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Fish and invertebrate bycatch and discards in New Zealand arrow squid fisheries from 1990–91 until 2010–11

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Commercial catch-effort data and fisheries observer records of catch and discards by species, provided by the Ministry for Primary Industries, were used to estimate the annual rate and level of fish bycatch and discards in the arrow squid trawl fishery from 1990–91 to 2010–11. Separate estimates, and estimates of precision, were made for the following categories of catch and discards: all QMS species combined, all non-QMS species combined, all invertebrate species combined. In addition, estimates were made of the annual bycatch of a wide range of individual species.

Linear mixed-effect models (LMEs) were used to identify key factors influencing variability in the observed rates of bycatch and discarding in order to provide appropriate stratification for the scaling up of observed bycatch and discards to the entire commercial arrow squid fishery. This process consistently identified the separate fishery areas as having the greatest influence on these rates and so this variable was used to stratify the calculation of annual bycatch and discard totals in each catch category.

A rate estimator, based on the bycatch or discards per arrow squid target trawl, was used to calculate bycatch and discard rates in each area and catch category for each fishing year. These rates were then multiplied by the total number of trawls in each stratum, derived from commercial catch-effort data, to make annual estimates for the target arrow squid fishery as a whole. Multi-step bootstrap methods, taking into account the effect of auto-correlation between trawls in the same observed trip and area stratum, were used to estimate the variance in the rates and provide confidence intervals for the annual bycatch and discard estimates.

Since 1990–91, arrow squid have accounted for about 80% of the total estimated catch weight recorded by observers in this fishery. The remainder of the observed catch comprised mainly the commercial fish species barracouta (8.5% of total catch weight), spiny dogfish (1.7%), and jack mackerel (1.1%). Invertebrate species made up a much smaller fraction of the bycatch overall (about 1%), but crabs (0.8%), especially the smooth red swimming crab (0.5%), were frequently caught—and mostly discarded.

Total annual bycatch in the arrow squid fishery ranged from about 4500 t to 25 000 t, with low levels in the early 1990s and after 2007–08, and a peak in the early 2000s. The large majority of bycatch has comprised QMS species, with less than 1000 t of non-QMS species and invertebrate species bycatch in most years, although invertebrate species bycatch was shown to have significantly increased over time. Suitable trawl survey time series with which to compare relative biomass estimates with observer bycatch rates were found not to exist.

Estimated total annual discards ranged from just over 200 t in 1995–96 to about 5500 in 2001–02 and, like bycatch, peaked in the early 1990s and were at relatively low levels after 2006–07. The majority of discards were QMS species (about 62% over all years), followed by non-QMS species (19%), invertebrate species (11%), and arrow squid (7%). Discards increased in all categories over the 21-year period; this increase was strongly significant for non-QMS species and total discards, and also marginally significant for QMS species and invertebrates. The species discarded in the greatest amounts were spiny dogfish, redbait, rattails, and silver dory.

The level of annual discards in the arrow squid fishery, calculated as a fraction of the catch of the target species, peaked at a level of 0.13 kg of discarded fish for every 1 kg of arrow squid caught in the early 1990s and subsequently declined to 0.02–0.07 kg after 2002–03.

1. INTRODUCTION

The Ministry for Primary Industries deepwater 10-year plan includes the following Environment Outcome related management objective: MO2.4. Identify and avoid or minimise adverse effects of deepwater and middle-depth fisheries on incidental bycatch species. This project addresses this objective by quantifying the level of bycatch of species or groups of species not managed separately in the QMS system. Significant changes in the relative catch of a species can be used to infer changes in abundance (though these may be due to other causes, such as changes in fishing practices). Bycatch species identified in this way as being in decline can be monitored and remedial action planned. The scampi (*Metanephrops challengeri*) trawl fishery was assessed in the first year of the programme (Anderson 2012), the arrow squid (*Nototodarus* spp.) trawl fishery is the main subject of this report, and similar analyses will be made in subsequent years for each of the other Ministry for Primary Industries Tier-1 fisheries, in the following order: ling (*Genypterus blacodes*) (bottom longline), hoki (*Macruronus novaezelandiae*)/hake (*Merluccius australis*)/ling trawl, jack mackerel (*Trachurus* spp.) trawl, southern blue whiting (*Micromesistius australis*) trawl, and orange roughy (*Hoplostethus atlanticus*)/oreo (Oreosomatidae) trawl.

The New Zealand arrow squid fishery is based on two closely related species: Sloan's arrow squid (*Nototodarus sloanii*) which are most abundant along or immediately to the south of the Subtropical Front (STF) and Gould's arrow squid (*N. gouldi*) which occur north of the STF (Smith et al. 1987, Anderson et al. 1998). Both species are found over the continental shelf in depths of up to 1000 m, although they are more common in depths of less than 500 m and even occur in surface waters (Anderson et al. 1998). Most commercial trawling effort is at depths of 160–200 m and is centred on the December–May period. Fishing is mainly by Korean and Ukrainian vessels under charter to New Zealand companies. Although large amounts of squid have been caught by jigging, especially in the 1980s and early 1990s, the trawl fishery has accounted for most of the squid catch in most years, especially since the mid to late 1990s (Ministry of Fisheries 2011). The main trawling areas are the Stewart-Snares shelf, around the Auckland Islands, and near Banks Peninsula. Observer data have shown that squid account for about 70–80% of the total catch in the target trawl fishery, the principal bycatch species previously listed were barracouta (*Thyrsites atun*), jack mackerel (*Trachurus* spp.), silver warehou (*Seriolella punctata*), and spiny dogfish (*Squalus acanthias*) (Anderson 2004, Ballara & Anderson 2009).

The arrow squid fishery is relatively large and valuable, with total reported landings in the 2010–11 fishing year of greater than 37 000 t and export earnings in 2011 of about NZ$120M (http://www.seafoodindustry.co.nz/), making it one of New Zealand's most valuable export fisheries. Annual catches have been restricted by a TACC since 1986–87, with separate TACCs for the Auckland Islands trawl fishery (SQU6T) and the remainder of the New Zealand EEZ excluding the Kermadecs (SQU1T and SQU1J). Landings have occasionally reached or exceeded the TACC in SQU1T and SQU6T, but not in SQU1J, so that the overall TACC has always been well undercaught (Ministry of Fisheries 2011).

The most recent analysis of bycatch and discards in the squid trawl fishery (Ballara & Anderson 2009) used a trawl duration-based estimator and covered the period 1999–2000 to 2005–06; two previous analyses, using the same estimator (Anderson 2004) or a target species catch-based estimator (Anderson et al. 2000), provide annual estimates of bycatch and discards back to 1990–91. These reports estimated total annual bycatch in the arrow squid fishery for the period 1990–91 to 2005–06 to have ranged from about 9000 t to about 27 000 t and total annual discards from about 1000 to about 6500 t. Estimates of the rate of discarding ranged from about 0.04 kg to 0.20 kg of discards for every 1 kg of arrow squid landed. In this assessment, new estimates of annual bycatch and discards were made for all years from 1990–91 to 2010–11, using a revised estimator, and the methods used in previous work were extended by examining temporal trends in more detail.

This report was prepared as an output from the Ministry for Primary Industries project DAE2010-02 “Bycatch monitoring and quantification of deepwater stocks” which has the following objectives.

Overall objective:

To estimate the level of non-target fish catch and discards of target and non-target fish species in New Zealand deepwater fisheries.

Specific objectives for year-2

1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded in the arrow squid trawl fishery, for the fishing years since the last review, using data from Ministry for Primary Industries Observers and commercial fishing returns.

2. To compare estimated rates and amounts of bycatch and discards from this study with previous projects on bycatch in the arrow squid trawl fishery.

3. To compare any trends apparent in bycatch rates in the arrow squid trawl fishery with relevant fishery independent trawl surveys.

4. To provide annual estimates of bycatch for nine Tier-1 species fisheries (SQU, SCI, HAK, HOK, JMA, ORH, OEO, LIN, SBW). This objective is reported on in a separate report (Anderson, in press), and repeated here for SQU only.

2. METHODS

2.1 Observer data

Ministry for Primary Industries observers have been making detailed records of catch and discards by species or species group, for each trawl or (frequently for discards) group of trawls, for a portion of the arrow squid fleet in each year since 1990–91. The allocation of observers on commercial vessels takes into account a range of data collection requirements and compliance issues for multiple fisheries. It has therefore not always been possible to achieve an even or random spread of observer effort in each fishery. Observer coverage in the arrow squid fishery has varied through time, though was very high in most years: less than 10% of the total catch was observed in a few years in the early 1990s but 20% or more was observed in most years after 1999–2000, with a maximum of 53% in 2000–01. Recent coverage, in each year since the end of the last review period (2005–06), has been particularly high, at 28–40%.

Overall, there was a considerable amount of observer data available for this analysis, with about 570–2880 observed trawls annually.

2.1.1 Data preparation and grooming

For the analysis of the arrow squid fishery, two datasets were prepared from the Ministry for Primary Industries observer databases *obs* and *cod*, based on all observed trawls targeting arrow squid since 1990–91, one comprising bycatch data and the other discard data. The *cod* database, which superseded the older *obs* database, was used to construct the bycatch dataset as this contains a complete set of catch by species for all relevant trawls. The discard dataset required data from both *obs* and *cod* to produce a complete set of discards by species for the years required, because of the lack of linkage in *cod* between processing data and station data in records from before about mid 2007. The *obs* database has this linkage, but contains no relevant data after April 2008.

After grooming, a total of 26 232 observed trawls targeting arrow squid were available for the analysis of bycatch. Because of variability in the recording of fish processing data, there were fewer observed trawls (19 780) available for the analysis of discards – see below. Data grooming was carried out in the same way for each dataset.

Trawl distance was calculated from the recorded start and finish positions. Records in which a start or finish position was missing were identified and groomed using median imputation. This process substitutes the missing value with an approximate one calculated from the median latitude or longitude for other trawls by the same vessel on the same day, if any exist. Long tows (over 50 km, approximately the 99^{th} percentile of the distribution of observed trawl distances) were accepted if in approximate agreement with the tow distance calculated from the recorded tow duration and trawling speed. Records with missing position data that could not be resolved were removed from the dataset. Trawl distances were then recalculated from a combination of the corrected positions and values derived from the recorded duration and trawling speed.

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. These trawl durations were then cross-checked with estimates based on the recorded fishing speed and calculated trawl distance. Missing fishing speed values and speeds greater than 4 knots (about 1.5% of the records) were substituted with values estimated by median imputation.

Fishing depth was calculated from the average of the recorded start and finish net depths where possible. For the records where one or both of these values was not recorded, bottom depth was taken from the remaining value or from the seabed depth (average of start and finish values where possible). Although the slight majority of observed trawls used midwater nets, these were used on or very close to the seabed as only about 5% of trawls were recorded as not being on the seabed at all times. Most trawls (78%) followed a straight line or constant depth contour, and most of the remainder followed an “out and back”, zig-zag or closed loop track.

Observers estimated the amounts “total greenweight on surface” and “total greenweight on board”, and these would sometimes differ if fish were lost from the net, either at or below the surface, but also simply because the observer may revise their estimate of the total catch once the net is aboard. Losses of fish from the net come about through a mixture of burst codends, burst windows/escape panels, and rips in the belly of the net. Valid differences in these values were interpreted here as lost fish and included as part of the discards from the trawl, with corrections made for any obvious recording errors. 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 it was clearly due to a transposition of the two values. These and any other differences in the two recorded values were interpreted as valid fish losses only if they were accompanied by an appropriate code identifying the cause of the loss. Genuine observed cases of lost fish were uncommon in this fishery, occurring in only 46 observed tows, with an average of about 5 t of lost fish.

Each record was assigned to an area (see Figure 1), based on a combination of natural breaks in the fishery and the arrow squid management areas, and matching those used in the previous review (Ballara & Anderson 2009). A few records fell outside these defined areas, but were retained for use in analyses and calculations where area was not relevant. The number of trawls observed in each area over the 21 years is shown in Table 1.

Observer data were available from 104 vessels ranging in length from 23 to 106 m. No vessel or company is identified in this report, and alpha-numeric codes are used to differentiate between vessels where necessary.

Table 1: Number of observed trawls targeting arrow squid by area (see Figure 1 for area boundaries) and fishing year.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA	WCSI	All areas
1990–91	327	0	0	0	0	840	0	0	1 167
1991–92	213	0	0	0	0	361	0	0	574
1992–93	139	28	0	0	5	1 394	1	0	1 567
1993–94	431	257	1	0	0	360	1	0	1 050
1994–95	278	1	0	0	0	435	0	0	714
1995–96	547	4	0	0	0	185	0	0	736
1996–97	708	4	0	0	0	478	0	0	1 190
1997–98	327	4	0	0	0	525	0	0	856
1998–99	154	18	0	0	0	813	0	0	985
1999–00	435	9	51	18	0	346	0	0	859
2000–01	565	80	9	0	0	2 228	0	0	2 882
2001–02	560	52	0	0	121	734	4	0	1 471
2002–03	414	50	1	2	309	498	20	0	1 294
2003–04	407	2	1	1	0	727	17	0	1 155
2004–05	780	48	9	0	62	1 345	1	0	2 245
2005–06	675	10	1	1	6	627	0	0	1 320
2006–07	535	28	1	4	1	685	0	1	1 255
2007–08	590	1	0	0	0	853	1	0	1 445
2008–09	753	0	1	0	1	507	0	0	1 262
2009–10	299	1	1	0	1	748	1	0	1 051
2010–11	493	5	8	0	16	631	2	0	1 155
All years	9 630	602	84	26	522	15 320	48	1	26 232

To create the dataset used to estimate discards, the weights of each species retained and discarded in each "processing group" were obtained from the observer databases. The processing group is the level at which observers record information on the processing of fish on board, including those discarded, and although usually represented by a single trawl, processing data 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 or processing area of a vessel. In order to examine how discard levels varied with fishing depth, area, season, and other factors that can vary between tows within a trip, 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 (which avoids also having to account for the effects of differences in discard variability between groups with one tow and groups with multiple tows), therefore disregarding about 25% of the available discard data. An examination was made to investigate whether the practice of combining multiple tows into single groups was related to the level of discards per tow, e.g., discards being tallied and recorded only when several small amounts had been accumulated. This showed that although median discards per tow was slightly greater for groups comprising a single tow (27 $kg.tow^{-1}$) compared with groups comprising two or three tows (16 $kg.tow^{-1}$ and 15 $kg.tow^{-1}$, respectively), it was lower than for groups comprising eight or nine tows (45 $kg.tow^{-1}$ and 69 $kg.tow^{-1}$, respectively).

Using the datasets described above, the weights of species caught and species discarded in each trawl were calculated for the following species categories.

- All Quota Management System species combined, excluding arrow squid (QMS). Observers recorded 76 QMS species in total, excluding arrow squid.
- All non-QMS species combined, excluding invertebrates (non-QMS).
- All non-QMS invertebrate species combined (INV).
- Individual species (bycatch only).

The above abbreviations (QMS, non-QMS, and INV) are used throughout the remainder of this report. Bycatch and discards were estimated separately for each of the combined species categories.

Summaries of the observed catch and percentage discarded of individual species and species groups are tabulated in Appendices 1–3. The catch in these appendices is based on the greenweight catch (Section 7) recorded in the observer catch effort logbook form (see Appendix 10), but the discards are based on a comparison of catch and discards from the “processed catch” and “all other fish” sections of the form (Sections 8 and 9). This is because the less common species are recorded in better detail (especially in terms of their fate, retained or discarded) in these sections. This is further complicated by the allowance in the forms for Sections 8 and 9 to apply to a different range of tows; to overcome this, summaries of fractions discarded by species were based on data from entire trips but, necessarily, only those trips in which arrow squid were the only species targeted.

For Objective 4, the total catch and frequency of capture of each bycatch species in the arrow squid fishery was examined, and those for which there was a total of less than 10 kg of observed catch over the entire 21-year period, or which were observed caught on less than six occasions, were ignored. It was considered that either the capture of such species was so rare as to be irrelevant, or the species code may have been incorrectly recorded by the observer.

2.2 Commercial fishing return data

Catch records from commercial fishing returns were obtained from Ministry for Primary Industries catch-effort databases for all trawls in which arrow squid was the stated target species, for the period 1 October 1990 to 30 September 2011. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort returns (TCERs); Catch, Effort and Landing Returns (CELRs) and high seas versions of these forms. Data were groomed for errors using simple checking and imputation algorithms developed in the statistical software package ‘R’ (Ihaka & Gentleman 1996). Tow positions, trawl length and duration, fishing speed, and depths, were all groomed in this manner, primarily employing median imputation and range checks to identify and deal with missing or unlikely values and outliers (Table 2).

Table 2: Numbers of missing values or outliers in commercial fishing return effort data, by form type. CEL, daily summary type forms (CELR); TCE, tow-by-tow type forms (TCEPR, TCER).

Field (range)	CEL	TCE
Missing/outlying start longitude (< 157° E or < 167° W)	–	27
Missing/outlying end longitude (< 157° E or < 167° W)	–	50
Missing/outlying start latitude (< 157° E or < 167° W)	–	16
Missing/outlying end latitude (<24° S or >58° S)	–	33
Calculated distance missing or > 100 km	–	1 429
Missing/outlying gear depths (<160 m or > 615 m)	–	1 756
Missing/outlying bottom depths (<160 m or > 615 m)	–	2 484
Missing/outlying fishing duration (>13.3 h)	6	556
Missing/outlying fishing speed (<1.2 or > 4.0 knots)	–	123

These records, representing 162 898 trawls, were assigned to the areas defined in Figure 1, as was done for the observer data, using the recorded position coordinates.

It is possible to use these commercial catch data to directly estimate the total annual non-target catch in this fishery, as for each trawl or group of trawls (CELR records) the total catch as well as the catch of the target species (unless it is outside of the top five species by weight and therefore generally negligible) is recorded. Such estimates are provided here for comparison with the observer-based estimates and are somewhat appealing because (in contrast to the observer-based estimates) no scaling is required. However, a study of the New Zealand ling longline fishery, comparing commercial catch reports between observed and unobserved vessels, indicated that under-reporting and non-reporting of bycatch species was common and only a quarter of the catch of the main bycatch species (spiny dogfish, *Squalus acanthias*) was reported between 2001 and 2004 (Burns & Kerr 2008). This method also has the limitation that, because only the top five or eight species by weight are recorded, it is not possible to properly estimate the bycatch of individual species or groups of species.

2.3 Analysis of factors influencing discards and bycatch

Regression analyses were used to identify the most useful strata for the calculations to scale up from the observer records to the whole fishery. Several potentially influential variables are recorded by observers for each observed trawl, but not all are useful for stratification of commercial data. For example, vessel and trip have been shown in previous analyses to be useful factors for predicting rates of bycatch and discards. But, since only a subset of the vessels and trips in any fishery are observed, it is problematic to calculate rates for those that were not. The influence of trip was, however, taken into account in this analysis. This was done by employing linear mixed-effects models (LMEs), in which the trip variable was treated as a random effect (whereby the trip associated with each record is assumed to be randomly selected from a population of trips), 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); month or fishing day (day of the fishing year, 1 to 366); headline height; start time (0–24); fishing year; area (see Figure 1); vessel tonnage; fishing speed; nationality; and gear code (bottom or midwater net).

Each species category (QMS, non-QMS, INV, and SQU (discards)) was examined separately and normal and, where appropriate, binomial mixed-effect regression models constructed. Binomial regression models were used only where there was a large proportion of zero values in the data. 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 normal model was fitted to records where the species category occurred in the bycatch (or discards) and the response variable was the log of the bycatch/discards.

From these regressions, summary tables were produced to show the order of variable selection in each model. Variables used to stratify data for bycatch and discard calculations were determined from these summaries.

2.4 Calculation of discard and bycatch rates

For each species category, the observed weights of catch and discards were summed within each stratum determined from regression analysis. Similarly, the target species catches and trawl durations were summed within strata. From this, the "discard rate", $\hat{D}$, was derived, with the following form,

$$\hat{DR} = \frac{\sum_{i=1}^{m} d_i}{m}$$

where m trawls were sampled from a stratum and d_i is the weight of discarded catch from the ith trawl sampled. In previous analyses (e.g. Ballara & Anderson 2009) two other forms of the discard rate were considered, based on the catch of squid and trawl duration within a stratum instead of the number of trawls. Comparison of the precision of the estimates produced from each of the alternative rates, using sets of trial data, showed that the number of trawls-based rate performed consistently better than the two alternatives, and so has now become the standard form for use in these analyses.

Using this rate estimator, estimates of $\hat{D}$ were derived for each stratum in each fishing year and variances were estimated by a multi-step bootstrapping procedure that allowed for correlation of discards between trawls within an observed trip. Separate rates were calculated only for fishing year/strata cells with 25 records or more. For cells with less than 25 records, overall rates based on all strata in the fishing year were substituted. And if there were less than 50 records across all strata for the year an overall rate based on all years for the stratum was substituted. The discard rate calculated for each cell was then multiplied by the total number of trawls in the cell, from commercial catch records for the target arrow squid fishery, to estimate total discards $\hat{D}$:

$$(1) \qquad \hat{D} = \sum_j \hat{DR}_j \times M_j$$

where M_j is the number of trawls in fishing year/strata cell j.

To obtain a 95% confidence interval for the total discards that takes into account vessel to vessel differences and variability in the total amount of fishing effort per trip, and allows for correlation between trawls within a trip, 1000 bootstrap samples were generated from the trawls within each cell using a three-step sequential sampling procedure.

First a trip was chosen at random, then a bootstrap sample was taken of the trawls from that trip that were in the cell. These steps were repeated until the effective number of trawls was approximately equal to the effective number of observed trawls for the cell. The effective number of trips in the bootstrap sample was then calculated. If this was within 5% of the effective number of observed trips in the cell, 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 (number of trawls) and reflected the contributions to the variance of the discard rate $\hat{D}$ from the variance of the discards and the covariance between pairs of discards within the same trip and cell. Matching a bootstrap sample to the cell 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 within a fishing year, 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).

