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EXECUTIVE SUMMARY

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Records of catch and discards by species collected by the Ministry of Fisheries (MFish) Observer Programme were used in conjunction with commercial catch-effort data to estimate the rates and annual levels of fish bycatch and discards in the jack mackerel trawl fishery, from 2001–02 to 2004–05. Estimates were made for several categories of catch, including jack mackerel (discards only), all other commercial species combined, all non-commercial species combined, and separately for four commonly caught individual species, barracouta, blue mackerel, frostfish, and redbait.

Linear regression models were applied to the observer data to identify factors influencing variability in rates of bycatch and discarding, with a focus on those factors which could be used to partition the observer and catch-effort data in an equivalent manner. Regression tree methods, which seek to maximise the explanatory power of a variable while minimising the number of categories, were used to group data into a number of discrete areas and periods. The area and period variables created in this way along with two other variables, vessel and tow type, were used to stratify data for the calculation of annual totals.

A ratio estimator, based on tow duration, was used to calculate bycatch and discard rates for each species category in each stratum, determined from the regression analyses, for each fishing year. These ratios were then applied to tow duration totals calculated from the commercial catch-effort data to produce annual estimates for the target fishery as a whole. Multi-step bootstrap methods, taking into account the effect of correlation between trawls in the same observed trip and stratum, were used to estimate the variance in these ratios, and hence provide confidence intervals for the annual bycatch and discard estimates.

Total annual bycatch estimates ranged from about 7700 to 11 900 t, compared with approximate target species catches in the same period of between about 23 000 and 33 000 t. Most of this bycatch (about 95%) comprised commercial species, with only about 250–550 t of non-commercial species caught annually. Total bycatch has been decreasing in this fishery for several years and current levels are similar to the low levels estimated in an earlier study for the early-mid 1990s. Bycatch of the major bycatch species barracouta, blue mackerel, and redbait are lower than, or at, similar levels to those of the previous three years.

Total annual discards also decreased during these four years, continuing a trend that began in the late 1990s. Annual discards now range from about 100 t to 700 t. The discarded fish are a mixture of commercial and non-commercial species in different proportions between years, with only a very small amount of jack mackerel species discarded. The detection of a decrease in bycatch and discard levels is an important outcome of this research, showing that discards have decreased from about 0.06 kg to 0.01 kg per kg of jack mackerel catch since the previous analysis.

1. INTRODUCTION

The Ministry of Fisheries (MFish) has an obligation under international treaties and the Fisheries Act 1996 to determine the impacts of fishing on any stock, area, and the aquatic environment. This obligation includes the principle that the abundance of associated or dependent species should be maintained above a level that ensures their long-term viability. To determine this level for each species affected by the jack mackerel fishery (which comprises the three species *Trachurus declivis*, *T. murphyi*, and *T. novaezelandiae*) would be an enormous task; more achievable is the identification of species or species groups that are impacted and an estimation of the level of that impact. In this project, the level of catch and discards of non-target species in the jack mackerel fishery is estimated based on MFish observer records of catch and discards by species. The fishery considered here does not include the small purse-seine fisheries conducted in the Bay of Plenty in JMA 1 (for mainly *T. novaezelandiae*) and off Kaikoura in JMA 3 (for mainly *T. murphyi*) (Taylor 2004).

Discarding of low value fish species is a global problem, with an estimated 7.3 million tonnes of dead or dying fish returned to the sea annually (Kelleher 2004). This is considerably less than in the late 1980s and early 1990s when it was estimated that 20–22 million tonnes were discarded annually (Clucas & James 1996) and the change is due mostly to higher retention rates and improved fishing methods.

The jack mackerel trawl fishery is an important one for New Zealand, with the amount exported third greatest by weight after arrow squid (*Nototodarus* spp.) and hoki (*Macruronus novaezelandiae*), earning almost NZ$30M in 2005. This fishery currently makes between 2400 and 3000 trawls within the New Zealand region each year, concentrated mostly off the west coast of the lower half of North Island, but also operating further south as far as Greymouth, as well as on the Stewart-Snares shelf south of New Zealand and on parts of the Chatham Rise. A fishery of this size has considerable 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 are not kept because of damage (crushing in the codend or factory line, contamination from being dropped, deterioration of flesh quality from processing delays), hold space limitations, or because they are of unwanted size. Fish can also be discarded without ever reaching the deck of the boat, when dead or dying fish are forced through the meshes of the net while fishing (unseen mortality) or as a result of a mechanical or other failure or an intentional release of fish from the cod-end, during gear retrieval.

Information on the level of non-target fish catch and discards in commercial fisheries is important for fisheries management, even if this information is frequently overlooked. Accurate estimates of the catch history of a stock are perhaps the single most important input to any stock assessment, yet this aspect often receives too little attention. Official landing records are often assumed to accurately reflect fishing mortality with an arbitrary amount (percentage) added for catch overruns caused by such things as illegal fishing, incorrect conversion factors, and unreported discarding. Figures produced from analyses such as those presented here could potentially be used to estimate additional mortality caused by undeclared discarding and losses from the net during hauling. Estimates of these additional mortalities are also necessary for determining the impact on non-target species, in line with the ecosystem approach to modern fisheries management.

The work undertaken here updates two earlier studies which examined discards in the jack mackerel fishery covering the 1990–91 to 2000–01 fishing years (Anderson et al. 2000, Anderson 2004a). Those studies found that bycatch in the jack mackerel fishery comprised mainly the commercial species barracouta (*Thyrsites atun*), blue mackerel (*Scomber australasicus*), frostfish (*Lepidopus caudatus*), redbait (*Emmelichthys nitidus*), blue warehou (*Seriolella brama*), and arrow squid, and the mostly non-commercial spiny dogfish (*Squalus acanthias*). Discards comprised mostly non-commercial species (about 400–1400 $t.y^{-1}$) with somewhat lesser amounts of commercial species (about 40–400 $t.y^{-1}$) and the target species (about 30–300 $t.y^{-1}$). Both bycatch and discard levels were influenced mainly by differences between vessels, area, and trawl type (bottom or midwater), with the latter two used to stratify the fishery to calculate annual estimates.

This study also builds on other recent examinations of bycatch and discards in other New Zealand trawl fisheries: e.g., the orange roughy (*Hoplostethus atlanticus*) fishery (Anderson, Unpublished results), the hoki fishery (Anderson & Smith 2005), the southern blue whiting (*Micromesistius australis*) and oreo (*P. maculatus, A. niger, N. rhomboidalis*) fisheries (Anderson 2004b), and the arrow squid and scampi (*Metanephrops challengeri*) fisheries (Anderson 2004a). With regular updates carried out for all the major trawl fisheries (as well as for the ling and tuna longline fisheries), the effects of commercial fishing on associated fish species is now being monitored for all the main offshore fisheries in New Zealand waters. This should assist in the detection of any general trends or sudden changes in levels of bycatch and discards.

This report was prepared as an output from the MFish project ENV2005-17 "Estimation of non-target fish catch and both target and non-target fish discards in jack mackerel trawl fisheries" and addresses the following objectives.

1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for jack mackerel for the fishing years 2001/2002 to 2004/05 using data from Mfish Observers and commercial fishing returns.

MFish observers have been collecting bycatch and discard information from the jack mackerel fishery since the early 1990s, in most years covering between 10% and 25% of the target fishery 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 fishing parameters. This study calculates estimates of bycatch and discards for the entire target fishery by scaling up estimates determined from the observed 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 this study "*non-target fish catch*" is interpreted 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). *Non-target catch* is defined 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 jack mackerel fishery is generally maintained at a high level due to its size and importance, and therefore a considerable amount of data is available for this study.

Two datasets were prepared from the MFish observer database *obs*; one comprising discard data from a link between the station data table (*new_observer_station*) and the catch processing data table (*new_observer_processed*), and the other comprising bycatch data by linking station data with the catch data table (*new_observer_greenweight*). Records were extracted for all tows with jack mackerel recorded as the target species, carried out within the fishing years being examined.

For all records, the trawl distance was calculated from the recorded start and finish positions. Records in which a start or finish position was incompletely recorded, or where the calculated distance was greater than 60 km were identified and groomed using median imputation to substitute approximate values for those missing. This process substitutes the missing value with the median latitude or longitude for other trawls by the vessel on the same day. Trawl distances were then recalculated from the corrected positions.

Trawl durations were 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 lifted off the bottom to avoid foul ground, brought to the surface during turning, or was temporarily left hanging in the water due to equipment malfunction). Errors resulting from confusion between the 12 and 24 h clock systems were identified and rectified where they 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 method was used only in these extreme cases as a considerable percentage of trawls (about 18%) were 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. Trawl durations of zero were substituted with an arbitrary value of 1 minute.

A mixture of bottom and midwater trawl gear is used in this fishery, and so "towtype" was assigned to observer records 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, and gear details were not recorded in as much detail on catch-effort forms, so two other variables were formed. The variable "nettype" 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.

Individual vessel data (gross registered tonnage (GRT), overall length, and company) were obtained from a combination of sources due to incomplete records in any single source; the *obs* database, observer trip reports, tcepr data for matching vessels.

When fish were lost from the net before it was brought aboard, observers estimated the loss by recording "total greenweight on surface" and "total greenweight on board". These losses came about due to 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. Obvious errors in these values were corrected; 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 zero 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 considered to be erroneous unless confirmed by the associated code identifying the cause of the loss. After these corrections, only one validated case of observed fish loss (out of eight recorded) remained, a 1 t loss at the stern ramp.

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/or from the processed states recorded for the vessel on the *obs* database.

Each record was assigned to one of three areas (Figure 1). These areas are the same as those used in the previous examination of bycatch in this fishery (Anderson 2004a) and are based on a combination of the natural spatial distribution of the main fishing grounds and the recognised quota management areas (QMAs). Areas CHAT and SNAR are within JMA 3 and area WEST is in JMA 7. The number of tows observed in each area over the four years is shown in Table 1. Observer coverage has increasingly been restricted to the area WEST during this short period, with only a handful of observed trawls in CHAT and SNAR in 2003–04 and 2004–05.

Observer data were available from 11 vessels operated by 8 companies. No vessel or company is identified in this report, and alphanumeric codes are presented where necessary.

