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EXECUTIVE SUMMARY

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Commercial catch-effort data and fisheries observer records of catch and discards by species provided by the Ministry of Fisheries (MFish) were used to estimate the rate and level of non-target fish catch (bycatch) and discards (fish returned to the sea whole) in the southern blue whiting trawl fishery for each fishing year from 2002–03 to 2006–07. Estimates were made separately for several categories of catch; southern blue whiting, other quota species combined, all commercial species combined, non-quota species combined, and three commonly caught individual species, hake, hoki, and ling.

Linear mixed-effect models (LMEs) were used to identify key factors influencing variability in observed bycatch and discard levels in order to provide appropriate stratification for the analyses. Regression tree methods were used to optimise the number of levels of the key variable, fishing depth, while maintaining the explanatory power of the models. This procedure divided fishing depth into two or three strata, depending on the catch category, and these were used to stratify the calculation of annual bycatch and discard totals in all catch categories.

A ratio estimator, based on trawl duration, was used to calculate bycatch and discard rates for each catch category in each depth stratum and fishing year. These ratios were then applied to trawl duration totals calculated from commercial catch-effort data to make 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 depth stratum, were used to estimate the variance in the ratios for all trawls in each stratum, and provide confidence intervals for the annual bycatch and discard estimates.

Southern blue whiting accounted for more than 99% of the total estimated catch recorded by observers and more than 99% of the total reported catch from the fishery based on catch-effort forms. The remainder of the catch comprised mainly the commercial species ling, hake, and hoki, as well as smaller amounts of a range of commercial and non-commercial species, including porbeagle shark, jack mackerel, rattails, Ray's bream, and silverside. None of the additional 100 or so species or species groups recorded by observers accounted for more than 0.02% of the observed catch during the period.

Total annual bycatch estimates for the period ranged from about 40 t to 390 t, compared with approximate target species catches in the same period of about 22 000 to 42 000 t. This bycatch was fairly evenly split between commercial species (55%) and non-commercial species (45%). Total annual bycatch decreased during the period, to an historic low of 40 t in 2006–07.

Total annual discard estimates between 2002 and 2007 ranged from about 90 t to 250 t per year. Discard amounts sometimes exceeded bycatch due to the large contribution of the target species (50–230 t per year) to total discards – the result usually of fish losses during recovery of the trawl. Discarding of commercial species was virtually non-existent in most years and discards of non-commercial species amounted to only 10–50 t per year. The main species discarded were rattails and porbeagle sharks. Discard levels during 2002–07 remained at the low values determined for the end of the preceding assessment period. The level of annual discards in this fishery, calculated as a fraction of the catch of the target species, is lower than in any other major New Zealand trawl fishery, with only 0.005 kg of discarded fish for every 1 kg of southern blue whiting caught.

1. INTRODUCTION

Discarding of low value fish species has been a major problem in fisheries the world over, with an estimated 7.3 million tonnes (t) of dead or dying fish returned to the sea annually (Kelleher 2004). This is an improvement on the situation in the late 1980s and early 1990s when it was estimated that 20–22 million t were discarded annually (FAO 1999) and is due mostly to higher retention rates and improved fishing methods.

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" in New Zealand waters. 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 southern blue whiting (*Micromesistius australis*) trawl fishery 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, and discards of southern blue whiting, in the southern blue whiting trawl fishery is estimated – based on MFish observer records of catch and discards by species and catch effort data collected by commercial vessels.

Southern blue whiting are restricted almost entirely to the waters of the sub-Antarctic, below the latitude of about 47° S (Anderson et al. 1998) (Figure 1). Spread around the Campbell Plateau and Bounty Plateau, they aggregate to spawn in August and September in several discrete areas, which are assumed to constitute four separate stocks for stock assessment. The fishery operates almost exclusively in these areas (less than 20 t per year has been reported from outside this area since 2000–01) and during these months. The fishery usually begins in each season at the Bounty Plateau, where 2–6 vessels fish for about 2 weeks before moving to the main Campbell Island Rise fishery where they are joined by 10–15 other vessels. The fishery on the Campbell Island Rise operates on two aggregations (divided by a line at latitude 52.5° S (Hanchet et al. 2006)), and runs from early September to early October, moving from north to south. Since about 2000 there has been very little targeted fishing in the smaller Auckland Islands fishery, with most of the landings now coming as bycatch from other fisheries outside the southern blue whiting spawning season. This was true too for the Pukaki Rise fishery in the early 2000s, but in the 2005–06 and 2006–07 fishing years most of the catch has come from targeted fishing, typically later in the spawning season.

Most of the catch is taken from depths of 250–600 m by chartered Japanese (surimi) and Russian or Ukranian (dressed fish) trawlers using a mixture of bottom and midwater trawling (Ministry of Fisheries 2007). In recent years, however, replacement and reflagging of vessels has led to increasing numbers of vessels from New Zealand, Korea, Malta, and other nations (Hanchet et al. 2006). The main bycatch species in this fishery, as identified by Clark et al. (2000) and Anderson (2004a), are ling (*Genypterus blacodes*), hake (*Merluccius australis*), and hoki (*Macruronus novaezelandiae*), with rattails (Macrouridae), porbeagle shark (*Lamna nasus*), white warehou (*Seriolella caerulea*), arrow squid (*Nototodarus* spp.), silverside (*Argentina elongata*), and dark ghost shark (*Hydrolagus novaezelandiae*) also frequently caught.

The southern blue whiting fishery is large, with average reported annual landings over the last five years of about 27 000 t (Ministry of Fisheries 2009) and export earnings of NZ$ 14 million in 2007 (MFish website figures). With up to 1000 trawls per year in this fishery, there is considerable potential to make significant catches of both target and non-target species that are unwanted due to species, size, damage, fish hold storage limitations, or which are lost and moribund through operational inefficiencies and predation.

Information on the level of bycatch and discards in commercial fisheries is important for ecosystem management of fisheries. This approach to fisheries management requires an assessment of the impact on non-target species which can be taken into account when making decisions on allowable fishing methods, area and seasonal closures, effort and catch limits, etc. Estimates of target species discards can be used to fine tune the catch history (fishing mortality) for the species being assessed, which often either does not take into account mortality over and above reported landings, or is simply increased by an arbitrary amount for some or all years. The analysis undertaken here provides some useful information for this process, including the identification of key factors influencing the level of bycatch and discards in the southern blue whiting trawl fishery.

This report updates two earlier studies which reported bycatch and discards in this fishery in 1994–95 and 1995–96 (Clark et al. 2000) and from 1990–91 to 2001–02 (Anderson 2004a). These studies found that the level of bycatch was generally very low, but variable, ranging from about 60 to 1500 t per year. Discard levels were at a similar level to bycatch overall, but were sometimes higher due to the effect of occasional large scale discarding arising from burst or ripped nets. Despite this, overall discard levels in the southern blue whiting fishery were shown to be very low compared with most New Zealand trawl fisheries, at about 0.015 kg of discards per kilogram of southern blue whiting landed.

This study also complements other recent studies on bycatch and discards in other New Zealand fisheries, including the trawl fisheries for orange roughy (*Hoplostethus atlanticus*), hoki, oreo (*Pseudocyttus maculatus, Allocyttus niger, Neocyttus rhomboidalis*), arrow squid, jack mackerel (*Trachurus* spp.), ling, and scampi (*Metanephrops challengeri*) (Anderson 2004a, 2004b, 2007, 2009, Anderson & Smith 2005).

This report was prepared as an output from the MFish project ENV2008-01 "Estimation of non-target fish catch and both target and non-target fish discards in southern blue whiting fisheries" and addresses the following objective.

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 southern blue whiting for the fishing years 2002/03 to 2006/07 using data from Scientific Observers and commercial fishing returns.

MFish observers have been collecting bycatch and discard information from the southern blue whiting trawl fishery since 1990–91. For the five fishing years examined here, between about 22% and 53% of the target southern blue whiting catch was observed annually. Observers recorded the catch weight and discard weight by species from each trawl as well as details of the location (start and finish position), bottom depth, trawl duration, and various other fishing parameters. This report provides estimates of bycatch and discards for the entire target fishery, calculated 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, correlation between trawls in the same trip, and variability in the total amount of fishing effort per trip.

2. METHODS

2.1 Definition of terms

For the purposes of this study *non-target fish species catch* 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). McCaughran further defined *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 is defined to include fish lost from the net at the surface. The *southern blue whiting trawl fishery* is defined as all fishing using trawling methods where the target species was recorded as southern blue whiting.

2.2 Observer data

The allocation of observers on commercial vessels takes into account a range of data collection requirements and compliance issues for multiple fisheries. It is therefore not always possible to achieve an even or random spread of observer effort in each fishery. In comparison to other large fisheries, however, the annual observer coverage in the southern blue whiting trawl fishery has been maintained at a relatively constant level in recent years. In each of the five fishing years being examined, between six and seven vessels had observers placed on them for a large part of the season. This has provided a considerable amount of data for this analysis.

2.2.1 Data preparation and grooming

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 trawls with southern blue whiting recorded as the target species carried out within the fishing years being examined. A total of 1369 observed trawls targeting southern blue whiting was extracted and used in the analysis of bycatch. Because of variability in the recording of fish processing data, there were fewer observed trawls available for the analysis of discards – see below. Data grooming was carried out in the same way for each dataset.

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 more than 50 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 same 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. The top 1% of these derived tow durations (those longer than 17 h) were compared with an estimate of duration based on the recorded fishing speed and calculated trawl distance, and substituted with this estimate where the absolute difference between the two alternative values was more than 50%. Where necessary, the few missing fishing speed values were substituted with the mean value for the remainder of the data set (4.2 knots). This method of recalculating tow duration was limited to obvious outliers (the longest 1% of trawls) as many were not straight and it was possible for a long trawl to finish near to the start position, which would result in an underestimate of the trawl duration.

For all records, the bottom depth was calculated from the average of the recorded start and finish bottom depths. For the few records where one or both of these values was not recorded, bottom depth was taken from the remaining value or from the seabed depth. Observers recorded details on the trawl path taken and these showed that 27% of the observed trawls were bottom trawls with no turns, 20% were midwater (constant depth) with no turns, 7% were straight with a mixture of bottom and midwater fishing, 31% (a mixture of bottom and midwater) had between 1 and 9 U-turns, and the remainder were a combination mainly of zig-zag or closed loop courses, or followed a constant depth contour. The variable "gear code" (bottom or midwater) was determined from the recorded net type.

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. 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 accepted as valid fish losses only if they were accompanied by the appropriate code identifying the cause of the loss. After these corrections, there remained 36 cases of genuine observed fish losses from the net, with a mean of 2.4 t per loss.

Each record was assigned to a fishing year (1 April to 31 March) and day of the fishing year (1–366). Records associated with vessels producing mostly surimi (as determined from the processed states recorded by the observers on each vessel) were coded as such. Other vessels processed the southern blue whiting catch mainly into the "dressed" state.

Each record was assigned to an area (Figure 1), based on known stock divisions or management areas. Only 21 records (1%) were from outside the Campbell Island Rise (NCAM and SCAM) and Bounty Plateau (BNTY) areas which are currently the mainstay of this fishery, and the split of the Campbell Island Rise into a northern and southern area was based on the existence of two separate spawning events in this region (Ministry of Fisheries 2007). The number of trawls observed in each area over the five years is shown in Table 1.

Observer data were available from 17 vessels operated by 9 companies. No vessel or company is identified in this report, and alphanumeric codes are used where necessary.

Table 1: Number of observed trawls targeting southern blue whiting by area (see Figure 1; OTHR, trawls not in any of the defined areas) and year.

Fishing year	Area						
	AUCK	BNTY	NCAM	SCAM	OTHR	PUKA	All areas
2002–03	1	9	124	149	1	3	287
2003–04	0	2	248	16	0	13	279
2004–05	1	7	189	49	0	1	247
2005–06	0	52	201	75	0	1	329
2006–07	0	82	96	49	0	0	227
All years	2	152	858	338	1	18	1 369

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. In order to examine how discard levels varied with fishing depth, area, season, etc., either these variables can be summarised over all trawls within each processing group, or processing groups representing more than one trawl can be disregarded. In this case the latter approach was adopted, with the loss of about 20% of the records.

From these datasets the weights of fish caught and fish discarded in each trawl were calculated for the following species categories.

- The target species, southern blue whiting (SBW).
- Other commercial species combined (COM).
- Non-commercial species combined (OTH).
- QMS species. Observers recorded 34 QMS species in total, but 3 species (hoki, hake, and ling) accounted for nearly 60% of the total observed bycatch.
- Individual bycatch species caught in substantial quantities; hoki (HOK), hake (HAK), and ling (LIN).

The abbreviations COM, OTH, QMS and the fish codes SBW, HOK, HAK, and LIN above are used throughout the remainder of this report. Bycatch and discards were estimated separately for each of these species or species categories. Summaries of the observed catch and percentage discarded of all individual species are tabulated in Appendix 1.

Commercial species (COM) 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 species for which 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 analysis (Anderson 2004a) and analyses of other fisheries (e.g., Anderson & Smith 2005). In this case the category was made up of the same three species as in Anderson (2004a), i.e., hoki, hake, and ling. The bycatch and discards of these species were assessed as a group (COM) and those of hoki, hake, and ling were assessed individually.

2.3 Commercial fishing return data

Catch records from commercial fishing returns were obtained from MFish catch-effort databases for all trips where southern blue whiting were caught or targeted at any time, for the fishing years 2002–03 to 2006–07. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs) and the high-seas version (HTCEPRs). No effort or catch data were reported on Catch, Effort and Landing Returns (CELRs) or HCELRs. Data were groomed for errors using routines developed in the statistical software package 'R' (Ihaka & Gentleman 1996). Obvious errors in transposition of total catch and southern blue whiting catch were corrected. If total catch was missing or less than the catch of southern blue whiting, it was calculated as the catch of southern blue whiting multiplied by (total catch/catch of southern blue whiting) based on all records where neither value was missing. Some vessels had more than one value for the registered vessel tonnage, and in these cases the most common value was used for all records. Trawl distance was calculated from the recorded start and finish positions. Missing position values and those associated with unusually long trawls were recalculated by a process of median imputation and replaced with these alternative values where the difference was above an arbitrary threshold level. Trawl duration was calculated from the recorded start and finish times. The top 1% longest duration trawls (over 13.9 h) were replaced by values calculated from trawl distance and fishing speed where the two values differed by more than 50% (for this purpose a few missing speeds were set to the mean value for all trawls).