2.5 Analysis of temporal trends in bycatch and discards

Annual estimates of bycatch and discards in each species category and overall, with confidence intervals, were plotted for the whole time-series. Locally weighted regression lines were calculated and shown on the same plots to highlight overall patterns of change over time.

In addition, to provide an indication as to the long-term trend in annual amounts, linear regressions (with lognormal errors) were also carried out. The direction and steepness of the slopes of these lines were determined and the significance of the difference of these slopes from a slope of zero (i.e. no trend) was tested.

2.6 Comparison of trends in bycatch with data from trawl surveys

The detection of a possible trend or pattern in the bycatch of the species categories assessed is one of the primary aims of this research. If such a pattern were detected, corroborative evidence from an independent source would greatly enhance its credibility and assist fishery managers to take appropriate action if required. The following trawl survey time series were considered.

1. The Chatham Rise hoki and middle depth species trawl survey time series (Livingston et al. 2002, O'Driscoll et al. 2011). These trawl surveys include strata at the extreme western end which include part of the BANK area of the arrow squid fishery. However, these strata have a minimum depth of 400 m, deeper than all but the deepest commercial arrow squid trawls, and therefore are not useful for this comparison.

2. The Southland and Sub-Antarctic trawl survey of middle depth species (Bagley et al. in press). This survey series also includes strata in the vicinity of the arrow squid fishery, in areas AUCK and SNAR, but again these strata overlap only with the deepest part of the arrow squid fishery and cannot be used to compare bycatch composition.

3. The Southland trawl surveys of inshore and middle depth species (Hurst & Bagley 1997). This four-year time series of *Tangaroa* trawl surveys on the Stewart-Snares shelf encompassed the area, depth range, and seasonality of the arrow squid fishery in areas SNAR and PUYS, but as this survey was discontinued in 1996 it too is of little use for assessing long term changes in arrow squid bycatch species in the area. An earlier comparison of the catch composition from these surveys with observed catch in the arrow squid fishery was made by Anderson et al. (2000). They found some marked differences including much higher rates of spiny dogfish catch and much lower rates of barracouta catch in the survey trawls than in the observed trawls. This may have been due to differences in the trawl gear used, especially the use of midwater trawl gear in the squid fishery, which would be likely to catch a different mix and amount of bycatch species.

Because of the lack of appropriate research survey time series within the geographical, temporal, and depth range of the arrow squid fishery, no comparisons were able to be made with the temporal patterns of bycatch determined from the present study.

2.7 Annual bycatch by individual species

Annual bycatch rates for individual QMS and non-QMS species (fish and invertebrates) in the arrow squid fishery were calculated from observer records for the period 1990–91 to 2010–11. As well as ignoring those species for which less than 10 kg of catch or less than 6 captures were recorded across all years, other species codes which were of no use in this study (e.g., FIS, unidentified fish; UNI, unidentified; and MIX, mixed fish) were also ignored (although these were included in calculations for total bycatch).

Annual species specific bycatch rates were multiplied by the annual effort in the fishery (number of tows) to produce estimates of total annual bycatch in the same way as described for the combined species categories (QMS, non-QMS, and INV) in Section 2.4, and precision was estimated using the same bootstrapping procedure. However, no attempt was made to determine the optimal stratification to use with individual species; the same stratification as used for the combined species categories was used by default.

This procedure rounds the estimates of total annual catch to the nearest 10 t and so species with less than this level of catch in at least one year were not reported on. An indication of whether the bycatch of each species increased, decreased, or stayed relatively unchanged over time is provided in the form of a slope coefficient for a loglinear regression fitted to the data.

3. RESULTS

3.1 Distribution and representativeness of observer data

The positions of all observed trawls in the target arrow squid fishery between 20 January 1991 (the date of the earliest observed trawl) and 30 September 2011 are shown, along with all trawls recorded with position data on commercial fishing returns from the same period, in Figures 1 and 2.

For the 21-year period as a whole, observer coverage included each of the major arrow squid fisheries, with observed trawls covering the Auckland Islands (AUCK) and Stewart-Snares shelf (SNAR) fisheries, as well as the smaller Puysegur (PUYS) and east coast South Island (BANK) fisheries (Figure 1). Sampling densities were relatively low in the BANK area, and there was no coverage of the commercial fishing effort in WCSI, and very little in CHAT and NRTH, but these fisheries are minor, with less than 200 commercial trawls in WSCI in this period and only a few tens of trawls in NRTH outside of the main period of these fisheries in the late 1990s to early 2000s. Although there was more regular commercial effort in CHAT, even there the fishery accounted for only about 1% of the total effort.

Some differences in commercial effort and observer coverage within time periods are apparent: commercial fishing in area NRTH (mainly limited to the Taranaki bight and around Northland) was restricted mostly to the 1996 to 2005 period, and the small fishery in CHAT virtually ceased after 2005. Distribution of effort in the main fisheries around the south and east coasts of the South Island has remained stable, although there has been declining effort in BANK in recent years. There was no observer coverage in PUYS in the 1996–2000 period, and declining levels of coverage in NRTH in 2006–11, but otherwise observer coverage was stable in the main fisheries in SNAR and AUCK (Figure 2).

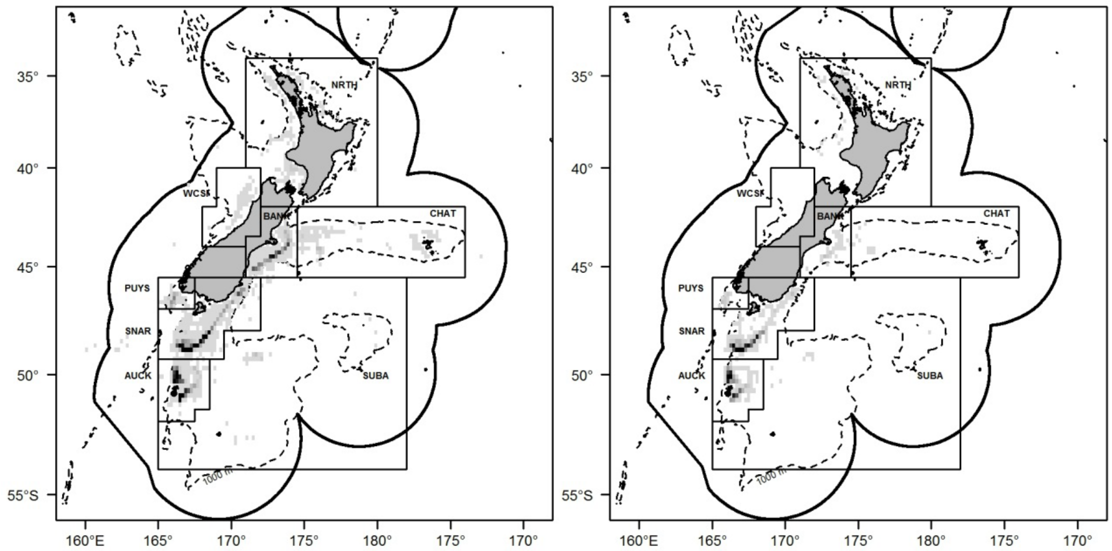

Figure 1: Density plots showing the distribution of all commercial trawls with position data targeting arrow squid (left, darkest pixels represent 2471–10526 trawls) and all trawls recorded by observers on vessels targeting arrow squid (right, darkest pixels are 936–944 trawls), for 1990–91 to 2010–11. Area divisions used in the analyses are shown: NRTH, North; WCSI, West Coast South Island; BANK, central East Coast South Island; CHAT, Chatham Rise; PUYS, Puysegur; SNAR, Snares; AUCK, Auckland Islands; SUBA, sub-Antarctic.

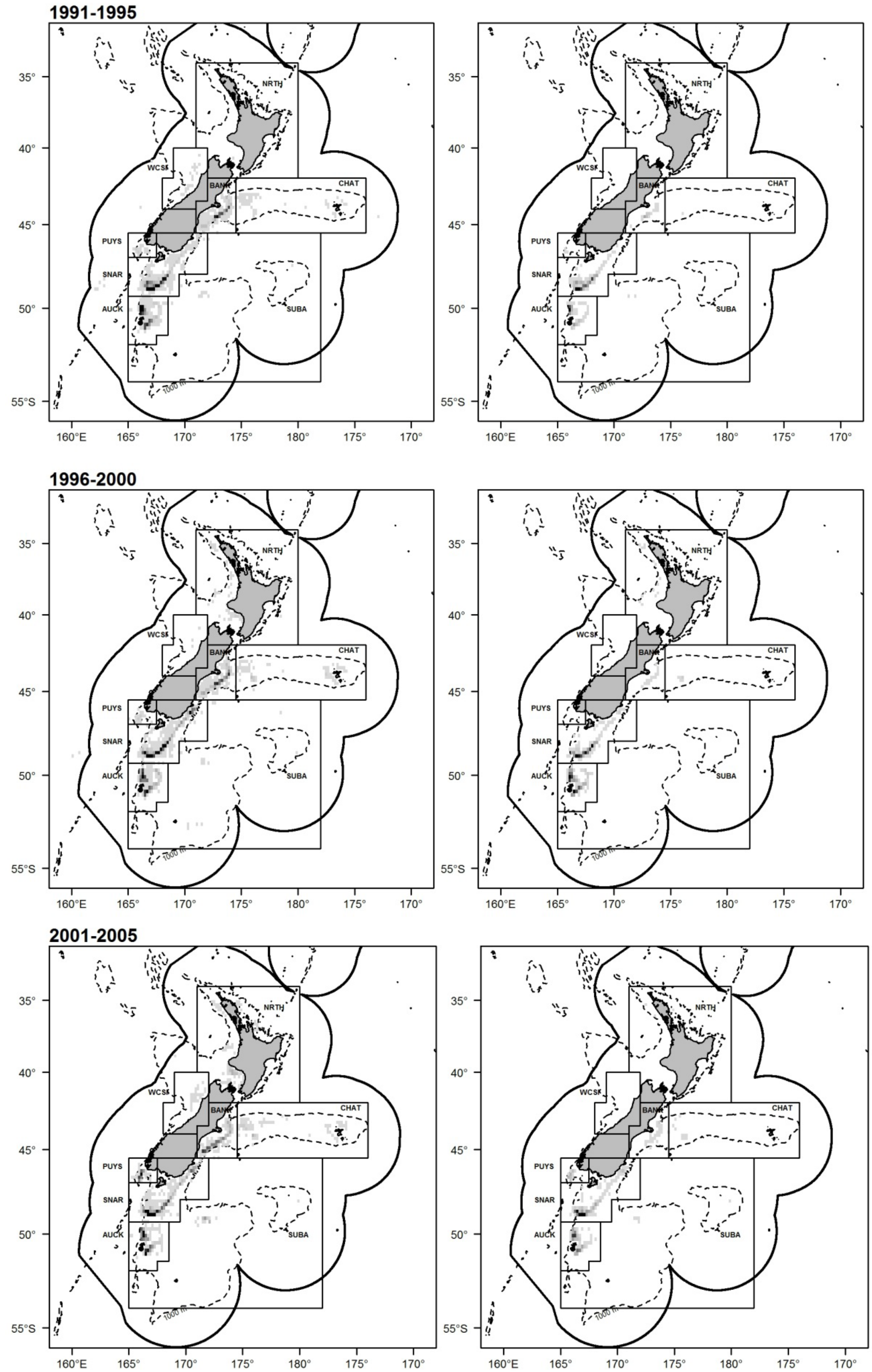

Figure 2: Density plots showing the distribution of all commercial trawls with position data targeting arrow squid (left) and all trawls recorded by observers on vessels targeting arrow squid (right), for 1990–91 to 2010–11, by blocks of years. Area divisions used in the analyses are shown. In the titles, 1991= fishing year 1990–91, etc.

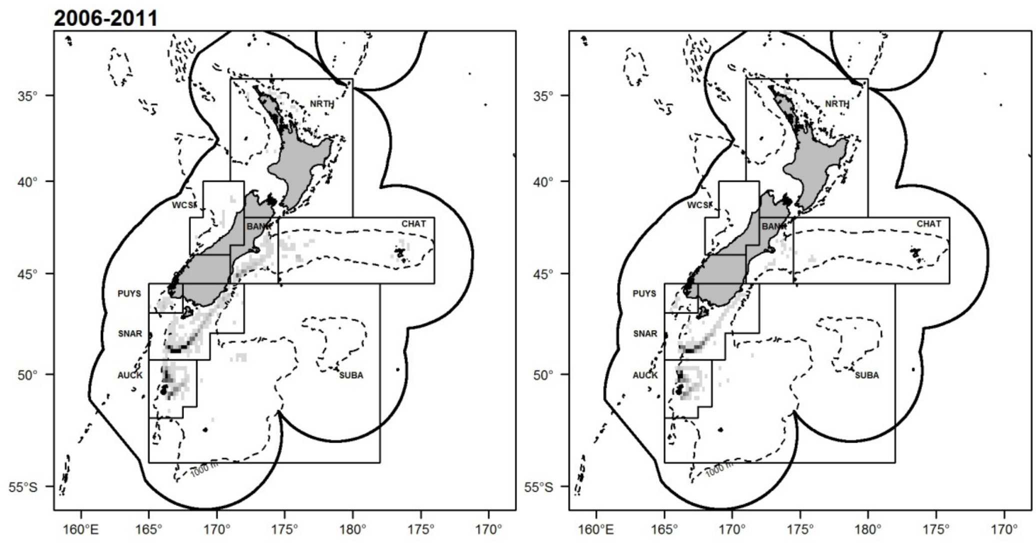

Figure 2—*Continued*

A spatial comparison of observed trawls with all commercial trawls recorded with position data was produced using density plots (Figure 3).

The spread of observed trawls over much of the longitudinal and latitudinal extent of the fishery was well matched to the spread of commercial trawls throughout much of the 21-year period examined. In particular, these plots show an excellent match for the main fishery regions (west of 170° E and south of 47° S, AUCK and SNAR) in all years. The observer coverage was not as good, however, in the smaller fishery in the central region (BANK) except for the 1991–95 period, when there was a reasonable amount of observer coverage, and after 2007–08, when there was very little commercial fishing in this area.

When all years are considered together, the southern region is shown to have been slightly oversampled and the central region substantially undersampled relative to the distribution of fishing effort.

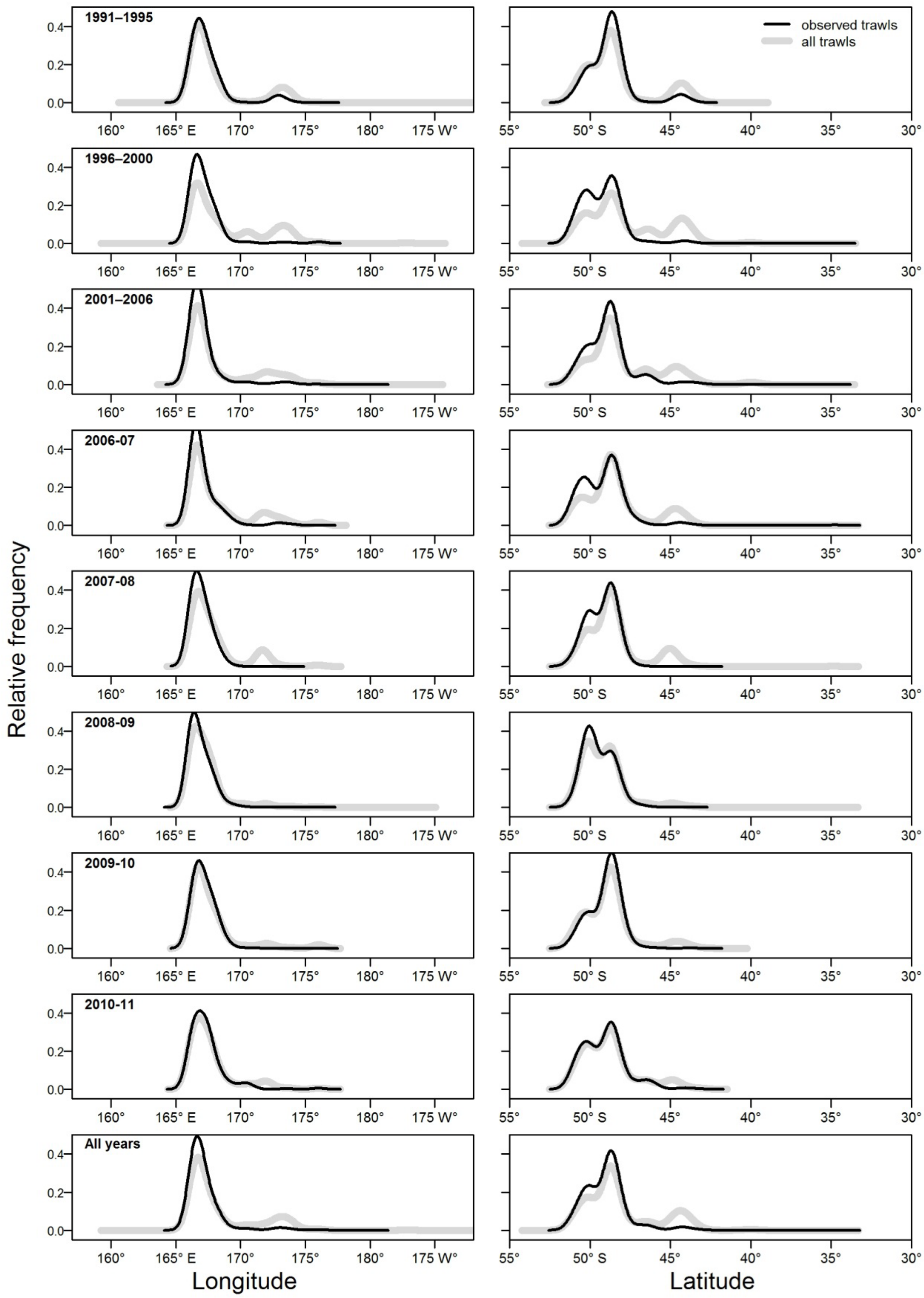

Figure 3: Arrow squid target fishery. Comparison of start positions (latitude and longitude) of observed trawls with those of all commercial trawls. Fishing years 1990–91 to 2005–2006 are shown in blocks of 5 or 6 years, fishing years 2006–07 to 2010–11 are shown by individual year and, in the bottom panel, all 21 fishing years are shown combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

The annual number of observed trawls in the arrow squid fishery ranged from 574 to 2882, but was over 1000 trawls in all but 6 of the 20 years and only once less than 700 (Table 3). The number of vessels observed in each year ranged from 7 to 25 (equivalent to 10–68% of the fleet), with the number of observed vessels (and the percentage of the fleet) increasing over time. The number of trips observed each year also increased over time, from less than 10 per year in 4 of the first 6 years, to more than 20 in each of the most recent 9 years. Although in some (early) years the observed catch accounted for less than 10% of the total catch (minimum of 6.3% in 1994–95) in most years coverage was considerably greater than 10% (and greater than 50% in 2000–01) and for the 21 years as a whole was 22.3%. The high observer coverage in this fishery in recent years is partly associated with management measures imposed for the protection of New Zealand sea lions (*Phocarctos hookeri*). The fishery is relatively discrete, with arrow squid being the exclusive target species in 170 of the 411 observed trips.

Table 3: Summary of effort and estimated catch in the target trawl fishery for arrow squid, for observed trawls and overall, by fishing year. Trips include those with any recorded targeting of arrow squid.

Fishing year	Number of trawls		Number of vessels		Number of trips		Arrow squid total catch (t)		Percentage observed (%)	
	Observed	All	Observed	All	Observed	All	Observed	All	Catch	Trawls
1990–91	1 167	11 144	9	59	9	171	3 233	26 730	12.1	10.5
1991–92	574	8 143	8	64	8	188	3 148	43 131	7.3	7.0
1992–93	1 567	8 106	14	60	16	173	5 747	28 608	20.1	19.3
1993–94	1 050	10 057	11	57	13	302	6 543	61 682	10.6	10.4
1994–95	714	10 875	7	67	7	280	3 776	60 332	6.3	6.6
1995–96	736	9 846	9	62	9	232	2 235	27 373	8.2	7.5
1996–97	1 190	10 032	17	58	17	231	5 035	40 231	12.5	11.9
1997–98	856	8 067	12	50	14	245	3 293	31 611	10.4	10.6
1998–99	985	7 724	16	55	17	275	2 849	21 519	13.2	12.8
1999–00	859	5 422	12	43	13	212	3 466	17 381	19.9	15.8
2000–01	2 882	8 046	25	50	39	377	16 606	31 228	53.2	35.8
2001–02	1 471	7 449	12	47	15	300	11 568	43 282	26.7	19.7
2002–03	1 294	8 404	18	54	22	336	8 154	37 645	21.7	15.4
2003–04	1 155	8 335	20	45	20	280	15 250	76 660	19.9	13.9
2004–05	2 245	10 481	24	53	31	324	20 916	73 279	28.5	21.4
2005–06	1 320	8 526	22	53	23	330	11 430	62 158	18.4	15.5
2006–07	1 255	5 880	23	46	28	302	23 053	62 016	37.2	21.3
2007–08	1 445	4 231	21	34	26	203	20 568	51 008	40.3	34.2
2008–09	1 262	3 822	23	34	25	140	15 832	42 798	37.0	33.0
2009–10	1 051	3 781	17	37	25	172	8 237	29 214	28.2	27.8
2010–11	1 155	4 207	20	39	35	174	9 686	33 275	29.1	27.5
All years	26 233	162 578	104	244	411	5 235	200 625	901 161	22.3	16.1

Comparisons made between vessel sizes in the commercial fleets and the observed portion (Figure 4) showed that a very wide size range of vessels operate in this fishery, from just a few hundred tonne GRT (Gross Registered Tonnage) to over 4000 t. Apart from the very smallest of these vessels, this range was well covered by observers although, as may be expected, the largest vessels which were more able to accommodate observers were somewhat oversampled compared to the smaller vessels.