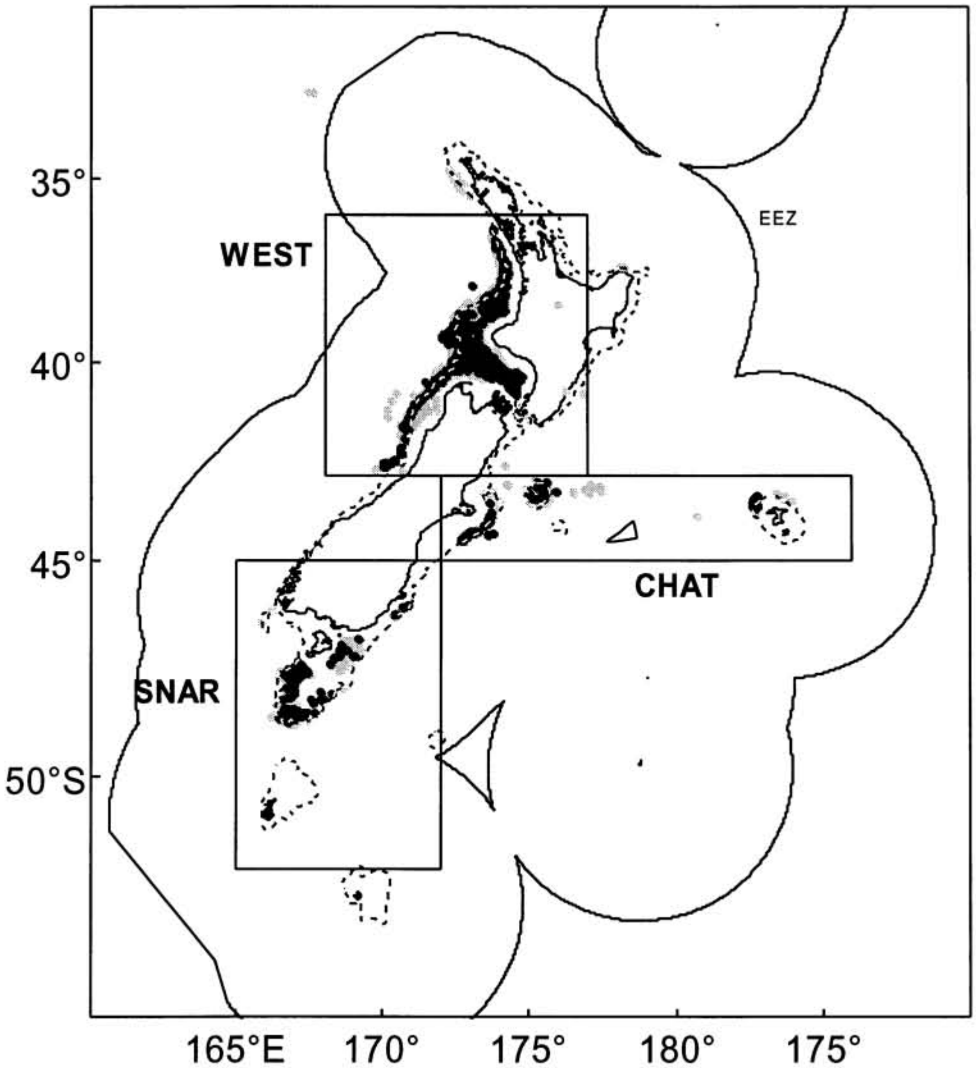

Figure 1: Distribution of tows recorded by observers on vessels targeting jack mackerel between 1 October 2001 and 30 September 2005, and all commercial tows with recorded position targeting jack mackerel in the same period (grey dots). Area divisions are those used in the analyses.

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

Area				Fishing year	
	2001–02	2002–03	2003–04	2004–05	All
CHAT	85	27	0	3	115
SNAR	117	42	3	9	171
WEST	150	268	155	549	1 122
All areas	352	337	158	561	1408

To create the dataset used to estimate discards, the weights of each species retained and discarded in each "processing group" were obtained from the MFish *obs* 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 trawls are frequently combined into one processing group. This grouping of processing data stems from the difficulty of keeping track of the catch from individual trawls in the factory of a vessel. For this set of data there were relatively few processing groups which comprised data from more than one trawl (representing 136 out of 1408 trawls) and so for simplicity only those groups which represented a single trawl were used in the analysis. The extraction of bycatch data was more straightforward because observers estimated or measured the weight of all species caught in each trawl, and therefore data from all trawls targeting jack mackerel were extracted.

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

- the target species, jack mackerel (JMA)
- other main commercial species combined (COM)
- all other species combined (OTH)
- individual bycatch species caught in substantial quantities; barracouta (BAR), blue mackerel (EMA), frostfish (FRO), and redbait (RBT)

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 given in Appendix 1.

Commercial species are defined here as those which represented 0.1% or more of the total observed catch during the period and either were quota species or 75% or more of the catch was retained. This definition is somewhat arbitrary, but ensures that species in this category are both saleable and are an important component of the bycatch in the fishery, and also is consistent with the definition used in the previous analyses (Anderson 2004a, Anderson et al. 2000) and analyses of other fisheries (e.g., Anderson & Smith 2005). In this case the category was made up of the following 13 species: barracouta, blue mackerel, frostfish, redbait, arrow squid, hoki, blue warehou, spiny dogfish, silver warehou (*Seriolella punctata*), silver dory (*Cyttus novaezealandiae*), snapper (*Pagrus auratus*), kingfish (*Seriola lalandi*), and trevally (*Pseudocaranx dentex)*. This differs from (and is larger than) the set of species identified as commercial in the previous (1998–99 to 2000–01) period (Anderson 2004a). The bycatch and discards of the commercial species defined for the present study were assessed as a group (COM) and those of barracouta (16% of the observed catch), blue mackerel (5%), frostfish (3%), and redbait (3%) were assessed separately.

A total of 1408 observed tows (and 1272 processing groups) targeting jack mackerel was used in the analysis.

2.3 Commercial fishing return data

Catch records from commercial fishing returns were obtained from MFish catch-effort databases for all jack mackerel target fishing during the period. This included all fishing recorded on Trawl, Catch, Effort and Processing Returns (TCEPRs), Catch, Effort and Landing Returns (CELRs), and high seas versions of both. Data were groomed for errors using routines developed in the statistical software package "R" (Ihaka & Gentleman 1996). Errors in the recorded position, depth, towing speed, and tow duration were corrected using a process of 'median imputation'. This process identifies, e.g., unusually long trawls and compares their start and finish positions with median values for all other trawls made by the vessel on that day, replacing them with those medians if necessary. 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 not all can be used to stratify commercial data as they are either not recorded, recorded differently, or not all levels of the variable, for example "trip", are observed. Some of these variables were considered along with more useful ones in preliminary regressions, in order to gauge their influence, but were ignored in the final set of regression models. The variables considered in the regressions for each species category included; fishing year, trip number, vessel key, company, area, month, season (high, November–April; low, May–October), depth of trawl, fishing day (day of the fishing year, 1–366), headline height, start time, crew and vessel nationality, vessel length and vessel tonnage. Processing type was considered but not used as almost all of the observed trawls were associated with factory vessels using meal plants.

The number of fishing periods per year and their start and finish points ("day of the fishing year") were 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, although there were only three, so that areas with sufficiently similar patterns of bycatch or discards could be combined to reduce model complexity with minimal loss of explanatory power.

Each species group was examined separately and a combination of linear and binomial regression models applied. Binomial regressions are useful where there is a large fraction of zero values in the data; in this example where there was a large fraction of trawls with no catch or discard of the species group. This applied to all species groups except for COM bycatch and JMA discards in this case. This enabled an examination of factors influencing both the *probability* and the *level* of a bycatch/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 on the response variable.

Regression models were run in turn for discards of the target species (JMA), bycatch and discards of other commercial species (COM), non-commercial species (OTH), and frequently caught individual species (BAR, EMA, FRO, and RBT). A more 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 selected for final stratification of the 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.

This bootstrap method 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 jack mackerel or the total tow duration in the stratum (depending on the version of the estimator chosen), from commercial catch records, to estimate total discards $\hat{D}$:

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

where L_j is the total catch of jack mackerel 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 $\widehat{DR}$ 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. Bootstrapping was carried out using the statistical software package R (Ihaka & Gentleman 1996).

3. RESULTS

3.1 Distribution and representativeness of observer data

The target trawl fishery is concentrated in one Quota Management Area (QMA) JMA 7, area WEST in this analysis. This area contributes about 80% of the observed target trawls and 90% of all commercial target trawls outside of the purse seine fisheries in JMA 1 and JMA 3.

The positions of all observed tows in the target jack mackerel fishery between 1 October 2001 and 30 September 2005 are shown, along with those of all commercial jack mackerel 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, with sampling heavily concentrated in the west coast fishery in JMA 7 (area WEST in this report) in the North and South Taranaki Bights, and extending south in a narrow band as far as about Greymouth on the west coast of South Island. A small region off the western tip of North Island (in JMA 7) was the focus of some targeted fishing for jack mackerel in this period, but received no observer coverage. Outside of this region, the smaller fishing grounds on the Chatham Rise, around Banks Peninsula, the Chatham Islands, and the Mernoo Bank (area CHAT) also received observer coverage, although one or two of the lightly fished locations in this area were missed. Further south, on the Stewart-Snares shelf (area SNAR), observer coverage was also well spread over the range of the commercial fishery. Examination of density plots (Figure 2) provides further evidence that the intensity of observer coverage was well matched to fishing effort, with observed tows distributed evenly throughout the latitudinal and longitudinal range of the fishery in at least three out of the four years. In 2001–02 observers oversampled slightly in the southern and western sector (SNAR) and undersampled slightly in the sector further north and east (WEST). In the other three years, 2004–05 in particular, the intensity of observer coverage was well matched to the commercial fishery.

The annual number of observed tows was quite variable, ranging from a low of 158 in 2003–04 to a high of 561 in the following year, although the number of vessels observed was more consistent, ranging from 6 to 9 (Table 2). The percentage of the jack mackerel trawl fishery observed (measured in terms of the estimated annual target fishery catch) ranged from 7.9% in 2003–04 to 27% in 2004–05. Eleven vessels were observed during this 4-year period, out of a total of 35 vessels which reported some target fishing for jack mackerel. Total target fishery effort also fluctuated during this period, from a low of about 5600 h in 2003–04 to a high of about 7400 h in 2001–02 and 2002–03.

