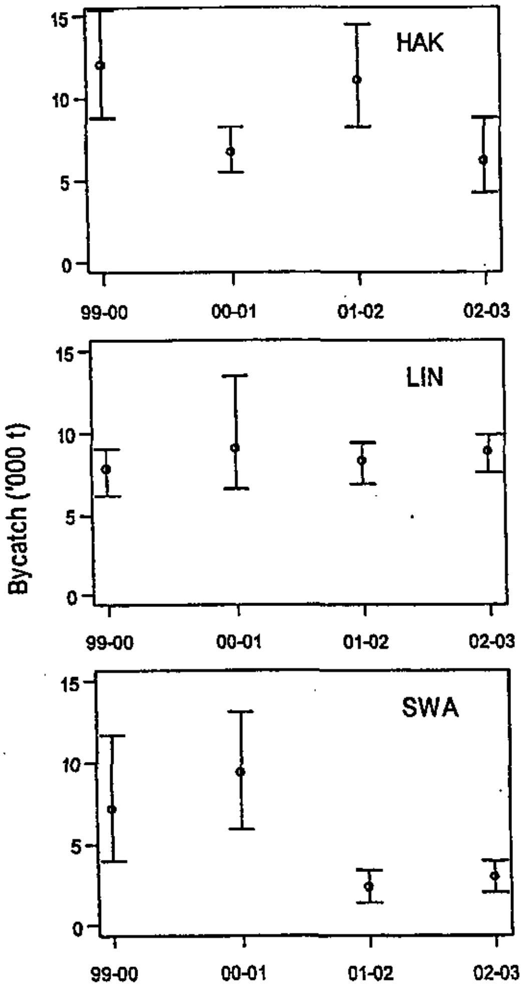

Figure 9: Annual estimates of hake (HAK), ling (LIN), and silver warehou (SWA) bycatch in the target *hoki trawl fishery for the 1999–2000 to 2002–03 fishing years.*

3.5.3 Comparison of bycatch estimates with those for the 1990–91 to 1998–99 fishing years

Total bycatch in each of the three years for which estimates were recalculated was slightly lower than for the 1999–2000 to 2002–03 period (range 37 000–48 000 t compared with 51 000–60 000 t), but higher than the earlier estimates (19 000–36 000 t). The difference between the old and new estimates is least for 1990–91 and greatest for 1994–95, in which year the 95% confidence intervals do not overlap. The more sophisticated variance calculations used in this study produced considerably wider confidence intervals than in the earlier study, and if such an approach had been taken then the confidence intervals would likely have overlapped with those for the current study (at least for 1998–99).

There are several possible explanations for the discrepancy between the point estimates from each study; firstly, there were differences in the stratification used. Although each study found that fishery area was the most critical factor influencing bycatch, considerably different groupings of areas were used in the present study, due to the use of regression trees to combine like areas. Only observer data from the four years examined in the current study were used to determine area groupings and these groupings may not have fitted the 1994–95 data as well. Because of the erratic distribution of bycatch values, the shift of an extreme value or two from one stratum to another can have a large influence on the bycatch rate for both strata. This difference will have a large effect on the total bycatch calculated if there are large differences in fishery effort between the two strata. Secondly, a major difference between the two studies was in the form of the ratio estimator. In the former study, bycatch in each tow was measured relative to the estimated catch of hoki but in this study it was measured relative to tow duration. Differences in hoki catch rates (catch per hour) between strata will produce differences in estimates of bycatch for each method. Thirdly, there may be differences in the catch-effort data used for each study. The catch-effort data used for this study were a new extract from MFish databases and underwent an updated and more automated grooming procedure than was applied to the data used in the previous study.

Estimates of COM and OTH bycatch were not recalculated for the earlier years (Table 8) as the species classified as commercial varied between studies and so estimates would not be strictly comparable.

3.6 Calculation of discards

3.6.1 Discard rates

Discard ratios for HOK were calculated from observer data for each year and for each of three super-areas (SUBA+CHAT, PUYS+WCSI+OTHR, COOK). Discard ratios for COM species were calculated for each vessel processing type (fresher, factory vessel, factory vessel with meal plant), and for OTH species for each net-type used (bottom trawl and midwater trawl). Discards were not calculated for the individual bycatch species (HAK, LIN, SWA) as too few discard events were recorded by observers to enable reliable ratios to be calculated. As with bycatch calculations, the same stratification was used to calculate ratios for the three earlier years for which estimates were remade.