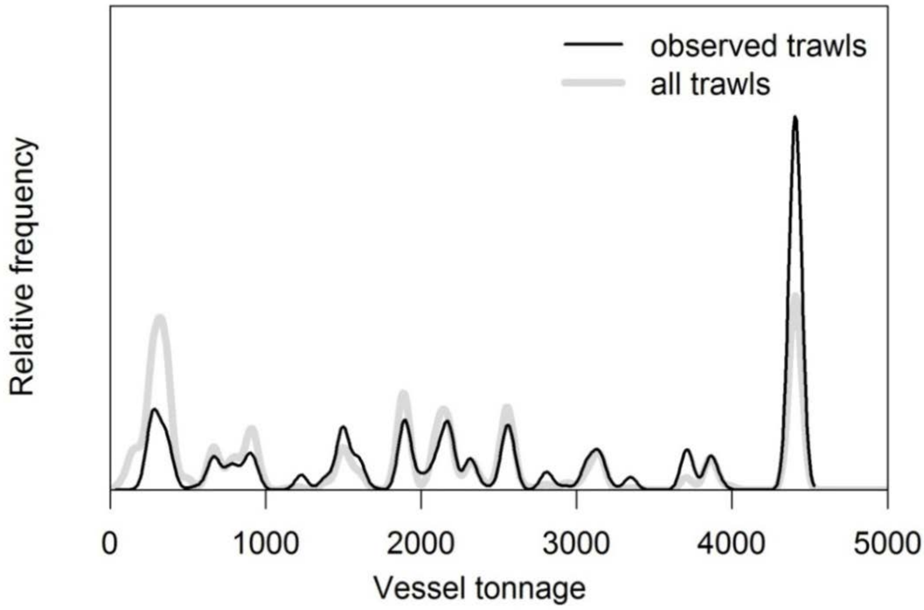

Figure 4: Comparison of vessel sizes (gross registered tonnage) in observed trawls versus all recorded commercial trawls for the period 1 October 1990 to 30 September 2011, in the arrow squid fishery. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Comparison of the distribution of fishing depths between the observed tows and all commercial tows shows good correspondence (Figure 5). The distribution of fishing depths shows a close to normal distribution. The small bulge on the left hand side of each distribution relates to the fishery in SNAR and AUCK operating in slightly shallower water on average than in BANK, and the secondary mode at about 300 m in the commercial tow data is associated mostly with deeper fishing in BANK. The long tails to the right result from the fishery (in each area) occasionally operating in depths much greater than the mean, where it is slightly undersampled.

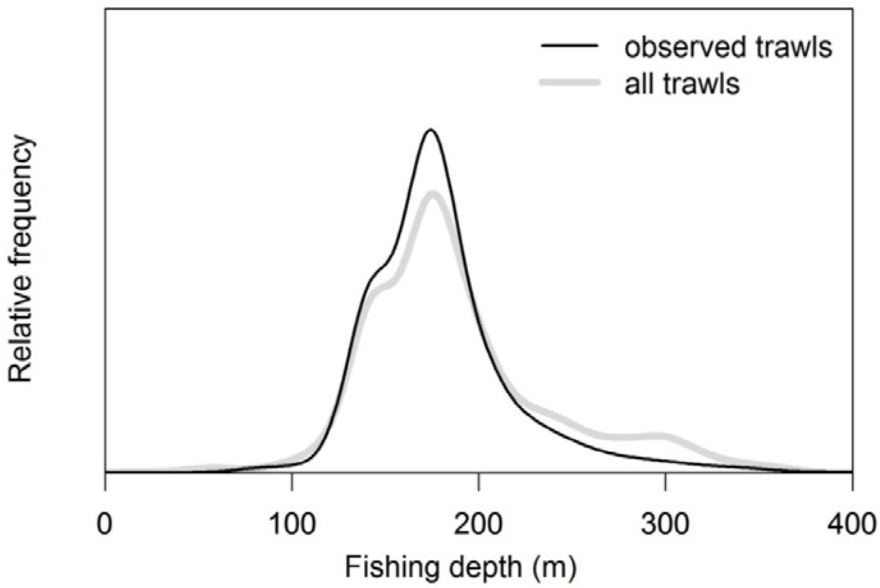

Figure 5: Comparison of fishing depth in observed trawls versus all recorded commercial trawls for the period 1 October 1990 to 30 September 2011, in the arrow squid fishery. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

The spread of observer effort throughout each fishing year was compared with the spread of total effort in the fishery by applying a density function to the numbers of trawls per day (Figure 6).

The plots show that commercial fishing for arrow squid generally began in mid-late January and went through to at least May and often through to June or July. There was almost no fishing between the end of July and the beginning of January in any year. Observer coverage in some years matched this pattern well, e.g., 1992–93, 2002–03, and 2010–11, but was often more unevenly spread, due to low coverage levels (e.g., 1990–91) or to the observer effort being compressed into a small portion of the season (e.g., 1999–2000). In many years the observer effort was focussed into the middle of the season so that, for all years combined, February and March were slightly oversampled, and January and May were slightly undersampled.

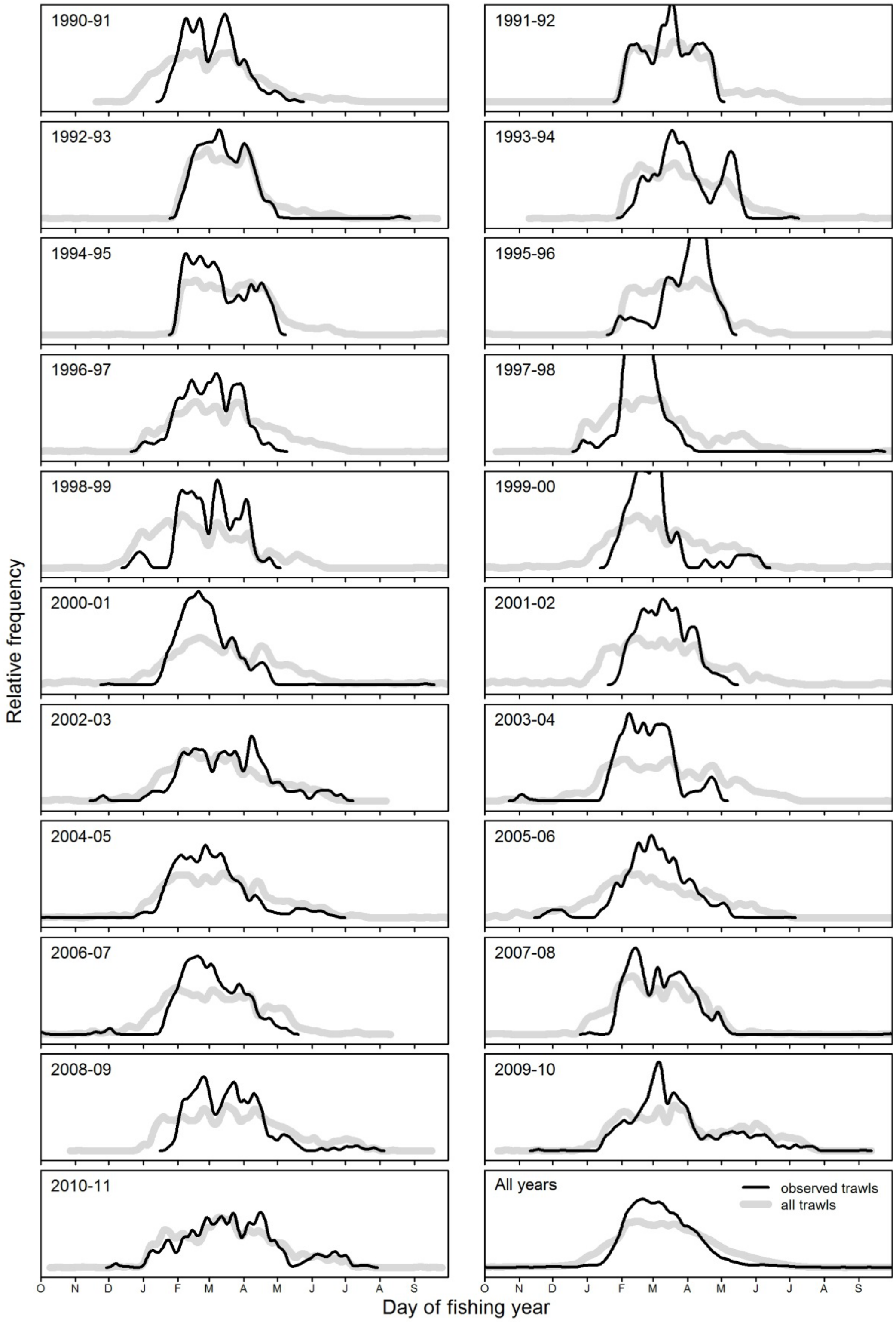

Figure 6: Arrow squid fishery: Comparison of the temporal spread of observed trawls with all recorded commercial trawls for 1990–91 to 2010–11, and for all fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Bycatch data

3.2.1 Overview of raw bycatch data

Over 470 species or species groups were identified as bycatch by observers in the arrow squid target fishery, most being non-commercial species, including invertebrate species, caught in low numbers (see Appendices 1–3). Arrow squid accounted for about 80% of the total estimated catch from all observed trawls targeting arrow squid between 1 October 1990 and 30 September 2011. The main bycatch species or species groups were barracouta (8.5%), silver warehou (2.5%), spiny dogfish (1.7%), and jack mackerel (1.1%); of these only spiny dogfish were mostly discarded (Figure 7). Of the other invertebrate groups crabs (0.8%), in particular smooth red swimming crabs (*Nectocarcinus bennetti*) (0.5%) were observed in the greatest amounts (and were mostly discarded, Figure 7), along with smaller amounts of octopus and squid, sponges, cnidarians, and echinoderms. When combined into broader taxonomic groups, bony fish (excluding rattails, tuna, flatfish, and eels) contributed the most bycatch (16.5% of the total catch), followed by sharks and dogfish (1.9%), crustaceans (0.8%), and rattails (0.2%). The combined bycatch of all other fish (tuna, rays and skates, chimaeras, flatfish, and eels) accounted for a further 0.5% of the total catch. More than 75% of the sharks and dogfish, rattails, and eels were discarded, whereas about half the flatfish were retained, as were most of the tuna, rays and skates, chimaeras, and other fish not in any of these groups. Of the invertebrates, 100% of echinoderms, 98% of other squid species, 99% of sponges, 95% of cnidarians, and 95% of polychaetes were discarded, but crustaceans (79%), octopuses (37%), and other molluscs (21%) were often retained. In the calculations for Appendices 1–3, discards of species or species groups expected to have been 100% discarded in this fishery, e.g., jellyfish, or bellowsfish (*Centriscops* spp.), sometimes came to slightly less than 100% suggesting (most likely incorrectly) that some were retained. This is partly due to the “destination” being assumed to be “retained” rather than “discarded” when this field was missing on the observer forms—a correct assumption in most, but not all, cases. Also, however, some species generally not considered commercial were occasionally recorded by observers as having been processed to meal, including: smooth red swimming crabs, toadfish (*Neophrynichthys* spp.), pigfish (*Congiopodus leucopaecilus*), bellowsfish, and jellyfish.

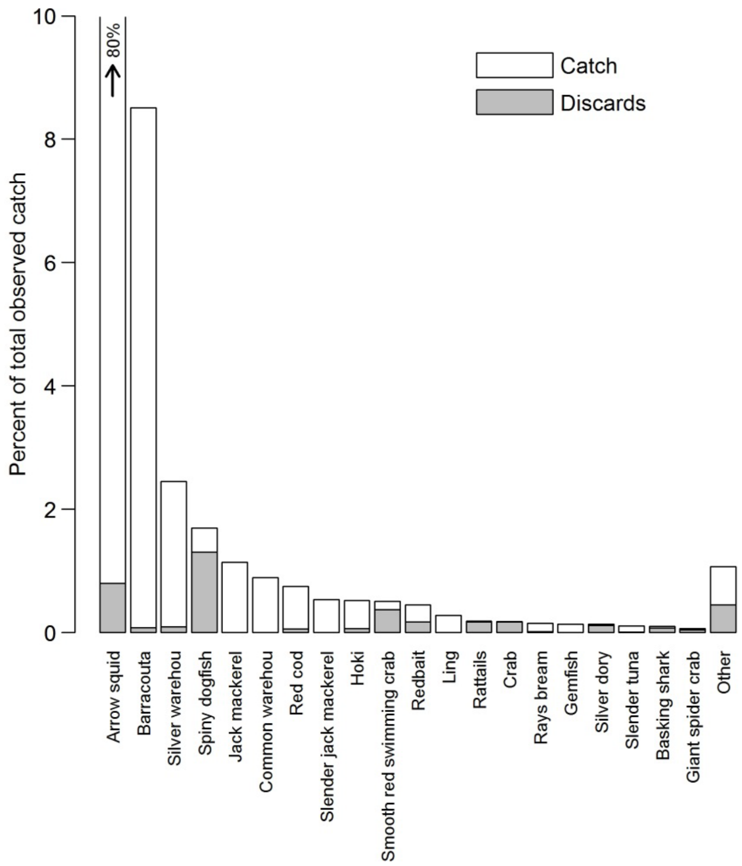

Figure 7: Percentage of the total catch contributed by the main bycatch species (those representing 0.05% or more of the total catch) in the observed portion of the arrow squid fishery, and the percentage discarded. The "Other" category is the sum of all bycatch species representing less than 0.05% of the total catch.

Many invertebrates, in particular corals, echinoderms, and crustaceans, were identified to species, especially in the more recent records. This is due to improving knowledge of the New Zealand marine invertebrate fauna, both in general and specifically by fisheries scientists and observers, and the use of invertebrate identification guides (e.g. Tracey et al. 2011) which have become available to observers. See Appendices 1 and 2 for a list of the main observed bycatch species and Appendix 3 for a summary by higher taxonomic group.

Exploratory plots were prepared to examine bycatch per trawl (plotted on a log scale) with respect to the available variables (Figures 8–10). Plots were prepared separately for QMS species, non-QMS species, and for total bycatch.

Total bycatch was highly variable between trawls, ranging from 0 t to 69 t (Figure 8). Trawls were mostly 2–5 h long, with a median of 3.9 h. Bycatch per trawl showed little variation with increasing trawl duration, but a fitted line to these data indicated a slight increase in bycatch for longer duration tows for non-QMS species (Figure 10) but not QMS species, which are frequently caught in large amounts from relatively short tows (Figure 9). More than 85% of observed trawls were at an average bottom depth of between 120 m and 220 m, with a median of 174 m. Total bycatch and QMS species bycatch increased only very slightly with increasing bottom depth, but the increase was much greater for non-QMS species. Mean bycatch of non-QMS species doubled from about 18 kg per trawl at 120 m to about 36 kg per trawl at 220 m.

There was substantial variation in bycatch between the 39 vessels represented by more than 200 records, with total bycatch medians ranging from about 50 kg per trawl to about 2000 kg per trawl, QMS bycatch medians from about 45 kg per trawl to about 1500 kg per trawl, and non-QMS bycatch medians from about 6 kg per trawl to about 110 kg per trawl. There was a slight indication of increasing total bycatch in recent years, with generally increasing median values since 2004–05, most obvious for non-QMS species.

There were some substantial differences in bycatch levels in each catch category between the seven main areas examined. The much lower total bycatch in AUCK than in the other areas is due more to lower catches of QMS species rather than non-QMS species. Although non-QMS species bycatch is low in AUCK, it is similarly low in the other main area SNAR. Outside of AUCK, total bycatch and QMS species bycatch is quite similar between areas. Non-QMS species bycatch is highest in CHAT, and is also high in BANK, NRTH, and SUBA. Observed fishing was mostly restricted to between January and June, and within these months there was little variation in total bycatch or QMS species bycatch, but non-QMS species bycatch steadily increased during this period.

The observed trawls were spread amongst 12 nations comprising charter vessels, e.g. NZPOL, Polish vessels under charter to New Zealand fishing companies; foreign licenced vessels, e.g. POL, Poland; and domestic vessels, NZL. There were some differences in bycatch between nations for each catch category, with bycatch being lower for Chinese vessels in all categories and generally higher for Korean, Japanese, and Ukranian vessels.

The net type used made a difference to bycatch also, with bottom trawls catching slightly more than midwater trawls in each catch category.

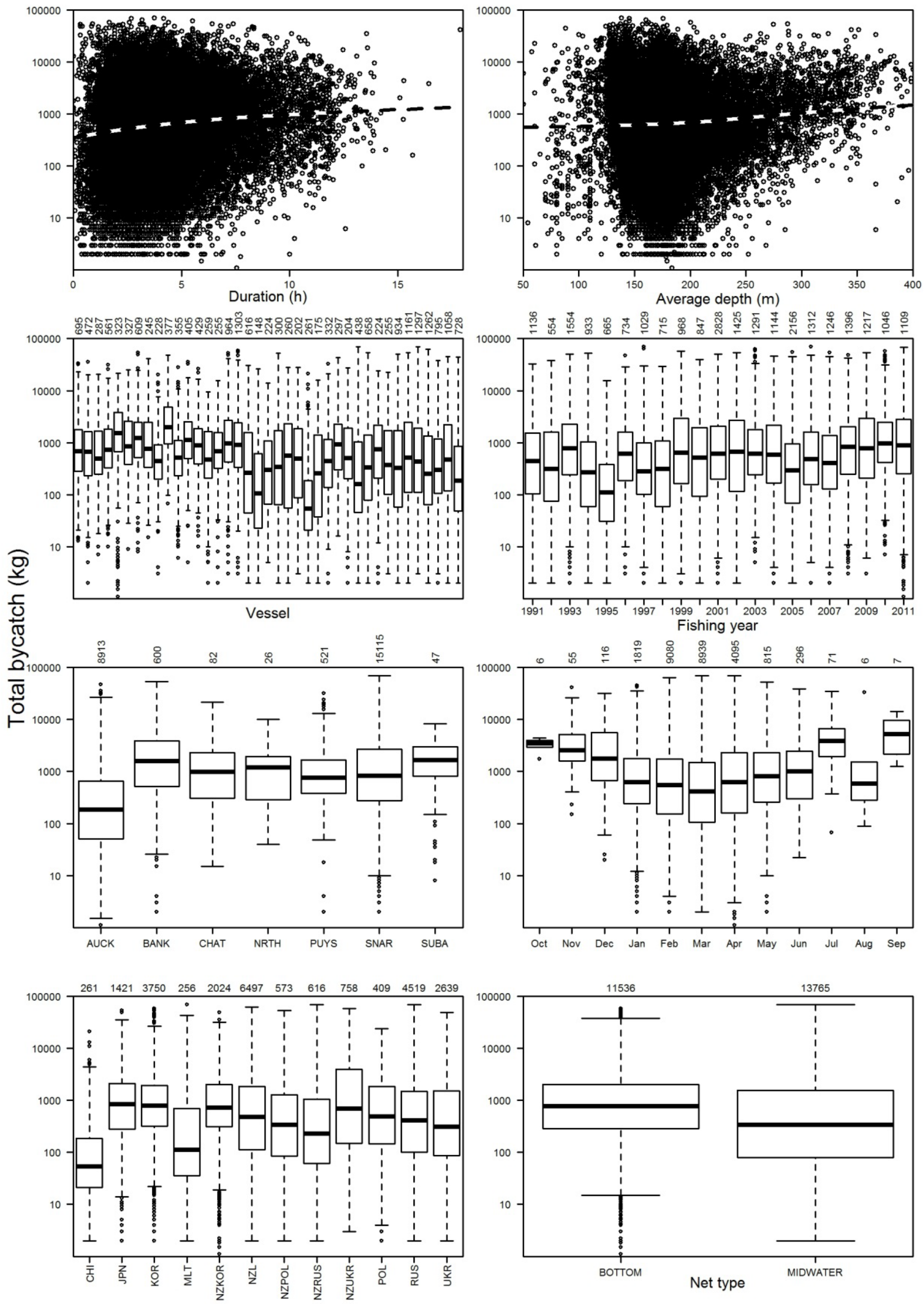

Figure 8: Total bycatch (all species) per trawl plotted against selected variables in the arrow squid target fishery. Total bycatch is plotted on a log scale. The dashed lines in the top panels represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted. The numbers above the plots indicate the number of records associated with that level of the variable. In the vessel plot, vessels are ordered by size, from shortest to longest; and vessels represented by fewer than 200 records were not plotted. Average depth is the average of the start and finish gear depth. CHI, China; JPN, Japan; KOR, Korea; MLT, Malta; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine. See Figure 1 for area codes.