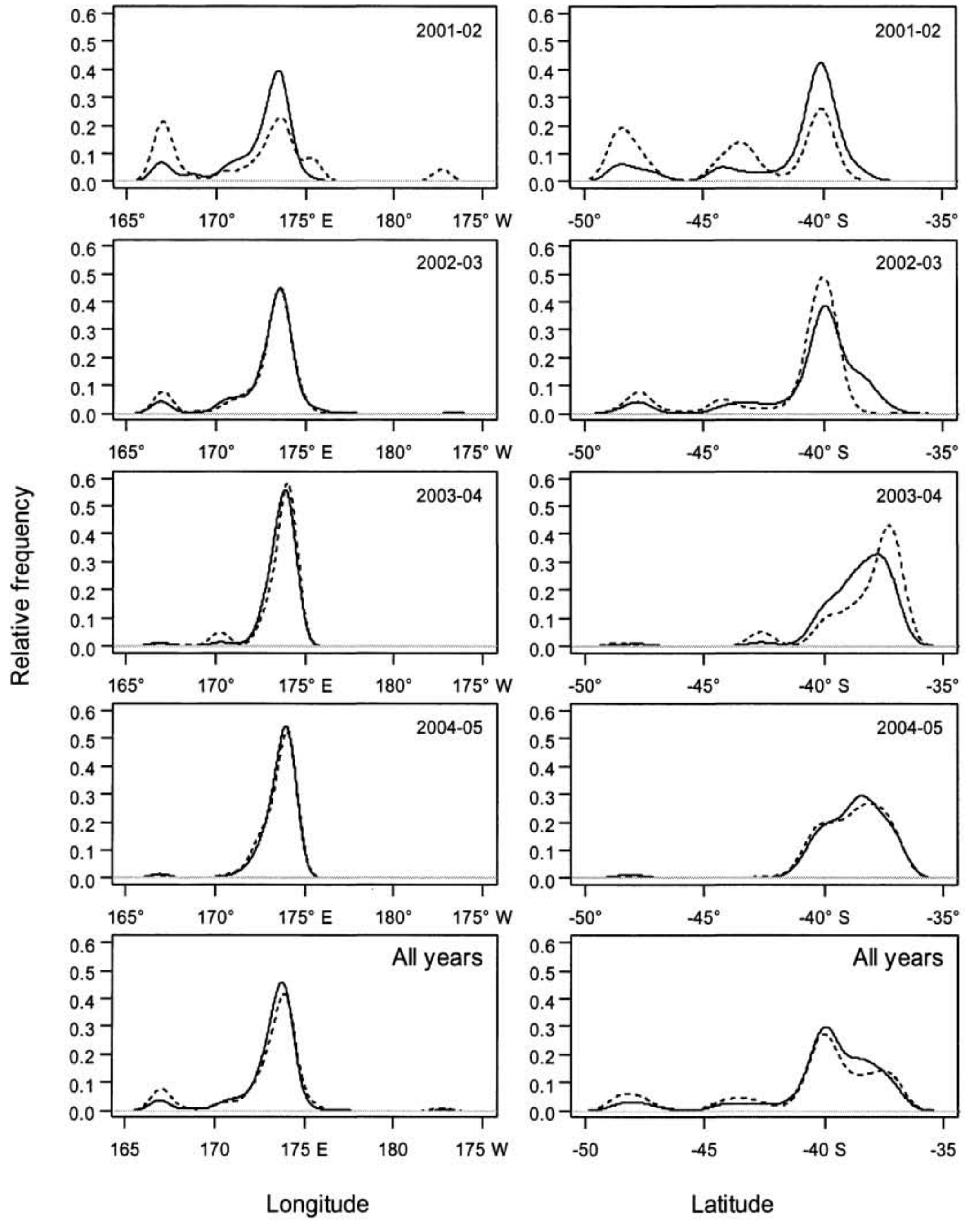

Figure 2: Comparison of position (latitude and longitude) of observed trawls (dashed lines) versus all trawls captured on TCEPR forms (solid line) for each fishing year from 2001–2002 to 2004–05, and for all four fishing years combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Table 2: Number of tows, vessels, and trips observed, the fraction of the target fishery catch observed, and the total target fishery effort in the jack mackerel 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)
2001–02	352	7	13	10.5	7 386
2002–03	337	7	12	8.9	7 375
2003–04	158	6	7	7.9	5 662
2004–05	561	9	14	27.0	5 922
All years	1 408	11	43	14.5	26 345

A central feature of this fishery is that it is dominated by a few large foreign chartered trawlers. The observer data come almost entirely (over 99% of the records) from seven Ukranian or Russian operated vessels of 104–105 m length, with only eight observed tows on smaller vessels (30–82 m long). This observer placement is appropriate, as the commercial catch effort data show that these seven vessels accounted for over 93% of the trawls in this fishery during the four years. Observer coverage was variable amongst these vessels, with one having just 6% of its trawls observed and another with 22% coverage. All seven vessels fished for jack mackerel in each of the three areas defined in this report, and observers were present on vessels in each area for five of the seven vessels.

The spread of observer effort throughout each fishing year was determined and compared to the spread of effort for the whole fishery, by applying a density function to numbers of trawls per day (Figure 3). These plots show a similar pattern of commercial effort from year to year, with most fishing taking place in the same three or four general periods. Fishing effort was high at the beginning of each fishing year through until the beginning of January but with a conspicuous break with little or no effort at some point in November. Fishing effort was then low again from early-mid January until at least April when effort became more sporadic and was also less consistent from year to year until June, when there was an increase in effort, which continued through into July in each year. Fishing effort then remained at low levels through to the end of the fishing year. Observer effort tended to be more concentrated into discrete periods than the commercial fishery, with high levels of coverage in each year at some point within the October–January fishing period, although not necessarily coinciding with the period of greatest effort in the fishery (e.g. 2001–02 and 2002–03 when intensive fishing in December received no observer coverage). The April fishery period was well covered (oversampled) by observers in the first two years and the June period was covered properly only in 2004–05. Although the seasonal representativeness of the observer coverage appears only fair when looked at one year at a time, when data from all years are combined we can see that all the main fishing periods were covered at some point over the four years, providing some opportunity to identify seasonal patterns in bycatch or discarding.

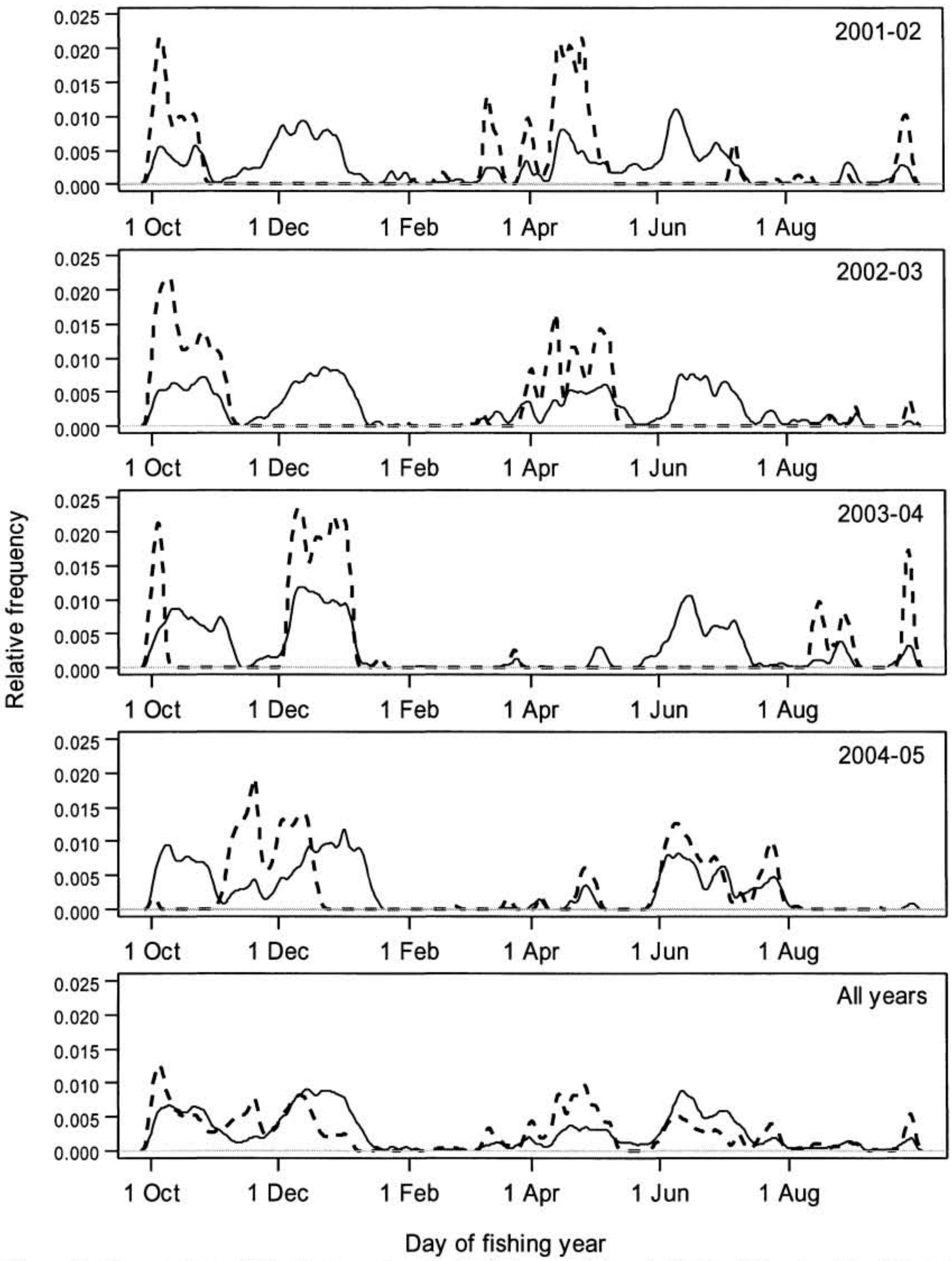

Figure 3: Comparison of the temporal spread of observed trawls (dashed lines) with all trawls recorded on TCEPR forms (solid line) for each fishing year from 2001–02 to 2004–05, and for all four fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Comparison of estimators

From observer data, the jack mackerel estimated catch-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 jack mackerel) 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, particularly so in the COM category, and although slightly smaller for COM bycatch than for OTH bycatch, were much greater for COM discards than for OTH species. Although differences in c.v.s between the two forms were small (range 0.28% to 1.22%), in each comparison the tow duration-based estimator provided a lower c.v. than the jack mackerel estimated catch based estimator.

On the basis of these comparisons, the tow-duration-based estimator was selected for all bycatch and discard calculations. A similar exercise carried out when examining bycatch and discards in the southern blue whiting, oreo, and hoki fisheries (Anderson 2004b, Anderson & Smith 2005) produced similar results, and also led to the use of a tow duration-based estimator.

Table 3: Comparison of ratio estimators.

Bycatch/discards	Species category	Estimator	Bycatch ratio	c.v. (%)
Bycatch	COM	JMA catch	0.399	5.06
	COM	Tow duration	1513	3.84
	OTH	JMA catch	0.011	6.16
	OTH	Tow duration	39.8	5.23
Discards	COM	JMA catch	0.007	20.71
	COM	Tow duration	26.7	20.43
	OTH	JMA catch	0.003	12.64
	OTH	Tow duration	10.7	12.02

3.3 Observer bycatch data

3.3.1 Overview of raw bycatch data

Jack mackerel species accounted for 70% of the total estimated catch from all observed trawls targeting jack mackerel between 1 October 2001 and 30 September 2005. The remaining 30% mostly comprised other commercial species; especially barracouta (15.6%), blue mackerel (4.8%), frostfish (3.1%), and redbait (2.7%). Altogether, over 99% of the observed catch comprised species which were commercial (as defined in Section 2.2). About 130 species or species groups were identified by observers, about half of which were non-commercial, non-quota, species caught in low numbers (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 fishery parameters (Figure 4). Total bycatch was highly variable between trawls, ranging from none to almost 50 t, and tended to increase with increasing tow duration. There was a slight increase in bycatch with increasing bottom depth, from a median of about 2.2 t in trawls shallower than 100 m up to 4.0 t greater than 200 m. There was considerable variability in bycatch among the five fishing companies and seven vessels for which there were more than 20 records. Median bycatch among companies ranged from 2.0 to 3.2 $t.trawl^{-1}$ and median bycatch among vessels ranged from 1.5 to 3.3 $t.trawl^{-1}$.

Median bycatch decreased in each fishing year, from about 3.6 $t.trawl^{-1}$ in 2001–02 to exactly half that rate in 2004–05, and was also variable between areas with the lowest median bycatch rate in area WEST (2.2 $t.trawl^{-1}$) and the highest in area SNAR (7.4 $t.trawl^{-1}$). Bycatch levels were high in March, dropping after this to a low in May, before increasing over the following months to their highest levels in August. After this bycatch levels remained at average levels through to the end of the calendar year. Median bycatch levels were considerably lower with midwater trawling (1.1 $t.trawl^{-1}$) than with bottom trawling (3.0 $t.trawl^{-1}$).