Discard rates of HOK were generally less than 30 $kg.h^{-1}$ and in most areas and years were much lower (Figure 10). Rates were higher in PUYS and WCSI than in COOK in each year, but both of these super-areas followed the same pattern of alternating low and high discard rates over the four years. Discards of HOK were consistently lowest in SUBA+CHAT, where they were close to zero in three of the four years.

Discarding of COM species was greater on factory vessels without meal plants (3–8 $kg.h^{-1}$) than on those with meal plants (0–1 $kg.h^{-1}$) or on fresher boats (1–4 $kg.h^{-1}$) (Figure 10). This is not surprising as it is relatively easy for fresher boats to store small amounts of marketable bycatch species, and for factory boats to meal them, compared to the difficulty of altering processing lines and dealing with incomplete cartons on factory boats not using meal plants. Discard rates were lowest on each type of vessel in 2001–02, a year in which HOK discard rates were also very low.

Fish discards were, not surprisingly, greatest in the non-commercial species category (OTH), ranging from 80 to 120 $kg.h^{-1}$ for bottom trawls to 40–80 $kg.h^{-1}$ for midwater trawls (Figure 10). Midwater trawls, although often used close to the bottom in this fishery, are much less likely to capture the numerous species of mostly unmarketable deepsea dogfishes and other chondrichthyans, squids, octopuses, and small benthopelagic fish species that live on or close to the sea floor, many of which are listed in Appendix 1.

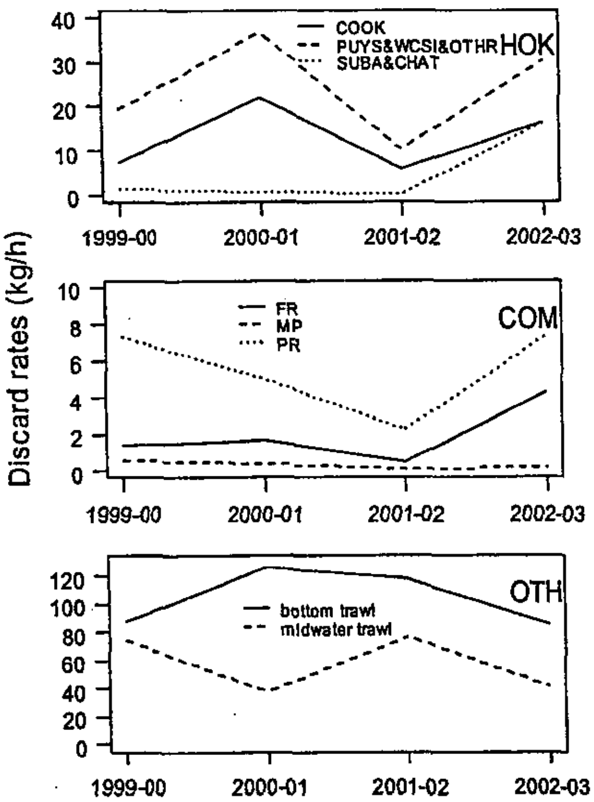

Figure 10: Annual discard rates of hoki (HOK), commercial species (COM), and non-commercial species (OTH), for each level of the factors used for stratification, in the hoki trawl fishery. Discard rates shown are the median of the bootstrap sample of 1000.

3.6.2 Annual discard levels

Annual discard levels were determined by multiplying the ratios calculated for each stratum by the target fishery tow duration totals for the equivalent stratum, as described in Section 2.5. Discards of HOK were infrequently recorded by observers and therefore the annual estimates of total discards of hoki were highly variable and tended to have wide confidence intervals (Table 10 and Figure 11). However, these figures are useful for gauging the approximate level of target species discards in the fishery, at least on vessels that have observers present. It is debatable whether discards are greater when observers are present (and quota species can be legally discarded in certain circumstances) or when they are not present and illegal discarding can take place unseen. Section 72 of the 1996 Fisheries Act requires all QMS species to be landed, unless included on the Sixth Schedule (which refers only to rock lobster, scallops, and oysters) or an observer is on board.