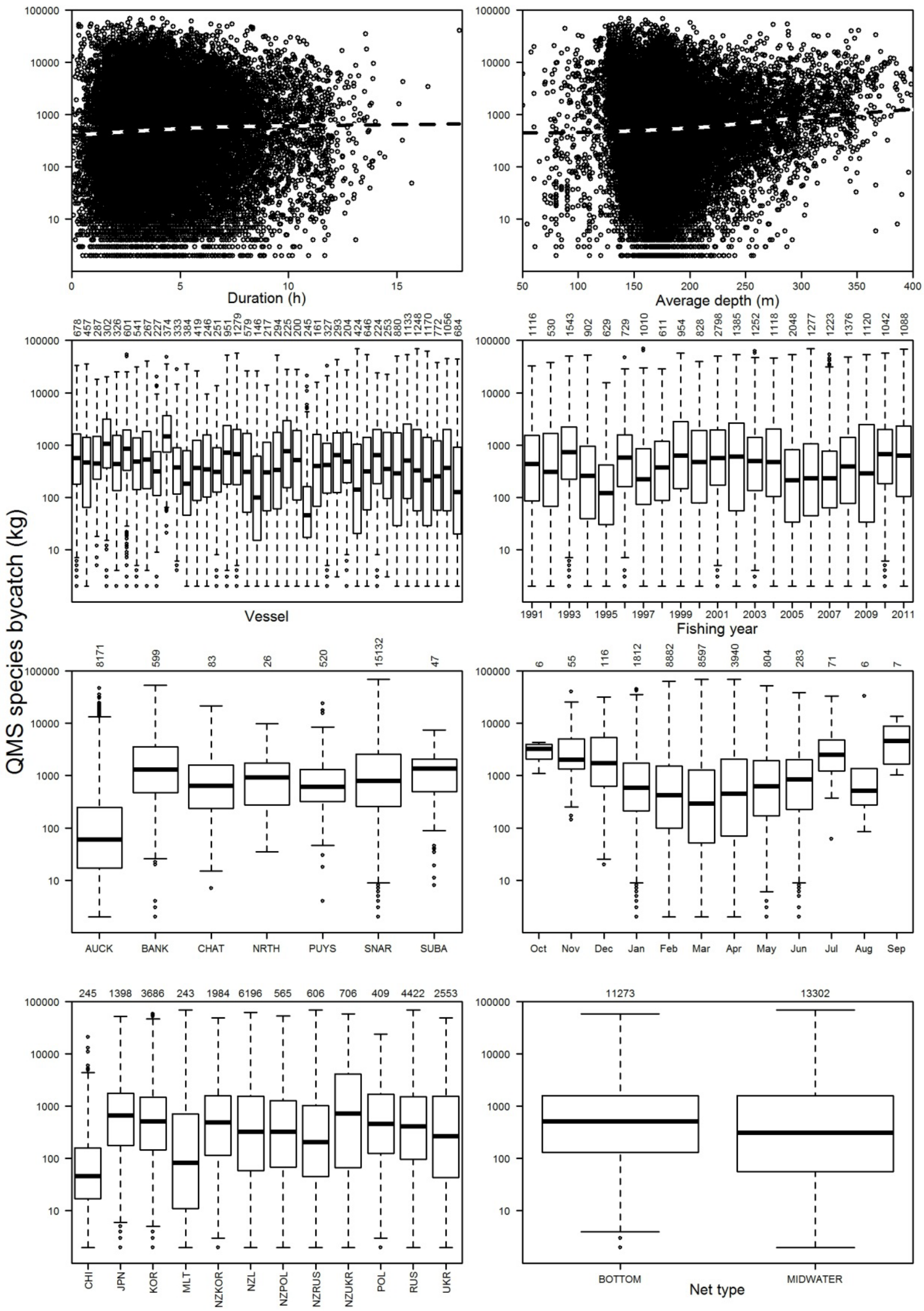

Figure 9: QMS species bycatch per trawl plotted against selected variables in the arrow squid target fishery. See Figure 8 for further details.

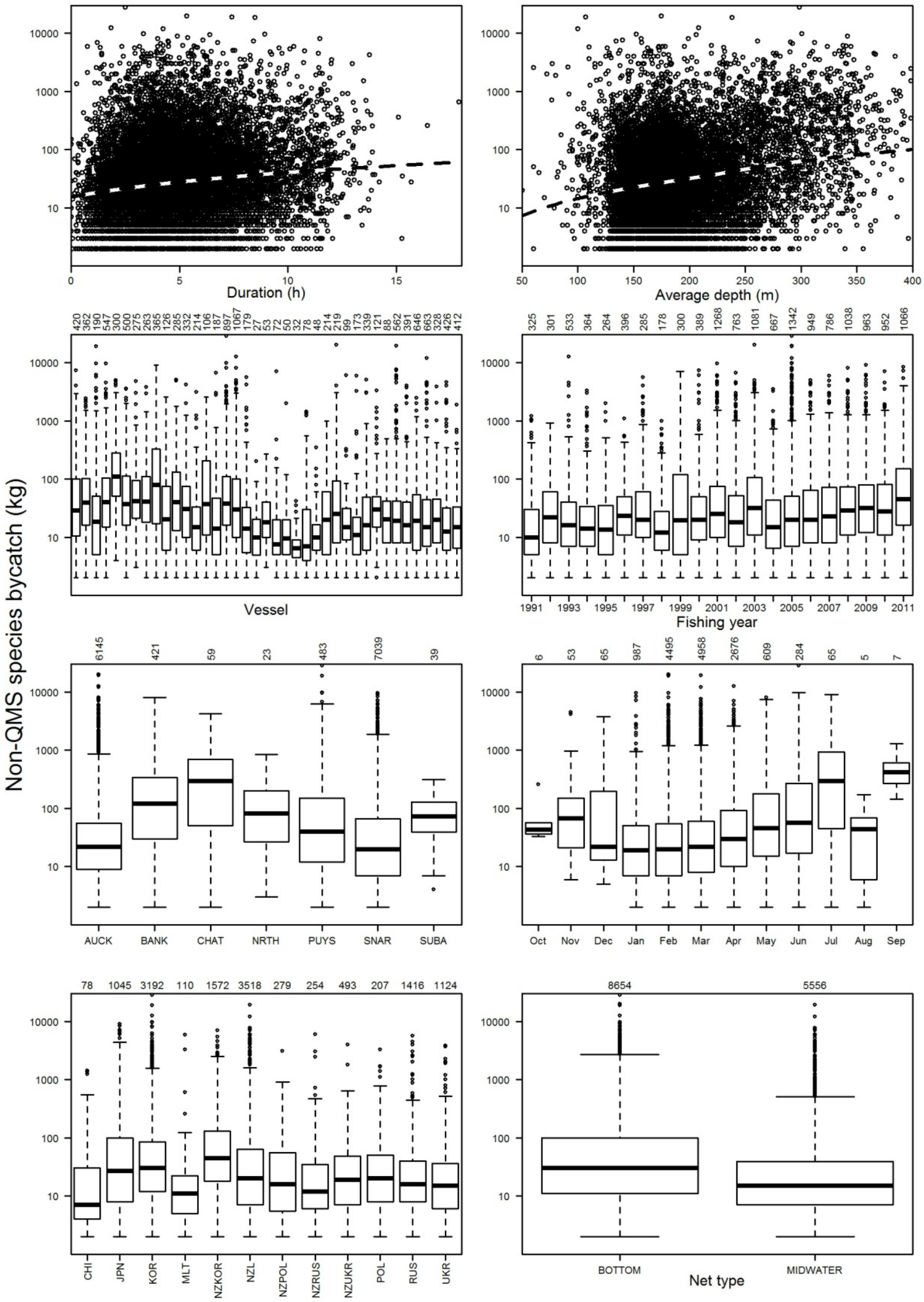

Figure 10: Non-QMS species bycatch per trawl plotted against selected variables in the arrow squid target fishery. See Figure 8 for further details.

3.2.2 Regression modelling and stratification of bycatch data

The dependent variable in the LME models was the bycatch rate, expressed as the log of catch (kg) per trawl. There was a substantial fraction of records with no bycatch of non-QMS species and invertebrate species, and so for these groups both log-linear and binomial models were constructed. This enabled identification of factors affecting both the level and likelihood of bycatch in these categories. For the QMS species category the fraction of records with no bycatch was less than 6%, and so a binomial model was not constructed.

In each of the models (except for non-QMS normal) *area* was the most influential variable, and generally *duration* was the next most important variable (Table 4). Most of the other variables tested also had some degree of influence in some or all of the models, especially *head-ht*, *fishing year*, *depth*, and *month*. Vessel *nationality* and vessel *speed* had little or no influence in any of the models.

Although trawl duration clearly has an influence on catch rates in each species category, the quantity of available observer data in this fishery limits the amount of stratification that can practically be used in the calculation of bycatch estimates. Therefore due to the consistent influence of area in each of the bycatch categories, this variable alone was used to stratify all bycatch calculations, as it was in the previous assessment of bycatch in this fishery (Ballara & Anderson 2009).

Table 4: Summary of LME modelling of bycatch in the arrow squid trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *head-ht*, headline height; *fyr*, fishing year; *gear code*, bottom or midwater; *grt*, vessel tonnage.

Species cat.	Model type	Variable									
		area	*duration*	*fyr*	*month*	*head-ht*	*speed*	*depth*	*start time*	*gear code*	*grt*
QMS	Normal	1	2	3	4	5	6	7	–	–	–
Non-QMS	Normal	3	1	7	8	6	–	2	4	5	9
Non-QMS	Binomial	1	2	–	4	3	–	–	5	–	–
INV	Normal	1	2	8	7	6	–	4	5	3	–
INV	Binomial	1	2	4	–	3	–	7	–	6	5

3.3 Discard data

3.3.1 Overview of raw discard data

Because the top ten observed bycatch species were all QMS species, discard rates were generally low. The individual species most discarded in the arrow squid fishery was spiny dogfish, which was introduced into the QMS in October 2004 but at the same time added to the 6th schedule of the Fisheries Act 1996, allowing it to be legally discarded at sea (see also section 3.5.5 for a discussion of observer-authorised QMS species discards). Spiny dogfish was the third most common bycatch species (after barracouta and silver warehou) and 77% of the 5000 t of the observed catch was discarded (see Appendix 1). Redbait, in the QMS only since 1 October 2009, were also frequently discarded—38% of the observed catch. Of the non-QMS species, rattails (90%), silver dory (86%), and basking sharks (78%) were also usually discarded (Appendix 1). Few of the major invertebrate bycatch species were retained with any frequency, exceptions being octopus (*Pinnoctopus cordiformis*) and queen scallop (*Zygochlamys delicatula*), with most being 80–100% discarded (Appendix 2).

Exploratory plots were prepared to examine the variability in the level of discards per trawl for QMS species, non-QMS species and all species combined, with respect to some of the available variables (Figures 11–13).

The level of total discards was highly variable between trawls, ranging from 0 t to 46 t (Figure 11). The quantity of discards increased slightly with trawl duration for both QMS species and non-QMS species, and also overall. The fitted line in Figure 11 shows mean discards of about 75 t for a tow duration of 2 h and 130 t for a tow duration of 5 h. Similarly, discards increased slightly with increasing depth in each species category, with total discards increasing from a mean of about 70 kg at 120 m to about 150 kg at 220 m.

There was substantial variation in discards between vessels (those represented by more than 200 records), with total discard medians ranging from about 10 kg per trawl to about 500 kg per trawl, QMS discard medians from about 8 kg per trawl to about 170 kg per trawl, and non-QMS discard medians from about 4 kg per trawl to about 125 kg per trawl. Although the presence and use of meal plants on vessels is not well recorded, those vessels in Figure 11 with lower discard rates tended to be larger vessels on which meal plants were known to be installed.

There was considerable variation in discard rates between years in each species category and, as for bycatch, an indication of increasing discards of non-QMS species over the last several years (note that due to problems with the observer databases there is no discard data available for 1997–98).

There were some substantial differences in discard levels in each catch category between the seven main areas examined, with non-QMS discards generally lowest in AUCK and SNAR, and highest in CHAT and BANK, and QMS discards also lowest in AUCK and highest in BANK. Total discards increased gradually over the main period of the fishery, from a median of about 60 kg per trawl in January to over 200 kg per trawl in June. This increase was seen in both QMS and non-QMS categories.

Total discards were greatest for Japanese and Korean vessels and least for Polish charter vessels. Patterns differed for QMS and non-QMS categories, with Chinese vessels having the lowest non-QMS species discards, and Polish foreign-licenced vessels having the greatest QMS species discards. Bottom trawls resulted in more discarding than midwater trawls in each category, with the median total discards per trawl for bottom trawls about 200 kg, compared with about 25 kg per trawl for midwater trawls.

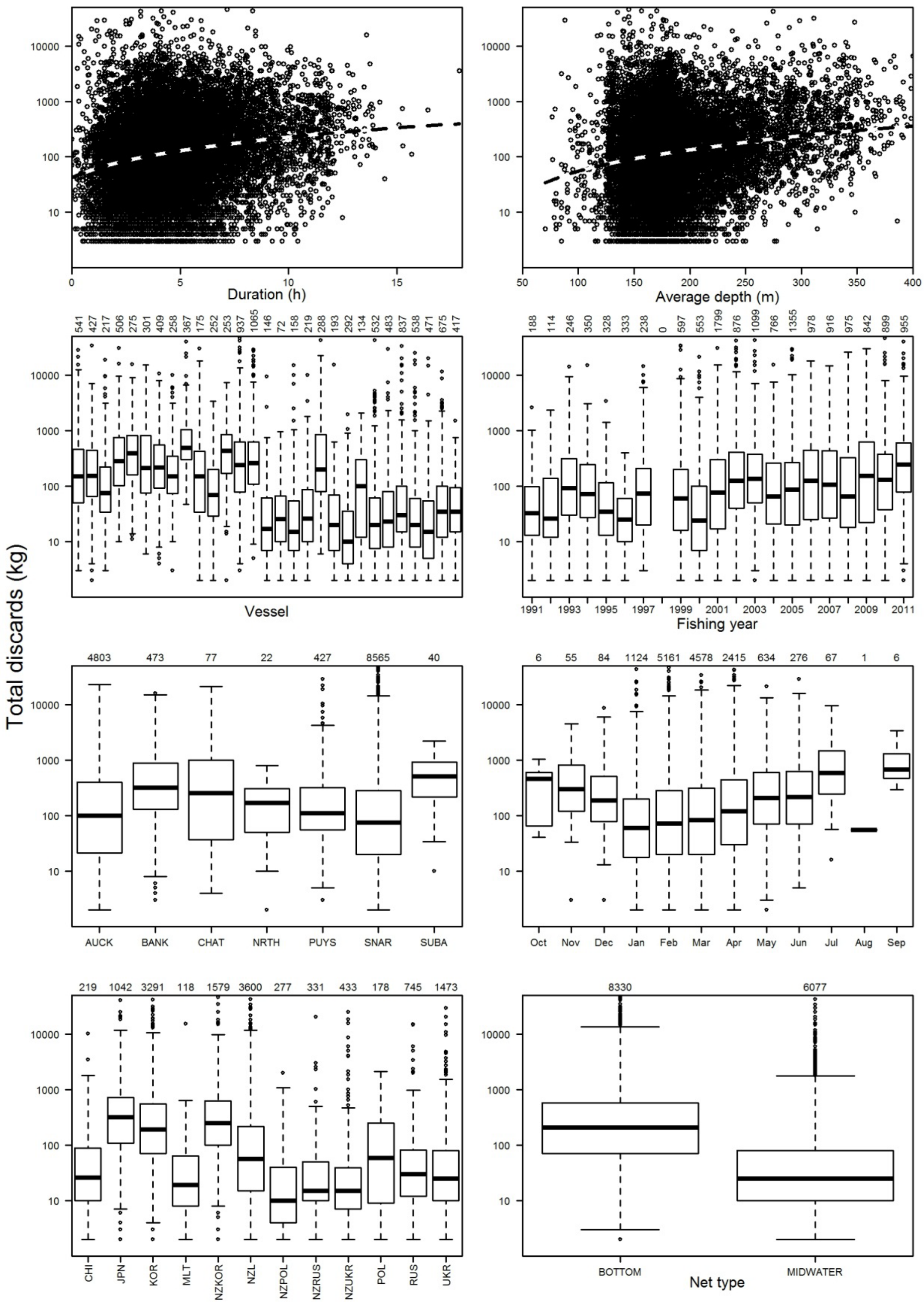

Figure 11: Total discards (all species) per trawl plotted against selected variables in the arrow squid target fishery. Total discards is plotted on a log scale. The dashed lines in the top panels represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5 times the interquartile range, and outliers individually plotted. The numbers above the plots indicate the number of (non-zero) records associated with that level of the variable. In the vessel plot, vessels are ordered by size, from shortest to longest; and vessels represented by fewer than 200 records (including those with zero discards) were not plotted. Average depth is the average of the start and finish gear depth. CHI, China; JPN, Japan; KOR, Korea; MLT, Malta; NZL, New Zealand; POL, Poland; RUS, Russia; UKR, Ukraine. No data for 1997–98 due to linkage error in database tables. See Figure 1 for area codes.

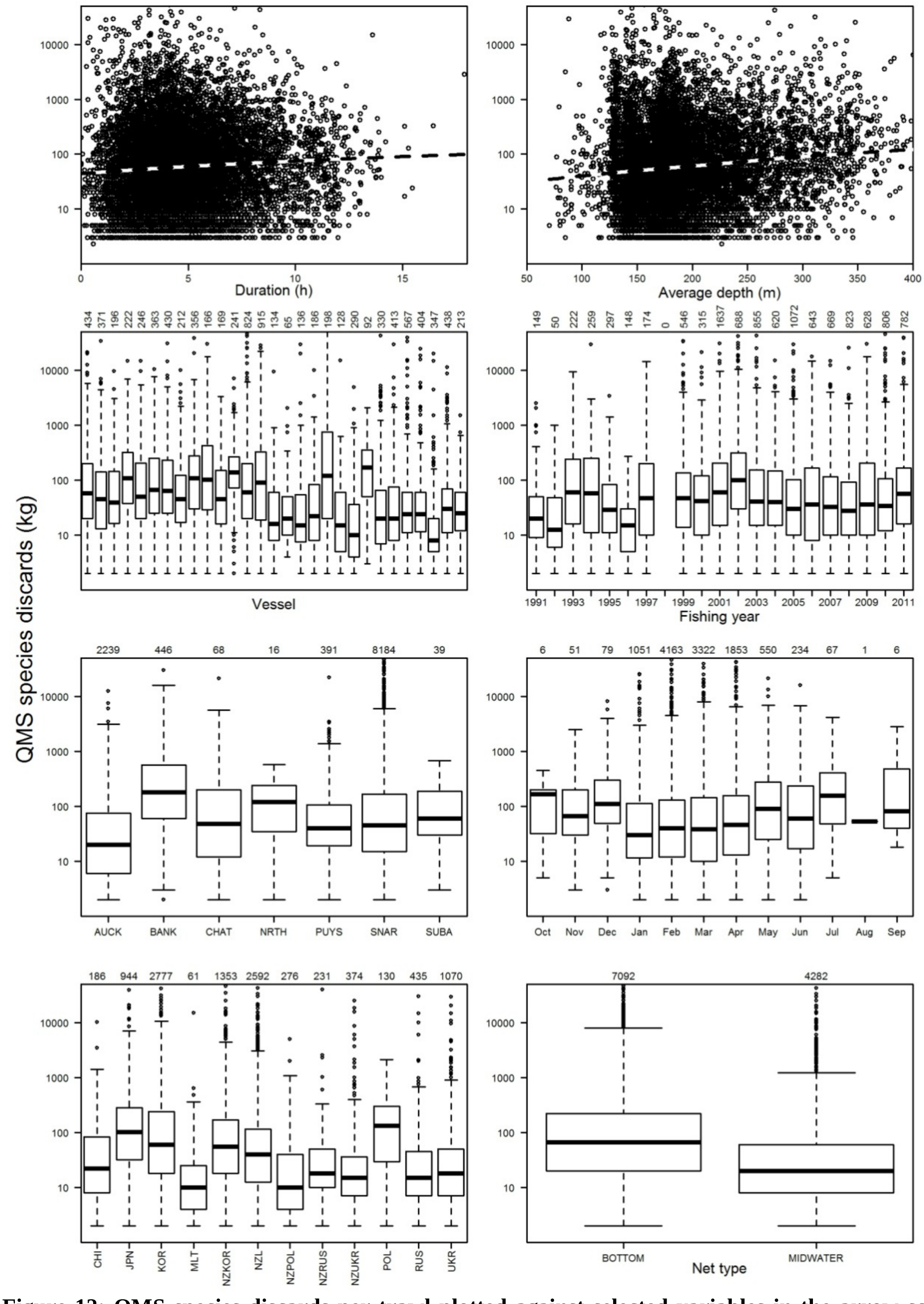

Figure 12: QMS species discards per trawl plotted against selected variables in the arrow squid target fishery. See Figure 11 for further details.

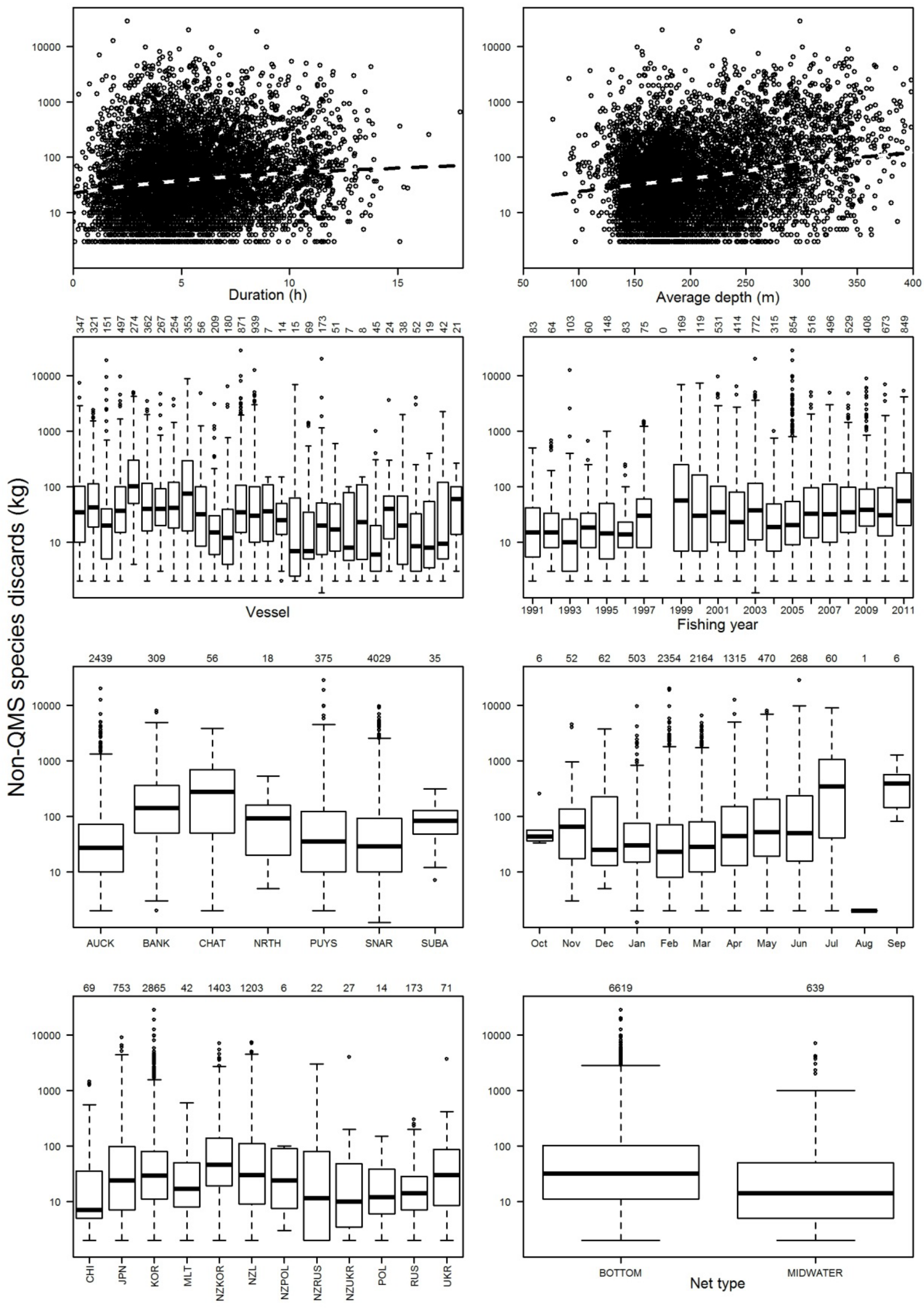

Figure 13: Non-QMS species discards per trawl plotted against selected variables in the arrow squid target fishery. See Figure 11 for further details.