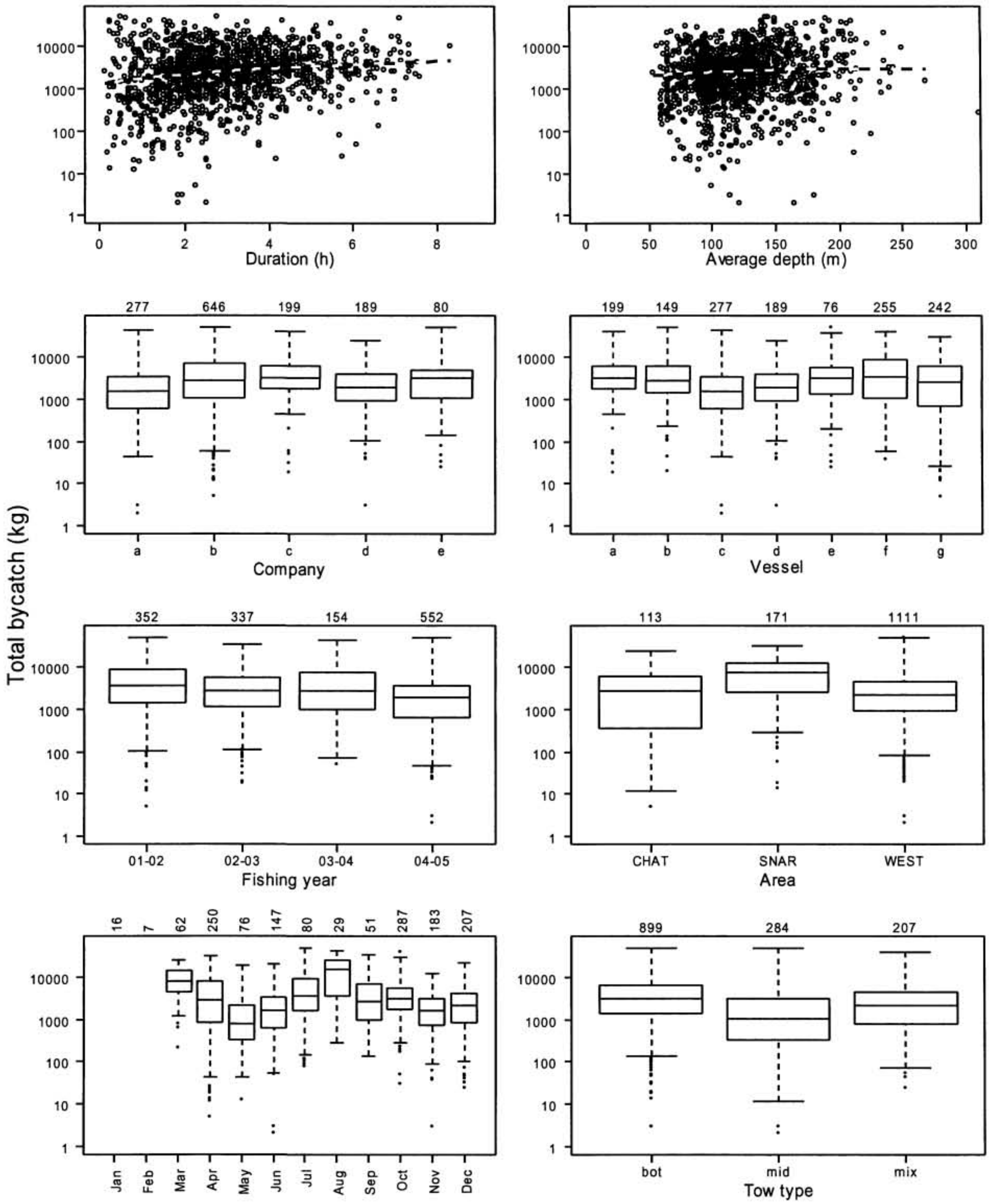

Figure 4: Total bycatch per tow plotted against some of the available variables. Total bycatch is plotted on a log scale. The dashed lines in the top two panels represent mean fits to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x 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: companies and vessels represented by fewer than 20 records were not plotted. Average depth is the average of the start and finish gear depths. See Figure 1 for area codes; bot, net on the bottom throughout the trawl; mid, net in midwater throughout the trawl; mix, trawl a mixture of bottom and midwater fishing.

3.3.2 Regression modelling and stratification of bycatch data

Regression tree analysis, using the log of the bycatch ratio (catch per hour trawled) as the predictand and examining each predictor in turn, was used to determine the most parsimonious combinations of areas and groupings of periods within the fishing year. Only about 1% of trawls caught no COM species bycatch and so no binomial regression was performed. The regression tree models did not indicate that any of the areas should be combined in the COM category but did suggest a split of the fishing year into five periods (Table 4). Combinations of the two smaller fisheries CHAT and SNAR were indicated in several models, especially for the individual species categories EMA, FRO, and RBT, and optimal splits of the fishing year were determined for all normal models for each species category and for binomial models where appropriate (Table 5). For species category BAR the binomial model predicting the probability of a catch of this species had such a low explanatory power that regression tree modelling was not pursued as stratification of the fishing year would be based on the more powerful normal model results. The regression tree models suggested splits of the fishing year into between three and eight periods, providing variables to use in subsequent models with as much explanatory power as the more arbitrary "month" variable but with considerably fewer degrees of freedom. The splitting process was restricted, in order to avoid creating variables with very few data points in its levels, by the constraint that there must be a minimum of 50 observations in a branch for a split to be attempted.

Table 4: Results of regression tree analyses on the optimal stratification of the area variable for describing rates of bycatch.

Species category	Area groupings	
	Normal model	Binomial model
COM	—	— (not done)
OTH	—	1) CHAT+SNAR 2) WEST
BAR	—	— (low power)
EMA	1) CHAT+SNAR 2) WEST	—
FRO	1) CHAT+SNAR 2) WEST	1) CHAT+SNAR 2) WEST
RBT	1) CHAT+SNAR 2) WEST	—

Table 5: Results of regression tree analyses on the optimal stratification of the fishing day variable for describing rates of bycatch. Split points are "day of the fishing year" where 1 = 1 October and 365 = 30 September.

Species category	Number of periods (split points)	
	Normal model	Binomial model
COM	5(29, 94, 204, 278)	— (not done)
OTH	4(19, 42, 212)	3(8, 163)
BAR	8(38, 47, 74, 82, 204, 281, 360)	— (low power)
EMA	6(15, 37, 65, 198, 208)	5(24, 37, 204, 332)
FRO	7(37, 64, 75, 219, 256, 272)	5(83, 103, 204, 266)
RBT	5(15, 155, 246, 299)	5(4, 180, 211, 264)

The unit of interest in the GLM models was the bycatch ratio, expressed as the log of catch (kg) per hour trawled. Of the 1408 observed trawls examined, only 15 (or 1%) did not record any bycatch of COM species, whereas 217 (15%) did not record any bycatch of OTH species. The equivalent percentages for the individual bycatch species were barracouta (BAR), 5%; blue mackerel (EMA), 40%; frostfish (FRO), 33%; redbait (RBT), 68%. For each species category except COM binomial regression models were run as well as normal models, thus allowing an examination of factors affecting the probability of catching the species.

In most of the initial models the variable *trip* had the greatest explanatory power, followed mostly by *duration*, *month* and *area*. The *trip* variable is of no use for stratification in this situation because many trips were not observed, and because of the difficulty of matching observer trips to vessel trips. When *trip* was removed from consideration in the models, much of its explanatory power was taken up by these other variables with little loss in the models' explanatory power. The influence of tow *duration* in the models indicates that not only do longer trawls tend to catch more bycatch species, but they also have a higher catch rate of bycatch species than shorter trawls. No variable stood out strongly as being the most influential in all models. The regression tree model-derived factor *period* was of greatest influence in COM bycatch, *vessel* or *duration* of greatest influence in OTH bycatch, and *period*, *area*, or *towtype* of greatest influence in the individual species models (Table 6). Despite falling levels of overall bycatch over time (see Section 3.3.1) *fyr* (fishing year) had little power in any of the models. The *depth* variable also was of lower importance in most of the models. Because of the limitations of the spread of observer data, stratification of ratios to use for annual bycatch estimates for each species group was restricted to two factors, fishing year plus one additional factor selected from the model results. Because of the unique nature of this fishery during the period being examined, whereby it is dominated by seven vessels all of which had some observer coverage, it was possible to use vessel as a factor for stratification, and this was done for OTH bycatch.

Table 6: Summary of GLM modelling of bycatch in the jack mackerel fishery. The numbers denote the order in which the variable entered the model; –, not selected; *towtype*, bottom or midwater; *v_length*, vessel length (m); *fyr*, fishing year.

Species category	Model type	R^2 (%)									Variable
			area	*duration*	*vessel*	*depth*	*period*	*towtype*	*v_ length*	*fyr*	*company*
COM	Normal	26.2	5	4	3	–	1	2	–	–	–
COM	Binomial	–	–	–	–	–	–	–	–	–	–
OTH	Normal	14.7	5	2	1	4	3	6	–	7	–
OTH	Binomial	12.8	5	1	3	–	2	6	–	4	–
BAR	Normal	34.5	3	4	6	5	1	2	–	–	–
BAR	Binomial	22.6	5	1	–	3	7	2	4	6	–
EMA	Normal	25.1	6	4	2	–	1	5	–	3	–
EMA	Binomial	27.0	1	6	4	3	2	5	–	–	–
FRO	Normal	29.2	4	7	3	5	2	1	–	6	–
FRO	Binomial	44.4	1	4	5	–	3	2	–	6	–
RBT	Normal	36.5	3	2	–	5	1	–	–	6	4
RBT	Binomial	22.5	2	–	3	5	1	6	–	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, the eighth most abundant bycatch species observed. A total catch of 101 t of this species was observed over the four years, and only 8% of it was retained. The next most discarded fish were thresher sharks, although the total observed catch amounted to only 13 t, most of which was discarded. After these two species only small amounts were discarded of a range of small bony fish and sharks, as well as a variety of invertebrates such as squids and jellyfish (see Appendix 1 for details).

Exploratory plots were prepared to examine the variability in the total level of discards per trawl with respect to some of the available factors (Figure 5). Unlike bycatch, the quantity of discards showed no relationship to trawl duration, with an overall median discard rate of about 45 $kg.h^{-1}$. Similarly, and again unlike bycatch, there was no relationship shown between median discard levels and depth. Discard levels varied considerably between companies and between vessels with median discard rates ranging from about 8 to 90 $kg.h^{-1}$ between the highest and lowest vessel and 8 to 70 $kg.h^{-1}$ between the highest and lowest company. As was the case for bycatch there was a decrease in discard levels in each year, from 80 $kg.h^{-1}$ in 2001–02 to 15 $kg.h^{-1}$ in 2003–04 and 2004–05, but as the median levels decreased the interquartile ranges widened indicating a high variability with the occasional high value remaining. Areas CHAT and SNAR had similar median discard levels (90–120 $kg.h^{-1}$) but in area WEST median discards were much less (about 30 $kg.h^{-1}$). There were insufficient data to describe discard patterns for all months, but plots show that discards were greatest in March and April and lowest in June and December. Discard levels were considerably lower in midwater trawls (13 $kg.h^{-1}$) than in bottom trawls (55 $kg.h^{-1}$).