Records were assigned to the areas defined in Figure 1 using the recorded position coordinates or the general statistical area.

These commercial catch data can be used directly to estimate total annual non-target catch, as for each trawl the total catch as well as the catch of southern blue whiting is recorded. These estimates are provided here and provide an attractive estimate of total bycatch in the fishery because no scaling is required (all reported fishing effort is accounted for) and these estimated values are not confounded by the lack of catch estimates for species outside the top five by weight in each trawl. However, a recent study comparing commercial catch reports in the New Zealand ling longline fishery between observed and unobserved vessels indicated that under-reporting and non-reporting of bycatch species was common in that fishery and only a quarter of the catch of the main bycatch species (spiny dogfish) was reported between 2001 and 2004 (Burns & Kerr 2008). In addition, this method is limited in that it is not possible to break these data down to provide estimates of the bycatch of individual species or groups of species because only the top five species by weight are recorded on catch effort forms. For this we are reliant on the other methods used in this study.

2.4 Analysis of factors influencing discards and bycatch

Regression analyses were used to identify the most useful strata for the calculations. Several potentially influential variables are recorded by observers for each observed trawl, but only a subset of these is common to, and therefore useful for stratification of, commercial data. For example, the individual vessel code and trip number could be examined, and previous analyses in other fisheries have shown these factors to be highly influential in the level of bycatch and discards. But, since only a subset of the vessels and trips in the fishery were observed, it is problematic to calculate a ratio for those that were not observed. These influences were addressed by employing linear mixed-effects models, in which the trip variable was treated as a random effect (whereby the trip is assumed to be randomly selected from an infinite number of trips) rather than a fixed categorical variable, and the other variables were treated as fixed effects. The fixed effect variables considered in the models for each species category were: trawl duration (h); depth (average of start and finish depth, m); fishing day (day of the fishing year, 1–365/6); fishing year; area (see Figure 1); month; processing type (surimi producing or non-surimi processing); vessel tonnage; nationality; vessel key; and company.

Each species category was examined separately and both normal and binomial regression models constructed. Binomial regression models are useful to examine where there are a large proportion of zero values in the data; in this case where there was a large proportion of trawls with no catch (or no discard) of the species group. This combined approach enabled an examination of factors influencing both the *probability* and the *level* of a bycatch or discard. The response variable in the binomial models comprised a binomial vector assigned “0” if no bycatch/discard was recorded and “1” otherwise. The response variable in the normal models was the log of the bycatch/discards of the species/species group divided by trawl duration, and the continuous fixed variables (duration, depth, vessel tonnage) were also log transformed.

Regressions were run in turn for discards of the target species (SBW), bycatch and discards of other commercial species (COM), non-commercial species (OTH), quota species (QMS), and bycatch of three individual species (LIN, HAK, HOK). A detailed examination of the influence of the main factors identified is outside the scope of this project, and there is no intention of using these regression models to predict future bycatch and discard rates, so summaries were made of only the order of variable selection in each model (see Tables 4 and 5). Variables used to stratify data for bycatch and discard calculations were determined from these summaries.

2.5 Calculation of discard and bycatch ratios

The observed catch and discards figures were summed within each species category for each stratum determined from regression analysis. Similarly, the target species catches and tow durations were summed within strata. 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, southern blue whiting, 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 trawls were sampled from a stratum; d_i is the weight of discarded catch from the ith trawl sampled; l_i is the weight of southern blue whiting caught in the ith trawl sampled; and t_i is the duration of the ith trawl. 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 of the two estimators was then made by examining the ratio variances derived from each of the initial subsets tested.

The standard bootstrap assumes that all trawls were sampled with equal probability. This assumption about the assignment of observers to trawls is not entirely valid, as some vessels received no observer coverage, but the full range of vessel sizes and processing types was observed, and the spread of observed trawl positions compared with all recorded trawl positions (see Figure 1) showed that the main fishing grounds were covered reasonably well.

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 trawls within an observed trip. Separate ratios were calculated only for strata with 40 records or more, and overall ratios (using all data) were substituted for strata with fewer than 40 records. The discard ratio calculated for each stratum was then multiplied by either the total estimated catch of southern blue whiting or the total trawl duration in the stratum (depending on the version of the estimator chosen), from commercial catch records, to estimate total discards $\hat{D}$:

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

where L_j is the total catch of southern blue whiting in stratum j and T_j is the total trawl duration in the stratum.

To obtain a 95% confidence interval for the total discards that allows for correlation between trawls within a trip, 1000 bootstrap samples were generated from the trawls within each stratum using a three-step sequential sampling procedure. First a trip was chosen at random, then a bootstrap sample of the trawls from that trip that were in the stratum. These steps were repeated until the effective number of trawls was approximately equal to the effective number of observed trawls 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 trawls 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 same 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 positions of all observed trawls in the target southern blue whiting trawl fishery between 1 April 2002 and 31 March 2007 are shown, along with all trawls recorded on commercial fishing returns from the same period, in Figures 1 and 2. For the 5-year period as a whole, observer coverage appeared to be very well spread over the spatial extent of this fishery, but this is not surprising given that this is strictly a spawning fishery, spatially confined to a discrete number of known spawning locations. Within the main fishery, on the Campbell Island Rise, observer effort was more intense on the northern than the southern spawning grounds and this matched very closely the relative effort in the commercial fishery as a whole, where about 30% of trawls in the Campbell Island Rise fishery were on the northern grounds. Some areas within the Campbell Island Rise, particularly centrally and around the fringes of the fishery, were not so well sampled by observers, and the spread of coverage in some individual years was also highly patchy (see e.g., 2003–04 and 2006–07 in Figure 2). The smaller fishery on the Bounty Plateau was well covered by observers for the period as a whole and for each year individually, except perhaps in 2003–04 when only 2 of the 26 trawls in the area were observed. Outside of these two fisheries there was very little commercial fishing for southern blue whiting, with a total of 50 trawls recorded in the Pukaki Rise fishery (18 observed) and 8 trawls recorded in the Auckland Islands fishery (2 observed) over the 5-year period.

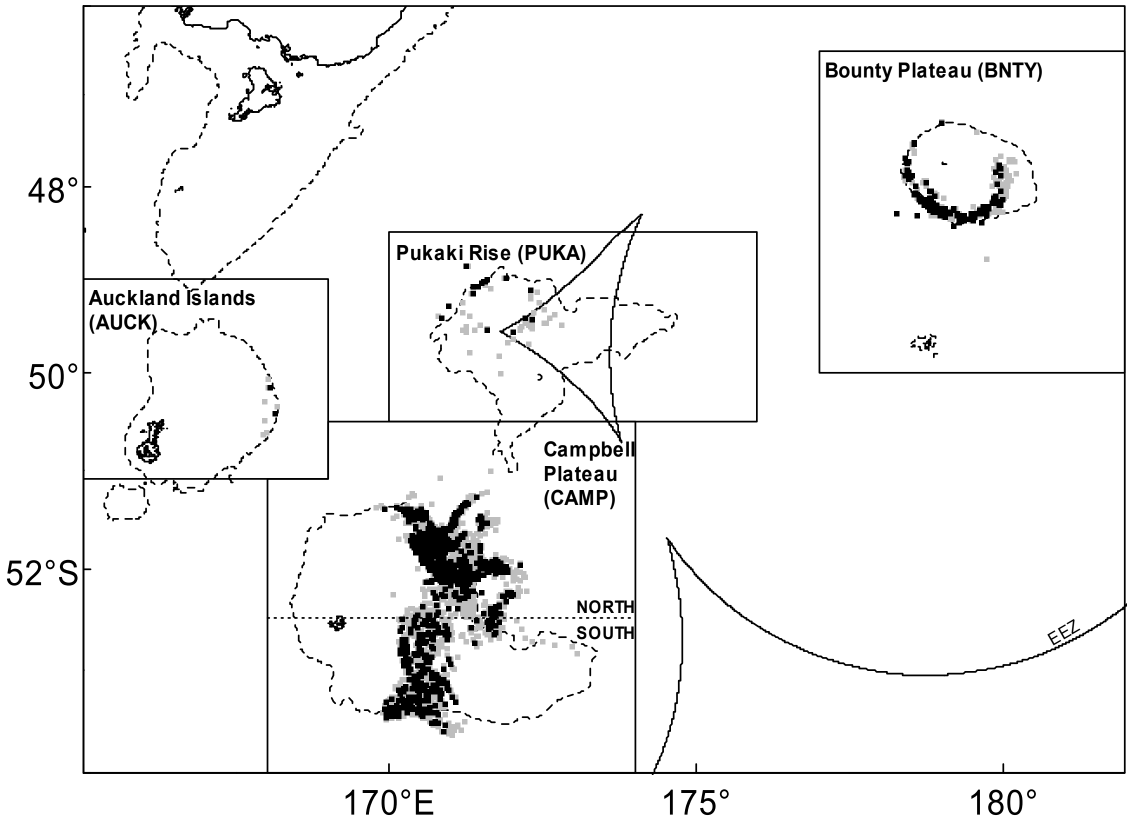

Figure 1: Distribution of trawl positions recorded by observers on vessels targeting southern blue whiting (black dots), and all commercial trawls targeting southern blue whiting (grey dots) for 2002–03 to 2006–07. Area divisions used in the analyses are shown. The dashed line represents the 500 m contour.

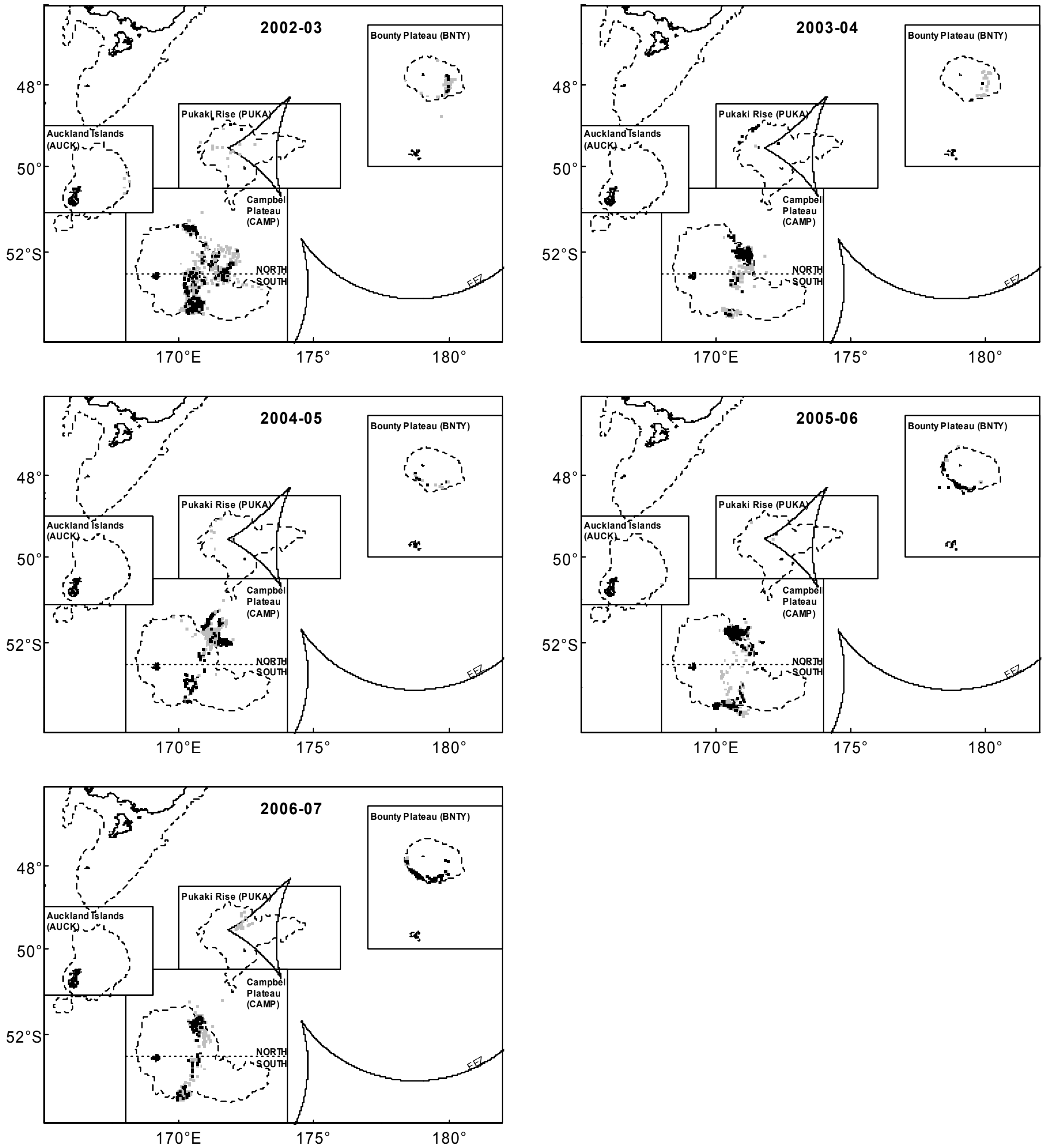

Figure 2: Distribution of trawl positions recorded by observers on vessels targeting southern blue whiting (black dots), and all commercial trawls targeting southern blue whiting (grey dots) for 2002–03 to 2006–07, by year. Area divisions used in the analyses are shown. The dashed line represents the 500 m contour.

A spatial comparison of observed trawls with all commercial trawls recorded with position data was produced using density plots (Figure 3). This showed that the spread of observed trawls over the longitudinal and latitudinal extent of the Campbell Island Rise fishery were well matched to the distribution of all target trawls in the commercial fishery, in all years. Although there was slight oversampling on the Campbell Island Rise and undersampling on the Bounty Plateau in 2002–03, and the opposite situation in 2006–07, these were relatively minor imperfections and for all years combined the spread of sampling was shown to be almost ideal.