3.3.2 Regression modelling and stratification of discard data

The dependent variable in the discard LME models was the discard rate, expressed as the log of discards (kg) per trawl. Both log-linear and binomial models were run for each species category except SQU, for which the fraction of records with no discards was very low (less than 6%).

In each of the SQU, QMS, and INV models *area* was the most influential variable, but it was less significant in the non-QMS models (Table 5). Also influential was *duration*, generally the second or third selected variable in each model and, in some models, *head-ht*, *depth*, and *nation*. The variable *depth* was more important than *area*, or *duration* in the non-QMS normal model, and *duration* was the most important variable in the QMS binomial model. The variable *fyr* was selected in at least one model for each species category, but had little priority in any model.

For the same reasons that area was used as the sole stratification in the calculation of bycatch estimates, and to be consistent with those calculations, this variable alone was used in the discard calculations.

Table 5: Summary of LME modelling of discards in the arrow squid trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *head-ht*, headline height; *fyr*, fishing year; *s.time*, start time; *gear*, bottom or midwater; *grt*, vessel tonnage, *fday*, day of the fishing year.

Species cat.	Model type	Variable											
		area	*duration*	*fyr*	*month*	*head-ht*	*speed*	*depth*	*s.time*	*gear*	*grt*	*nation*	*fday*
SQU	Normal	1	2	4	8	7	–	3	5	–	–	6	–
QMS	Normal	1	3	5	7	2	–	4	–	8	–	6	–
QMS	Binomial	1	3	–	–	4	5	–	–	–	–	2	–
Non-QMS	Normal	3	2	–	–	–	–	1	5	4	8	6	7
Non-QMS	Binomial	6	1	4	–	–	–	5	–	–	3	2	–
INV	Normal	1	3	8	6	2	9	4	5	7	10	–	–
INV	Binomial	1	3	5	–	4	7	–	–	–	8	2	6

3.4 Estimation of bycatch

3.4.1 Bycatch rates

Bycatch rates by area and year were calculated for each species category from the observer data. The calculations focussed on the four main fishery areas (SNAR, AUCK, PUYS, and BANK), which together account for over 98% of the total arrow squid catch; average bycatch rates across all areas in each year were calculated to apply to fishing effort in areas other than these. The variance associated with these estimates was calculated using the bootstrap methods described in section 2.4.

As well as providing the basis from which annual bycatch can be determined by application to target fishery effort totals, these rates also provide some insight as to how bycatch varies between the different regions of the arrow squid fishery (Figure 14, Appendices 4 and 5). Limitations in the data, especially in the spread of observer effort across areas in each year, meant that bycatch rates for several year/area combinations were based on data from all areas for the year, or all years for the area, as described in Section 2.4.

Median bycatch rates of QMS species were consistently low in AUCK, and in most years were only a few hundred kg.tow^{-1} or less. In other areas bycatch rates of QMS species were variable but generally between 1 and 3 t.tow^{-1} and increasing slightly over time. The high catch rate of QMS species in BANK in 2006–07 is due to several large catches of silver warehou (maximum 53 t) and spiny dogfish (maximum 17 t).

Bycatch rates of non-QMS species were less than about 200 kg.tow^{-1} in most years in each area, but were occasionally much greater than this in PUYS and BANK between 1999–2000 and 2007–08. The high catch rate of non-QMS species in PUYS in 2004–05 was largely due to several large catches of silver dory (maximum 28 t), and javelinfish was the species most responsible for the high catch rates seen in BANK.

Bycatch rates of invertebrate species increased over time in AUCK, BANK, and PUYS from less than 50 kg.tow^{-1} up to the mid-1990s to a few hundred kg.tow^{-1} in most years after 1999–2000. In contrast, invertebrate bycatch rates remained consistently low in SNAR—less than 50 kg.tow^{-1} in each year. The increase in bycatch rates of invertebrate species was especially strong in AUCK, where the observed catch of unspecified crab species, giant spider crabs (*Jaquinotia edwardsii*), and smooth red swimming crabs all increased after about 2000.

Regression modelling indicated increasing bycatch rates over time (positive slopes) in all species categories and areas except for QMS species in SNAR and BANK (Table 6). These trends of increasing bycatch rate were statistically significant ($p<0.05$) for non-QMS species in SNAR and for invertebrate species in all areas (Table 6).

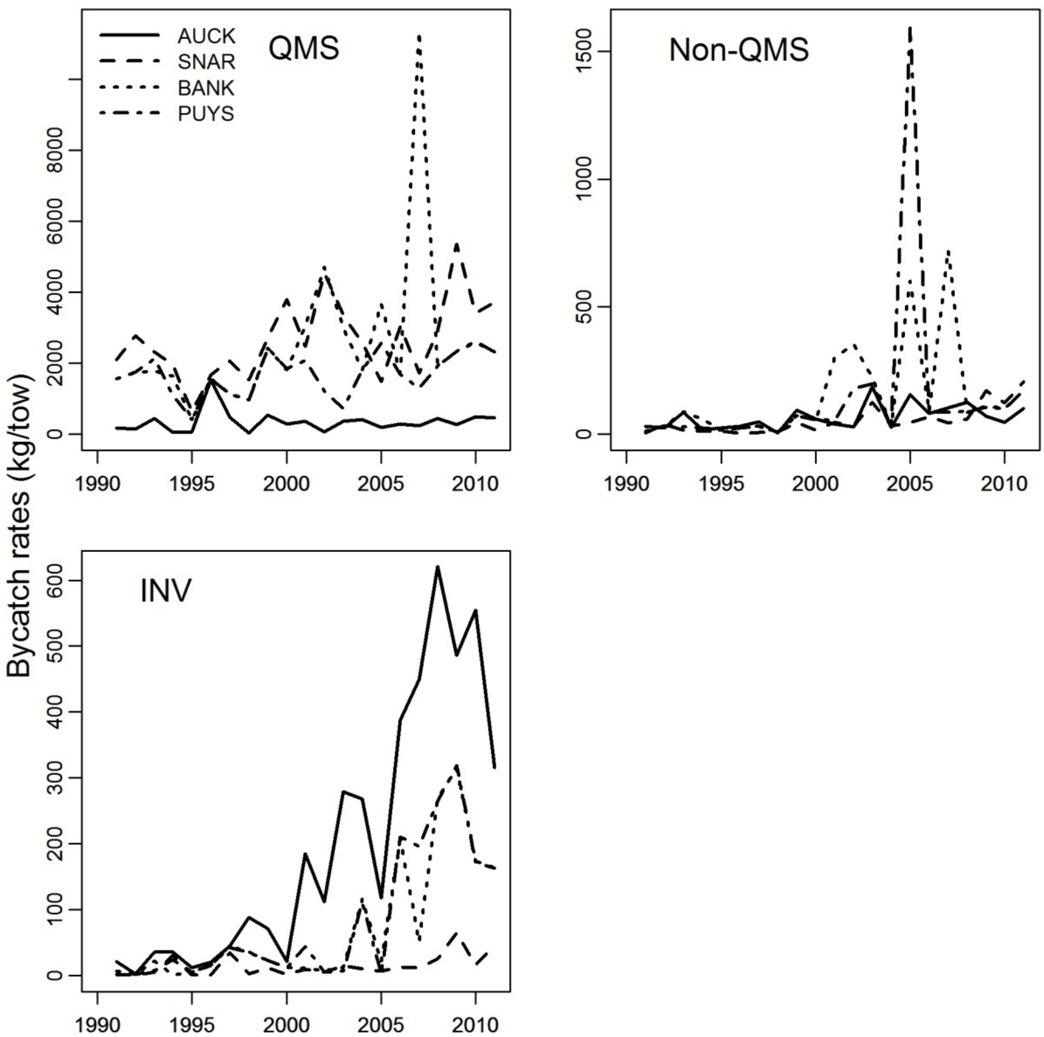

Figure 14: Annual bycatch rates by species category and areas used for stratification, in the arrow squid trawl fishery. Bycatch rates are the median of the bootstrap sample of 1000.

Table 6: Summary of results of regression analyses for trends in annual bycatch rates, by species category and area. The *p* values indicate how significantly the slopes differed from zero. Those results where *p* values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Area	Slope	*p*
QMS	AUCK	0.017	0.638
QMS	SNAR	-0.003	0.833
QMS	BANK	-0.028	0.472
QMS	PUYS	0.045	0.426
Non-QMS	AUCK	0.045	0.153
Non-QMS	**SNAR**	**0.111**	**0.001**
Non-QMS	BANK	0.036	0.515
Non-QMS	PUYS	0.111	0.139
Invertebrates	**AUCK**	**0.182**	**<0.001**
Invertebrates	**SNAR**	**0.138**	**0.017**
Invertebrates	**BANK**	**0.168**	**0.001**
Invertebrates	**PUYS**	**0.100**	**0.036**

3.4.2 Annual bycatch levels

Annual bycatch in each species category was estimated by multiplying the rates calculated from observer data for each area and year stratum by the number of trawls in the target arrow squid fishery for the equivalent stratum, as described in Section 2.4. Precision of the estimates was determined from the variability in the bootstrap samples of 1000 rates (Table 7, Figure 15).

The annual bycatch of QMS species ranged from 4230 t in 1994–95 to 24 190 t in 2001–02 (Table 7). Between 1990–91 and 2006–07 QMS species bycatch was generally between 10 000 t and 20 000 t per year, with a slight pattern of decreasing then increasing levels over time. In the four following years, however, annual bycatch of QMS species dropped to a lower level, ranging from 8 800 t to 10 400 t. This reduction in bycatch was not due to lower bycatch rates during this period (see Section 3.4.1 above) but to a much reduced level of effort—as shown in the lower panel of Figure 15. The estimates for the years 1999–2000 to 2005–06 are similar to those estimated for QMS species for this period by Ballara & Anderson (2009), with confidence intervals almost fully overlapping in each year. The earliest study of bycatch in the arrow squid fishery (Anderson 2004) used different species categories to those used in the two subsequent assessments, and therefore no useful comparisons of results are possible.

The annual bycatch of non-QMS species was much lower than that of QMS species, and in most years was less than 1000 t although higher in several years between 2000–01 and 2006–07—reaching a maximum of 2160 t in 2004–05. Estimates made by Ballara & Anderson (2009) for 1999–2000 to 2005–06 were generally higher than those from this study, with confidence intervals not all overlapping, but showed the same pattern of higher levels between 2000–01 and 2006–07.

Invertebrate species were also only a very small component of the total annual bycatch, usually less than 1000 t, but showed an increase over time with much higher levels between 2002–03 and 2010–11 than in the previous 12 years (Table 7).
Total bycatch (all categories combined) showed the same pattern as QMS species bycatch—as it was dominated by that category—decreasing during the early 1990s to a low of 4490 t in 1994–95 then increasing to a peak of 21 000–25 000 t in the early 2000s, with lower, steady levels (10 000–12 000 t) in the last four years examined (Figure 15). Sea lion exclusion devices (SLEDs) were introduced into the fishery between 2000 and 2007, and since the 2006–07 fishing year have been used by all vessels in the Auckland Is. fishery, but it is unknown to what extent these devices influence bycatch rates of fish species and whether they could be responsible for recent lowered bycatch. The total bycatch estimates of Ballara & Anderson (2009) are similar to those of the present study, although overall about 10% greater,

with confidence intervals almost fully overlapping in each year. The variation in total annual bycatch over time shows little correspondence with the annual effort in the fishery or the reported annual landings of arrow squid, and the early closure of the fishery in some years due to reaching the sea lion fishing-related mortality limit (FRML) also seemed to have little effect.

Table 7: Estimates of total annual bycatch (rounded to the nearest 10 t) in the arrow squid trawl fishery for the species categories QMS, non–QMS, invertebrates, and overall, based on observed catch rates; 95% confidence intervals in parentheses.

	QMS		Non-QMS		Invertebrate		Total bycatch	
1990–91	16630	(12100–22370)	150	(80–280)	80	(40–160)	16860	(12220–22810)
1991–92	15430	(11220–20140)	270	(140–440)	10	(0–40)	15710	(11360–20620)
1992–93	17020	(14490–19940)	280	(160–520)	70	(20–150)	17370	(14670–20610)
1993–94	9990	(7740–13570)	290	(130–520)	240	(50–590)	10520	(7920–14680)
1994–95	4230	(3000–5860)	200	(100–350)	60	(30–130)	4490	(3130–6340)
1995–96	15570	(11860–20430)	200	(160–240)	120	(80–170)	15890	(12100–20840)
1996–97	13410	(9920–17680)	270	(150–420)	450	(170–1020)	14130	(10240–19120)
1997–98	9240	(7280–11590)	70	(30–130)	200	(80–340)	9510	(7390–12060)
1998–99	19570	(14990–24710)	430	(180–790)	140	(70–230)	20140	(15240–25730)
1999–00	12230	(9900–14880)	270	(190–380)	50	(40–70)	12550	(10130–15330)
2000–01	19630	(16340–23080)	1120	(690–1880)	230	(150–340)	20980	(17180–25300)
2001–02	24190	(19320–29260)	860	(580–1240)	230	(110–400)	25280	(20010–30900)
2002–03	18770	(15200–22920)	1450	(1090–1850)	540	(390–750)	20760	(16680–25520)
2003–04	14930	(10740–20720)	260	(170–390)	900	(440–1650)	16090	(11350–22760)
2004–05	15550	(11520–20830)	2160	(1420–3180)	390	(240–560)	18100	(13180–24570)
2005–06	17140	(13060–22180)	650	(400–1050)	1380	(840–2180)	19170	(14300–25410)
2006–07	21390	(16270–29500)	1280	(720–2080)	750	(430–1170)	23420	(17420–32750)
2007–08	8770	(6610–11320)	350	(250–480)	970	(590–1350)	10090	(7450–13150)
2008–09	10390	(8170–13300)	440	(190–900)	1100	(650–1760)	11930	(9010–15960)
2009–10	9210	(7120–11860)	360	(210–600)	760	(510–1050)	10330	(7840–13510)
2010–11	9880	(7580–12380)	690	(530–870)	670	(430–990)	11240	(8540–14240)

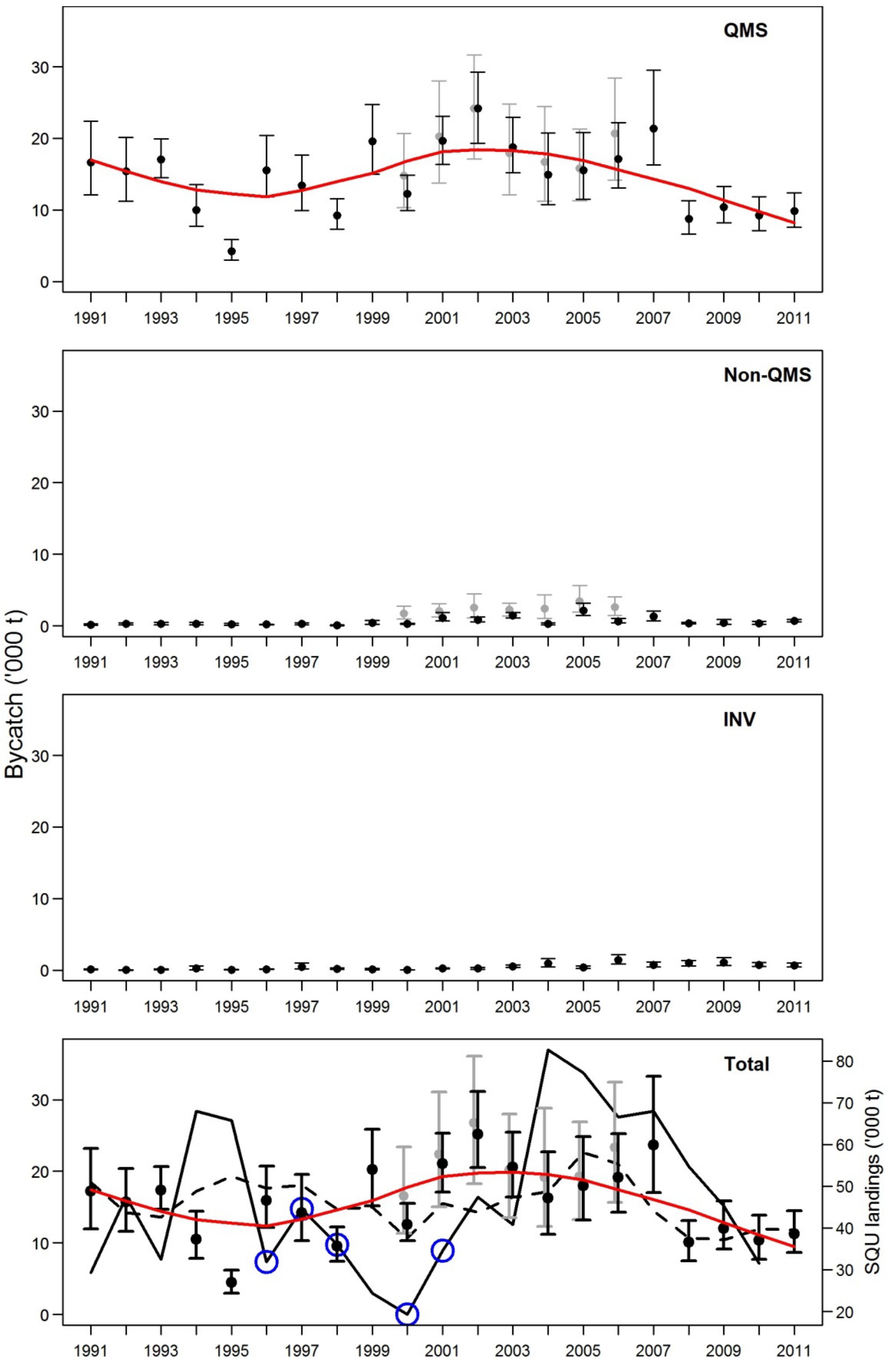

Figure 15: Annual estimates of bycatch in the arrow squid trawl fishery, for QMS species, non-QMS species, invertebrates (INV), and overall for 1990–91 to 2010–11. Also shown (in grey) are estimates of bycatch in each category (excluding INV) calculated for 1999–2000 to 2005–06 (Ballara & Anderson 2009). Error bars indicate 95% confidence intervals. The red lines show the fit of a locally-weighted polynomial regression to annual bycatch. In the bottom panel the solid black line shows the total annual reported trawl-caught landings of arrow squid (Ministry of Fisheries 2011), with circles indicating years in which the fishery closed early after reaching the sea lion FRML; and the dashed line shows annual effort (scaled to have mean equal to that of total bycatch).

Total annual bycatch calculated directly from commercial catch records (by comparing total catch with the catch of the target species in each trawl or group of trawls, depending on form type) was in most years substantially lower than the observer data-based estimate, and frequently outside of its 95% confidence interval (Figure 16, Table 8). However, in some years (e.g. 1994–95, 1996–97, and 1999–2000) the catch record-based estimate was similar to or higher than the observer data-based estimate. The 1994–95 fishing year was unusual in that both estimates of bycatch were low and the catch-effort based estimate was substantially greater than the observer-based estimate. Bycatch based on catch-effort data can be overestimated if arrow squid is not in the top 5 species, and therefore is not recorded on the catch effort form, or if some other recording errors persist. However, given that the observer coverage in 1994–95 was lower than in any other year (6.2%, see Table 3) it is more likely that the observer-based method underestimated bycatch in this year. Overall, the total catch record-based annual bycatch for the 21-year period was about 80% of the observer data-based bycatch. The general pattern over time was quite similar between the two estimates, especially before 1998–99 and after 2006–07.

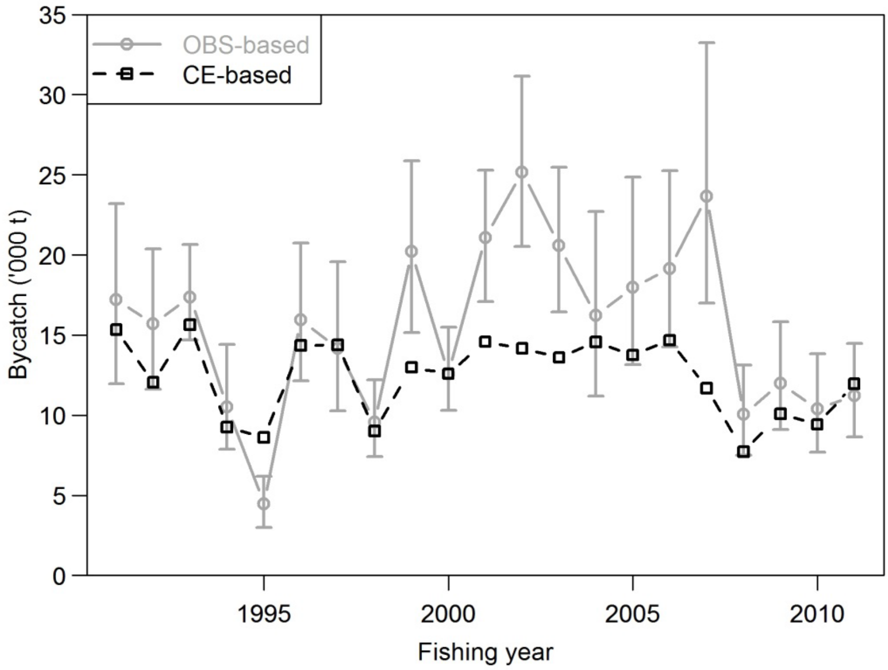

Figure 16: Total annual bycatch in the arrow squid fishery from scaled up observer catch rates and commercial catch effort records.