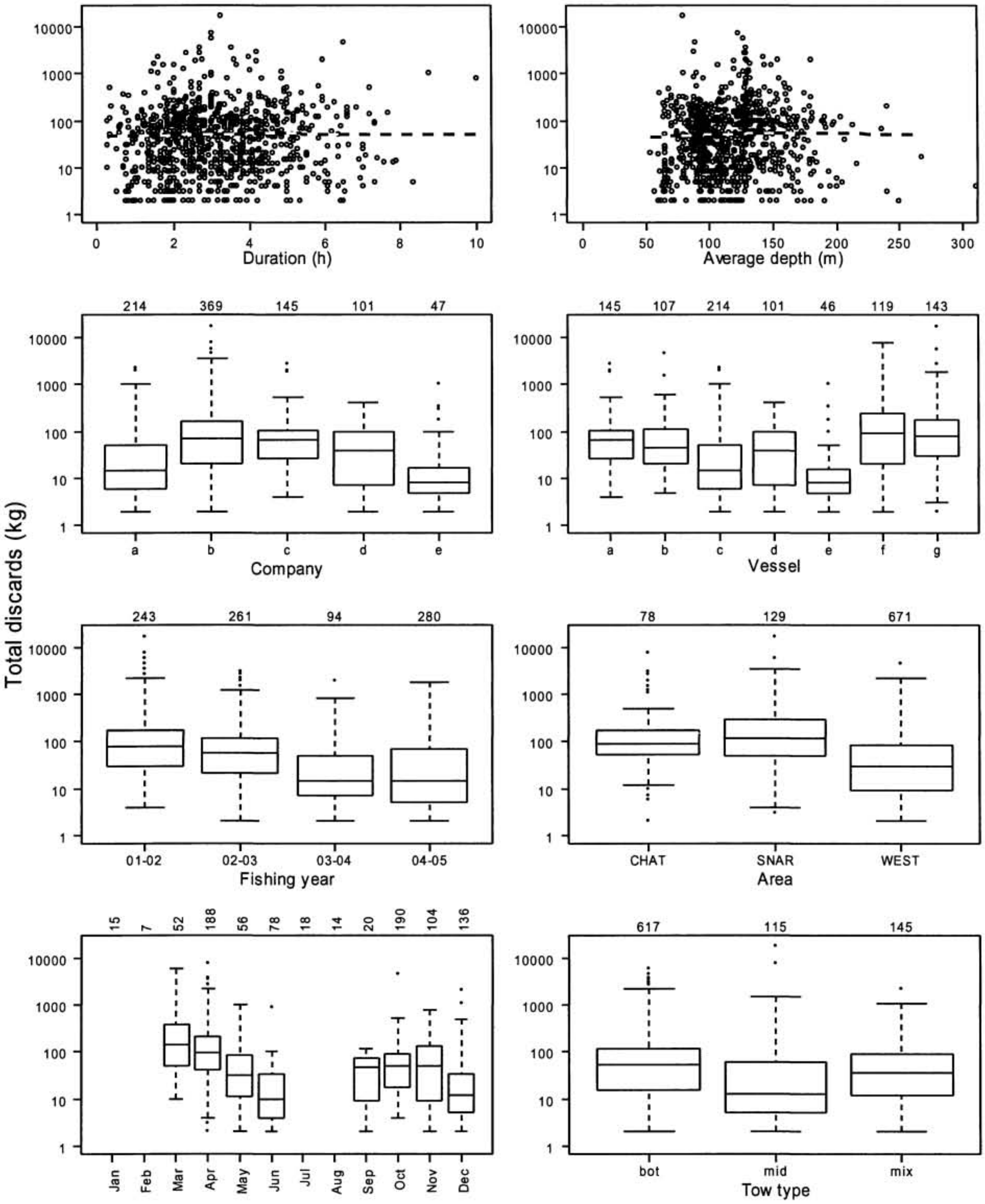

Figure 5: Total discards per tow plotted against some of the available variables (records with no discards excluded). Discards are plotted on a log scale. The dashed lines in the top two panels represent a mean fit to the data. The box and whisker plots show medians and lower and upper quartiles in the 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. Average depth is the average of the start and finish gear depths. See Figure 1 for area codes; bot, net on the bottom throughout the trawl; mid, net in midwater throughout the trawl; mix, trawl a mixture of bottom and midwater fishing.

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 areas CHAT and SNAR should be combined for both the COM and OTH species categories (Table 7). This grouping is convenient as it combines data from the two areas with the least number of records and reduces the number of area levels from three to two. Regression trees run using binomial models produced results which agreed with this pairing. Models also indicated the optimal number of split points for separating the fishing year into discrete periods; four for the normal COM and binomial OTH models and five for the binomial COM and normal OTH models (Table 8).

Table 7: Results of regression tree analyses on the optimal stratification of the area variable for describing rates of discards in the COM and OTH species categories.

Species category	Area groupings	
	Normal model	Binomial model
COM	1) CHAT+SNAR	1) CHAT+SNAR
	2) WEST	2) WEST
OTH	1) CHAT+SNAR	1) CHAT+SNAR
	2) WEST	2) WEST

Table 8: Results of regression tree analyses on the optimal stratification of the fishing day variable for describing rates of discards in the COM and OTH species categories.

Species category	Number of periods (split points)	
	Normal model	Binomial model
COM	4(44, 204, 299)	5(9, 36, 91, 269)
OTH	5(19, 69, 109, 270)	4(11, 80, 141)

The unit of interest in the normal regression analyses was the discard ratio, expressed as the log of discards (kg) per hour, and in the binomial models the probability of a discard was modelled. The observer data indicated that, as in other fisheries, discarding of the target species was very rare, occurring in only 9 of the 1272 (under 1%) single tow processing groups observed. Discarding was far more common for COM species (686 groups, 54%), and for OTH species (529 groups, 41%), but not for the most commonly caught individual bycatch species (all under 1%). Both linear and binomial regressions were run for the COM and OTH categories but, with such a low frequency of discarding, models were not run for the target species and individual bycatch species and no stratification of the data was attempted for these species.

As for bycatch, initial models showed that the *trip* variable had the most influence in both the COM and OTH species categories for both types of model. When *trip* was not considered in the COM regressions, fishing year (*fyr*) (in the linear model) and *period* (in the binomial model) were elevated to primary importance (Table 9). The importance of *period* in the binomial model of COM discards is offset by its minor influence in, and the high explanatory power of, the normal model. The *period* variable was only fifth most important in the normal model and the number of periods and their split points differed in any case between models. In the models for OTH, vessel was the main explanatory variable for both normal and binomial models. Stratification was therefore by fishing year alone for COM discards, and for fishing year and vessel for OTH discards.

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; –, not selected; *towtype*, bottom or midwater; *v_tonnage*, vessel tonnage (t); *fyr*, fishing year; *company*, vessel company; *v_nation*, vessel nationality.

Species category	Model type	R^2 (%)	Variable								
			vessel	*depth*	*duration*	*fyr*	*period*	*towtype*	*v_nation*	*v_tonnage*	*company*
COM	Linear	45.7	–	–	2	1	5	4	3	6	–
COM	Binomial	19.9	–	–	3	–	1	2	5	–	4
OTH	Linear	24.2	1	5	2	4	3	–	–	–	–
OTH	Binomial	22.8	1	–	4	5	2	3	–	–	–

3.5 Calculation of bycatch

3.5.1 Bycatch ratios

Bycatch ratios for COM species were calculated from the observer data for each of the five periods and four fishing years. Insufficient records (either less than 50 or representing only a single trip) were available from some periods in some years to enable ratios to be estimated and in these cases an overall ratio (representing all years for the period) was substituted in the total bycatch calculations. For OTH bycatch there were fewer year/vessel strata with sufficient numbers of records. Because of this and because bycatch rates of OTH species were shown not to have been influenced by fishing year, bycatch ratios were calculated for each vessel using data from all years. The small number of records from vessels which were not one of the fleet of seven major operators were combined into an 'other vessels' category. Fishing year was also shown to have had little influence on bycatch rates of BAR, FRO, and RBT, and so bycatch rates for these species similarly were calculated for the selected strata using data from all years. Fishing year had some effect on bycatch rates of EMA and so rates were calculated for each period and fishing year where data were sufficient. Variance in bycatch rates in each stratum was calculated using the bootstrap methods described above.

These ratios are used primarily in conjunction with target fishery effort totals to provide estimates of total bycatch in each species category; however, they are also useful for describing broad patterns in bycatch rates (Figure 6). Bycatch rates of COM species were higher in the July–September and January–April periods than at other times of the year area. Overall bycatch rates of OTH species by vessel were between about 25 and 50 $kg.h^{-1}$ for the seven main vessels, but much greater (nearly 200 $kg.h^{-1}$) for the other (smaller) vessels combined. Bottom trawls caught BAR at nearly twice the rate of midwater trawls, and EMA was caught at low rates in areas CHAT and SNAR and higher but variable rates in area WEST. Similarly, FRO was caught at a much higher rate in area WEST than in the other two areas. RBT catch rates were lowest in the mid-October–March period and highest in August/September. A summary of bycatch rates, with standard deviations, is given in Appendix 2.

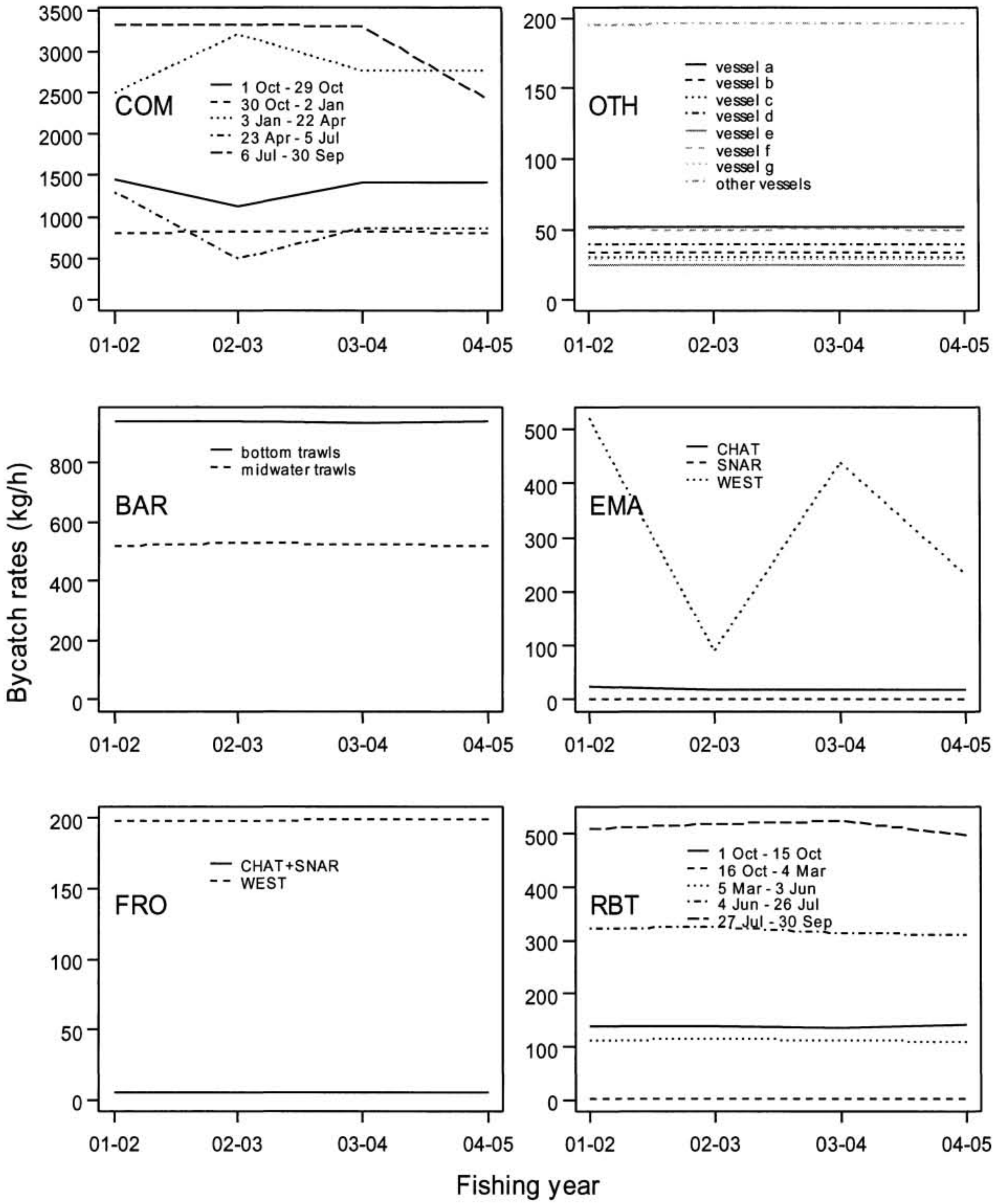

Figure 6: Annual bycatch rates by the areas, periods, vessels, or trawl types used for stratification for five species categories, in the jack mackerel trawl fishery. Bycatch rates shown are the median of the bootstrap sample of 1000.