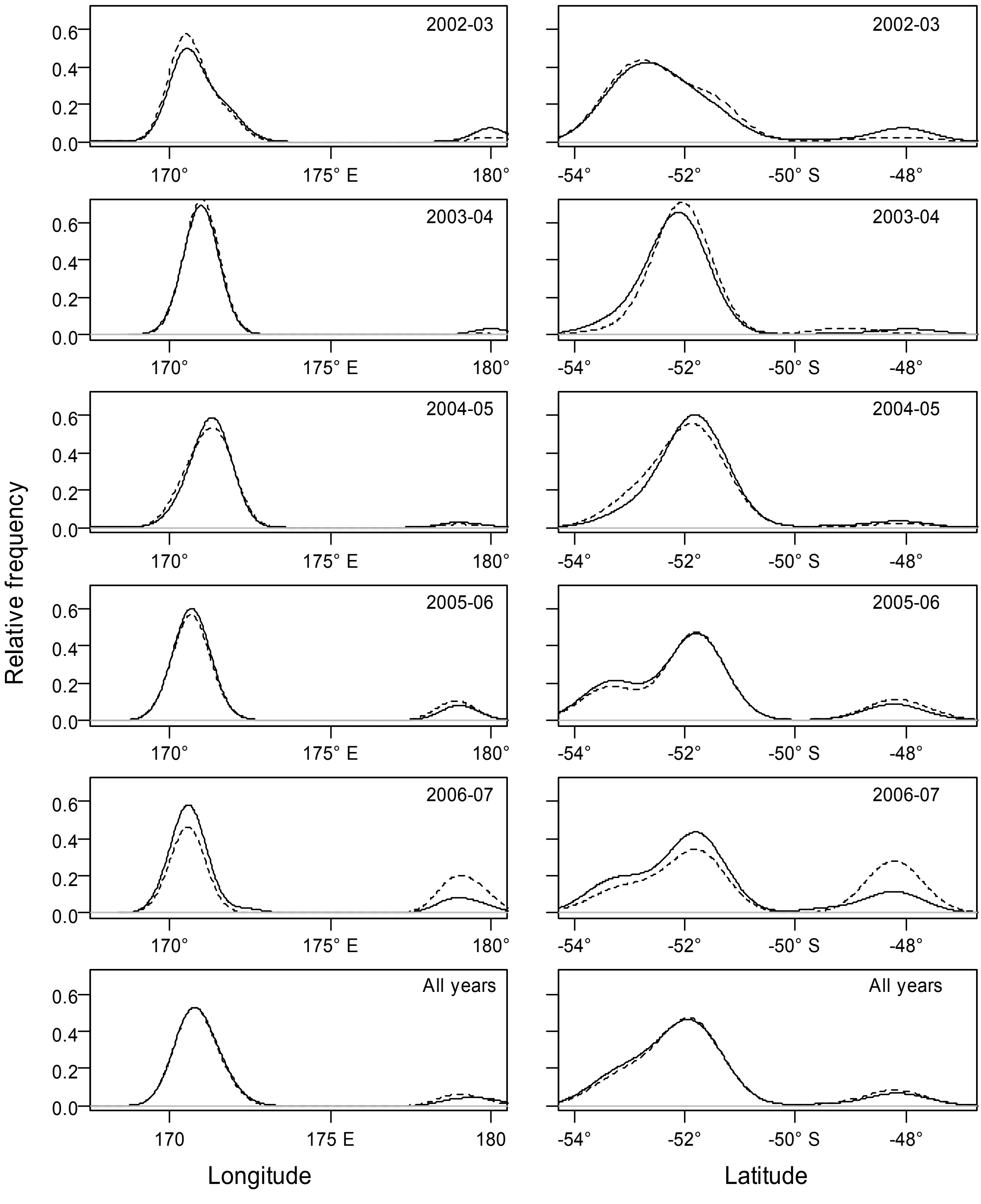

Figure 3: Comparison of start positions (latitude and longitude) of observed trawls (dashed lines) with those of all commercial trawls (solid lines) in the target fishery for southern blue whiting for 2002–03 to 2006–07, and for all five fishing years combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Comparisons were made between vessel sizes in the commercial fleet and the observed portion (Figure 4), showing that the range of vessel sizes was well covered by observers. The 26 vessels formed roughly into eight size groups between about 400 t and 5000 t, but most effort was by vessels of about 4400 t. Only a small amount of effort by the largest vessels in the fleet (about 5000 t) was not covered by observers. This fishery is restricted to relatively large vessels compared with other major offshore New Zealand fisheries (e.g., hoki, orange roughy) and, unlike in these other fisheries, all are capable of accommodating observers on board and therefore do not leave a gap in coverage of the smaller vessels. It is useful to note that although about a third of the vessels in the fishery received no observer coverage, these vessels accounted for only about 12% of the total catch of southern blue whiting.

A comparison of the number of trawls, number of vessels and trips, and catch of southern blue whiting between the observed portion and the entire fishery is given in Table 2. The annual number of observed trawls ranged from 227 to 329 and the number of vessels observed was stable at 6–7. Seventeen of the 26 vessels operating in the fishery were observed for at least one trip during the 5-year period. Thirty-two trips were observed, with an average of 43 trawls per trip, at a constant level of 6 or 7 observed trips per year. Total target fishery effort fluctuated during the period, from a high of about 1000 trawls in 2002–03 to a low of about 630 trawls in 2003–04 and 2006–07. With most of the vessels operating in this fishery, including the main operators, carrying observers at some point during the period, the observed fraction of the annual target catch (22–53%) and number of trawls (29–44%) was high (the target level of observer coverage usually considered sufficient to adequately represent the total fishery is 10%). Even so, this is slightly lower overall than achieved for much of the 1990–91 to 2001–02 period previously examined (Anderson 2004a), but still high compared with the observer coverage usually achieved in other New Zealand fisheries.

Table 2: Summary of effort and estimated catch in the target trawl fishery for southern blue whiting, for observed trawls and overall, by fishing year.

Fishing year	Number of trawls		Number of vessels		Number of observed trips	Total southern blue whiting catch (t)		% observed	
	observed	all	observed	all		observed	all	catch	trawls
2002–03	287	997	7	18	7	12 318	35 655	34.5	28.8
2003–04	279	629	6	15	6	5 827	26 281	22.2	44.4
2004–05	247	730	7	18	7	10 729	21 039	51.0	33.8
2005–06	329	859	6	18	6	13 348	29 040	46.0	38.3
2006–07	227	634	6	13	6	12 793	24 166	52.9	35.8
All years	1 369	3 849	17	26	32	55 015	13 6182	40.4	35.6

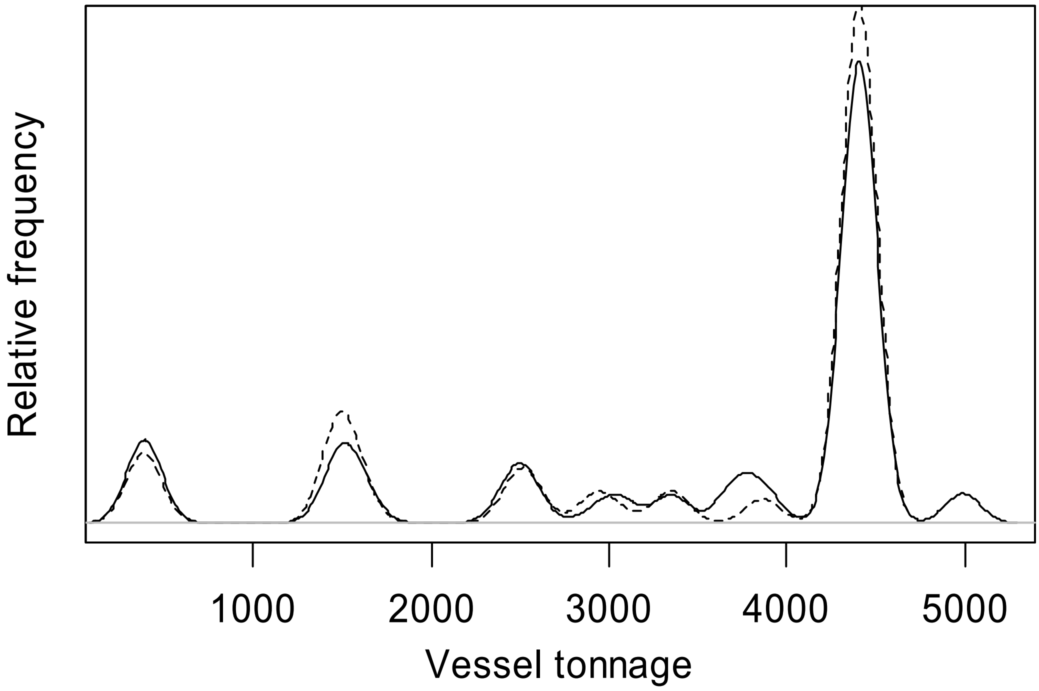

Figure 4: Comparison of vessel sizes (Gross Registered Tonnage) in observed trawls (dashed lines) versus all recorded commercial trawls (solid line), 1 April 2002 to 31 March 2007. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

The spread of observer effort over 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 5). These plots confirm that the fishery operated over a short period in each year, centred around September. Fishing began in late August in 2002–03 and 2003–04 with a peak in effort at about mid September which tapered off through the second half of September to low levels which persisted into October or even November. Fishing began earlier in the two most recent years, near the beginning of August, but still peaked in mid September and carried on through into October. The pattern of observed trawls was generally similar to that of the fishery as a whole, especially in 2004–05, 2005–06, and for all years combined. Some fishing effort in late September–early October in 2003–04 was not observed (with slight oversampling in the peak of the fishing season), and intensive sampling in August 2006–07 was carried out at the expense of coverage in early September, but these appear to be minor imperfections of sampling coverage, with observers present in the fishery throughout each of the five seasons examined.

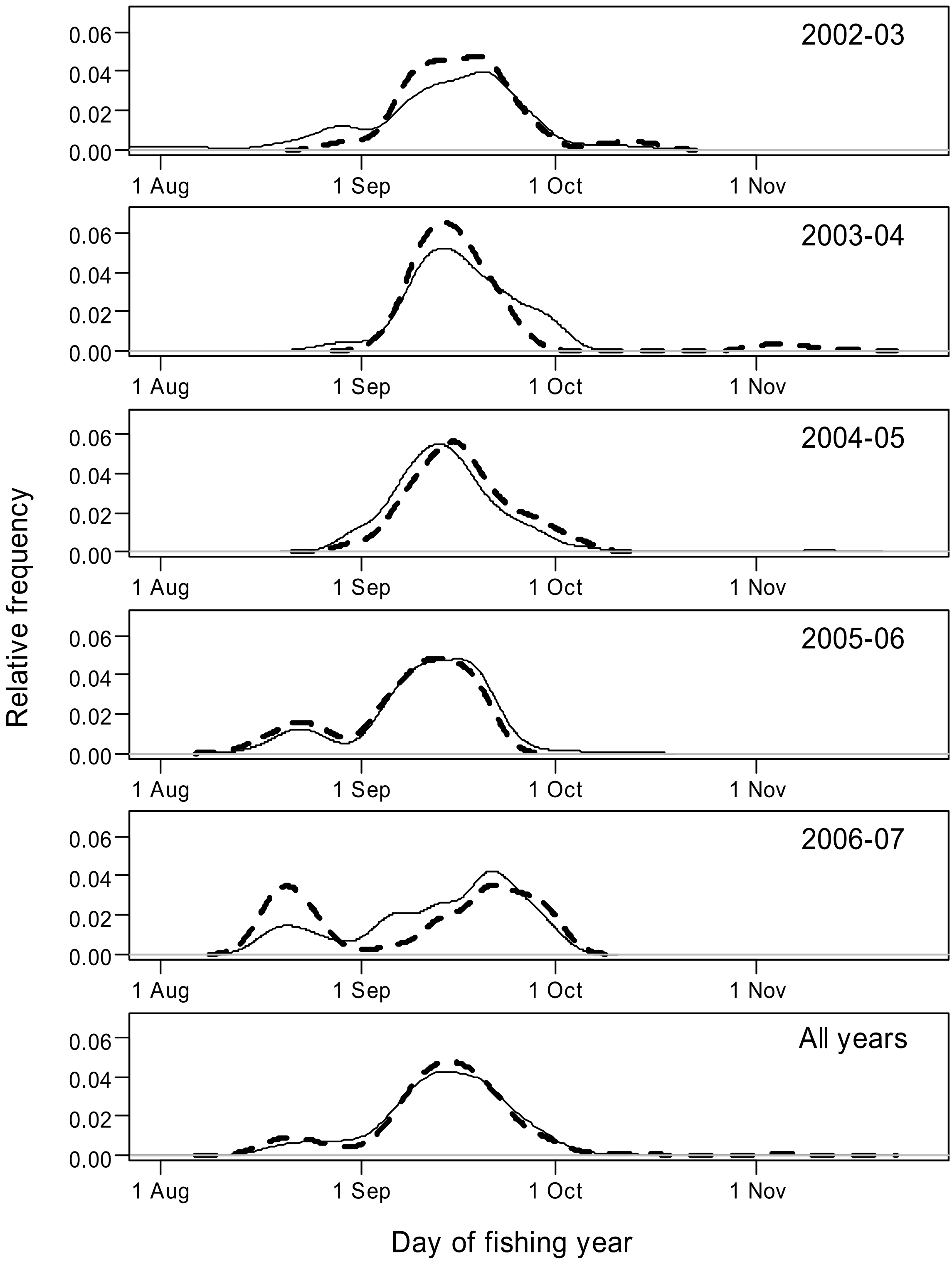

Figure 5: Comparison of the temporal spread of observed trawls (dashed lines) with all recorded commercial trawls (solid lines) for 2002–03 to 2006–07, and for all five fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Selection of ratio estimators

In the most recent examination of bycatch and discards in this fishery (Anderson 2004a), and in other fisheries (e.g., Anderson 2007, 2008), the choice of ratio estimator was based on a comparison of bootstrap estimated c.v.s from various sets of trial data. This procedure usually resulted in very small c.v.s which, although tending to slightly favour the effort-based estimator over the target species catch-based estimator, were not significantly different from each other. The same comparisons made using the current set of southern blue whiting observer data gave a similar result (Table 3), but a decision to use the trawl length-based estimator for these analyses was mainly based on the desire to be consistent with the procedure used in the previous analysis (Anderson 2004a).

Table 3: Comparison of ratio estimators.