Table 8: Total annual bycatch estimates for the arrow squid fishery, based on catch effort records, compared with the observer-based estimates. Estimates are derived by summing the difference between the recorded total catch and arrow squid catch for each trawl (TCE) or group of trawls (CEL).

Fishing year	Total bycatch (t)	% of observer-based estimate
1990–91	15 332	90
1991–92	12 052	76
1992–93	15 641	90
1993–94	9 247	88
1994–95	8 606	193
1995–96	14 343	90
1996–97	14 387	101
1997–98	9 009	94
1998–99	12 984	64
1999–00	12 586	101
2000–01	14 581	69
2001–02	14 169	57
2002–03	13 601	66
2003–04	14 571	90
2004–05	13 757	77
2005–06	14 674	77
2006–07	11 686	50
2007–08	7 722	77
2008–09	10 085	85
2009–10	9 419	91
2010–11	11 961	107

3.4.3 Trends in annual bycatch

A strongly significant trend of increasing bycatch over time was shown only for invertebrate species, and a weaker increasing trend was indicated for non-QMS species (Table 9). Although annual bycatch does not show a very linear trend in the QMS, non-QMS, or total bycatch categories, these linear regressions are useful for indicating any long-term changes. The increased invertebrate catch over time may indicate either an increased abundance of invertebrate species vulnerable to the fishery or a change in the operation of the fishery which has increased catch rates of these species.

Table 9: Summary of results of regression analyses for trends in annual bycatch, by species category. The *p* values indicate whether the slopes differed significantly from zero. Those results where *p* values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Slope	*p*
QMS	0.015	0.416
Non-QMS	0.054	0.084
Invertebrate	**0.198**	**<0.001**
Total	0.021	0.248

3.5 Estimation of discards

3.5.1 Discard rates

Discard rates by area and year were calculated for each species category from the observer data (Figure 17, Appendices 6 and 7). The variance associated with the discard estimates was calculated using the bootstrap methods described above.

As for bycatch, the limited spread of observer effort required that discard rates for several year/area combinations were based on data from all areas for the year, or all years for the area, as described in Section 2.4.

Median discard rates of arrow squid were highly variable between years and areas; the highest rates (50–100 $kg.tow^{-1}$) were observed in AUCK in the early and late years of the series, and rates were low (less than 50 $kg.tow^{-1}$) in all areas between about 1995–96 and 2004–05 (Figure 17). Annual discard rates of QMS species were also variable, especially in SNAR and BANK where they were frequently greater than 300 $kg.tow^{-1}$ or, in some years when data were too sparse to calculate area/year specific rates (BANK) or discards of spiny dogfish were substantially lower (SNAR), less than 100 $kg.tow^{-1}$. In contrast, annual QMS species catch rates in AUCK were generally less than 50 $kg.tow^{-1}$.

Because of generally low catches, median annual discard rates of non-QMS species were mostly much lower than those of QMS species—usually less than 100 $kg.tow^{-1}$. In BANK and PUYS, however, discard rates were in excess of 500 $kg.tow^{-1}$ in a few years in the mid-2000s, due mainly to increased catch rates of rattails (especially javelinfish), slender tuna (*Allothunnus fallai*), and silver dory (*Cyttus novaezealandiae*). Annual discard rates of invertebrate species were mostly less than 50 $kg.tow^{-1}$ in all areas up until 1999–2000, but then increased in all areas except for SNAR, over the following ten years; invertebrate discard rates were consistently highest in AUCK throughout the period (due mainly to greater catch rates of crab species, as discussed above), reaching to about 300 $kg.tow^{-1}$ or more in several years.

Regression modelling indicated increasing discard rates over time (positive slopes) in all species categories and areas except for SQU in BANK (Table 10), matching closely the trends shown for bycatch rates (see section 3.4.1 above). These trends of increasing discard rate were statistically significant ($p<0.05$) for QMS species in AUCK, non-QMS species in SNAR, and for invertebrate species in AUCK and BANK.

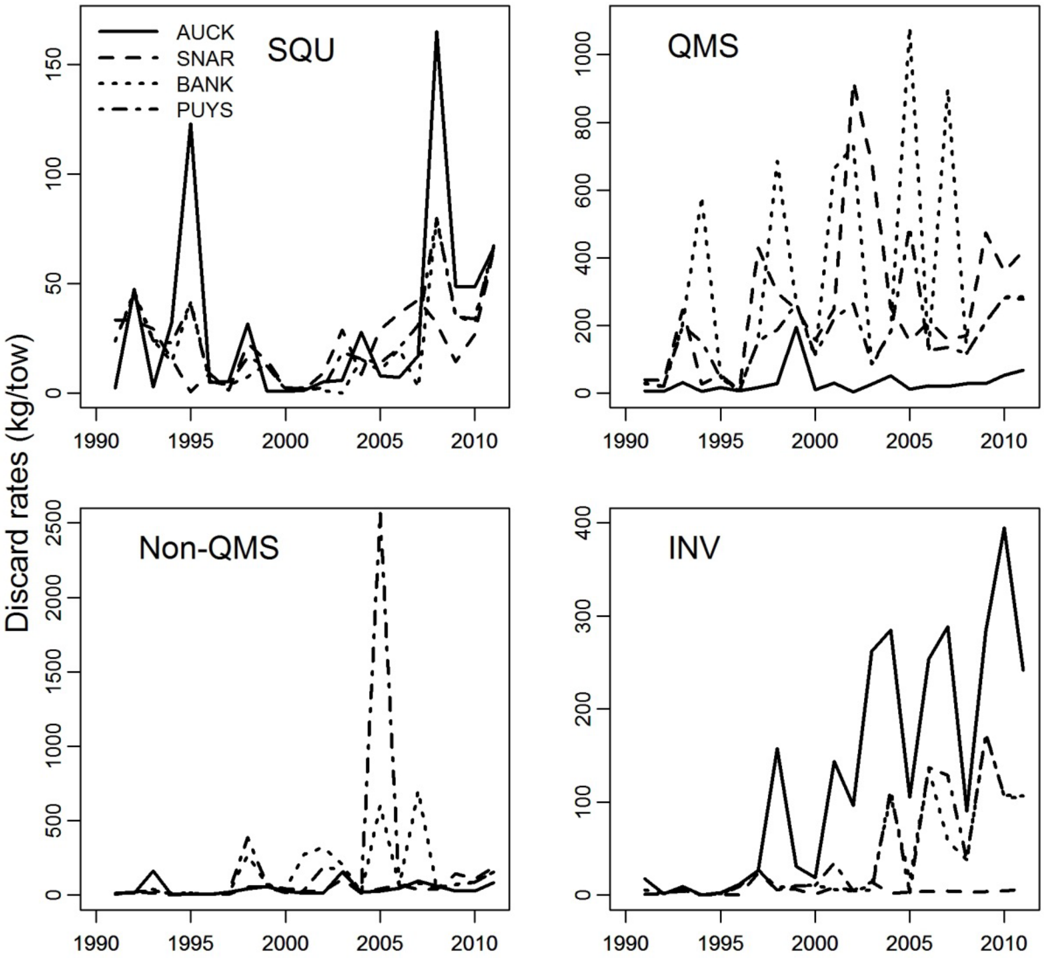

Figure 17: Annual discard rates by species category and areas used for stratification, in the arrow squid trawl fishery. Discard rates are the median of the bootstrap sample of 1000.

Table 10: Summary of results of regression analyses for trends in annual discard rates, by species category and area. The *p* values indicate how significantly the slopes differed from zero. Those results where *p* values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Area	Slope	*p*
SQU	AUCK	0.060	0.379
SQU	SNAR	0.033	0.567
SQU	BANK	-0.078	0.132
SQU	PUYS	0.009	0.750
QMS	**AUCK**	**0.057**	**0.031**
QMS	SNAR	0.070	0.097
QMS	BANK	0.017	0.774
QMS	PUYS	0.084	0.233
Non-QMS	AUCK	0.057	0.079
Non-QMS	**SNAR**	**0.135**	**0.008**
Non-QMS	BANK	0.086	0.194
Non-QMS	PUYS	0.088	0.253
Invertebrates	**AUCK**	**0.247**	**<0.001**
Invertebrates	SNAR	0.069	0.189
Invertebrates	**BANK**	**0.170**	**<0.001**
Invertebrates	PUYS	0.071	0.109

3.5.2 Annual discard levels

The level of annual discards in each species category was estimated by multiplying the rates calculated from observer data for each area and year stratum by the number of trawls in the target arrow squid fishery for the equivalent stratum, as described in Section 2.4. Precision of the estimates was determined from the variability in the bootstrap samples of 1000 rates (Table 11, Figure 18).

Discarding of arrow squid was generally low, less than 400 t per year in all but one year, 1994–95. Discard levels were especially low (mostly less than 100 t per year) between 1995–96 and 2001–02 then relatively stable thereafter at 130–330 t per year.

Discard levels of QMS species were generally greater than other categories, but highly variable—ranging from a low of 70 t in 1995–96 (when discard rates were low in all areas, see Figure 17) to a high of over 4500 t in 2001–02 (Table 11). Overall, QMS species discards increased from low levels in the early 1990s to peak in the early 2000s, and have been decreasing since. Estimates of QMS species discards for 1999–2000 to 2005–06 by Ballara & Anderson (2009) were similar to the estimates for this period in the current study, with confidence intervals for the pairs of estimates all well overlapped (Figure 18).

Discards of non-QMS species were low throughout the early to mid-1990s, generally less than 200 t per year, but generally increased between 1997–98 and 2006–07 when they were mostly over 500 t per year, then decreased again during the most recent four years to 200–600 t per year (Table 11). The estimates for 1999–2000 to 2005–06 are lower than those of Ballara & Anderson (2009), but the trend in values through this period is similar (Figure 18).

Annual discards of invertebrates showed a similar pattern to bycatch (as most of the catch in this category is discarded), with generally increasing levels throughout the period. Between 1990–91 and 1999–2000 invertebrate discards were generally less than 100 t per year, but subsequently were mostly greater than 200 t per year, reaching a maximum of 880 t in 2003–04.

Estimates of total annual discards ranged from 230 t in 1995–96 to 5540 in 2001–02. The estimates for 1999–2000 to 2005–06 generally match well with those of Ballara & Anderson (2009), with considerable overlap of confidence intervals in most years, but on the whole are slightly lower than these earlier estimates.

In several years the majority of the non-QMS and invertebrate species catch was discarded in this fishery. Because of this and also due to the smaller set of observer data used for discard calculations compared with bycatch calculations (only records with a one-to-one match of processing data to station data), it is possible for annual estimates of discards in these categories to exceed those of bycatch. Although this occurred in a few cases the differences were small and well accounted for by the 95% confidence intervals.

Table 11: Estimates of total annual discards (rounded to the nearest 10 t) in the arrow squid trawl fishery for the species categories SQU, QMS, non–QMS, invertebrates, and overall, based on observed discard rates; 95% confidence intervals in parentheses.

	SQU		QMS		Non-QMS		Invertebrate		Total discards	
1990–91	260	(40–830)	330	(110–580)	70	(30–140)	60	(0–220)	720	(180–1770)
1991–92	330	(150–650)	210	(80–420)	190	(60–410)	20	(0–30)	750	(290–1510)
1992–93	220	(100–460)	1810	(1060–2740)	210	(70–610)	40	(20–60)	2280	(1250–3870)
1993–94	230	(140–360)	1830	(940–3460)	40	(10–90)	0	(0–10)	2100	(1090–3920)
1994–95	570	(10–1910)	420	(160–750)	130	(40–250)	20	(0–50)	1140	(210–2960)
1995–96	60	(20–120)	70	(50–110)	30	(20–60)	70	(30–130)	230	(120–420)
1996–97	30	(10–100)	2370	(770–4620)	120	(40–250)	270	(90–530)	2790	(910–5500)
1997–98	180	(110–250)	2570	(1960–3250)	780	(520–1060)	270	(190–360)	3800	(2780–4920)
1998–99	100	(20–370)	1950	(810–3810)	450	(170–840)	70	(30–110)	2570	(1030–5130)
1999–00	10	(0–20)	820	(420–1400)	210	(130–320)	50	(30–70)	1090	(580–1810)
2000–01	20	(10–30)	3020	(2170–3890)	890	(470–1650)	180	(120–280)	4110	(2770–5850)
2001–02	40	(10–110)	4540	(2810–6750)	760	(500–1140)	200	(100–340)	5540	(3420–8340)
2002–03	140	(50–270)	2710	(1340–4910)	1270	(910–1730)	510	(350–740)	4630	(2650–7650)
2003–04	140	(50–350)	1520	(900–2280)	130	(80–200)	880	(450–1500)	2670	(1480–4330)
2004–05	220	(70–500)	2730	(1160–5170)	2030	(1080–3350)	340	(200–500)	5320	(2510–9520)
2005–06	210	(40–510)	1210	(680–2040)	520	(240–1000)	870	(510–1310)	2810	(1470–4860)
2006–07	160	(60–330)	1790	(860–3000)	1220	(620–2150)	520	(290–810)	3690	(1830–6290)
2007–08	330	(70–780)	510	(310–840)	200	(120–300)	140	(70–250)	1180	(570–2170)
2008–09	130	(60–210)	930	(580–1480)	320	(90–760)	580	(290–950)	1960	(1020–3400)
2009–10	140	(30–310)	970	(560–1720)	310	(160–540)	520	(290–760)	1940	(1040–3330)
2010–11	280	(180–490)	1150	(700–1810)	610	(470–790)	440	(230–710)	2480	(1580–3800)

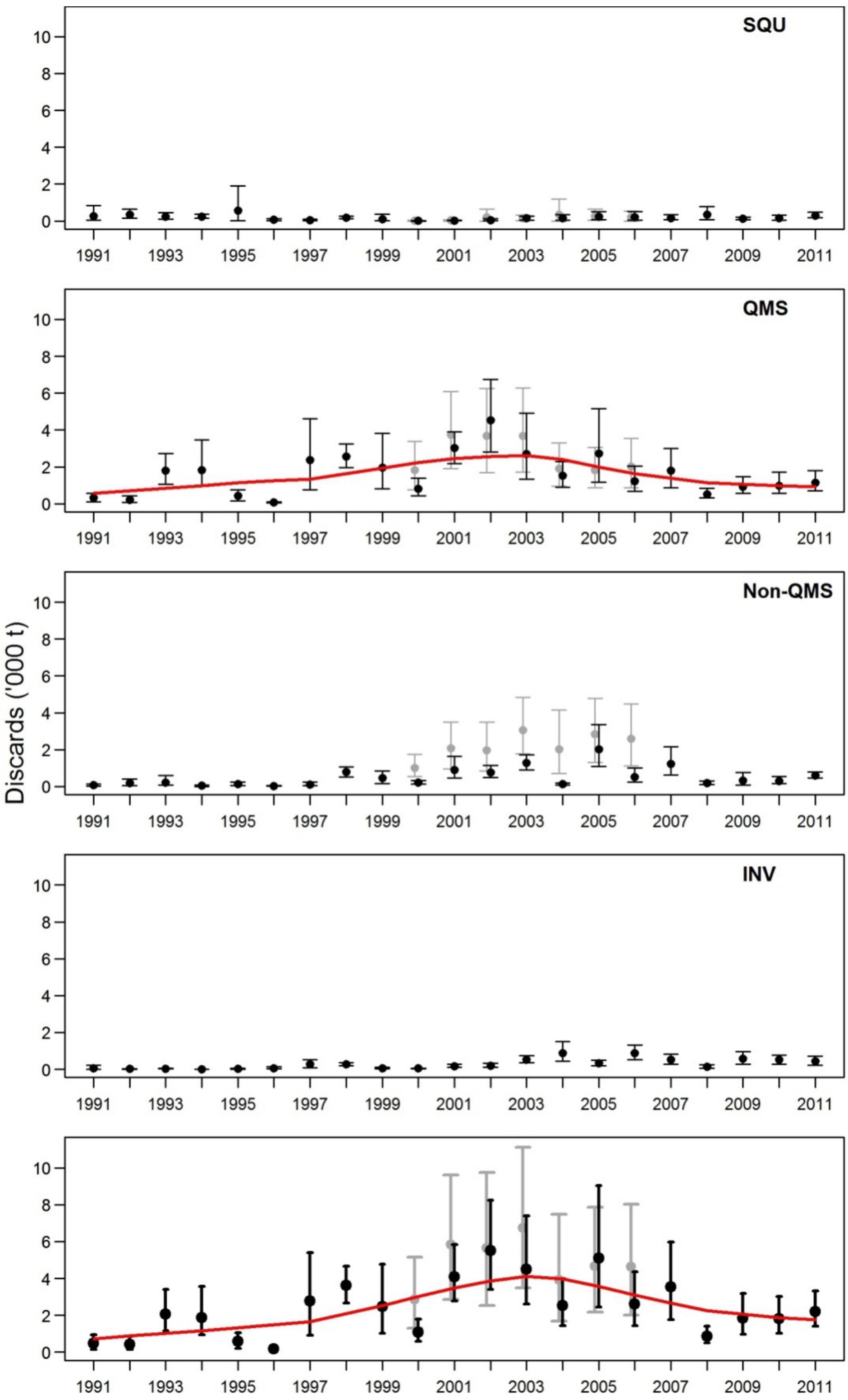

Figure 18: Annual estimates of discards in the arrow squid trawl fishery, for arrow squid (SQU), QMS species, non-QMS species, invertebrates (INV), and overall for 1990–91 to 2010–11. Also shown (in grey) are estimates of discards in each category (excluding INV) calculated for 1999–2000 to 2005–06 (Ballara & Anderson 2009). Error bars indicate 95% confidence intervals. The red lines show the fit of a locally-weighted polynomial regression to annual discards.

3.5.3 Trends in annual discards

As with bycatch, linear trends in annual discards are also not strongly suggested in the categories examined (see fitted regression lines in Figure 18); however, linear regressions can be useful for indicating long-term changes. These regressions showed positive slopes, i.e., increasing discards over time, in each category, and these slopes were moderately significant for all but discards of arrow squid (Table 12).

Table 12: Summary of results of regression analyses for trends in annual discards, by species category. The *p* values indicate whether the slopes differed significantly from zero. Those results where *p* values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Slope	*p*
SQU	0.103	0.240
QMS	0.108	0.052
Non-QMS	**0.116**	**0.004**
Invertebrate	0.370	0.055
Total	**0.103**	**0.016**

3.5.4 Discard information from Catch Landing Returns

The disposal of all catch taken by vessels in the arrow squid fishery is recorded on Catch Landing Returns (CLRs). Codes used on this form under *destination_type* which may provide information on discarding include:

A	Accidental loss
D	Discarded (non-ITQ)
M	QMS species returned to sea (those in Part 6A of the Fisheries (Reporting) Regulations 2001, currently only spiny dogfish)
X	QMS species returned to sea (those listed in Schedule 6 of the Fisheries Act (1996) but excluding those in Part 6A of the Fisheries (Reporting) Regulations 2001 (spiny dogfish).

Although these returns are designed to capture information on the disposal of all catch recorded in catch/effort forms, in reality there has probably been more of a focus on fish physically landed onshore, with discarded bycatch not fully recorded. In addition, these returns relate to the catch from several days or from whole trips rather than from individual tows, and so they may relate to more than one target fishery. A summary of this information is nevertheless made here, to gauge the level of reported discarding—in particular the discarding of QMS species, which is permitted for species listed in Schedule 6 of the Fisheries Act (1996) and for species not so listed when an observer is on board the vessel and approves it.

Catch Landing Return data were examined from all trips which were mainly targeting arrow squid, i.e., greater than 50% of tows/days. In about half of these trips arrow squid were exclusively targeted. Recorded accidental losses of fish ranged from 0–319 t per year and discarding of non-ITQ species ranged from 0–3179 t per year (Table 13). Both these types of discards were considerably greater after 2000–01 than before. Destination types M and X are more recent codes, introduced in the mid-1990s. These show very small amounts of recorded discards of Schedule 6 QMS species but larger amounts of Part 6A (spiny dogfish) discards (up to 1000 t per year). The codes listed in Table 13 are the only destination type codes available for recording discards, and there is no code provided to record observer/fishery officer approved discards. Such discards are therefore unaccounted for by Catch Landing Records.

Table 13: Summary of discard and loss weights (t) by destination type and fishing year, from arrow squid fishery Catch Landing Returns. A, Accidental loss; D, Discarded (NON-ITQ); M, QMS species returned to sea (Part 6A, currently only spiny dogfish); X, QMS species returned to sea (not Part 6A, i.e., excluding spiny dogfish).