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 10).

Bycatch of COM species decreased from 11 400 t in 2001–02 to less than 8000 t in 2004–05, and bycatch of OTH species was low in each year, ranging from 240 t to 540 t. Bycatch of all species combined (TOT) decreased from about 12 000 t in 2001–02 to about 8000 t in 2004–05. Total annual bycatch was at its highest level in this fishery from 1997–98 to 2001–02. The decreasing catches over the last four fishing years has brought total bycatch down to the levels of the mid 1990s (Figure 7). Estimates of COM and OTH bycatch are not shown for the earlier years in Figure 7 as the species classified as commercial varied between studies and so estimates would not be comparable.

Barracouta (BAR) was the main commercial species caught in each year, contributing about 40% of the COM species bycatch, followed by blue mackerel (EMA), frostfish (FRO), and redbait (RBT) (Table 11). Together these four species accounted for 70% or more of the commercial catch in each year. The raw observer data summarised in Appendix 1 serves as a rough check on this figure, showing that these four species made up 86% of the observed bycatch between 2001–02 and 2004–05. Bycatch levels of these species (excluding frostfish which is examined for the first time here) have changed little since the previous analysis (Anderson 2004a) (Figure 8). The variability in the confidence intervals between studies is due mainly to different methods of calculation.

Table 10: Estimates of bycatch (rounded to the nearest 10 or 100 t) in the target jack mackerel trawl fishery by fishing year and species categories COM, OTH, and overall (TOT), with 95% confidence intervals in parentheses.

	Species category					
	COM		OTH		TOT	
2001–02	11 400	(9 900–13 200)	540	(280–620)	11 940	(10 180–13 820)
2002–03	9 900	(8 000–11 700)	400	(280–440)	10 300	(8 280–12 140)
2003–04	7 500	(6 700–8 600)	240	(210–270)	7 740	(6 910–8 870)
2004–05	7 800	(7 000–8 600)	250	(210–270)	8 050	(7 210–8 870)

Table 11: Estimates of bycatch (rounded to the nearest 10 t) in the target jack mackerel trawl fishery by fishing year for the species categories (barracouta (BAR), blue mackerel (EMA), frostfish (FRO), and redbait (RBT)) examined separately, with 95% confidence intervals in parentheses.

	Species category							
	BAR		EMA		FRO		RBT	
2001–02	4 400	(2 500–6 900)	3 200	(1 400–7 500)	1 100	(900–1 500)	1 100	(500–1 800)
2002–03	4 200	(2 200–7 000)	600	(400–900)	1 200	(1 000–1 600)	1 000	(500–1 600)
2003–04	3 100	(1 600–5 300)	2 500	(1 400–3 500)	1 100	(800–1 400)	900	(400–1 500)
2004–05	3 200	(1 500–5 500)	1 300	(700–2 100)	1 100	(900–1 500)	700	(300–1 200)

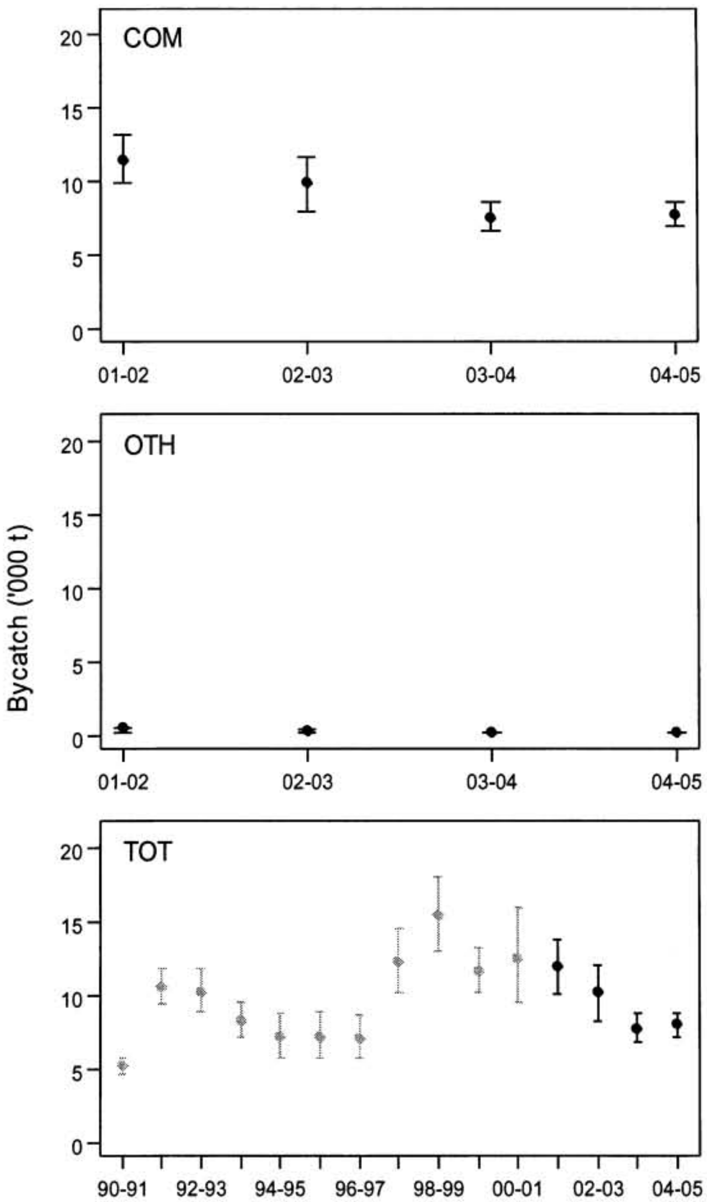

Figure 7: Annual estimates of fish bycatch in the target jack mackerel trawl fishery for the 2001–02 to 2004–05 fishing years (in black), calculated for commercial species (COM), non-commercial species (OTH), and overall (TOT). Also shown (in grey) are estimates of overall bycatch calculated for 1990–91 to 2000–01 by Anderson et al. (2000) and Anderson (2004a). Error bars show the 95% confidence intervals.

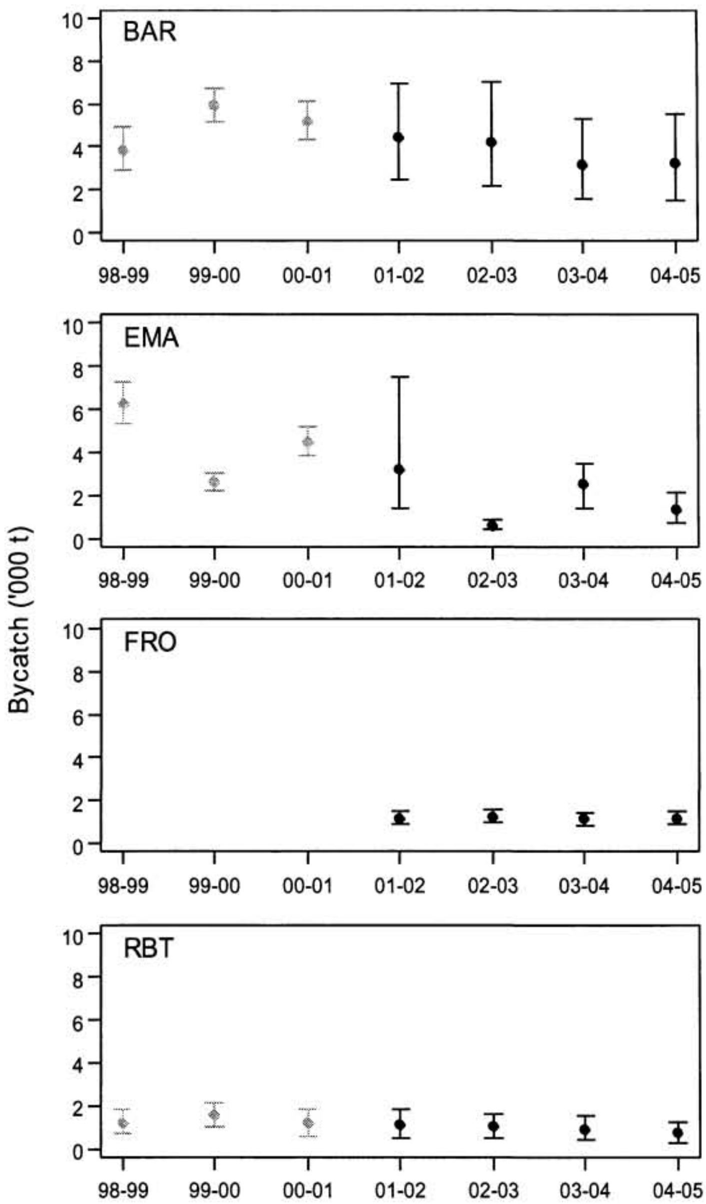

Figure 8: Annual estimates of bycatch in the target jack mackerel trawl fishery for the 2001–02 to 2004–05 fishing years (in black), calculated for barracouta (BAR), blue mackerel (EMA), frostfish (FRO), and redbait (RBT). Also shown (in grey) are estimates of barracouta, blue mackerel, and redbait bycatch calculated for 1998–99 to 2000–01 by Anderson (2004a). Error bars show the 95% confidence intervals.

3.6 Calculation of discards

3.6.1 Discard ratios

Because of the very infrequent discarding of jack mackerel nothing but an overall discard rate was calculated for the target species, based on all observed trawls. Discard ratios for COM species were calculated for each fishing year and for OTH species for each vessel and fishing year where possible. Discards were not calculated for the individual bycatch species (BAR, EMA, FRO, RBT) as discarding of these species was very low and infrequent.

Discarding of COM species decreased from almost 70 $kg.h^{-1}$ in 2001–02 to less than 10 $kg.h^{-1}$ in 2003–04 and 2004–05 (Figure 9).