Bycatch/discards	Species category	Estimator	Bycatch ratio	c.v. (%)
Bycatch	COM	SBW catch	0.004	10.25
	COM	Trawl duration	35.9	9.01
	OTH	SBW catch	0.003	22.37
	OTH	Trawl duration	29.9	21.82
Discards	COM	SBW catch	0.00004	37.85
	COM	Trawl duration	0.36	37.75
	OTH	SBW catch	0.0008	19.35
	OTH	Trawl duration	8.18	18.64

It is uncertain whether commercial catch-effort records of target species catch are more reliable than records of trawl duration – although it may be easier to accurately measure trawl duration than to estimate catch weights, two values are required (start and finish times) both of which need to be correct. The weight of the target species catch is likely to be of more interest to the vessel skipper than the time of day and for this reason more care may be taken in recording it. Intuitively, it would seem that longer duration trawls would catch greater amounts of the perhaps more evenly distributed background community of fish species than short trawls, and large, “clean” catches of southern blue whiting can be made from relatively short trawls. This is confirmed in Figure 6, which suggests that non-target catch is more influenced by duration than by southern blue whiting catch. However, this may not hold true for discards, as high levels of discards can be associated with larger catches of the target species due to the occasional large loss of fish from the net.

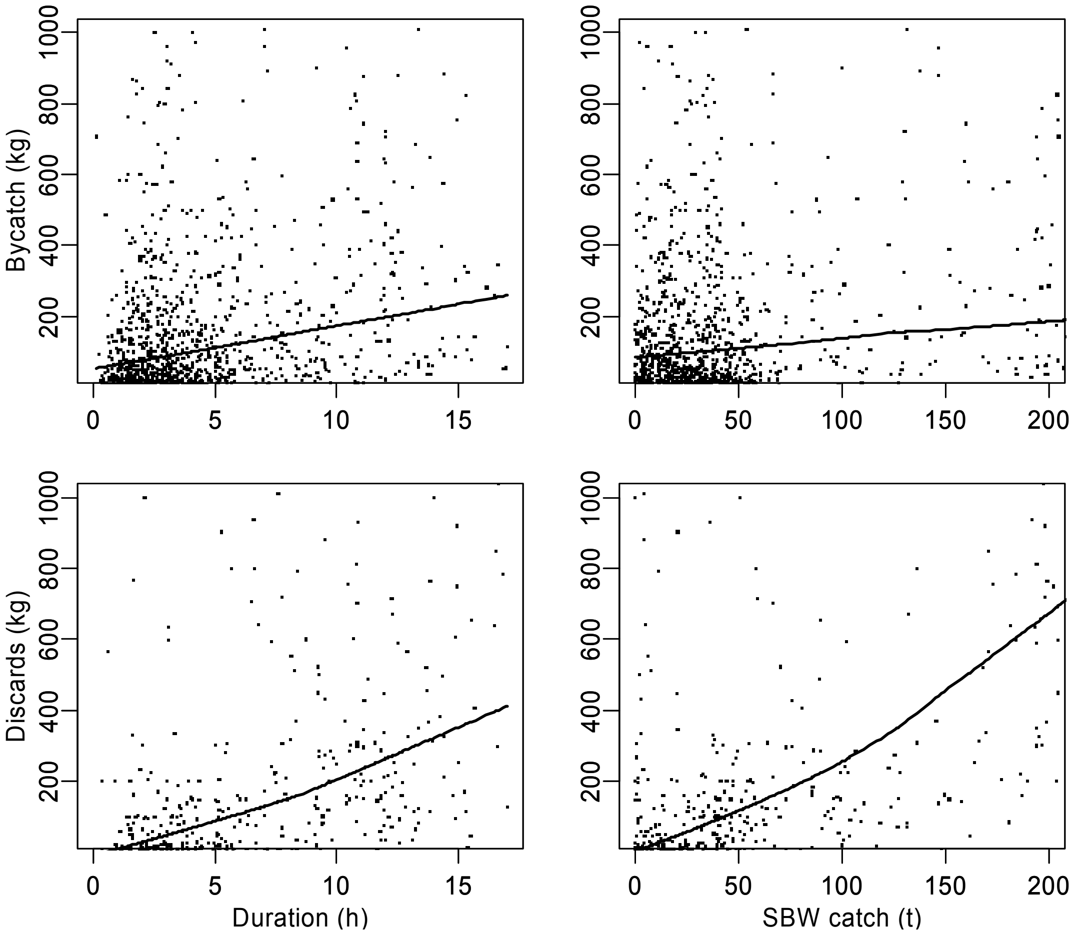

Figure 6: Total non-target catch and total discards plotted against the two alternative ratio estimator variables, trawl duration and target species catch. A locally weighted polynomial regression line is fitted to each plot.

3.3 Bycatch data

3.3.1 Overview of raw bycatch data

Southern blue whiting accounted for more than 99% of the total estimated catch from all observed trawls targeting southern blue whiting between 1 April 2002 and 31 March 2007. About half of the remainder of the total catch comprised three important commercial species: ling (0.2%), hake (0.1%), and hoki (0.1%), and over 80% of the non-southern blue whiting catch consisted of these and other QMS species. Over 120 species or species groups were identified by observers, most being non-commercial species caught in low numbers. Porbeagle sharks (introduced into the QMS in 2004), javelinfish and other rattails, and silverside, accounted for much of the non-commercial catch. Invertebrate species (mainly sponges, crabs, and echinoderms) were also recorded by observers, but no species or species group accounted for more than 0.01% of the total observed catch (see Appendix 1 for a full list of observed bycatch species).

Commercial catch reporting (based on the top five species caught in each trawl) suggested that southern blue whiting accounted for a similar fraction (99.5%) of the total catch to that calculated from observer records, with ling, hake, and hoki (in similar proportions to the observer data) the next most commonly caught species (see Appendix 2). Although observer catch records are likely to be more accurate (and take into account all species caught from each trawl) the commercial records are available for the entire fishery and potentially can better reflect the total catch of at least the commercially valuable quota species that are frequently in the top five species by weight in the trawls. This is especially true for a clean fishery such as this one, where the top five species are likely to account for virtually the entire catch in most trawls. It is also reassuring that the main catch species recorded in the fishery are very similar between the observer and catch-effort data sets, and the top 10 species by weight are in a very similar order.

Exploratory plots were prepared to examine total bycatch per trawl (plotted on a log scale) with respect to the available variables (Figure 7). Total bycatch was highly variable between trawls, ranging from 0 to 33 t. Total bycatch tended to increase with increasing trawl duration, from a mean of about 60 kg for a 1 h trawl to about 170 kg for a 10 h trawl (only about 9% of trawls were longer than 10 h). Trawling was mostly at bottom depths of 350–550 m but the full depth range of fishing was between about 150 m and 650 m. Total bycatch tended to increase with bottom depth, from means of about 70 kg at 350 m to 170 kg at 550 m. The four surimi-producing vessels tended to have less bycatch than the 13 non-surimi-producing vessels (medians of 63 $kg.trawl^{-1}$ and 188 $kg.trawl^{-1}$ respectively). There were differences in bycatch levels between companies, with medians for those providing more than 100 records ranging from 54 $kg.trawl^{-1}$ to 144 $kg.trawl^{-1}$, and there were considerable differences between vessels, with two orders of magnitude separating those with the highest (vessel D) and lowest (vessel A) median bycatch. Median bycatch levels were similar in the first three of the five fishing years examined, but dropped slightly in the last two years. There was little apparent difference in median bycatch between the three main areas fished (60–85 $kg.trawl^{-1}$), but observed bycatch was greater in October than in August and September. Median bycatch was greatest for Japanese vessels (200 $kg.trawl^{-1}$) and lowest for Ukranian vessels (50 $kg.trawl^{-1}$). Although bottom nets were used on only 31 of the trawls plotted, they caught far more bycatch than midwater nets (medians of 3200 $kg.trawl^{-1}$ and 80 $kg.trawl^{-1}$ respectively) and even the least of these bottom net bycatch values was twice the median bycatch of the midwater nets.

Table 4: Summary of LME modelling of bycatch in the southern blue whiting trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year; *surimi*, vessel producing surimi or not; *tonnage*, vessel tonnage.

Species cat.	Model type											Variable
		duration	*depth*	*fday*	*fyr*	*area*	*month*	*surimi*	*tonnage*	*nation*	*vessel*	*company*
COM	Normal	1	2	4	7	3	5	6	–	–	–	–
COM	Binomial	2	1	5	7	3	4	–	–	–	6	–
OTH	Normal	1	2	–	–	–	–	4	3	–	–	–
OTH	Binomial	2	1	–	4	3	–	–	–	–	–	5
QMS	Normal	3	2	1	6	7	4	5	–	–	–	–
QMS	Binomial	2	1	5	3	–	4	–	–	–	–	–
LIN	Normal	1	3	2	5	7	8	6	4	–	–	–
LIN	Binomial	3	1	–	6	2	4	–	–	–	5	–
HAK	Normal	1	2	3	5	–	6	7	4	–	–	–
HAK	Binomial	3	2	4	–	1	6	–	7	–	–	5
HOK	Normal	2	1	–	3	4	8	6	5	–	–	7
HOK	Binomial	–	1	5	3	2	–	–	–	–	4	–

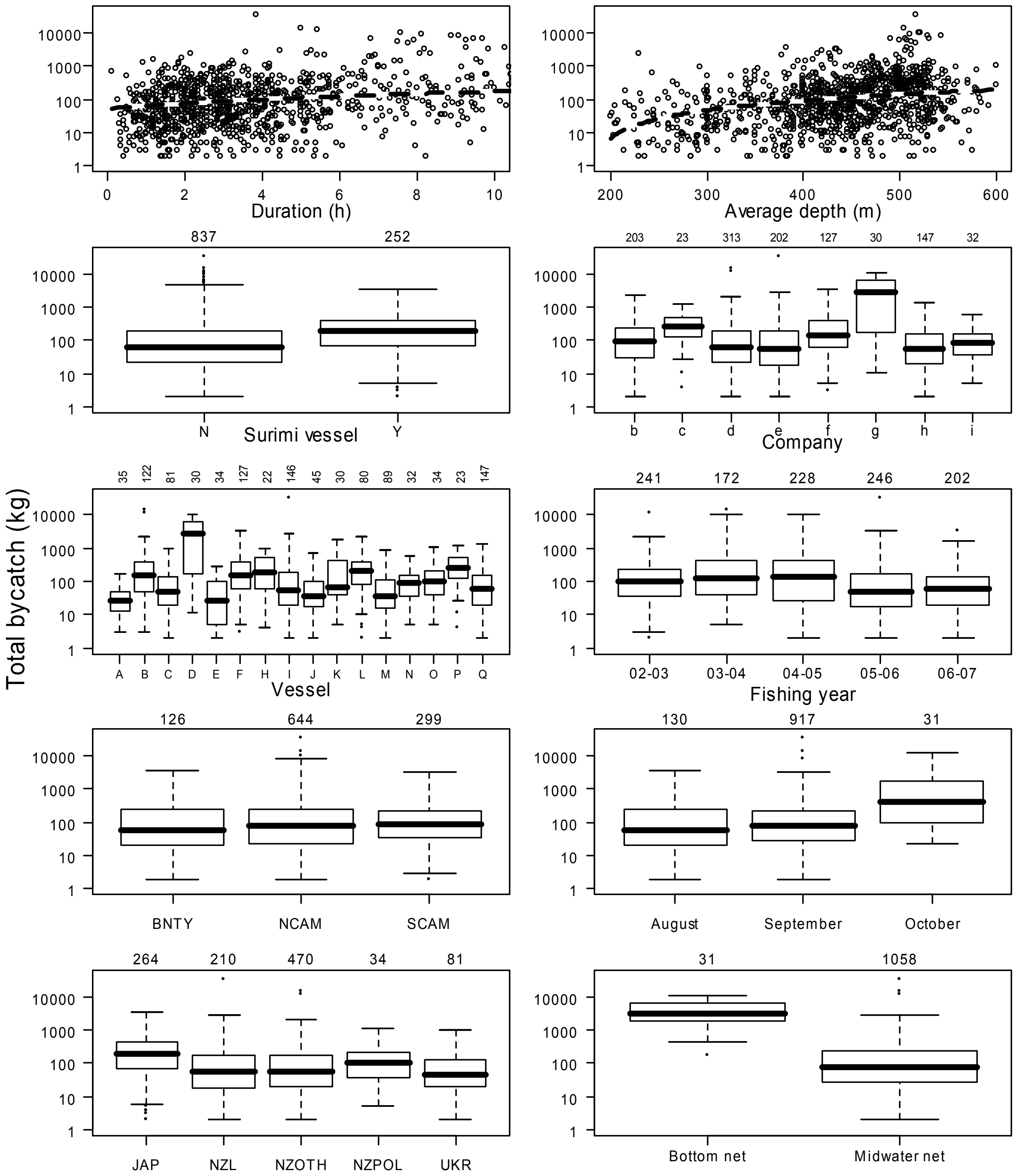

Figure 7: Total bycatch per trawl plotted against selected variables. Total bycatch is plotted on a log scale. The dashed lines in the top panel represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the 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: levels of variables represented by fewer than 20 records were not plotted. Average bottom depth is the average of the start and finish depths. See Figure 1 for area codes (BNTY, NCAM, SCAM).

3.3.2 Regression modelling and stratification of bycatch data

The dependent variable in the LME models was the bycatch ratio, expressed as the log of catch (kg) per hour trawled. Of the 1369 observed trawls in the data set, 41% recorded no bycatch of COM species, 30% recorded no bycatch of OTH species, and 24% recorded no bycatch of any QMS species. The equivalent percentages for the individual bycatch species were hake (HAK), 58%; hoki (HOK), 86%; ling (LIN), 55%. Because there was a significant fraction of trawls with no bycatch in each of these species groups, both linear and binomial models were constructed to enable the identification of factors affecting both the level and likelihood of bycatch of the species.

The variables *duration* and *depth* were the most influential in both normal and binomial models of COM and OTH species bycatch, and one or other of these variables was selected first in each of the models run for most of the other species groups. The exceptions were the QMS linear model, where *fday* was selected first, and the HAK binomial model where *area* was selected first (Table 4). Together these four variables accounted for most of the variability in each of the models run, with only *fyr* and *month* occasionally being selected, and no higher than third or fourth in importance.