Annual estimates of discards were very low in the COM category (70–400 t) with a wide confidence interval for the 2002–03 estimate, and much higher in the OTH species category (8500–11 600 t) with confidence intervals of more consistent width (Figure 11). A large number of species make up this group and a more even spread of catch weights per tow would be expected.

In each of the four species categories examined there is an overlap in the confidence intervals around the estimates for each year and generally similar values of the point estimates from 1999–2000 to 2002–03 (Figure 11). This shows that there is no detectable trend of increasing or decreasing discard levels in any of these categories during this period. Total annual discard estimates ranged from about 11 000 to 14 000 t.

Table 10: Estimates of discards (t) in the target hoki trawl fishery by year, for the species categories HOK, COM, OTH, and overall (TOT), with 95% confidence intervals in parentheses. Rows in bold show results for the years for which estimates from Anderson et al. (2001) were repeated. Results from this study are rounded to the nearest 10 or 100 t.

	Species category							
Fishing year	HOK		COM		OTH		TOT	
1990–91	**4 800**	**(2 300–8 300)**	**–**	**–**	**–**	**–**	**12 100**	**(6 900–24 300)**
1994–95	**9 700**	**(5 300–14 100)**	**–**	**–**	**–**	**–**	**17 900**	**(10 300–26 700)**
1998–99	**1 580**	**(600–2 800)**	**–**	**–**	**–**	**–**	**11 800**	**(7 600–17 000)**
1999–00	900	(300–1 700)	300	(100–700)	9 700	(6 000–15 100)	10 900	(6 400–17 500)
2000–01	2 100	(200–3 800)	200	(100–400)	11 600	(7 300–14 700)	13 900	(7 600–18 800)
2001–02	600	(10–1 600)	70	(10–140)	11 200	(6 700–18 100)	11 800	(6 700–19 800)
2002–03	1 800	(600–5 000)	400	(40–1 300)	8 500	(5 000–13 400)	10 700	(5 700–19 700)
Estimates from Anderson et al. (2001)								
1990–91	3258	(2 281–4 512)	–	–	–	–	9 178	(6 729–12 529)
1991–92	2397	(1 343–3 696)	–	–	–	–	7 873	(5 691–10 507)
1992–93	4511	(3 069–6 305)	–	–	–	–	7 103	(4 668–10 129)
1993–94	3626	(2 572–4 897)	–	–	–	–	6 628	(4 939–8 662)
1994–95	5636	(4 010–7 517)	–	–	–	–	10 896	(7 886–14 670)
1995–96	2846	(1 820–4 200)	–	–	–	–	9 187	(6 786–12 133)
1996–97	2893	(1 781–4 413)	–	–	–	–	9 484	(6 234–13 823)
1997–98	4023	(3 135–5 114)	–	–	–	–	12 123	(10155–14 609)
1998–99	2862	(2 159–3 816)	–	–	–	–	10 962	(8 869–13 627)