	Destination type			
	A	D	M	X
1990–91	39	71	0	0
1991–92	47	95	0	0
1992–93	12	189	0	0
1993–94	36	139	0	0
1994–95	56	106	0	0
1995–96	1	255	0	0
1996–97	9	0	0	0
1997–98	1	0	0	0
1998–99	52	0	0	0
1999–00	32	872	0	0
2000–01	0	0	0	0
2001–02	66	3 179	0	0
2002–03	52	2 528	0	0
2003–04	102	2 624	0	0
2004–05	118	1 422	697	0
2005–06	69	1 655	1 011	0
2006–07	133	924	503	2
2007–08	183	793	434	1
2008–09	112	912	805	1
2009–10	66	1 115	466	2
2010–11	319	1 254	597	4

3.5.5 Observer-authorised discarding

Section 72 of the Fisheries Act (1996) allows for the legal discarding of QMS species not listed in Schedule 6 if authorised by an observer (or fishery officer) who is present at the time. Such discarding is recorded at sea on an "Authority to return or abandon fish to the sea" form. These forms are returned to Ministry for Primary Industries where they are stored, but not recorded in any electronic database. In addition, observers provide a summary of all approved discarding for each trip in their trip report, but again this is not recorded in a database. A complicating factor with the data from both of these sources (if they were to be incorporated into this study) is that usually the records relate to the combined discards from several tows, or the entire trip, and could not be properly reconciled with the catch from individual tows or processing groups.

An examination was made of the trip reports from a random selection of 19 of the 411 observed trips in this study. About a third of these recorded no authorised QMS species discarding and the remaining recorded authorised discards of between 25 kg and 36 t per trip. Most of the discards comprised arrow squid which were considered too small, damaged, or decomposed to process, but occasionally large amounts of barracouta, jack mackerel, hoki, silver warehou, and red cod (up to about 15 t) were discarded—for the same reasons.

Observer authorised discarding clearly has the potential to bias estimation of discards which are based on observed discard rates. Ideally such discards would be ignored in the calculation of these rates but this could be done only by assuming that all QMS species discards in the observer databases were properly approved. Disregarding these discards would lead to a discard rate of zero and the result that there was zero discarding of (non-Schedule 6) QMS species in the unobserved portion of the fishery.

The annual QMS discard estimates presented above therefore make the assumption that the level of discarding of QMS species not listed in Schedule 6 of the Fisheries Act 1996 is unaffected by the presence of an observer on the vessel.

3.6 Efficiency of the arrow squid trawl fishery

Annual discard estimates in the arrow squid fishery were compared with the estimated annual catch and total annual bycatch, to get a measure of the efficiency of the fisheries (Table 14).

The annual discard fraction (kg of discards/kg of arrow squid catch) ranged from 0.01 in 1995–96 to 0.13 in 2000–01 and 2001–02, with an overall value for the 21-year period of 0.06. Although quite variable, the discard fraction generally increased to peak levels in the late 1990s and early 2000s, and then reduced to lower levels during most of the following years. Between 1% and 40% of the annual bycatch was discarded, with no obvious pattern over time.

Table 14: Estimated annual arrow squid trawl catch (t), total bycatch (t), and total discards (t) in the target arrow squid trawl fishery; discard fraction (kg of total discards per kg of arrow squid caught); and discards as a fraction of bycatch.

Fishing year	Arrow squid estimated catch	Total bycatch	Total discards	Discard fraction	Discards/ bycatch
1990–91	26 730	17 200	720	0.03	0.04
1991–92	43 131	15 700	750	0.02	0.05
1992–93	28 608	17 360	2 280	0.08	0.13
1993–94	61 682	10 500	2 100	0.03	0.20
1994–95	60 332	4 470	1 140	0.02	0.26
1995–96	27 373	15 950	230	0.01	0.01
1996–97	40 231	14 180	2 790	0.07	0.20
1997–98	31 611	9 550	3 800	0.12	0.40
1998–99	21 519	20 220	2 570	0.12	0.13
1999–00	17 381	12 580	1 090	0.06	0.09
2000–01	31 228	21 090	4 110	0.13	0.19
2001–02	43 282	25 170	5 540	0.13	0.22
2002–03	37 645	20 590	4 630	0.12	0.22
2003–04	76 660	16 230	2 670	0.03	0.16
2004–05	73 279	17 970	5 320	0.07	0.30
2005–06	62 158	19 140	2 810	0.05	0.15
2006–07	62 016	23 660	3 690	0.06	0.16
2007–08	51 008	10 060	1 180	0.02	0.12
2008–09	42 798	11 980	1 960	0.05	0.16
2009–10	29 214	10 380	1 940	0.07	0.19
2010–11	33 275	11 230	2 480	0.07	0.22

3.7 Annual bycatch by individual species in the arrow squid fishery

A table of annual bycatch estimates for individual species, and regression slopes indicating general trends in abundance, is given in Appendix 11. In some cases the apparent increase or decrease in bycatch of a species is likely to be due to improvements in species identification over time. For example, the increase in bycatch of smooth red swimming crabs appears to be at the expense of bycatch of the similar-looking paddle crabs.

The most commonly caught bycatch species were barracouta (BAR), silver warehou (SWA), and spiny dogfish (SPD). Of the 101 bycatch species examined, 15 have shown a decrease in catch over time and 54 an increase in catch. The species showing the greatest decline were paddle crabs (*Ovalipes catharus*, PAD), jack mackerels (*Trachurus* spp., JMA), and slender jack mackerel (*Trachurus murphyi*, JMM). The species showing the greatest increase were giant spider crab (GSC), smooth red swimming crab (NCB), and silver dory (SDO) (Figure 19).

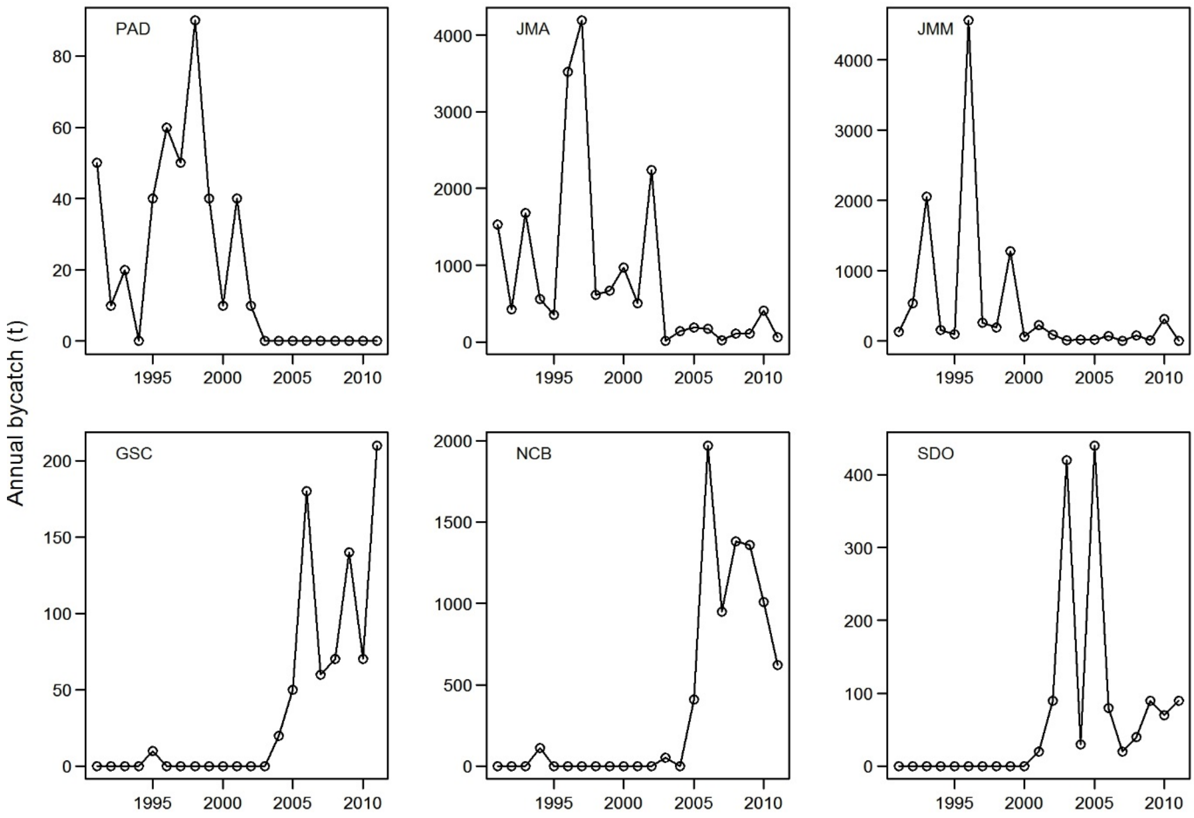

Figure 19: Annual bycatch estimates in the arrow squid trawl fishery for the species which have shown the greatest decrease (top) and greatest increase (bottom) between 1990–91 and 2010–11. See text above for explanation of the species codes.

4. DISCUSSION

The annual estimates of bycatch and discards in the fishery are based on observed bycatch and discard rates and, as such, the precision of these estimates is strongly dependent on the level and spread of observer coverage as well as the quality of this coverage.

The level of observer coverage in the arrow squid fishery is typical of the other deepwater fisheries for which bycatch and discard levels are assessed. The long-term level of observer coverage in most of these fisheries is greater than 18% (and over 40% for southern blue whiting) by weight of the target fishery catch, and for the arrow squid fishery the level is about 22%. The fisheries with the lowest level of coverage are the jack mackerel and scampi fisheries (Anderson 2004, 2007, 2012), at about 11–12% of the target fishery catch. Coverage in the arrow squid fishery was highly variable before the end of the 1990s, and less than 10% in a few years, but increased to be consistently greater than 20% in most years since 1999–2000. This has allowed for improved estimates of bycatch and discard rates/amounts for most years.

The distribution of observer effort was representative of effort across the whole fishery across the array of explanatory variables used in models to estimate bycatch and discards. The main arrow squid fisheries are well defined and consistent from year to year and, apart from lower than ideal coverage in the east coast South Island fishery, observer sampling was spread relatively evenly among them throughout the 21 years examined. The vessels involved in this fishery were spread across a wide size range, but even the smallest vessels (300–400 t) received a substantial level of coverage. The full depth range of the fishery was covered and the entire fishing year also, although overall it was slightly oversampled in the peak season and undersampled at the beginning and end of the season.

The rate estimator used in the analysis is the same as used in recent assessments of other Tier-1 fisheries (e.g., Anderson 2012) but differs from that used in the most recent assessment of the arrow squid fishery (Ballara & Anderson 2009). This "per tow" estimator is preferred to the alternatives ("per trawl duration" or per "arrow squid catch") mainly because of the reduced possibility of measurement error and the better precision achievable. Overall, area was the most critical factor influencing bycatch and discard rates in this fishery and although trawl duration was also important in all catch categories, there was insufficient observer data to stratify by more than two variables, i.e., area and fishing year. Thus stratification was identical to that applied in the previous assessment (Ballara & Anderson 2009).

Estimation of bycatch and discards focussed on three broad categories of catch; QMS species, non-QMS species, and invertebrates. Only the first two of these categories match those previously assessed, and these only in the most recent assessment (Ballara & Anderson 2009), limiting comparisons between studies to the 1999–2000 to 2005–06 period. The repeated estimates were in most cases similar to the earlier estimates. The main difference between the earlier assessment and this one was in the form of the rate estimator, catch per hour in the former compared with catch per tow in this study. This is likely to be the primary cause of the differences in estimates between studies, especially in the relative sizes of the confidence intervals, which tended to be narrower in the present study. Slight differences in data grooming methods, especially in assembling discard data in different formats from two separate databases, and the procedure used for dealing with data poor strata, will also have contributed.

The top ten bycatch species or species groups are QMS species, and therefore direct controls exist to limit overall harvest levels. Spiny dogfish, however, despite being a QMS species, are an important component of the discards in this fishery—as they are also in the scampi, hoki, hake, ling, southern blue whiting, and jack mackerel fisheries (Anderson 2007, 2008, 2009, 2012, Ballara et al. 2010). Because of its inclusion in schedule 6 of the Fisheries Act (1996), allowing it to be legally discarded, much of the annual catch of this species is discarded (Manning et al. 2004) due to its low commercial value. Despite these large catches, there is no evidence that the abundance of this species has been affected, and stock sizes may actually be increasing (Ministry for Primary Industries 2012).

The species most at risk from the adverse effects of the arrow squid fishery are likely to be those not under the management of the QMS, examined here in the non-QMS and invertebrate categories. As a group, rattails form the largest non-QMS bycatch category but, according to observer records, these comprise only about 0.2% of the catch in the target arrow squid fishery. The smooth red swimming crab is another non-QMS species with substantial levels of bycatch (and which is usually discarded), comprising about 0.5% of the total catch and regularly observed caught in large amounts (up to 14 t). Although the bycatch of this species was shown to have increased strongly over time, this result is uncertain due to possible confusion with the paddle crab (*Ovalipes catharus*) in earlier years. The substantial increase in observed invertebrate species bycatch and discard rates seen after about 2000 appear to be valid, i.e., not due to more conscientious recording of non-commercial species or some other change in observer practices at that time. Although the taxonomic level to which observers have recorded catch species has improved in recent years, there is no evidence from this fishery (apart from the crab species discussed) or from other deepwater fisheries that the overall level of observed invertebrate species catch has been increasing.

Bycatch and discards in each of the combined species categories showed a generally increasing trend over the 21-year period, and this trend was statistically significant for bycatch of invertebrate species, discards of non-QMS species, and overall discards. Although bycatch of non-commercial species is clearly undesirable, the analysis indicates that it was increasing rates of bycatch and discards, rather than increasing effort, which was primarily responsible for these trends, suggesting that overall abundance within these species categories may have increased.

The current rate of discarding in this fishery is similar to the long term average, with values since the previous assessment of 0.02–0.07 kg of discards per kilogram of arrow squid comparable to the 0.06 kg average value for entire 21-year period. This fishery has a similar discard ratio to the oreo (0.03 kg), orange roughy (0.04 kg), jack mackerel (0.06 kg), and hoki (0.06 kg) fisheries, but is much greater than that of the southern blue whiting fishery (0.005 kg) and much lower than that of the scampi (4.2 kg) and ling longline (0.35 kg) fisheries (Anderson 2007, 2008, 2009, 2011, 2012, Ballara & Anderson 2009).

These analyses would benefit from better identification of bycatch species, especially the highly diverse rattails, which have been almost universally identified only to family level, and invertebrates in general. Although improvements in this area have been made in recent years, particularly with the availability of new field guides such as those of McMillan et al. (2011a, 2011b, 2011c) and Tracey et al. (2011), observers still require a level of training as well as sufficient time alongside their other duties while at sea to carry out accurate species identifications.

The estimation of bycatch for a wide range of species in the arrow squid fishery fisheries has provided an initial overview of both the level of this catch and the changes in catch over time. This may provide initial evidence of, or supporting evidence for, non-target species which are being adversely affected by this fishery.

Worthwhile comparisons of bycatch rate estimates from this study with abundance estimates from time series of trawl surveys were not possible. Therefore this study has not been able to provide any independent support for the patterns seen in the bycatch rates of the main species groups or bycatch levels of individual species over time.

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APPENDICES

Appendix 1: Observed fish bycatch. Species codes, common and scientific names, estimated catch, percentage of total catch, and overall percentage discarded of the top 100 fish species or species groups by weight from observer records for the arrow squid target fishery from 1 Oct 1990 to 30 Sep 2011. Records are ordered by decreasing percentage of catch, codes in bold are QMS species. Estimated catches are based on all observed target arrow squid tows; discards are based on all trips where arrow squid was the sole target species.

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
BAR	Barracouta	*Thyrsites atun*	25 030	8.51	1
SWA	Silver warehou	*Seriolella punctata*	7 203	2.45	4
SPD	Spiny dogfish	*Squalus acanthias*	5 006	1.70	77
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae*	3 359	1.14	0
WAR	Common warehou	*Seriolella brama*	2 617	0.89	0
RCO	Red cod	*Pseudophycis bachus*	2 203	0.75	8
JMM	Slender jack mackerel	*Trachurus murphyi*	1 581	0.54	0
HOK	Hoki	*Macruronus novaezelandiae*	1 540	0.52	13
RBT	Redbait	*Emmelichthys nitidus*	1 324	0.45	38
LIN	Ling	*Genypterus blacodes*	823	0.28	1
RAT	Rattails	Macrouridae	551	0.19	90
RBM	Rays bream	*Brama brama*	446	0.15	10
SKI	Gemfish	*Rexea solandri*	421	0.14	1
SDO	Silver dory	*Cyttus novaezealandiae*	404	0.14	86
STU	Slender tuna	*Allothunnus fallai*	330	0.11	7
BSK	Basking shark	*Cetorhinus maximus*	282	0.10	78
GSH	Ghost shark	*Hydrolagus novaezealandiae*	255	0.09	9
STA	Giant stargazer	*Kathetostoma giganteum*	221	0.08	5
HAP	Hapuku	*Polyprion oxygeneios*	196	0.07	1
JMD	Greenback jack mackerel	*Trachurus declivis*	173	0.06	0
WWA	White warehou	*Seriolella caerulea*	156	0.05	1
SSK	Smooth skate	*Dipturus innominatus*	144	0.05	8
SCH	School shark	*Galeorhinus galeus*	143	0.05	5
MIX	Mixed fish		141	0.05	98
RSK	Rough skate	*Zearaja nasuta*	123	0.04	6
JAV	Javelin fish	*Lepidorhynchus denticulatus*	111	0.04	90
SPE	Sea perch	*Helicolenus* spp.	103	0.04	3
HPB	Hapuku & bass	*Polyprion oxygeneios* & *P. americanus*	100	0.03	4
FRO	Frostfish	*Lepidopus caudatus*	73	0.02	0
POS	Porbeagle shark	*Lamna nasus*	57	0.02	48
CAR	Carpet shark	*Cephaloscyllium isabellum*	54	0.02	100
TAR	Tarakihi	*Nemadactylus macropterus*	51	0.02	2
HAK	Hake	*Merluccius australis*	42	0.01	3
SSI	Silverside	*Argentina elongata*	39	0.01	89
BCO	Blue cod	*Parapercis colias*	37	0.01	7
SPO	Rig	*Mustelus lenticulatus*	35	0.01	29
RDO	Rosy dory	*Cyttopsis roseus*	32	0.01	98
CBE	Crested bellowsfish	*Notopogon lilliei*	29	0.01	100
SBW	Southern blue whiting	*Micromesistius australis*	28	0.01	14
MAK	Mako shark	*Isurus oxyrinchus*	27	0.01	77
BEL	Bellowsfish	*Centriscops* spp.	27	0.01	93
GON	Sandfish	*Gonorynchus forsteri* & *G. greyi*	25	0.01	91
WIT	Witch	*Arnoglossus scapha*	25	0.01	91
JMN	Yellowtail jack mackerel	*Trachurus novaezelandiae*	25	0.01	0
BCD	Black cod	*Paranotothenia magellanica*	24	0.01	80
CDO	Capro dory	*Capromimus abbreviatus*	20	0.01	99
SKA	Skate	Rajidae & Arhynchobatidae	20	0.01	53
PIG	Pigfish	*Congiopodus leucopaecilus*	19	0.01	92
BWS	Blue shark	*Prionace glauca*	14	<0.01	63

Appendix 1 — *Continued*

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
OSD	Other sharks and dogs	Selachii	13	<0.01	100
STN	Southern bluefin tuna	*Thunnus maccoyii*	13	<0.01	3
THR	Thresher shark	*Alopias vulpinus*	12	<0.01	100
TOA	Toadfish	*Neophrynichthys* sp.	11	<0.01	83
OPE	Orange perch	*Lepidoperca aurantia*	11	<0.01	45
BRA	Short-tailed black ray	*Dasyatis brevicaudata*	10	<0.01	100
LAN	Lantern fish	Myctophidae	10	<0.01	5
GSP	Pale ghost shark	*Hydrolagus bemisi*	10	<0.01	6
GMU	Grey mullet	*Mugil cephalus*	9	<0.01	100
BBE	Banded bellowsfish	*Centriscops humerosus*	9	<0.01	100
LDO	Lookdown dory	*Cyttus traversi*	8	<0.01	29
SUN	Sunfish	*Mola mola*	8	<0.01	96
SQI	Squirrelfish	*Pristilepis oligolepis*	8	<0.01	0
BSH	Seal shark	*Dalatias licha*	8	<0.01	100
BGZ	Banded stargazer	*Kathetostoma binigrasella*	7	<0.01	16
SNA	Snapper	*Pagrus auratus*	7	<0.01	0
GFL	Greenback flounder	*Rhombosolea tapirina*	7	<0.01	33
BAS	Bass groper	*Polyprion americanus*	6	<0.01	1
BNS	Bluenose	*Hyperoglyphe antarctica*	6	<0.01	7
FLA	Flats		6	<0.01	1
WPS	White pointer shark	*Carcharodon carcharias*	5	<0.01	100
YCO	Yellow cod	*Parapercis gilliesi*	5	<0.01	92
SHA	Shark		4	<0.01	100
SND	Shovelnose spiny dogfish	*Deania calcea*	4	<0.01	100
GUR	Gurnard	*Chelidonichthys kumu*	4	<0.01	0
UNI	Unidentified		4	<0.01	75
SNI	Snipefish	*Macroramphosus scolopax*	3	<0.01	87
SCD	Smallscaled cod	*Paranotothenia microlepidota*	3	<0.01	72
CON	Conger eel	*Conger* spp.	3	<0.01	92
RIB	Ribaldo	*Mora moro*	3	<0.01	0
FHD	Deepsea flathead	*Hoplichthys haswelli*	3	<0.01	100
CSH	Catshark		3	<0.01	100
POR	Porae	*Nemadactylus douglasii*	3	<0.01	100
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	3	<0.01	100
NOT	Antarctic rock cods	Nototheniidae	3	<0.01	14
MDO	Mirror dory	*Zenopsis nebulosus*	3	<0.01	89
ETL	Lucifer dogfish	*Etmopterus lucifer*	3	<0.01	100
RBY	Ruby fish	*Plagiogeneion rubiginosum*	2	<0.01	40
DRE	Regan's lanternfish	*Diaphus regani*	2	<0.01	100
SFL	Sand flounder	*Rhombosolea plebeia*	2	<0.01	13
ALB	Albacore tuna	*Thunnus alalunga*	2	<0.01	0
PLS	Plunkets shark	*Centroscymnus plunketi*	2	<0.01	100
TOR	Pacific bluefin tuna	*Thunnus orientalis*	2	<0.01	0
TOD	Dark toadfish	*Neophrynichthys latus*	2	<0.01	94
OPA	Opalfish	*Hemerocoetes* spp.	2	<0.01	98
ODO	Smalltooth sand tiger shark	*Odontaspis ferox*	2	<0.01	100
DSP	Deepsea pigfish	*Congiopodus coriaceus*	2	<0.01	98
JGU	Spotted gurnard	*Pterygotrigla picta*	2	<0.01	100
BIG	Bigeye tuna	*Thunnus obesus*	2	<0.01	12
HEX	Sixgill shark	*Hexanchus griseus*	1	<0.01	45
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	1	<0.01	100

Appendix 2: Observed invertebrate catch. Species codes, common and scientific names, estimated catch, percentage of total catch, and overall percentage discarded of the top 100 invertebrate species or species groups by weight from observer records for the arrow squid target fishery from 1 Oct 1990 to 30 Sep 2011. Records are ordered by decreasing percentage of catch, codes in bold are QMS species. Estimated catches are based on all observed target arrow squid tows; discards are based on all trips where arrow squid was the sole target species.