The regular selection of *duration*, particularly in the normal models, shows that although bycatch tends to increase with increasing trawl duration, the *rate* of bycatch decreases – longer duration trawls catch non-target species at a considerably lower rate than shorter duration trawls. This may be due in part to target misidentification; short trawls targeting a mark on the ships echo-sounder which turns out to be ling or hoki rather than southern blue whiting, compared with longer duration trawls which may have missed the fish mark but are persevered with in the hope of catching acceptable amounts of more scattered fish or coming across a large mark in the near vicinity. However, the *probability* of catching some bycatch species increases strongly with trawl duration, particularly for the combined COM and OTH species categories where the percentage of trawls catching these species increases from 45–55% for trawls of less than 2 h to about 85% for trawls over 14 h.

Average trawl depth, *depth*, the first variable selected in all binomial models except that for HAK bycatch, strongly influences the likelihood of taking some bycatch of the main non-target species. Most of the observed trawls were between 400 m and 550 m, and the average depth for southern blue whiting, based on research trawl catches, has been estimated at about 500 m (Anderson et al. 1998). Although ling have a similar average depth to southern blue whiting, the other main bycatch species, hoki and hake, are more commonly found slightly deeper (average depth 650–660 m, Anderson et al. 1998). Although the depth distribution of all these species overlap considerably, the differences are sufficient for the model to detect a significant pattern, showing a greater likelihood of a catch in each of the species categories with increasing depth, and also greater catch rates with increasing depth.

The variable *duration*, although stronger in the normal models (which excluded zero tows), was rejected because it conflicted with the trends shown in the binomial models. For example, 40% of trawls did not record any catch of COM species, and the linear model ignores these records, but there was a large difference in mean duration between those trawls (2.4 h) and those that did record a catch of COM species (3.6 h). This biases the linear model result as the model predicts higher catch rates of COM for shorter tows, but a significant number of short tows that caught no COM species at all were not available to the model.

The variable *depth* was therefore chosen for stratification of the bycatch calculations. Recorded values of depth were converted into two or three strata in each species category with the use of regression tree partitioning. Separate ratios were calculated only for strata in which at least two vessels were represented, to acknowledge the influence of *vessel* on rates of bycatch.

3.4 Discard data

3.4.1 Overview of raw discard data

The associated species most affected by discarding in this fishery were porbeagle sharks, which were the fifth most important observed bycatch species by weight, and more than half were discarded (see Appendix 1). The porbeagle shark was also the fifth most important observed bycatch species by weight in the 1990–2002 period (Anderson 2004a) when close to 80% was discarded. Rattails, especially javelinfish, Ray's bream (*Brama brama*), silverside, arrow squid, and opah (*Lampris immaculatus*) were also caught in relatively large amounts and were frequently discarded. Of the invertebrate species identified by observers, only sponges and spider crabs were caught in significant amounts and these, along with the various echinoderms, cnidarians, molluscs, and crustaceans were virtually all discarded. Most of the non-QMS, low-value species, including rattails, silverside, and opah were retained by the vessel and presumably mealed.

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 8). As for bycatch, the quantity of discards tended to increase with increasing trawl duration, from a mean of about 15 kg for a 1 hour trawl to about 200 kg for a 10 hour trawl. Discard levels varied little with depth, with mean levels decreasing only slightly across the main depth range, from about 135 kg at 350 m to about 95 kg at 550 m. The large difference in discard levels between surimi vessels and non-surimi vessels may not be related to the processing methods but more to vessel nationality. The surimi vessels are all Japanese and discards from vessels of this nationality were considerably greater than from vessels of the other nations sampled. There was considerable variation in discard levels between companies and vessels, with a mean discard rate of 15–450 $kg.trawl^{-1}$ (companies) and 6–450 $kg.trawl^{-1}$ (vessels). Discard levels were very constant over time, increasing only slightly from about 90 $kg.trawl^{-1}$ in 2002–03 to 120 $kg.trawl^{-1}$ in 2006–07. Fishing was mostly restricted to August and September, with mean discards slightly lower in September (90 $kg.trawl^{-1}$) than in August (130 $kg.trawl^{-1}$). The few trawls made with a bottom net produced much greater levels of discards than trawls made with a midwater net (850 $kg.trawl^{-1}$ vs. 90 $kg.trawl^{-1}$). These 22 observed trawls were associated with two main vessels and represented almost half of all bottom trawls recorded for the period (99% of all trawls used a midwater net).

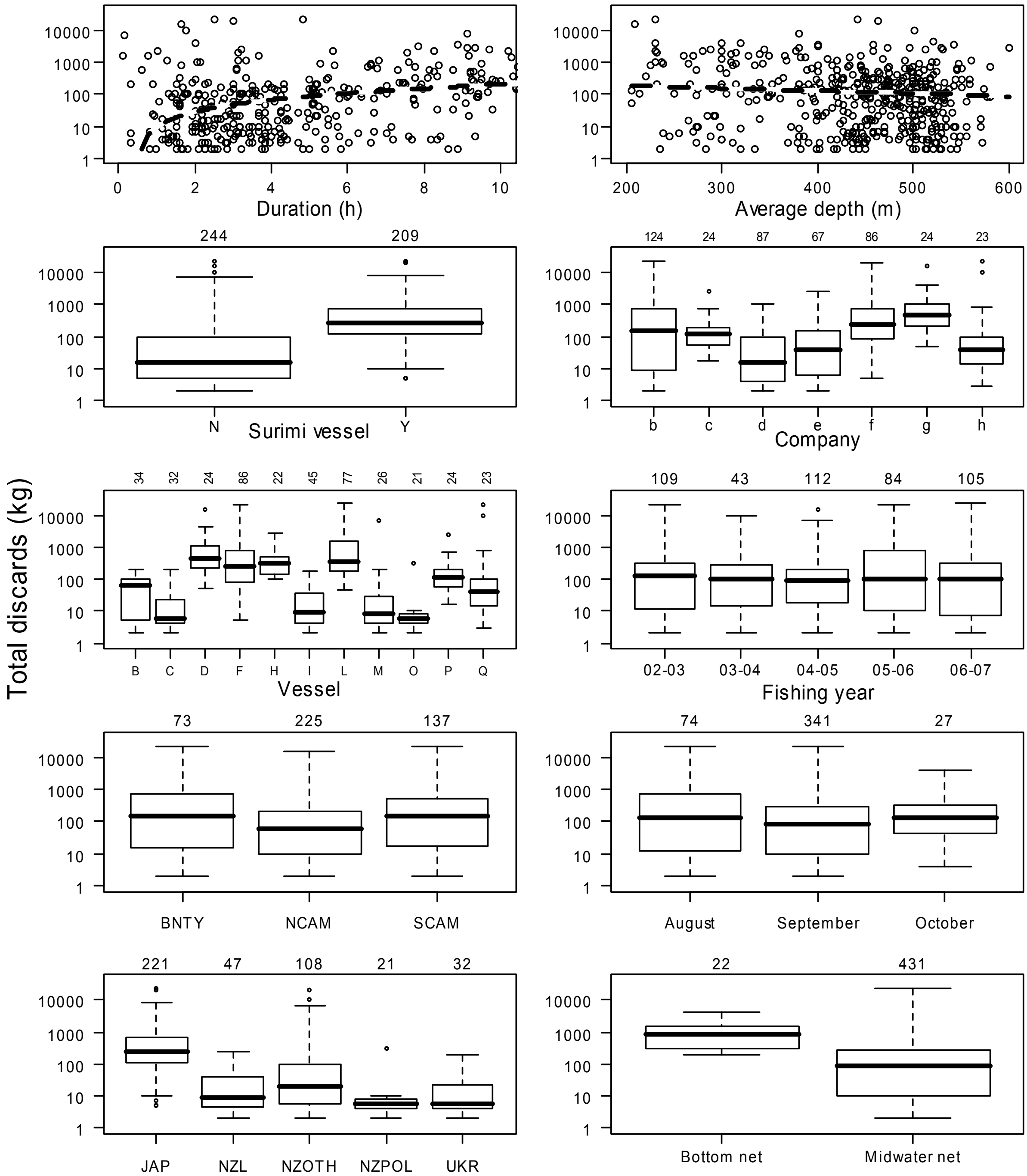

Figure 8: Total discards per trawl plotted against selected variables. Total discards is plotted on a log scale. The dashed lines in the top panel represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the 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: levels of variables represented by fewer than 20 records were not plotted. Average bottom depth is the average of the start and finish depths. See Figure 1 for area codes (BNTY, NCAM, SCAM).

3.4.2 Regression modelling and stratification of discard data

The dependent variable in the discard LME models was the discard ratio, expressed as the log of discards (kg) per hour trawled.

Of the 1092 records in the data set only 39 recorded a discard of COM species, and there were fewer still for LIN (16), HAK (23), and HOK (21). Because of this there was no stratification applied to the discard calculations for these species groups. For SBW (240 discards), OTH (413 discards), and QMS (250 discards), both linear and binomial models were constructed to enable identification of factors affecting both the level and likelihood of discards.

As in the models for bycatch, the variables *duration* and *depth* were overall the most influential in both normal and binomial models (Table 5). The variable *depth* was selected consistently in each model, usually as first or second variable, and although *duration* was the first variable selected in each of the normal models, it did not feature in the binomial models. Because of this, and to be consistent with the bycatch analyses, stratification by *depth* category and *fishing year* was used in the discard calculations for SBW, OTH, and QMS.

As in the bycatch calculations above, separate ratios were calculated only for strata in which at least two vessels were represented, to acknowledge the influence of *vessel* on rates of discarding.

Table 5: Summary of LME modelling of discards in the southern blue whiting trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year; *surimi*, vessel producing surimi or not; *tonnage*, vessel tonnage.

Species cat.	Model type											Variable
		duration	*depth*	*fday*	*fyr*	*area*	*month*	*surimi*	*tonnage*	*nation*	*vessel*	*company*
SBW	Normal	1	2	–	4	–	–	–	–	–	3	–
SBW	Binomial	–	4	3	2	–	–	–	–	–	1	–
OTH	Normal	1	2	–	5	–	–	6	3	–	–	4
OTH	Binomial	–	1	–	–	–	–	–	–	–	2	–
QMS	Normal	1	2	–	5	–	6	–	3	–	–	4
QMS	Binomial	4	2	–	5	1	–	3	–	–	–	–

3.5 Estimation of bycatch

3.5.1 Bycatch rates

Bycatch ratios for each of the species categories were calculated from the observer data separately for each of the depth categories determined from regression tree partitioning, for each year separately. The variance in these bycatch rates was calculated using the bootstrap methods described above.

As well as providing the basis from which total bycatch can be determined from target fishery effort totals, these ratios also indicate how the catch rates of each species group vary by depth (see Table 6). Median bycatch rates of COM species were higher in the deeper (over 470 m) category in each year. Although this difference was minor for the two most recent years, for the other years, 2003–04 in particular, the difference was large. Catch rates of QMS species also increased consistently with depth in each of the five years (Table 7). Regression tree partitioning in this case split depth into three categories, and in each year bycatch rates of QMS species were lowest in the shallowest (under 390 m) category and (except for 2005–06) highest in the deepest (over 457 m) category. In each year catch rates of QMS species in the deepest category were at least twice that of the shallowest category and in 2003–04, when the median catch rate deeper than 457 m was 209 kg/h, were higher by a factor of 20. Bycatch rates of OTH species, also in three depth categories, showed a similar pattern to COM and QMS species in that they were again consistently higher in the deeper strata – a pattern which was more pronounced in 2003–04 than in other years and less pronounced in the most recent two years (Table 8). Bycatch rates for the individual species LIN, HAK, and HOK also followed the pattern of increasing catch rates with depth, with few exceptions (Tables 9–11). Catch rates of LIN and HAK were generally similar overall, although exact comparison is not possible due to the different depth categories used, and those of HOK were, except for the high rate of almost 80 kg/h in the deep stratum in 2003–04, considerably lower.

Table 6: Bycatch rates of commercial (COM) fish species in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

Fishing year	Bycatch rate (kg/h)	
	<470 m	>470 m
2002–03	11	31
2003–04	18	165
2004–05	22	87
2005–06	27	28
2006–07	9	11

Table 7: Bycatch rates of QMS fish species in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

Fishing year	Bycatch rate (kg/h)		
	<390 m	390–457 m	>457 m
2002–03	21	26	47
2003–04	10	46	209
2004–05	14	45	85
2005–06	17	41	35
2006–07	8	16	22

Table 8: Bycatch rates of non-commercial (OTH) fish species in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

Fishing year	Bycatch rate (kg/h)		
	<424 m	424–496 m	>496 m
2002–03	12	21	37
2003–04	6	37	97
2004–05	8	19	67
2005–06	9	13	19
2006–07	6	13	17

Table 9: Bycatch rates of ling (LIN) in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

Fishing year	Bycatch rate (kg/h)	
	<476 m	>476 m
2002–03	4	14
2003–04	13	81
2004–05	10	68
2005–06	17	9
2006–07	3	8

Table 10: Bycatch rates of hake (HAK) in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

Fishing year	Bycatch rate (kg/h)	
	<449	>449
2002–03	6	5
2003–04	6	29
2004–05	12	23
2005–06	8	15
2006–07	4	8

Table 11: Bycatch rates of hoki (HOK) in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000.

Fishing year	Bycatch rate (kg/h)		
	<427 m	427–489	>489 m
2002–03	0.6	3.3	12.2
2003–04	0.0	0.0	79.5
2004–05	0.3	0.5	0.6
2005–06	0.1	0.1	0.4
2006–07	0.1	0.5	0.0

3.5.2 Annual bycatch levels

Annual bycatch was estimated from observer data by multiplying the ratios calculated for each depth and year stratum by the target fishery trawl duration totals for the equivalent stratum, as described in Section 2.5, and precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Tables 12 & 13, Figures 9 & 10).