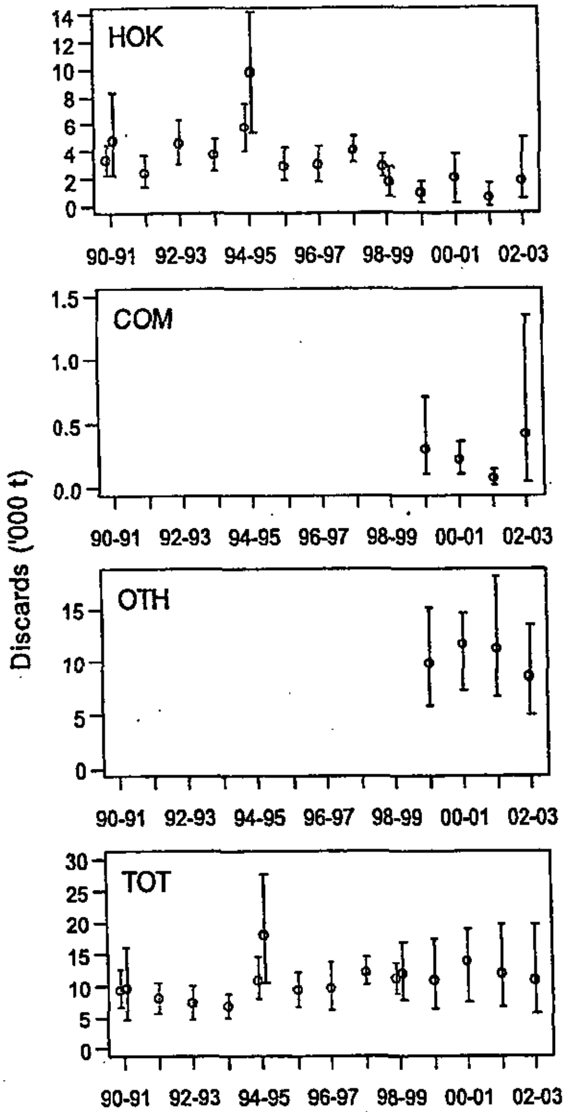

Figure 11: Annual estimates of fish discards in the target hoki trawl fishery, calculated for commercial species (COM), non-commercial species (OTH), and overall (TOT). Also shown (in grey) are estimates of overall discards calculated for 1990–91 to 1998–99 by Anderson et al. (2001), and re-estimates for three of those years made in this study (in black) using different stratification and revised variance calculation methods.

3.6.3 Comparison of discard estimates with those for the 1990–91 to 1998–99 fishing years

Annual hoki discards in the 1999–2000 to 2002–03 period (range 600–2100 $t.y^{-1}$) were lower than for any year in the 1990–91 to 1998–99 period (range 2400 to 5600 $t.y^{-1}$) (Table 10). Repeat estimates of discards for the 1990–91, 1994–95, and 1998–99 years confirm the higher values for those years, with broadly overlapping confidence intervals between studies in each year and very similar estimates for the first and last of those years (Figure 11). The repeat estimate for 1994–95 is 4000 t (or about 70%) greater than the original estimate, but is bracketed within a very broad confidence interval. The 1994–95 fishing year stood out in both studies as having the highest level of discards, and a closer examination of the raw data showed that this was largely due to the observation of high levels of discarding in areas CHAT and WCSI compared to other years. This was not related to a higher instance of, or one or two large values of, fish lost during landing of the gear, but rather to the influence of two or three vessels on which regular instances of discarding of hoki were recorded in those areas.

Total (TOT) discards remained within the range 6600–13 900 t.y^{-1} between the 1990–91 and 2002–03 fishing years, although the repeat estimate for 1994–95 was almost 18 000 t. This large value, and the apparent discrepancy between it and the earlier estimate for 1994–95, is mostly due to the revised estimate of HOK discards for this year (Figure 11). Total discards were slightly greater in the last four years than from 1990–91 to 1998–99, but again wide confidence intervals rule out the detection of any trend of increasing levels over time.

Estimates of COM and OTH discards were not recalculated for the earlier years for the same reasons that bycatch was not recalculated for these groups (see Section 3.7.3).

As was the case for bycatch calculations, the more sophisticated variance calculations used in this study produced considerably wider confidence intervals than in the earlier study, the degree of which is shown most clearly in the years with repeated estimates. The wider intervals give a more realistic measure of the ability to accurately estimate discard levels by scaling up from a small (observed) fraction of the fishery. The possible reasons for the differences in discard estimates between the earlier study and this one for the repeat years (although small) are the same as those described for bycatch; i.e., differences in the stratification used, in the form of the ratio estimator (discards per hour towed vs. discards per catch of hoki), and differences in the catch-effort data used.

3.7 Fraction of the hoki fishery represented by the target trawl fishery

Estimated annual catches from the hoki target trawl fishery represented between 94% and 97% of the total annual landings of this species during the period examined (Table 11). Discarding associated with hoki caught while trawling for other species (the catch which accounts for the remainder of the hoki trawl fishery, and is not considered here) therefore is likely to contribute only a small fraction of the total hoki trawl fishery discards.

Table 11: Estimated catch totals of hoki from the target trawl fishery, and all reported landings of hoki from the QMS, by year.