Fish discards for the main vessels in the OTH species category ranged from about 6 $kg.h^{-1}$ (vessel e) to as much as 20 $kg.h^{-1}$ (vessel f in 2001–02). For the other (smaller) vessels combined, the all years rate of OTH discards was considerably greater, at close to 40 $kg.h^{-1}$. A summary of the discard rates, with standard deviations, is given in Appendix 3.

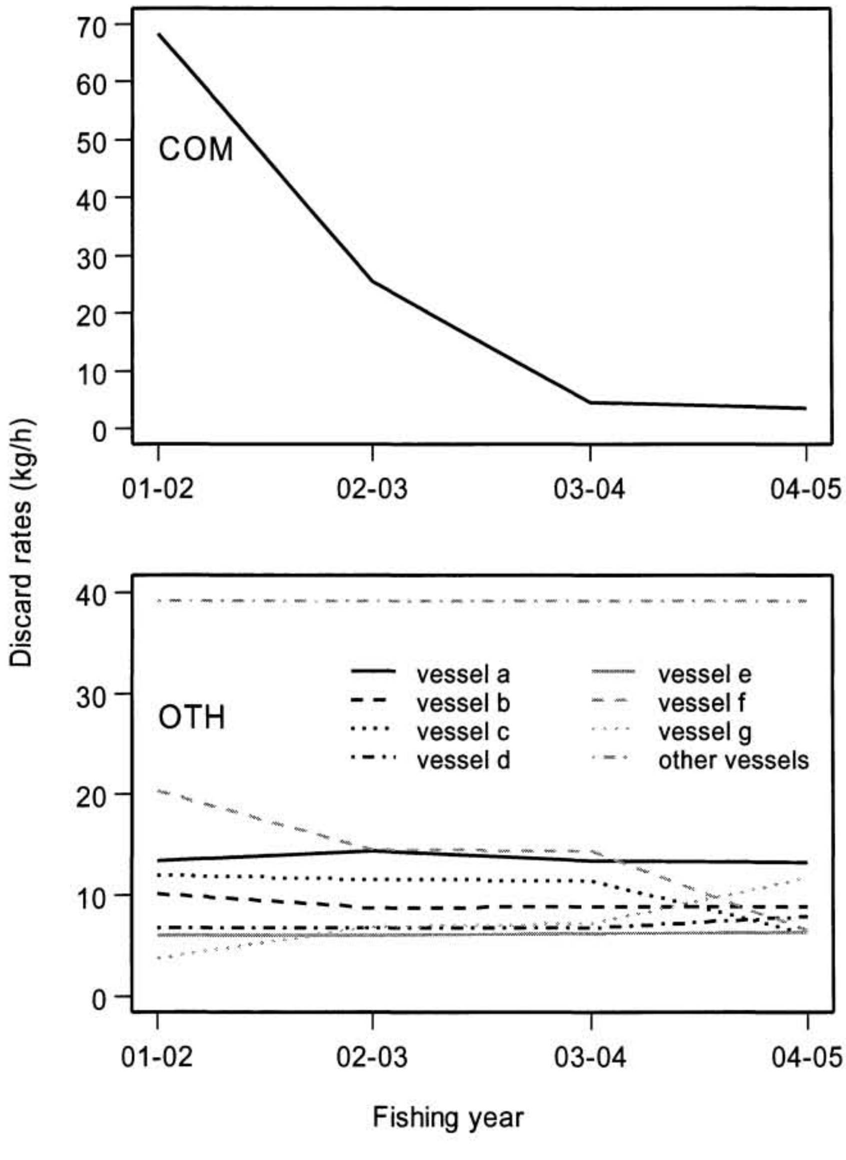

Figure 9: Annual discard rates of commercial species (COM) and non-commercial species (OTH), for each level of the factors used for stratification, in the jack mackerel trawl fishery. Discard rates shown are the median of the bootstrap sample of 1000.

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.

Only 9 of the 1272 observed tows in the analysis recorded any discards of JMA, amounting to just 1.3 kg per hour trawled. With such little data it was not sensible to provide anything other than a very simple estimate of annual discard levels. This fraction was therefore simply applied to the total annual trawl duration in the target fishery, giving a (rounded) estimate of 10 t in each year, with no attempt made to provide an estimate of precision (Table 12). The frequency of observed instances of JMA discards was greater during the periods examined before this study, when estimated discards were between 30 and 340 t per year (Figure 10). The apparent decrease in JMA discards may be overemphasised by these figures, as a few instances of large amounts of lost fish from rips in the net or intentional releases of fish during landing can have a big influence of the estimates if these rare events happen to be observed. Although no instances of large fish losses have been observed in recent years, they are likely to occur from time to time, and the real variability in JMA discards is not shown by the confidence intervals in Figure 10.

Annual estimates of discards were low but variable in the COM category (20–550 t) with a wide confidence interval for the 2001–02 estimate, and all confidence intervals overlapping. Annual discard levels were consistently low in the OTH species category (60–130 t) with relatively tight confidence intervals, reflecting the low catches of fish in this category (Figure 10).

Total annual discards decreased over the four years, continuing a trend that began in 1998–99, to a level of 90–100 t. This is about 5% of the level of 1997–98 and is lower than in any previous year going back as far as 1990–91 (Figure 10).

Estimates of COM and OTH discards were not shown for the earlier years for the same reasons that bycatch was not shown for these groups (see Section 3.5.2).

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 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.

Table 12: Estimates of discards (t) in the target jack mackerel trawl fishery by year, for the species categories JMA, COM, OTH, and overall (TOT), with 95% confidence intervals in parentheses. Results are rounded to the nearest 10 or 100 t. –, not estimated

	Species category							
Fishing year	JMA		COM		OTH		TOT	
2001–02	10	–	550	(100–1 100)	130	(70–150)	690	(170–1 250)
2002–03	10	–	190	(100–300)	100	(70–130)	300	(170–430)
2003–04	10	–	30	(0–100)	60	(50–80)	100	(50–180)
2004–05	10	–	20	(0–100)	60	(50–70)	90	(50–170)

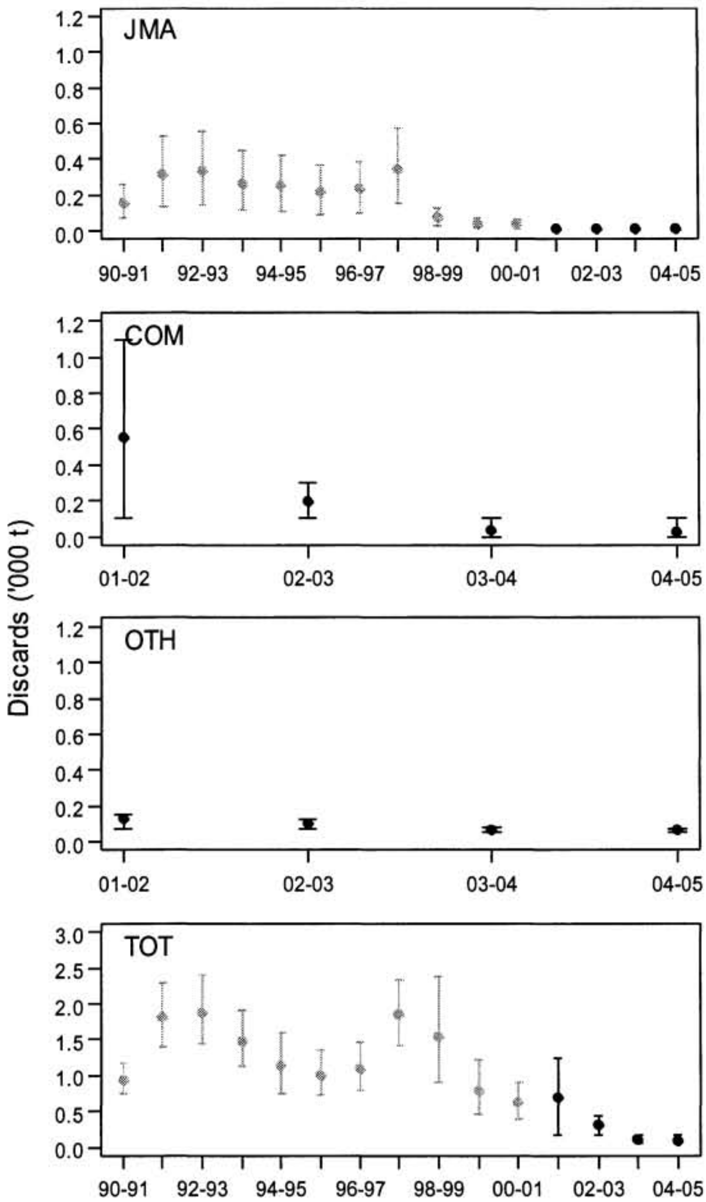

Figure 10: Annual estimates of fish discards in the target jack mackerel trawl fishery for the 2001–02 to 2004–05 fishing years (in black), calculated for jack mackerel (JMA), commercial species (COM), non-commercial species (OTH), and overall (TOT). Also shown (in grey) are estimates of jack mackerel and overall discards calculated for 1990–91 to 2000–01 by Anderson et al. (2000) and Anderson (2004a). Error bars show the 95% confidence intervals.

3.7 Fraction of the jack mackerel fishery represented by the target trawl fishery

Estimated annual catches from the jack mackerel target trawl fishery represented between 86% and 92% of the total annual landings of jack mackerel in this fishery (landings associated with the purse-seine fishery in JMA 1 are excluded) during the period examined (Table 13). Discarding associated with jack mackerel caught while trawling for other species (the catch which accounts for the remainder of the jack mackerel trawl fishery, and is not considered here) therefore is likely to contribute only a small fraction of the total jack mackerel trawl fishery discards.

Table 13: Estimated catch totals of jack mackerel from the target trawl fishery, and all reported landings of jack mackerel from the QMS, by year.

Fishing year	Target fishery estimated catch (t)	Total fishery reported catch (t)*	Target/total (%)
2001–02	23 423	27 338	86
2002–03	26 108	28 309	92
2003–04	26 826	29 588	91
2004–05	33 351	37 213	90

* From Ministry of Fisheries, Science Group (2006), sum of JMA 3 and JMA 7 landings.

4. DISCUSSION

The precision of the estimates of bycatch and discard levels using these methods is strongly linked to the coverage of the fishery achieved by observers. Not only must a reasonable fraction of the target fishery be observed, but also observer placements must be well spread over the spatial extent of the fishery, the different types of vessels, times of the year, and any other factor which may affect patterns of bycatch.

There is also potential for bias in these estimates of bycatch and discards. A critical assumption when scaling ratios from the observed portion of the fishery to the entire fishery is that fishing and processing behaviour on observed vessels is no different from that on unobserved vessels. If vessels tended to discard more or less fish when an observer was present, or fish in areas which would maximise or minimise bycatch, this would clearly bias the results. There are few studies which have attempted to detect this sort of bias but one which did, an examination of a multispecies trawl fishery off the east coast of Australia, found little evidence of bias (Liggins et al. 1997). The percieved benefits of altered behaviour under observation will vary among fisheries and among the management regimes of different states so it doesn't necessarily follow that there is no such bias in the New Zealand jack mackerel fishery. However, 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, etc., which can generally be returned to the sea unharmed) or an observer is on board. There are no regulations regarding discarding of non-quota species.