Annual bycatch of commercial species (COM) ranged from 20 t to 260 t and has been reducing since 2003–04 (Table 12). Estimates of individual commercial species bycatch show that this catch was mainly composed of LIN and HAK, with HOK contributing only in 2002–03 and 2003–04 (Table 13). Annual catches of non-commercial species (OTH) ranged from 20 t to 140 t and showed a more consistent decline over the five years. Estimated total annual bycatch (TOT) in the fishery was greatest in 2003–04 and showed a decline over time, abruptly falling to an estimated 40 t in 2006–07. The COM and OTH species groups contributed more or less equally to total bycatch overall, although bycatch of COM was twice that of OTH in 2003–04 and only about 60% of it in 2002–03. Total bycatch for 2002–03 to 2006–07 (40–390 t), as well as COM and OTH bycatch, was at a similar level to that estimated by Anderson (2004a) for the preceding nine years, but generally far lower than for 1990–91 and 1991–92 when total annual bycatch was estimated to be 500–1500 t. There is a clear relationship between total annual bycatch and total estimated annual landings of southern blue whiting (Figure 9), as both are closely linked to fishing effort. Annual landings of southern blue whiting have, apart from 1991–92 when both bycatch and landings were exceptionally high, remained between about 20 000 t and 40 000 t, and fluctuations in bycatch have followed a broadly similar path. There is no evidence from this plot that bycatch as a proportion of landings has changed over time, although the most recent year shown (2006–07) was unusual in that bycatch was at its lowest point in the 16-year series while landings remained at an average level.

Table 12: Estimates of total annual bycatch (rounded to the nearest 10 t) in the southern blue whiting trawl fishery and species categories COM, OTH, and overall (TOT), based on observed catch rates (95% confidence intervals in parentheses), and total bycatch (t) calculated from the difference between TCEPR records of total catch and southern blue whiting catch.

	COM		OTH		TOT		Total bycatch from TCEPR records
2002–03	90	(60–120)	140	(70–270)	230	(130–390)	334
2003–04	260	(80–440)	130	(50–260)	390	(130–700)	313
2004–05	150	(90–250)	100	(30–210)	250	(120–460)	172
2005–06	90	(60–140)	100	(20–250)	190	(80–390)	137
2006–07	20	(10–30)	20	(20–40)	40	(30–70)	145

Table 13: Estimates of total annual bycatch (rounded to the nearest 10 t) in the southern blue whiting trawl fishery for the species categories QMS, ling (LIN), hake (HAK), and hoki (HOK), based on observed catch rates. 95% confidence intervals are shown in parentheses.

	QMS		LIN		HAK		HOK	
2002–03	190	(120–380)	40	(20–60)	20	(10–40)	30	(10–50)
2003–04	370	(110–610)	120	(30–210)	60	(30–90)	80	(0–190)
2004–05	170	(100–270)	110	(50–210)	50	(30–70)	0	(0–0)
2005–06	110	(70–160)	50	(30–90)	40	(20–60)	0	(0–0)
2006–07	30	(30–50)	10	(10–20)	10	(10–20)	0	(0–0)

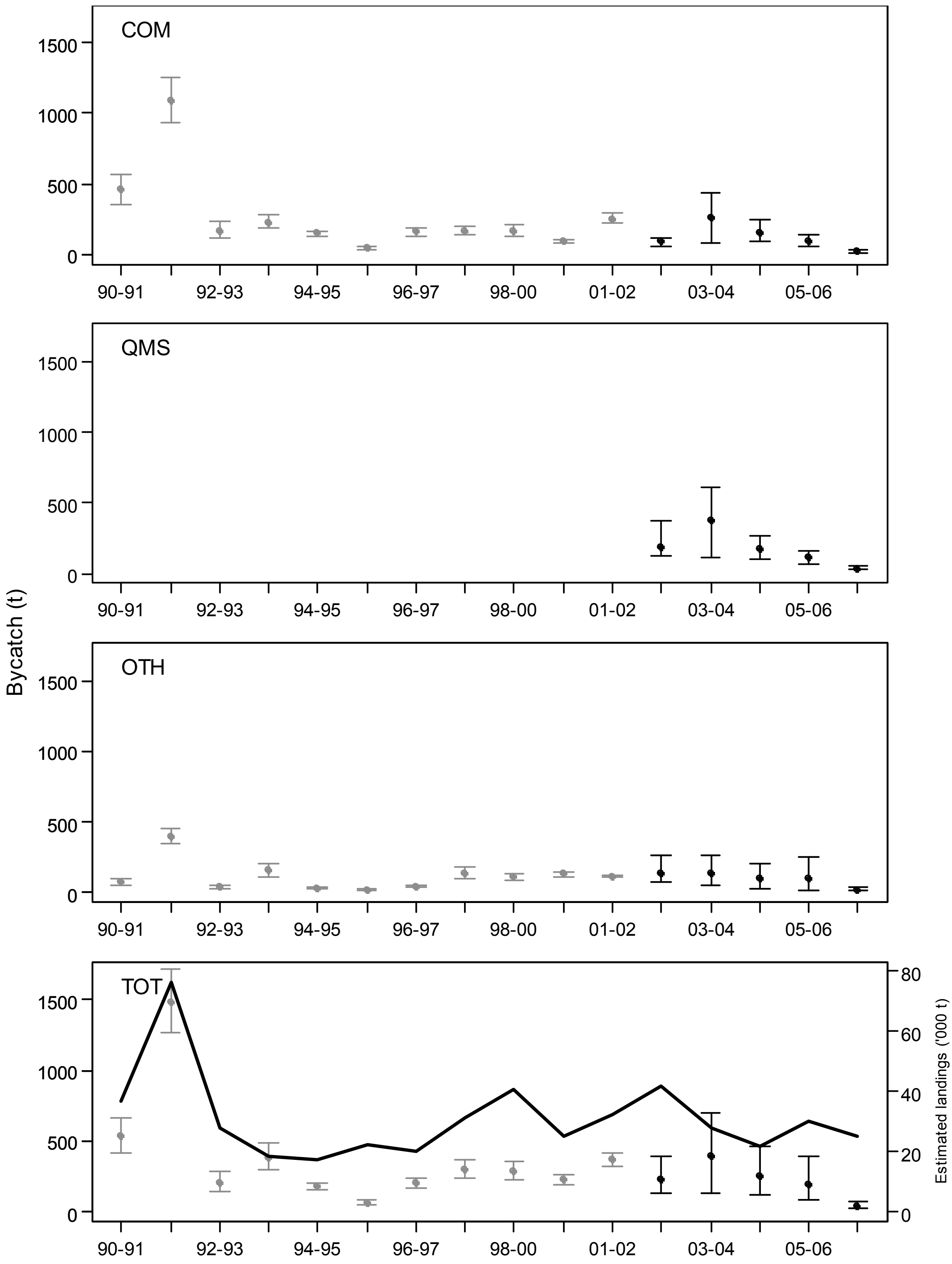

Figure 9: Annual estimates of fish bycatch in the southern blue whiting trawl fishery, calculated for commercial species (COM), QMS species, non-commercial species (OTH), and overall (TOT) for 2002–03 to 2006–07 (in black). Also shown (in grey) are estimates of bycatch in each category (excluding QMS) calculated for 1990–91 to 2001–02 by Anderson (2004a). Error bars show the 95% confidence intervals. Note: the 98–00 fishing year encompasses the 18 months between September 1998 and March 2000, the transitional period between the Oct–Sep and Apr–Mar fishing year. The dark line in the bottom panel shows the total annual estimated landings of SBW (Ministry of Fisheries 2009).

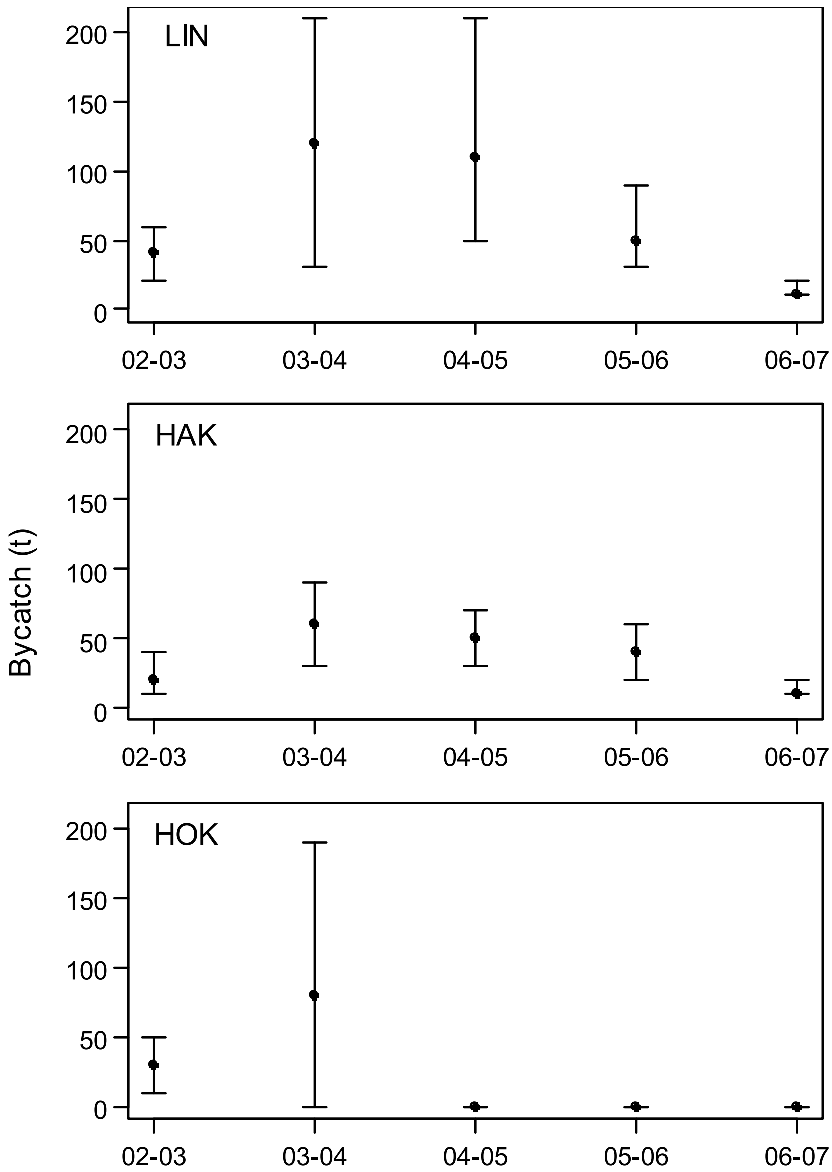

Figure 10: Annual estimates of the bycatch of ling (LIN), hake (HAK), and hoki (HOK) in the southern blue whiting trawl fishery for 2002–03 to 2006–07. Error bars show the 95% confidence intervals.

The lack of significant bycatch in this fishery compared to other large offshore New Zealand fisheries, and the very similar sets of main bycatch species recorded by the vessels and observers, would seem to suggest that bycatch may be well and fully recorded on commercial catch-effort forms. Therefore it might be expected that total bycatch derived from the difference between the total catch and southern blue whiting catch recorded for each trawl on TCEPRs should provide a good estimate of total annual bycatch. Closer examination, however, reveals some deficiencies in the commercial catch-effort data. The distribution of total bycatch recorded by observers in the observed fraction of the fishery was compared graphically with that recorded on catch-effort forms for the target fishery as a whole (Figure 11). The low frequency of small bycatch amounts in the plot based on catch-effort data compared to the plot based on observer data in this figure indicates that small amounts of bycatch are frequently not recorded on catch-effort forms. Although it may be expected that observers record the bycatch more rigorously than the vessel skippers, as has recently been demonstrated in the west coast South Island hoki fishery (Bremner et al. 2008), it is likely that the main reason for this discrepancy is the limitation on the TCEPR forms to only the top five species. This is supported by a breakdown of the frequency of the numbers of species recorded on TCEPRs, which shows that five species are recorded in almost 60% of trawls (Table 14).

Total annual bycatch derived from commercial catch reporting declined during the 2002–03 to 2006–07 period, from 334 t to 145 t (see Table 12). These figures fall within the 95% confidence intervals calculated for the observer data derived values in four out of the five years. Although the observer data based method also indicates a decline in total bycatch during the period, it shows a much sharper drop for 2006–07 than indicated by the TCEPR data.

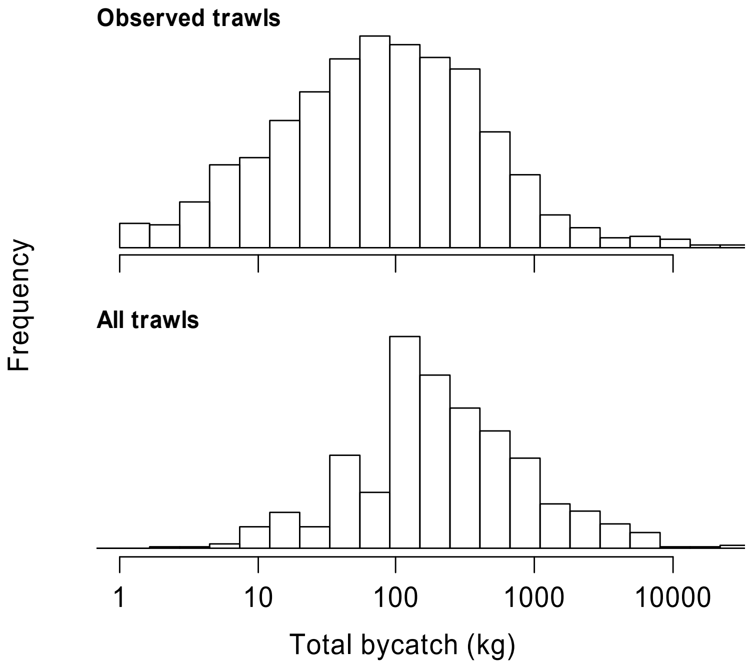

Figure 11: Histograms of total bycatch per trawl for the observed fraction of the southern blue whiting target fishery, from observer data, (top) and for the entire target fishery, from commercial catch-effort data, (bottom). Data were log transformed.

Table 14: Percentage of number of species recorded on TCEPR forms in the southern blue whiting fishery, 2002–07. The catch of no more than five species can be recorded on these forms.

Number of bycatch species recorded	Percentage
1	15.7
2	6.5
3	9.1
4	9.3
5	59.4
Total	100.0

3.6 Estimation of discards

3.6.1 Discard rates

Discard ratios for SBW, COM, LIN, HAK, and HOK were calculated for each fishing year, but no stratification by depth was used for these species categories because of the small number of discards recorded by observers (see Section 3.4.2) or, for SBW, because of insufficient data in several of the strata. Discard ratios for OTH and QMS species were calculated from the observer data separately for each of the depth categories determined from regression tree partitioning, for each year separately. The variance in these discard rates was calculated using the bootstrap methods described above.