Fishing year	Target fishery estimated catch (t)	Total fishery reported catch (t)*	Target/total (%)
1999–00	231 470	242 000	96
2000–01	219 036	230 000	95
2001–02	190 067	196 000	97
2002–03	174 164	185 000	94

*From Annala et al. (2004)

4. DISCUSSION

The ability of these methods to precisely estimate bycatch and discard levels is highly dependent on the level and spread of observer coverage achieved. It is not sufficient that simply a reasonable fraction (usually 10–15% by target species catch or effort) is observed, as it is also necessary for observers to be well spread over the range of vessel types, areas, and times of year among which most of the variation in bycatch and discard rates are spread.

The level of observer coverage in this fishery represented between 11% and 15% of the target fishery catch in the years examined, and graphical analysis showed that this coverage appeared to be adequately spread geographically, temporally, and amongst vessel sizes with respect to the entire target fishery. Even so, only a modest degree of precision was achieved, and this has much to do with the extreme variability in bycatch and discard levels among tows. The observer data characteristically showed many small values (and, especially with discards of hoki and other commercial species, many zero values) with occasional very large values caused by accidental capture due to mixed schools, misreading echo-sounder pictures, ripped nets, etc. Confidence intervals were generally narrower for 2001–02 estimates than for the following year (see, e.g., Figure 11 COM and HOK discards) and this is linked to the difference in observer coverage between the two years (14.8% vs. 10.7%) as no error is apportioned to the fraction of the fishery which was sampled.

Small improvements in precision may be possible at similar levels of observer coverage with improvements in the spread of coverage and stratification methodology in the analysis, but large improvements will be possible only by significantly increasing the overall level of observer coverage or alternatively by improving the catch effort data system to record in greater detail, and with more consistency, catch and discard weights of bycatch species.

The methods used here help to address the assumption, made in previous analyses, that the observed tows were a simple random sample of all the tows within each stratum and which, on average, lead to under-estimates of the variability, and confidence intervals that were too short. Our bootstrap procedure gives more realistic estimates of precision as it includes the effect of correlation between tows that are in the same trip and stratum. Nevertheless the method used does not account for correlation between pairs of tows within the same trip but in different strata. At this stage we were not able to design a bootstrapping scheme that allows for this while at the same time giving good estimates for the within stratum variance.

Regression tree modelling refined the approach used to stratify the fishery. By combining like areas and grouping the fishing year into periods with similar patterns in bycatch and discarding, redundancy in the number of levels in the strata was reduced and greater numbers of observations were available in the final combined strata. Of the strata considered for stratification, fishery area and period (which varied between species category according to the outcome of the regression tree partitioning) explained most of the variability in rates of bycatch. Fishing year had little influence on rates of bycatch, indicating that no great changes took place with the short time period examined. For both bycatch and discards, area groupings tended to place geographically close areas together (e.g., PUYS and WCSI, OTHR and COOK) and split the fishing year into three or four periods. Fishery area was most important in discards of hoki and examination of discard rates showed that the west coast and smaller Puysegur fisheries were largely responsible for this. The higher discards in the west coast fishery in particular are likely to be linked to the much higher catch rates in this area during the spawning season — the greater the catch, the greater the potential for a large discard event. The low level of discarding of commercial species shown for vessels with meal plants is a great advertisement for these machines, and was also useful for stratifying discards by processing type. It was interesting to note that discards of commercial species by factory vessels without meal plants was between 2 and 13 times greater than by fresher boats and boats with meal plants. The influence of net type in discards of non-commercial species (the group comprising the majority of discards) indicates the benefits to associated species of fishing less hard-down on the sea bed. The hoki fishery has been considered to have low discard rates relative to other fisheries, both in New Zealand and internationally, but discards could potentially be reduced further with increased use of meal plants and decreased use of bottom trawling.

Regression analysis showed that the factor with the most influence on discards was the fishing vessel. This is also the case in several other New Zealand fisheries, e.g., jack mackerel and arrow squid (Anderson 2004b), southern blue whiting and oreos (Anderson 2004a), and orange roughy and hoki (Anderson et al. 2001). The methods used here were able to account for some of that variability by categorising vessels into processing types and ensuring that a minimum number of vessels were included in each stratum for which rates were calculated separately. However, this emphasises the need to spread observer effort over as many vessels as possible and also indicates that some vessels are much better at avoiding unwanted bycatch than others, demonstrating that there is potential for reducing discard levels.