The annual level of observer coverage in this fishery varied considerably during the four years examined representing between 8% and 27% of the target fishery catch (14.5% over all years). The 2003–04 fishing year received the least coverage, 158 tows compared with 340–560 in the other three years, and lower than in any year for this fishery since 1990–91 (see Anderson et al. 2000). Graphical analysis showed that observers covered almost the complete geographical range of the commercial target fishery and, although there was very low coverage (total 15 trawls) outside of the main fishery (WEST) in 2003-04 and 2004–05, observer coverage was rightly concentrated in this area. This is a year round fishery and it would be unreasonable to expect the observer programme to be able to match their level of effort to that of the fleet when there are commitments to other, strongly seasonal, fisheries. Observer coverage was therefore more punctuated over the fishing year, with periods in each year when large chunks of commercial fishing effort were not observed. However, observer effort was spread differently in each year so that, over the four years combined, coverage was reasonably well matched to the total commercial effort. With the fleet dominated by just seven large trawlers observer placements were able to be arranged so as to cover each of these vessels in most years.

The multi-level bootstrap methods used to calculate precision provided more realistic estimates than in previous analyses as they took into account the effect of correlation between tows in the same trip and stratum. The difference between the methods can be gauged to some extent by comparing confidence intervals from the two methods in Figures 7 and 8. These show considerably wider ranges for the updated method in some cases, e.g., discards of barracouta, but similar ranges in other species categories. Another difference between this study and the previous two studies (Anderson et al. 2000, Anderson 2004a) which may have affected estimates of precision was the form of the ratio estimator. In the previous analyses, bycatch in each tow was measured relative to the estimated catch of jack mackerel whereas in this study it was measured relative to tow duration.

The use of regression tree modelling was a useful development in the methodology from the previous analyses. This technique enabled a refinement of the approach used to stratify the fishery and, by combining areas and periods with similar patterns of bycatch and discards, reduced the number of strata and therefore simplified the bootstrap procedures. The dominance of this fishery by a few similar vessels not only enabled the analyses to be stratified by vessel where appropriate, but probably also helped to decrease the variability in bycatch and discard rates caused by a wide range of vessel sizes and types, as has been observed in, e.g., the hoki fishery (Anderson & Smith 2005). It was clearly apparent that the *vessel* variable had less influence overall in the regression models run in this analysis than in those run for other fisheries. The variable *period* (as determined from regression tree partitioning) proved to be useful for categorising variability in two cases, bycatch of commercial species and redbait separately, and *tow type* (bottom or midwater), and *area* were also used to stratify calculations of bycatch and discards.

These methods appear to estimate levels of bycatch and discards reasonably well for this fishery, but precision is only estimated and with no data available from 70–90% of the fishery there is potential for the precision to have been underestimated. Small improvements in precision may be possible at similar levels of observer coverage with improvements in the spread of coverage, but large improvements will be possible only by significantly increasing the overall level of observer coverage. Alternatively, improvements in commercial catch effort data collection, to require recording of catch and discard weights in greater detail, might provide a viable alternative to the current methodology.

The jack mackerel fishery has previously been shown to be among New Zealand's more efficient fisheries, with about 0.06–0.07 kg of discards per kg of jack mackerel caught from 1990–91 to 2000–01 (Anderson et al. 2000, Anderson 2004a). This study shows that this may have improved further, as while the annual catch has been increasing, annual discards have been decreasing. The equivalent value for the current period (2001–02 to 2004–05) is 0.011 for the four years combined. Equivalent values for other New Zealand trawl fisheries are: southern blue whiting 0.02 kg; oreos, 0.05 kg; hoki, 0.06 kg; arrow squid, 0.14 kg; orange roughy, 0.16; scampi 3.5 kg (Anderson, Unpublished results, Anderson 2004a, 2004b, Anderson & Smith 2005).

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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 or species groups by weight from all observer records for the target trawl fishery for jack mackerel from 1 Oct 2001 to 30 Sep 2005. 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
JMA	Jack mackerel	*Trachurus declivis, T.m., T.nz.*	15 978	69.53	100.0
BAR	Barracouta	*Thyrsites atun*	3 593	15.64	100.0
EMA	Blue mackerel	*Scomber australasicus*	1 093	4.76	100.0
FRO	Frostfish	*Lepidopus caudatus*	712	3.10	100.0
RBT	Redbait	*Emmelichthys nitidus*	627	2.73	95.0
SQU	Arrow squid	*Nototodarus sloanii & N. gouldi*	184	0.80	100.0
HOK	Hoki	*Macruronus novaezelandiae*	138	0.60	100.0
WAR	Blue warehou	*Seriolella brama*	128	0.56	100.0
SPD	Spiny dogfish	*Squalus acanthias*	101	0.44	8.0
SWA	Silver warehou	*Seriolella punctata*	73	0.32	100.0
SDO	Silver dory	*Cyttus novaezealandiae*	65	0.28	100.0
SNA	Snapper	*Pagrus auratus*	51	0.22	100.0
KIN	Kingfish	*Seriola lalandi*	30	0.13	99.7
TRE	Trevally	*Pseudocaranx dentex*	27	0.12	100.0
GUR	Gurnard	*Chelidonichthys kumu*	17	0.08	100.0
RBM	Rays bream	*Brama brama*	17	0.07	100.0
JDO	John dory	*Zeus faber*	13	0.06	99.5
THR	Thresher shark	*Alopias vulpinus*	13	0.06	3.4
SCH	School shark	*Galeorhinus galeus*	11	0.05	100.0
PIL	Pilchard	*Sardinops neopilchardus*	10	0.04	100.0
TAR	Tarakihi	*Nemadactylus macropterus*	9	0.04	99.9
HAK	Hake	*Merluccius australis*	9	0.04	100.0
POP	Porcupine fish	*Allomycterus jaculiferus*	8	0.04	15.6
STU	Slender tuna	*Allothunnus fallai*	7	0.03	56.9
LIN	Ling	*Genypterus blacodes*	7	0.03	100.0
SQX	Squid		6	0.03	100.0
JFI	Jellyfish		5	0.02	0.0
HPB	Hapuku & bass	*Polyprion oxygeneios & P. americanus*	4	0.02	100.0
SAL	Salps		4	0.02	27.5
SUN	Sunfish	*Mola mola*	4	0.02	0.3
RCO	Red cod	*Pseudophycis bachus*	3	0.01	99.4
MAK	Mako shark	*Isurus oxyrinchus*	3	0.01	51.3
LEA	Leatherjacket	*Parika scaber*	2	0.01	12.7
JAV	Javelin fish	*Lepidorhynchus denticulatus*	2	0.01	100.0
BEN	Scabbardfish	*Benthodesmus* spp.	2	0.01	100.0
POS	Porbeagle shark	*Lamna nasus*	2	0.01	14.6
LDO	Lookdown dory	*Cyttus traversi*	2	0.01	100.0
CDO	Capro dory	*Capromimus abbreviatus*	1	0.01	99.7
SKI	Gemfish	*Rexea solandri*	1	0.01	100.0
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	1	0.01	100.0
ANC	Anchovy	*Engraulis australis*	1	0.01	100.0
RAT	Rattails	Macrouridae	1	0.01	97.6
RDO	Rosy dory	*Cyttopsis roseus*	1	0.00	100.0
BWS	Blue shark	*Prionace glauca*	1	0.00	44.3
SSK	Smooth skate	*Dipturus innominatus*	1	0.00	94.0
ERA	Electric ray	*Torpedo fairchildi*	1	0.00	38.9
SKA	Skate	Rajidae & Arhynchobatidae (Families)	1	0.00	2.1
KAH	Kahawai	*Arripis trutta*	1	0.00	100.0
GSH	Ghost shark	*Hydrolagus novaezealandiae*	1	0.00	100.0
STN	Southern bluefin tuna	*Thunnus maccoyii*	1	0.00	53.8

Appendix 2: Bycatch rates by fishing year and stratum for six bycatch species categories in the jack mackerel fishery. Standard deviations calculated from bootstrap samples are shown in parentheses. See Figure 1 for area boundaries

COM: one, 1 Oct–29 Oct; two, 30 Oct–2 Jan; three, 3 Jan–22 Apr; four, 23 Apr–5 Jul; five, 6 Jul–30 Sep

	Mean bycatch rate (kg/h)				
	one	two	three	four	five
2001–02	1465(153)	812(70)	2496(237)	1324(297)	3365(594)
2002–03	1138(117)	812(69)	3214(737)	502(60)	3382(596)
2003–04	1431(190)	814(70)	2784(310)	861(107)	3363(578)
2004–05	1435(193)	798(85)	2788(300)	859(85)	2425(429)

OTH

	Mean bycatch rate (kg/h)							
	vessel a	vessel b	vessel c	vessel d	vessel e	vessel f	vessel g	other vessels
2001–02	52(5)	34(4)	31(6)	40(6)	25(5)	51(9)	29(5)	179(60)
2002–03	52(5)	34(4)	31(6)	40(6)	25(5)	50(9)	29(6)	180(58)
2003–04	52(5)	34(4)	31(6)	40(6)	25(5)	51(9)	29(5)	179(59)
2004–05	52(5)	34(4)	31(6)	39(6)	25(5)	51(9)	29(5)	180(61)

BAR

	Mean bycatch rate (kg/h)	
	bottom trawl	midwater trawl
2001–02	944(129)	538(179)
2002–03	939(132)	544(182)
2003–04	941(132)	541(183)
2004–05	946(130)	534(175)

EMA

	Mean bycatch rate (kg/h)		
	CHAT	SNAR	WEST
2001–02	23(13)	0.02(0.02)	596(293)
2002–03	19(13)	0.01(0.01)	93(17)
2003–04	19(13)	0.01(0.01)	442(97)
2004–05	19(14)	0.01(0.01)	232(61)

FRO

	Mean bycatch rate (kg/h)	
	CHAT+SNAR	WEST
2001–02	6(4)	198(27)
2002–03	6(4)	198(26)
2003–04	6(4)	200(26)
2004–05	6(4)	199(26)

RBT: one, 1 Oct–15 Oct; two, 16 Oct–4 Mar; three, 5 Mar–3 Jun; four, 4 Jun–26 Jul; five, 27 Jul–30 Sep

	Mean bycatch rate (kg/h)				
	one	two	three	four	five
2001–02	145(75)	2(1)	120(50)	341(178)	561(310)
2002–03	148(75)	2(1)	119(47)	350(189)	555(319)
2003–04	143(72)	2(1)	118(48)	341(188)	578(329)
2004–05	149(76)	2(1)	116(45)	333(173)	548(309)

Appendix 3: Discard rates by fishing year and stratum for the commercial (COM) and non-commercial (OTH) species categories in the jack mackerel fishery. Standard deviations calculated from bootstrap samples are shown in parentheses.

COM

	Mean discard rate (kg/h)
2001–02	71(36)
2002–03	26(9)
2003–04	5(2)
2004–05	4(2)

OTH

							Mean discard rate (kg/h)	
	vessel a	vessel b	vessel c	vessel d	vessel e	vessel f	vessel g	other vessels
2001–02	13(2)	10(2)	12(5)	7(1)	6(4)	21(9)	4(1)	36(10)
2002–03	14(2)	9(1)	12(5)	7(1)	6(4)	16(9)	7(3)	36(10)
2003–04	13(2)	9(1)	12(5)	7(1)	7(4)	15(8)	7(4)	37(9)
2004–05	13(2)	9(1)	7(3)	8(1)	7(4)	7(2)	12(3)	37(10)