The annual discard rate of SBW ranged from 16 to 60 kg/h, a much greater rate than estimated for any other species category (Table 15). Discard rates for COM species decreased in each year, from about 1.3 kg/h in 2002–03 to 0.02 kg/h in 2006–07, but none of the main COM species, LIN, HAK, and HOK showed a consistent pattern over time. So few discards were recorded for LIN and HOK that in several years the bootstrap median rate was zero. Discard rates of HAK were slightly greater, but still less than 0.1 kg/h in most years. Rates of discarding of OTH species were higher in each year for deep trawls (deeper than 443 m) than for shallow trawls, and at their peak (in 2003–04 and 2004–05 were at a similar level (at least in deeper trawls) to discard rates of SBW (Table 16). No trend of increasing or decreasing discard rates over time was apparent for OTH species. Discard rates of QMS species (0.1–3.0 kg/h in trawls shallower than 423 m, 0.3 to 7.7 kg/h in trawls deeper than 423 m) were slightly less than for OTH species overall, although were similar in the shallow trawl category (split at 423 m), and tended to decrease over time (Table 17). Discard rates of COM and QMS species were a small fraction of the bycatch rates for these species groups (between about 0.1 and 0.01), and although discard rates of OTH species were much closer to the bycatch rates for this species group, they were still significantly lower.

Table 15: Discard rates of southern blue whiting (SBW), commercial species (COM), ling (LIN), hake (HAK), and hoki (HOK) in the southern blue whiting trawl fishery, by fishing year, based on observed catch data. Discard rates are the median of the bootstrap sample of 1000.

Fishing year	Discard rate (kg/h)				
	SBW	COM	LIN	HAK	HOK
2002–03	49	1.28	0.00	0.05	1.14
2003–04	16	0.17	0.00	0.14	0.00
2004–05	32	0.11	0.06	0.01	0.02
2005–06	60	0.05	0.00	0.05	0.00
2006–07	52	0.02	0.01	0.02	0.00

Table 16: Discard rates of non-commercial (OTH) fish species in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Discard rates are the median of the bootstrap sample of 1000.

Fishing year	Discard rate (kg/h)	
	<443 m	>443 m
2002–03	2.8	7.6
2003–04	0.3	17.7
2004–05	4.3	25.8
2005–06	3.4	4.4
2006–07	0.7	2.3

Table 17: Discard rates of QMS fish species in the southern blue whiting trawl fishery, by depth category and fishing year, based on observed catch data. Discard rates are the median of the bootstrap sample of 1000.

Fishing year	Discard rate (kg/h)	
	<423 m	>423 m
2002–03	2.6	7.7
2003–04	0.1	2.9
2004–05	3.0	6.1
2005–06	0.6	0.9
2006–07	0.1	0.3

3.6.2 Annual discard levels

Annual discard levels were estimated from observer data by multiplying the ratios calculated for each depth and year stratum by the target fishery trawl duration totals for the equivalent stratum, as described in Section 2.5, and precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Table 18, Figure 12).

Annual discards of SBW ranged from 50 to 230 t, and OTH discards from 10 to 50 t, between 2002–03 and 2006–07 (Table 18). Discards of COM species were negligible, with median bootstrap values of zero in all but the first of these years. Intentional discarding of quota species (which includes all species in the COM category) is not permitted (under Section 72 of the 1996 Fisheries Act) and so discards of these species would be expected to be low and limited mainly to accidental losses of fish due to gear malfunctions (burst nets, etc.). Total annual discards and annual discards of SBW have generally decreased since 1990–91, a trend not shared with total estimated landings (Figure 12) or total bycatch (see Figure 9). Between the 1990–91 and 1998–2000[1] fishing years total annual discard estimates followed very closely the variations in total estimated landings, but in subsequent years discards have not only been at a consistently low level, they also have been much lower as a proportion of landings. Confidence intervals around the estimates made in this study were generally wide in comparison to those from the earlier study, due to changes in the methodology used to calculate them (allowing for a correlation between trawls within a trip), and indicate that any variation in discard levels between these years is not statistically significant.

Table 18: Estimates of discards (to the nearest 10 t) in the target southern blue whiting trawl fishery by fishing year, for the species categories SBW, COM, OTH, and overall (TOT), based on observed catch rates and total effort. The 95% confidence intervals are shown in parentheses.

Fishing year	SBW		COM		OTH		TOT	
2002–03	220	(10–500)	10	(0–20)	20	(10–30)	250	(30–550)
2003–04	50	(0–160)	0	(0–0)	40	(0–60)	90	(0–220)
2004–05	110	(20–250)	0	(0–0)	50	(10–120)	160	(30–370)
2005–06	230	(80–440)	0	(0–0)	10	(0–30)	240	(80–470)
2006–07	110	(10–280)	0	(0–0)	10	(0–10)	120	(10–290)

[1]The 1998–2000 fishing year covered an 18 month period due to the transition from a 1 Oct–30 Sep fishing year to a 1 Mar–30 April fishing year.

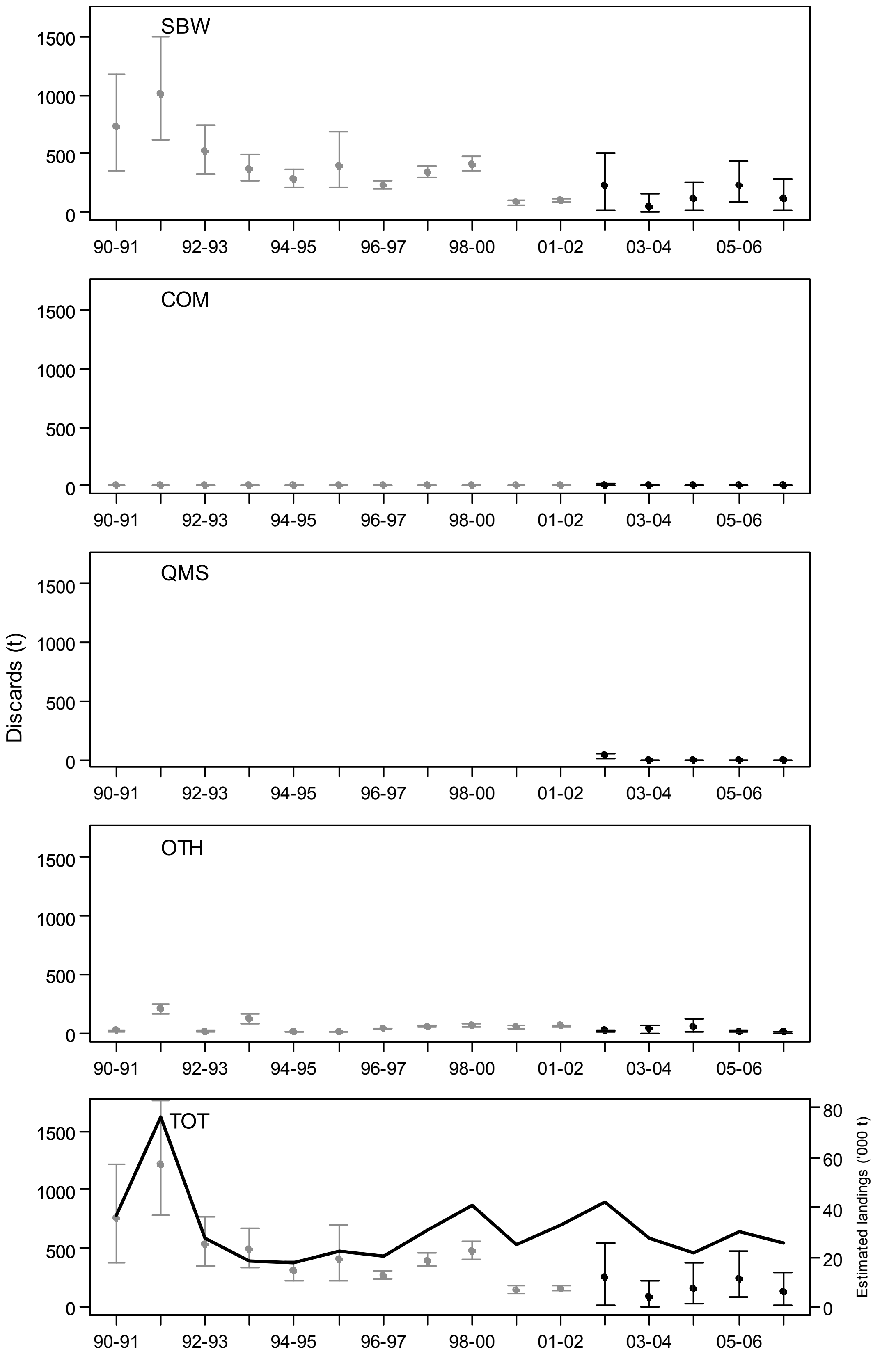

Figure 12: Annual estimates of fish discards in the southern blue whiting trawl fishery, calculated for the target species (SBW), commercial species (COM), QMS species, non-commercial species (OTH), and overall (TOT) for 2002–03 to 2006–07 (in black). Also shown (in grey) are estimates of discards in each category (excluding QMS) calculated for 1990–91 to 2001–02 by Anderson (2004a). Error bars show the 95% confidence intervals. The dark line shows the total annual estimated landings of SBW (Ministry of Fisheries 2009).

3.7 Efficiency of the southern blue whiting trawl fishery

Annual discards in the southern blue whiting trawl fishery were compared to the estimated total annual estimated landings of southern blue whiting and the total annual bycatch to get a measure of the efficiency of the fishery (Table 19). The comparison included estimates from this study and the earlier study by Anderson (2004a). The discard fraction (kg of discards/kg of southern blue whiting catch) fluctuated at about 0.02 between 1990–91 and 1995–96, decreased over the next four years to 0.005 in 2000–01, and has remained at about this level over the last seven years. Total discards were often greater than total bycatch, especially in the earlier part of this series, due to the bulk of discarding being of the target species. The drop in discards and hence the drop in the discard fraction in recent years is due largely to the lower frequency of observer reports of fish lost from the nets during retrieval. Because this fishery is quite discrete in terms of location and timing, the level of further discarding associated with the trawl catch of southern blue whiting while targeting other species is likely to be minimal.

Table 19: Total estimated landings of southern blue whiting (t) in the target trawl fishery, total estimated bycatch and discards (t), and the discard fraction (kg of total discards per kg of southern blue whiting caught) by fishing year for 1990–91 to 2006–07.

Fishing year	SBW landings	Total bycatch	Total discards	Discard fraction
1990–91	36 870	533	746	0.020
1991–92	76 255	1 479	1 218	0.016
1992–93	27 708	206	537	0.019
1993–94	18 560	382	483	0.026
1994–95	17 477	178	302	0.017
1995–96	22 279	62	407	0.018
1996–97	20 147	203	270	0.013
1997–98	31 165	295	391	0.013
1998–00	40 926	283	471	0.012
2000–01	24 938	223	137	0.005
2001–02	32 501	364	159	0.005
2002–03	41 775	230	250	0.006
2003–04	27 812	390	90	0.003
2004–05	21 567	250	160	0.007
2005–06	30 260	190	240	0.008
2006–07	25 363	40	120	0.005

4. DISCUSSION

The precision of the estimates of bycatch and discard levels using these methods is heavily reliant on the coverage of the fishery achieved by observers. In order to maximise precision, a reasonable fraction of the target fishery, well spread over its spatial and temporal range and across the range of vessels involved, must be covered by observers. In this fishery, the level of observer coverage represented between about 22% and 53% of the target fishery catch in the years examined. This coverage is high in comparison to other major New Zealand fisheries but similar to the level achieved in this fishery between 1990–91 and 2001–02 (Anderson 2000a).

Graphical analysis of the spread of the observer data compared with that of the fishery as a whole, across a range of variables, showed no shortcomings of any significance. The highly restricted distribution of southern blue whiting in New Zealand seas, along with highly directed target fishing for the species over a short and predictable spawning period, and a stable and uniform fleet composition, make this an ideal fishery for the type of analyses used here. In addition, the spatial extent of this fishery has been contracting since 2002–03, further minimising a potential source of variability. With almost no fishing taking place around the Auckland Islands and only occasional trawls around the Pukaki Rise, the fishery in 2002–03 to 2006–07 was restricted almost entirely to two areas; the Campbell and Bounty Plateaus.

Despite the high level of coverage, the precision of the final estimates of bycatch and discards was variable. This is because the frequency and level of bycatch and discards were very low for some of the species groups, in particular bycatch of commercial and QMS species, and discards of southern blue whiting. The occasional large bycatch or discard event led directly to high variability in the bootstrap estimates from which precision was calculated for these groups. Precision was better for the non-commercial species category, which was made up of a large number of species caught in generally small amounts. The multi-level bootstrap methods, not used in the previous examination of this fishery (Anderson 2004a), produced more conservative confidence intervals around the median values due the allowance for correlation between trawls within the same trip. Such a correlation is to be expected, even in a very uniform fishery such as this one, due to small differences between vessels and between different crews on the same vessel, in the set-up of the fishing gear and how it is used, and to the proximity in space and time between one trawl and the next.

Regression tree modelling was a useful tool in this analysis, providing an objective method of finding the split points at which to separate trawls into depth strata, thereby optimising the number of strata and simplifying the bootstrap procedures. Although trawl duration was identified as having a similar level of influence on bycatch and discards in the regression models, especially the normal models, this factor was not used due to a conflict in the trends shown by the binomial models. The trawls not used in the linear models (those with zero catch of the species category) were shown to be considerably shorter in duration than trawls with positive catches. It remains clear, however, that long trawls tend to catch (and therefore discard) bycatch species at a lower rate than short trawls – possibly due to a tendency of skippers to persevere with trawls which appear to have missed the targeted aggregation of fish.

Fishing vessel, or fishing trip, typically has the strongest influence in these fisheries bycatch models (see, e.g., Anderson 2004b, Anderson & Smith 2005), but these variables cannot be used for stratification. For the first time in New Zealand trawl fishery bycatch modelling, linear mixed effects models were used here to separate the effect of trip and vessel from the other variables in the model. This provides us with more confidence in the ability of the regression models to identify the most influential variables with which to stratify the calculations. It was reassuring that, in almost all cases, the bycatch and discard rates calculated from the raw data (see Tables 6–11, 16 & 17) matched the model predictions, being consistently greater in deeper strata.