The hoki fishery has previously been shown to be among New Zealand's less wasteful fisheries, with about 0.05 kg of discards per kg of hoki caught (Anderson et al. 2001). This study confirms this, with the equivalent value being 0.06 for the four years combined. The equivalent values for other New Zealand fisheries are: orange roughy and jack mackerel, 0.06 kg; oreos, 0.05 kg; southern blue whiting 0.02 kg; arrow squid, 0.14 kg; scampi 3.5 kg (Anderson 2004a, 2004b, Anderson et al. 2000, 2001).

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Appendix 1: Species codes, common and scientific names, estimated catch weight, percentage of the total catch, and overall percentage retained, of the top 50 species by weight from all observer records for the target fishery for hoki from 1 Oct 1999 to 30 Sep 2003. 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	% retained
HOK	Hoki	*Macruronus novaezelandiae*	109 446	82.92	99.61
HAK	Hake	*Merluccius australis*	4 578	3.47	99.86
LIN	Ling	*Genypterus blacodes*	3 612	2.74	99.95
SWA	Silver warehou	*Seriolella punctata*	2 272	1.72	99.94
JAV	Javelinfish	*Lepidorhynchus denticulatus*	2 229	1.69	66.24
RAT	Any rattail	Macrouridae	1 659	1.26	60.26
SPD	Spiny dogfish	*Squalus acanthias*	1 368	1.04	9.50
FRO	Frostfish	*Lepidopus caudatus*	850	0.64	97.63
GSP	Pale ghost shark	*Hydrolagus bemisi*	663	0.50	99.69
SBW	Southern blue whiting	*Micromesistius australis*	398	0.30	99.99
RIB	Ribaldo	*Mora moro*	367	0.28	99.76
SPE	Sea perch	*Helicolenus* spp.	358	0.27	99.27
BAR	Barracouta	*Thyrsites atun*	352	0.27	94.41
WWA	White warehou	*Seriolella caerulea*	344	0.26	99.95
SHA	Shark	Selachii	283	0.21	4.85
LDO	Lookdown dory	*Cyttus traversi*	269	0.20	94.75
SQU	Arrow squid	*Nototodarus sloanii & N. gouldi*	240	0.18	99.22
OEO	Oreos	*Pseudocyttus maculatus, Neocyttus rhomboidalis, Allocyttus niger*	233	0.18	99.90
SND	Shovelnose spiny dogfish	*Deania calcea*	216	0.16	6.21
BSH	Seal shark	*Dalatias licha*	194	0.15	8.63
RBM	Ray's bream	*Brama brama*	144	0.11	91.45
STA	Giant stargazer	*Kathetostoma giganteum*	140	0.11	99.81
ONG	Sponges	Porifera	135	0.10	0.00
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae.*	123	0.09	99.95
GSH	Dark ghost shark	*Hydrolagus novaezealandiae*	113	0.09	97.32
WSQ	Warty squid	*Moroteuthis* spp.	112	0.08	2.96
ORH	Orange roughy	*Hoplostethus atlanticus*	81	0.06	99.98
SKA	Skate	Rajidae, Arhynchobatidae	71	0.05	22.03
SSK	Smooth skate	*Dipturus innominatus*	68	0.05	66.94
BYX	Alfonsino & long-finned beryx	*Beryx splendens & B. decadactylus*	63	0.05	97.57
POS	Porbeagle shark	*Lamna nasus*	55	0.04	32.12
LCH	Long-nosed spookfish	*Harriotta raleighana*	54	0.04	60.91
SKI	Gemfish	*Rexea solandri*	53	0.04	98.56
BEN	Scabbardfish	*Benthodesmus* spp.	43	0.03	85.20
RUD	Rudderfish	*Centrolophus niger*	38	0.03	51.84
DEA	Dealfish	*Trachipterus trachypterus*	37	0.03	89.52
BSK	Basking shark	*Cetorhinus maximus*	36	0.03	0.00
RCO	Red cod	*Pseudophycis bachus*	34	0.03	97.02
WAR	Blue warehou	*Seriolella brama*	34	0.03	99.99
BNS	Bluenose	*Hyperoglyphe antarctica*	33	0.02	98.90
RBT	Redbait	*Emmelichthys nitidus*	30	0.02	88.27
BBE	Banded bellowsfish	*Centriscops humerosus*	30	0.02	33.35
ECH	Echinoderms	Echinodermata	29	0.02	1.47
CON	Conger eel	*Conger* spp.	29	0.02	26.78
FHD	Deepsea flathead	*Hoplichthys haswelli*	27	0.02	26.25
SSI	Silverside	*Argentina elongata*	27	0.02	70.85
TOA	Toadfish	*Neophrynichthys* sp.	23	0.02	35.36
ETM	Etmopterus sp.	*Etmopterus* sp.	21	0.02	1.00
SCH	School shark	*Galeorhinus galeus*	21	0.02	78.36
SWO	Broadbill swordfish	*Xiphias gladius*	18	0.01	78.00