This study confirms that the New Zealand southern blue whiting trawl fishery has a very low discard rate, and that this rate has become lower in recent years. The average value across the last five years of 0.005 kg of discards per kilogram of southern blue whiting caught, is considerably lower than recorded for any other New Zealand finfish trawl fisheries examined, for which the equivalent values range from 0.01 kg (jack mackerel fishery) to 0.16 kg (orange roughy fishery), and far less than in the ling longline fishery (0.35 kg) and the scampi trawl fishery (3.5 kg) (Anderson 2004b, 2008, 2009).

Despite the low discard rates, there is still some potential for better use of the bycatch in this fishery. The species discarded most (by weight) were porbeagle shark and rattails, and markets currently exist for these species. Porbeagle sharks that are discarded may survive, and this is recognised in its inclusion in the Sixth Schedule of the 1996 Fisheries Act, which allows the return to the sea of live QMS species on the list. It is likely that a fraction of the porbeagle sharks discarded in the data used here survived, but such survival has not been examined.

5. ACKNOWLEDGMENTS

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Appendix 1: Species codes, common and scientific names, estimated catch weight, percentage of the total catch, and percentage discarded of all species or species groups from all observer records for the target southern blue whiting trawl fishery from 1 Apr 2000 to 30 Mar 2008. Records are separated into fish/squid and (other) invertebrates and then ordered by decreasing percentage of catch. Quota species are shown in bold.

Fish and squid

Species code	Common name	Scientific name	Estimated catch (t)	% of catch	% discarded
SBW	Southern blue whiting	*Micromesistius australis*	78199	99.30	0.23
LIN	Ling	*Genypterus blacodes*	152	0.19	0.19
HAK	Hake	*Merluccius australis*	86	0.11	0.33
HOK	Hoki	*Macruronus novaezelandiae*	76	0.10	2.02
POS	Porbeagle shark	*Lamna nasus*	47	0.06	57.20
JMD	Jack mackerel	*Trachurus declivis*	28	0.04	0.00
JAV	Javelinfish	*Lepidorhynchus denticulatus*	24	0.03	47.71
RBM	Rays bream	*Brama brama*	22	0.03	38.66
SSI	Silverside	*Argentina elongata*	18	0.02	15.69
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	14	0.02	65.14
RAT	Rattails	Macrouridae	14	0.02	18.86
PAH	Opah	*Lampris immaculatus*	12	0.01	30.21
GSP	Pale ghost shark	*Hydrolagus bemisi*	9	0.01	6.04
MOO	Moonfish	*Lampris guttatus*	8	0.01	56.19
SPD	Spiny dogfish	*Squalus acanthias*	5	0.01	96.58
WSQ	Warty squid	*Moroteuthis* spp.	4	0.01	89.28
SWA	Silver warehou	*Seriolella punctata*	3	<0.01	0.00
FRO	Frostfish	*Lepidopus caudatus*	3	<0.01	0.19
WWA	White warehou	*Seriolella caerulea*	2	<0.01	9.09
LDO	Lookdown dory	*Cyttus traversi*	2	<0.01	3.42
BAR	Barracouta	*Thyrsites atun*	2	<0.01	0.00
WIT	Witch	*Arnoglossus scapha*	2	<0.01	9.64
GSH	Ghost shark	*Hydrolagus novaezealandiae*	1	<0.01	3.74
LCH	Long-nosed chimaera	*Harriotta raleighana*	1	<0.01	52.83
RSK	Rough skate	*Dipturus nasutus*	1	<0.01	11.37
EMA	Blue mackerel	*Scomber australasicus*	1	<0.01	0.00
PIG	Pigfish	*Congiopodus leucopaecilus*	1	<0.01	97.41
RCO	Red cod	*Pseudophycis bachus*	1	<0.01	2.53
MAK	Mako shark	*Isurus oxyrinchus*	1	<0.01	98.87
ETB	Baxter's lantern dogfish	*Etmopterus baxteri*	1	<0.01	100.00
MAN	Finless flounder	*Neoachiropsetta milfordi*	1	<0.01	4.24
SQX	Squids		<1	<0.01	59.79
BSH	Seal shark	*Dalatias licha*	<1	<0.01	100.00
TOA	Toadfish	*Neophrynichthys* sp.	<1	<0.01	95.98
CON	Conger eel	*Conger* spp.	<1	<0.01	97.78
SSK	Smooth skate	*Dipturus innominatus*	<1	<0.01	7.63
JMM	Jack mackerel	*Trachurus symmetricus murphyi*	<1	<0.01	0.00
PDS	False frostfish	*Paradiplospinus gracilis*	<1	<0.01	100.00
STU	Slender tuna	*Allothunnus fallai*	<1	<0.01	66.67
STA	Giant stargazer	*Kathetostoma giganteum*	<1	<0.01	0.00
LAN	Lanternfish	Myctophidae	<1	<0.01	0.00
STN	Southern bluefin tuna	*Thunnus maccoyii*	<1	<0.01	0.00
RBT	Redbait	*Emmelichthys nitidus*	<1	<0.01	1.32
BBE	Banded bellowsfish	*Centriscops humerosus*	<1	<0.01	100.00

Species code	com_name	sci_name	Estimated catch (t)	% of catch	% discarded
TAR	Tarakihi	*Nemadactylus macropterus*	<1	<0.01	0.00
TOP	Pale toadfish	*Ambophthalmos angustus*	<1	<0.01	65.43
JMA	Jack mackerel	*Trachurus declivis, T. s. murphyi, T. novaezelandiae*	<1	<0.01	0.00
GUR	Gurnard	*Chelidonichthys kumu*	<1	<0.01	0.00
BCD	Black cod	*Paranotothenia magellanica*	<1	<0.01	65.45
DSK	Deepwater spiny skate	*Amblyraja hyperborea*	<1	<0.01	100.00
DEA	Dealfish	*Trachipterus trachypterus*	<1	<0.01	0.00
OSD	Sharks (unidentified)	Selachii	<1	<0.01	100.00
DSP	Deepsea pigfish	*Congiopodus coriaceus*	<1	<0.01	60.53
CHI	Chimaeras	*Chimaera* spp.	<1	<0.01	17.24
AGR	Ribbonfish	*Agrostichthys parkeri*	<1	<0.01	65.38
SDO	Silver dory	*Cyttus novaezealandiae*	<1	<0.01	3.85
FTU	Frigate tuna	*Auxis thazard*	<1	<0.01	0.00
SMI	Sleeper shark	*Somniosus microcephalus*	<1	<0.01	100.00
RIB	Ribaldo	*Mora moro*	<1	<0.01	0.00
SOM	Little sleeper shark	*Somniosus rostratus*	<1	<0.01	100.00
OAR	Oarfish	*Regalecus glesne*	<1	<0.01	70.59
HCO	Hairy conger	*Bassanago hirsutus*	<1	<0.01	66.67
SCO	Swollenhead conger	*Bassanago bulbiceps*	<1	<0.01	100.00
SRI	Scymnodon ringens	*Scymnodon ringens*	<1	<0.01	100.00
PDG	Prickly dogfish	*Oxynotus bruniensis*	<1	<0.01	100.00
RUD	Rudderfish	*Centrolophus niger*	<1	<0.01	7.69
JGU	Spotted gurnard	*Pterygotrigla picta*	<1	<0.01	0.00
SKA	Skates	Rajidae, Arhynchobatidae	<1	<0.01	90.91
BCO	Blue cod	*Parapercis colias*	<1	<0.01	0.00
SCD	Smallscaled cod	*Paranotothenia microlepidota*	<1	<0.01	0.00
API	Alert pigfish	*Alertichthys blacki*	<1	<0.01	60.00
BCA	Barracudina	*Magnisudis prionosa*	<1	<0.01	20.00
NSD	Northern spiny dogfish	*Squalus griffini*	<1	<0.01	100.00
SBO	Southern boarfish	*Pseudopentaceros richardsoni*	<1	<0.01	100.00
SEE	Silver conger	*Gnathophis habenatus*	<1	<0.01	0.00
FLA	Flatfish	Bothidae, Pleuronectidae, Soleidae	<1	<0.01	0.00
BEN	Scabbardfish	*Benthodesmus* spp.	<1	<0.01	0.00
BRI	Brill	*Colistium guntheri*	<1	<0.01	0.00
DWE	Deepwater eels		<1	<0.01	0.00
RAG	Ragfish	*Icichthys australis*	<1	<0.01	0.00
SBR	Southern bastard cod	*Pseudophycis barbata*	<1	<0.01	0.00
SHE	Sherwood’s dogfish	*Scymnodalatias sherwoodi*	<1	<0.01	100.00
SPO	Rig	*Mustelus lenticulatus*	<1	<0.01	100.00
SPZ	Spotted stargazer	*Genyagnus monopterygius*	<1	<0.01	66.67
HJO	Johnson's cod	*Halargyreus johnsonii*	<1	<0.01	100.00
MDO	Mirror dory	*Zenopsis nebulosus*	<1	<0.01	50.00
PAL	Barracudinas	Paralepididae	<1	<0.01	0.00
SPE	Sea perch	*Helicolenus* spp.	<1	<0.01	0.00
BOA	Sowfish	*Paristiopterus labiosus*	<1	<0.01	0.00
BSP	Big-scale pomfret	*Taratichthys longipinnis*	<1	<0.01	0.00
BYS	Alfonsino	*Beryx splendens*	<1	<0.01	0.00
HAG	Hagfish	*Eptatretus cirrhatus*	<1	<0.01	100.00
PLA		*Platyberyx* sp.	<1	<0.01	0.00

Species code	com_name	sci_name	Estimated catch (t)	% of catch	% discarded
SDF	Spotted flounder	*Azygopus pinnifasciatus*	<1	<0.01	0.00
TOD	Dark toadfish	*Neophrynichthys latus*	<1	<0.01	0.00
Invertebrates					
ONG	Sponges	Porifera	2	<0.01	100.00
SPI	Spider crabs		2	<0.01	99.74
OCT	Octopuses		<1	<0.01	83.93
SFI	Starfish	Asteroidea	<1	<0.01	96.66
ANT	Anemones	Anthozoa	<1	<0.01	100.00
OPH	Brittle stars	Ophiuroidea	<1	<0.01	100.00
JFI	Jellyfish		<1	<0.01	100.00
ECN	Sea urchins	Echinoidea	<1	<0.01	100.00
CRB	Crabs		<1	<0.01	33.33

Appendix 2: Species codes, common and scientific names, estimated catch weight, and percentage of the total catch of all species or species groups from all commercial fishing returns (TCEPRs) for the target southern blue whiting trawl fishery from 1 Apr 2002 to 30 Mar 2007. Records are ordered by decreasing percentage of catch. NB: only the top 5 species, by weight, are recorded on these forms. Quota species are shown in bold

Species code	Common name	Scientific name	Estimated catch (t)	% of catch
SBW	Southern blue whiting	*Micromesistius australis*	136210	99.47
LIN	Ling	*Genypterus blacodes*	214	0.16
HAK	Hake	*Merluccius australis*	157	0.11
HOK	Hoki	*Macruronus novaezelandiae*	59	0.04
RBM	Ray's bream	*Brama brama*	58	0.04
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	53	0.04
JAV	Javelinfish	*Lepidorhynchus denticulatus*	42	0.03
POS	Porbeagle shark	*Lamna nasus*	17	0.01
SSI	Silverside	*Argentina elongata*	12	0.01
RAT	Rattails	Macrouridae	11	0.01
GSP	Pale ghost shark	*Hydrolagus bemisi*	4	<0.01
MOO	Moonfish	*Lampris guttatus*	4	<0.01
PAH	Opah	*Lampris immaculatus*	3	<0.01
WWA	White warehou	*Seriolella caerulea*	2	<0.01
SPD	Spiny dogfish	*Squalus acanthias*	2	<0.01
GSH	Ghost shark	*Hydrolagus novaezealandiae*	1	<0.01
STU	Slender tuna	*Allothunnus fallai*	1	<0.01
LCH	Long-nosed chimaera	*Harriotta raleighana*	1	<0.01
LDO	Lookdown dory	*Cyttus traversi*	1	<0.01
PIG	Pigfish	*Congiopodus leucopaecilus*	1	<0.01
MAK	Mako shark	*Isurus oxyrinchus*	1	<0.01
MIQ	Warty squid	*Moroteuthis ingens*	1	<0.01
RSK	Rough skate	*Dipturus nasutus*	1	<0.01
RCO	Red cod	*Pseudophycis bachus*	1	<0.01
SWA	Silver warehou	*Seriolella punctata*	1	<0.01
SKA	Skates	Rajidae, Arhynchobatidae	0.4	<0.01
WIT	Witch	*Arnoglossus scapha*	0.3	<0.01
STA	Giant stargazer	*Kathetostoma giganteum*	0.2	<0.01
LAN	Lantern fish	Myctophidae	0.2	<0.01
DEA	Dealfish	*Trachipterus trachypterus*	0.2	<0.01
RBY	Ruby fish	*Plagiogeneion rubiginosum*	0.1	<0.01
OSD	Sharks (unidentified)	Selachii	0.1	<0.01
SCH	School shark	*Galeorhinus galeus*	0.1	<0.01
SSK	Smooth skate	*Dipturus innominatus*	0.1	<0.01
SSO	Smooth oreo	*Pseudocyttus maculatus*	0.1	<0.01
POR	Porae	*Nemadactylus douglasi*	0.1	<0.01
SDO	Silver dory	*Cyttus novaezealandiae*	0.1	<0.01
GSQ	Giant squid	*Architeuthis* spp.	0.1	<0.01
LIM	Limpets	Gastropoda	0.1	<0.01
BSH	Seal shark	*Dalatias licha*	0.03	<0.01
MDO	Mirror dory	*Zenopsis nebulosus*	0.03	<0.01
SCI	Scampi	*Metanephrops challengeri*	0.03	<0.01
WSQ	Warty squid	*Moroteuthis* spp.	0.02	<0.01
BYX	Alfonsino & Long-finned Beryx	*Beryx splendens* & *B. decadactylus*	0.02	<0.01
BSL	Black slickhead	*Xenodermichthys* spp.	0.02	<0.01

Species code	Common name	Scientific name	Estimated catch (t)	% of catch
TOA	Toadfish	*Neophrynichthys* sp.	0.02	<0.01
DWD	Deepwater dogfish	Squalidae	0.01	<0.01
RBT	Redbait	*Emmelichthys nitidus*	0.003	<0.01