Appendix 2: Bycatch rates by fishing year and "super-area" or period for each of the five species categories examined. Standard deviations calculated from bootstrap samples are shown in parentheses. See Figure 1 for area boundaries

COM: CHPS=CHAT, PUYS, SUBA; COOT=COOK, OTHR.

	Median bycatch rate (kg/h)		
	CHPS	COOT	WCSI
99-00	204(25)	139(31)	596(68)
00-01	260(34)	92(17)	407(41)
01-02	199(16)	61(10)	522(64)
02-03	241(27)	110(25)	292(54)

OTH: CHOT=CHAT, OTHR; PUWC=PUYS, WCSI.

	Median bycatch rate (kg/h)			
	CHOT	COOK	PUWC	SUBA
99-00	249(38)	1235(239)	119(17)	121(23)
00-01	205(25)	478(98)	81(16)	112(24)
01-02	324(44)	501(238)	96(17)	268(49)
02-03	297(41)	1433(522)	59(7)	133(23)

HAK: CCOPS=COOK, CHAT, OTHER, PUYS, SUBA

	Median bycatch rate (kg/h)	
HAK	CCOPS	WCSI
99-00	38(8)	322(57)
00-01	28(3)	144(21)
01-02	38(9)	293(50)
02-03	27(5)	136(35)

LIN: first=1 Oct–24 Nov; second=25 Nov–5 Aug; third=6 Aug–30 Sep

	Median bycatch rate (kg/h)		
	first	second	third
99-00	24(3)	80(8)	59(12)
00-01	74(18)	92(24)	44(11)
01-02	48(10)	85(8)	89(19)
02-03	56(14)	96(7)	50(18)

SWA: first=1 Oct–5 Nov; second=6 Nov–22 May; third=23 May–17 Aug; fourth=18 Aug–30 Sep

	Median bycatch rate (kg/h)			
	first	fourth	second	third
99-00	55(25)	149(41)	44(33)	57(12)
00-01	144(31)	170(60)	37(19)	84(35)
01-02	18(11)	90(39)	13(5)	17(4)
02-03	95(26)	81(28)	7(3)	17(3)

Appendix 3: Discard rates by fishing year and "super-area", processing type, or net-type for each of the three species categories examined. Standard deviations calculated from bootstrap samples are shown in parentheses. See Figure 1 for area boundaries

HOK: PUYC=PUYS, WCSI; SUCH=SUBA, CHAT

	Median discard rate (kg/h)		
	COOK	PUYC	SUCH
99-00	8.2(4.7)	21.2(12.7)	1.6(0.6)
00-01	24.1(14.5)	39.5(24.8)	0.9(0.6)
01-02	7.0(6.2)	12.7(13.6)	1.5(1.8)
02-03	18.5(11)	32.5(20.6)	18.5(11.0)

COM: FR=Fresher; PR=Factory vessel; MP=Factory vessel with meal plant

	Median discard rate (kg/h)		
	FR	MP	PR
99-00	1.49(0.72)	0.62(0.25)	8.49(5.22)
00-01	1.76(0.63)	0.56(0.46)	5.26(1.75)
01-02	0.48(0.30)	0.07(0.05)	2.28(1.13)
02-03	4.81(3.51)	2.93(4.22)	7.90(5.91)

OTH: bot=bottom trawl; mid=mid-water trawl

	Median discard rate (kg/h)	
	bot	mid
99-00	90(25)	80(34)
00-01	125(22)	39(11)
01-02	123(36)	80(37)
02-03	90(27)	44(17)