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	235549	80.11	1
NCB	Smooth red swimming crab	*Nectocarcinus bennetti*	1488	0.51	73
CRB	Crab		531	0.18	98
GSC	Giant spider crab	*Jacquinotia edwardsii*	208	0.07	63
PAD	Paddle crab	*Ovalipes catharus*	64	0.02	97
NCA	Hairy red swimming crab	*Nectocarcinus antarcticus*	59	0.02	99
SPI	Spider crab		33	0.01	98
SSC	Giant masking crab	*Leptomithrax australis*	17	0.01	92
OCT	Octopus	*Pinnoctopus cordiformis*	15	0.01	37
SQX	Squid		12	<0.01	75
ONG	Sponges	Porifera	12	<0.01	99
JFI	Jellyfish		10	<0.01	86
SFI	Starfish	Asteroidea & Ophiuroidea	9	<0.01	100
QSC	Queen scallop	*Zygochlamys delicatula*	8	<0.01	14
CBD	Coral rubble-dead		4	<0.01	100
WSQ	Warty squid	*Onykia* spp.	4	<0.01	100
NCR	Northern smooth shore crab	*Cyclograpsus insularum*	3	<0.01	100
CRM	Airy finger sponge	*Callyspongia* cf *ramosa*	2	<0.01	100
HYA	Floppy tubular sponge	*Hyalascus* sp.	2	<0.01	100
EEX	Swimming holothurian	*Enypniastes eximia*	2	<0.01	100
CRA	Rock lobster	*Jasus edwardsii*	2	<0.01	25
GSQ	Giant squid	*Architeuthis* spp.	2	<0.01	100
LLC	Long-legged masking crab	*Leptomithrax longipes*	1	<0.01	100
CRU	Crustacea		1	<0.01	100
SMO	Cross-fish	*Sclerasterias mollis*	1	<0.01	100
COF	Flabellum coral	*Flabellum* spp.	1	<0.01	100
ANT	Anemones	Anthozoa	1	<0.01	100
CBB	Coral rubble		1	<0.01	100
ACS	Deepsea anemone	Actinostolidae	1	<0.01	100
CHC	Red crab	*Chaceon bicolor*	1	<0.01	100
SCA	Scallop	*Pecten novaezelandiae*	<1	<0.01	80
PHW	Rubber sponge	*Psammocinia* cf *hawere*	<1	<0.01	100
EZE	Yellow octopus	*Enteroctopus zealandicus*	<1	<0.01	12
CRN	Sea lily, stalked crinoid		<1	<0.01	100
COU	Coral (unspecified)		<1	<0.01	67
FMA	Triton	*Fusitriton magellanicus*	<1	<0.01	100
ANZ	Knobbly sandpaper sponge	*Ancorina novaezelandiae*	<1	<0.01	100
MIQ	Warty squid	*Onykia ingens*	<1	<0.01	95
RSQ	Ommastrephid squid	*Ommastrephes bartrami*	<1	<0.01	33
GMC	Garrick's masking crab	*Leptomithrax garricki*	<1	<0.01	100
URP	Squat lobster	*Uroptychus* spp.	<1	<0.01	100
SCI	Scampi	*Metanephrops challengeri*	<1	<0.01	67
CIC	Orange frond sponge	*Crella incrustans*	<1	<0.01	100
ZPF	Flagellates		<1	<0.01	100
KIC	King crab	*Lithodes aotearoa, Neolithodes brodiei*	<1	<0.01	0
OPL	Opheliids	Opheliidae	<1	<0.01	95
HMT	Deepsea anemone	Hormathiidae	<1	<0.01	100
BIV	Bivalves unidentified	Bivalvia	<1	<0.01	98
BOC	Deepsea anemone	*Bolocera* spp.	<1	<0.01	100
ASR	Asteroid (starfish)	Asteroidea	<1	<0.01	100
NTO	Masking crab	*Notomithrax* spp.	<1	<0.01	100

Appendix 2 — *Continued*

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
MIN	Worm-commensal bamboo coral	*Minuisis* spp.	<1	<0.01	100
PHB	Grey fibrous massive sponge	*Phorbas* spp.	<1	<0.01	100
PSI	Geometric star	*Psilaster acuminatus*	<1	<0.01	100
GAS	Gastropods	Gastropoda	<1	<0.01	72
DAP	Antlered crab	*Dagnaudus petterdi*	<1	<0.01	100
EGA	Euciroa	*Euciroa galatheae*	<1	<0.01	100
CMT	Feather star	Comatulida	<1	<0.01	100
VKI	Scallop	*Veprichlamys kiwaensis*	<1	<0.01	100
MOQ	Giant warty squid	*Onykia* sp.	<1	<0.01	100
OPI	Umbrella octopus	*Opisthoteuthis* spp.	<1	<0.01	100
SCC	Sea cucumber	*Stichopus mollis*	<1	<0.01	100
HTH	Sea cucumber	Holothurian unidentified	<1	<0.01	100
HSI	Jackknife prawn	*Haliporoides sibogae*	<1	<0.01	0
GLS	Glass sponges	Hexactinellida	<1	<0.01	100
TLD	Furry oval sponge	*Tetilla leptoderma*	<1	<0.01	100
SOT	Chubby sun-star	*Solaster torulatus*	<1	<0.01	100
PRU	Sea-star	*Pseudechinaster rubens*	<1	<0.01	100
LMI	Masking crabs	*Leptomithrax* spp.	<1	<0.01	100
NUD	Nudibranchs	Nudibranchia	<1	<0.01	100
SUA	Fleshy club sponge	*Suberites affinis*	<1	<0.01	100
GVE	Convoluted ostrich egg sponge	*Geodinella vestigifera*	<1	<0.01	100
MOL	Molluscs		<1	<0.01	100
CTU	Cooks turban shell	*Cookia sulcata*	<1	<0.01	100
LAO	New Zealand king crab	*Lithodes aotearoa*	<1	<0.01	100
APD	Seamice	Aphroditidae	<1	<0.01	100
MNI	Munida unidentified	*Munida* spp.	<1	<0.01	100
KWH	Knobbed whelk	*Austrofucus glans*	<1	<0.01	100
TAM	Tam O' Shanter sea urchin	Echinothuriidae & Phormosomatidae	<1	<0.01	100
TSQ	Todarodes squid	*Todarodes filippovae*	<1	<0.01	100
CJA	Sun star	*Crossaster multispinus*	<1	<0.01	100
DWO	Deepwater octopus	*Graneledone* spp.	<1	<0.01	100
SLG	Sea slug	*Scutus breviculus*	<1	<0.01	100
AMA	Acesta maui	*Acesta maui*	<1	<0.01	100
BPI	Sea-star	*Benthopecten pikei*	<1	<0.01	100
RGR	Sea-star	*Radiaster gracilis*	<1	<0.01	100
SIA	Stony corals	Scleractinia	<1	<0.01	100
BSQ	Broad squid	*Sepioteuthis australis*	<1	<0.01	100
DIR	Pagurid	*Diacanthurus rubricatus*	<1	<0.01	100
OCP	Octopod		<1	<0.01	100
OVM	Swimming crab	*Ovalipes molleri*	<1	<0.01	100
VSQ	Violet squid	*Histioteuthis* spp.	<1	<0.01	100
GOU	Cidarid sea urchin	*Goniocidaris umbraculum*	<1	<0.01	100
ZOR	Rat-tail star	*Zoroaster* spp.	<1	<0.01	100
LCO	Dwarf swimming crab	*Liocarcinus corrugatus*	<1	<0.01	100
SEQ	Sepiolid squid	Sepiolidae	<1	<0.01	100
ECH	Echinoderms	Echinodermata	<1	<0.01	0
MSL	Sladen's star	*Mediaster sladeni*	<1	<0.01	100
SDM	Pagurid	*Sympagurus dimorphus*	<1	<0.01	100
FAR	Lacey honeycomb sponge	*Farrea* sp.	<1	<0.01	100

Appendix 3: Observed bycatch by species group. Estimated catch, percentage of total catch, and overall percentage discarded by species group from observer records for the arrow squid target fishery from 1 Oct 1990 to 30 Sep 2011. Records are ordered by decreasing percentage of catch. Estimated catches are based on all observed target arrow squid tows; discards are based on all trips where arrow squid was the sole target species.

Group	Observed catch (t)	% of catch	% discarded
Invertebrates			
Crustacea	2 409	0.8	79
Squid (other)	18	<0.1	98
Sponges	17	<0.1	99
Cnidaria	17	<0.1	95
Octopuses	16	<0.1	37
Echinoderms	13	<0.1	100
Other molluscs	9	<0.1	21
Polychaetes	0	<0.1	95
Fish and arrow squid			
Fish (other)	48 659	16.5	5
Sharks & dogfish	5 678	1.9	76
Rattails	662	0.2	90
Tuna	349	0.1	7
Rays & Skates	297	0.1	9
Chimaeras	265	0.1	9
Flatfish	40	<0.1	58
Eels	3	<0.1	76

Appendix 4: Bycatch rates (t/trawl) of QMS fish species in the arrow squid trawl fishery, by area 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.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	0.2	*1.6	*1.6	*1.6	*1.6	2.1	*1.5
1991–92	0.1	*1.8	*1.8	*1.7	*1.8	2.7	*1.8
1992–93	0.5	1.8	*2.1	*2.1	*2.1	2.3	*2.1
1993–94	0.1	1.7	*1.1	*1.1	*1.1	1.9	*1.1
1994–95	0.1	*0.4	*0.4	*0.4	*0.4	0.6	*0.4
1995–96	1.5	*1.6	*1.6	*1.6	*1.6	1.7	*1.6
1996–97	0.5	*1.2	*1.1	*1.1	*1.1	2.1	*1.1
1997–98	0.0	*1.0	*1.0	*1.0	*1.0	1.5	*1.0
1998–99	0.5	*2.4	*2.4	*2.4	*2.4	2.7	*2.4
1999–00	0.3	*1.8	1.5	*1.8	*1.8	3.8	*1.8
2000–01	0.4	3.0	*2.1	*2.1	*2.1	2.5	*2.1
2001–02	0.1	4.8	*2.6	*2.6	1.2	4.6	*2.6
2002–03	0.4	3.0	*1.7	*1.7	0.7	3.3	*1.7
2003–04	0.4	*1.8	*1.8	*1.8	*1.8	2.6	*1.8
2004–05	0.2	3.7	*1.1	*1.1	2.6	1.5	*1.1
2005–06	0.3	*1.7	*1.7	*1.7	*1.7	3.1	*1.7
2006–07	0.2	11.3	*1.3	*1.3	*1.3	1.7	*1.3
2007–08	0.4	*1.9	*1.9	*1.9	*1.9	3.0	*1.9
2008–09	0.3	*2.3	*2.3	*2.4	*2.3	5.4	*2.3
2009–10	0.5	*2.6	*2.6	*2.6	*2.6	3.4	*2.6
2010–11	0.5	*2.3	*2.3	*2.3	*2.3	3.7	*2.3

* Insufficient records in this area and year, bycatch rates based on bycatch data from all areas for this year.

Appendix 5: Bycatch rates (kg/trawl) of non-QMS fish species in the arrow squid trawl fishery, by area 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.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	32	*12	*12	*11	*11	5	*12
1991–92	25	*33	*33	*32	*33	37	*32
1992–93	87	87	*29	*29	*28	17	*29
1993–94	18	57	*25	*25	*25	11	*25
1994–95	24	*17	*17	*17	*17	13	*17
1995–96	31	*24	*24	*24	*24	3	*24
1996–97	49	*32	*31	*32	*31	6	*31
1997–98	4	*9	*10	*10	*9	10	*10
1998–99	100	*73	*74	*75	*70	47	*70
1999–00	57	*57	131	*58	*57	16	*58
2000–01	40	308	*57	*56	*56	48	*56
2001–02	29	356	*56	*58	181	32	*58
2002–03	183	220	*168	*168	192	124	*167
2003–04	26	*34	*34	*34	*34	33	*34
2004–05	156	*613	*147	*146	1620	47	*147
2005–06	83	85	*85	*87	*86	66	*86
2006–07	103	*720	*88	*87	*86	45	*87
2007–08	122	*88	*88	*87	*86	59	*89
2008–09	71	*107	*108	*107	*106	164	*110
2009–10	47	*98	*101	*100	*99	122	*103
2010–11	101	*170	*171	*169	*171	207	*171

* Insufficient records in this area and year, bycatch rates based on bycatch data from all areas for this year.

Appendix 6: Bycatch rates (kg/trawl) of invertebrate species in the arrow squid trawl fishery, by area 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.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	20	*7	*7	*7	*7	2	*7
1991–92	3	*1	*1	*1	*1	1	*1
1992–93	36	22	*8	*8	*7	5	*7
1993–94	35	1	*25	*24	*24	30	*23
1994–95	12	*5	*5	*5	*5	1	*5
1995–96	20	*15	*15	*15	*15	0	*15
1996–97	44	*43	*44	*42	*42	38	*42
1997–98	89	*35	*36	*36	*35	2	*36
1998–99	69	*21	*22	*22	*22	12	*22
1999–00	21	*11	2	*12	*12	1	*12
2000–01	185	10	*44	*43	*44	9	*44
2001–02	114	7	*51	*50	4	5	*51
2002–03	277	12	*98	*98	6	14	*96
2003–04	275	*108	*115	*115	*115	11	*110
2004–05	116	21	*46	*45	2	6	*46
2005–06	389	*208	*203	*207	*205	12	*209
2006–07	441	51	*197	*191	*196	12	*197
2007–08	598	*273	*268	*266	*265	25	*263
2008–09	486	*328	*320	*321	*325	65	*322
2009–10	564	*174	*170	*169	*176	16	*171
2010–11	313	*162	*165	*165	*163	46	*163

* Insufficient records in this area and year, bycatch rates based on bycatch data from all areas for this year.

Appendix 7: Discard rates (kg/trawl) of QMS fish species in the arrow squid trawl fishery, by area and fishing year, based on observed discard data. Discard rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	7	*28	*28	*27	*29	40	*28
1991–92	5	*18	*19	*19	*19	36	*19
1992–93	31	*204	*201	*204	*199	245	*201
1993–94	4	580	*162	*158	*152	26	*156
1994–95	17	*45	*46	*47	*45	53	*46
1995–96	6	*7	*7	*7	*7	10	*7
1996–97	16	*156	*161	*152	*154	428	*154
1997–98†	27	686	478	101	186	296	111
1998–99	194	*263	*264	*260	*264	248	*264
1999–00	9	*107	620	*117	*114	156	*110
2000–01	29	664	*220	*220	*220	250	*220
2001–02	4	731	*484	*490	264	920	*494
2002–03	27	80	*307	*320	85	680	*303
2003–04	51	*184	*177	*183	*181	253	*178
2004–05	11	1080	*140	*143	490	153	*143
2005–06	22	*125	*125	*125	*125	211	*124
2006–07	20	898	*128	*130	*135	159	*133
2007–08	29	*117	*116	*116	*117	169	*117
2008–09	28	*209	*214	*209	*211	475	*211
2009–10	53	*283	*278	*280	*280	359	*280
2010–11	67	*283	*278	*282	*277	421	*277

* Insufficient records in this area and year, discard rates based on discard data from all areas for this year.
† Insufficient records in this year, discard rates based on discard data from all years for this area.

Appendix 8: Discard rates (kg/trawl) of non-QMS fish species in the arrow squid trawl fishery, by area and fishing year, based on observed discard data. Discard rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	12	*6	*6	*6	*6	4	*6
1991–92	14	*21	*20	*20	*20	27	*19
1992–93	163	*32	*34	*40	*40	12	*34
1993–94	2	11	*4	*4	*4	1	*4
1994–95	10	*12	*12	*12	*12	13	*12
1995–96	3	*3	*3	*3	*3	3	*3
1996–97	20	*15	*15	*15	*16	3	*16
1997–98†	42	266	407	81	386	54	78
1998–99	56	*70	*70	*69	*73	52	*72
1999–00	28	*41	135	*41	*42	16	*41
2000–01	13	273	*33	*33	*34	25	*33
2001–02	11	319	*51	*50	189	28	*50
2002–03	155	208	*142	*143	167	105	*146
2003–04	18	*17	*17	*17	*17	14	*17
2004–05	29	602	*101	*100	2564	44	*103
2005–06	45	*60	*59	*61	*59	67	*60
2006–07	96	699	*80	*79	*80	38	*81
2007–08	61	*49	*49	*49	*49	39	*49
2008–09	28	*71	*71	*72	*70	143	*73
2009–10	26	*88	*87	*87	*87	109	*89
2010–11	82	*153	*151	*153	*154	187	*154

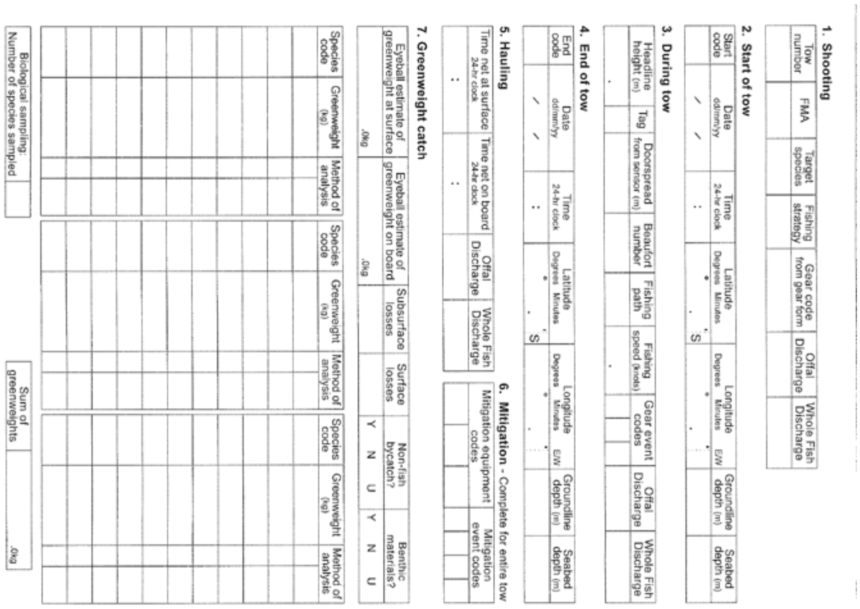
* Insufficient records in this area and year, discard rates based on discard data from all areas for this year.

Appendix 9: Discard rates (kg/trawl) of invertebrate species in the arrow squid trawl fishery, by area and fishing year, based on observed discard data. Discard rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	AUCK	BANK	CHAT	NRTH	PUYS	SNAR	SUBA
1990–91	18	*5	*6	*6	*6	0	*6
1991–92	2	*2	*2	*2	*2	2	*2
1992–93	9	*6	*6	*6	*6	4	*6
1993–94	0	0	*0	*0	*0	0	*0
1994–95	3	*1	*1	*1	*1	1	*1
1995–96	11	*9	*10	*9	*9	0	*9
1996–97	27	*28	*27	*28	*27	24	*28
1997–98†	157	8	3	4	5	6	338
1998–99	31	*10	*10	*10	*10	6	*10
1999–00	19	*11	0	*10	*11	1	*11
2000–01	144	6	*34	*35	*34	9	*34
2001–02	96	4	*44	*45	5	5	*45
2002–03	262	10	*91	*90	6	14	*91
2003–04	285	*107	*110	*110	*113	2	*113
2004–05	105	16	*40	*39	3	3	*40
2005–06	254	*135	*142	*137	*137	4	*139
2006–07	289	58	*129	*125	*129	4	*128
2007–08	90	*38	*38	*37	*39	3	*37
2008–09	284	*175	*171	*171	*173	4	*176
2009–10	395	*106	*107	*109	*107	4	*108
2010–11	241	*104	*103	*104	*107	7	*106

* Insufficient records in this area and year, discard rates based on discard data from all areas for this year.

Appendix 10: The observer catch effort logbook form version x.



1. Shooting

Tow number	FMA	Target species	Fishing strategy	Gear code from gear form	Offal Discharge	Whole Fish Discharge

2. Start of tow

Start code	Date dd/mm/yy	Time 24-hr clock	Latitude Degrees Minutes	Longitude Degrees Minutes	E/W	Groundline depth (m)	Seabed depth (m)
	/ /	:	° . S	° .			

3. During tow

Headline height (m)	Tag	Doorspread from sensor (m)	Beaufort number	Fishing path	Fishing speed (knots)	Gear event codes	Offal Discharge	Whole Fish Discharge
.					.			

4. End of tow

End code	Date dd/mm/yy	Time 24-hr clock	Latitude Degrees Minutes	Longitude Degrees Minutes	E/W	Groundline depth (m)	Seabed depth (m)
	/ /	:	° . S	° .			

5. Hauling

Time net at surface 24-hr clock	Time net on board 24-hr clock	Offal Discharge	Whole Fish Discharge
:	:		

6. Mitigation - Complete for entire tow

Mitigation equipment codes	Mitigation event codes

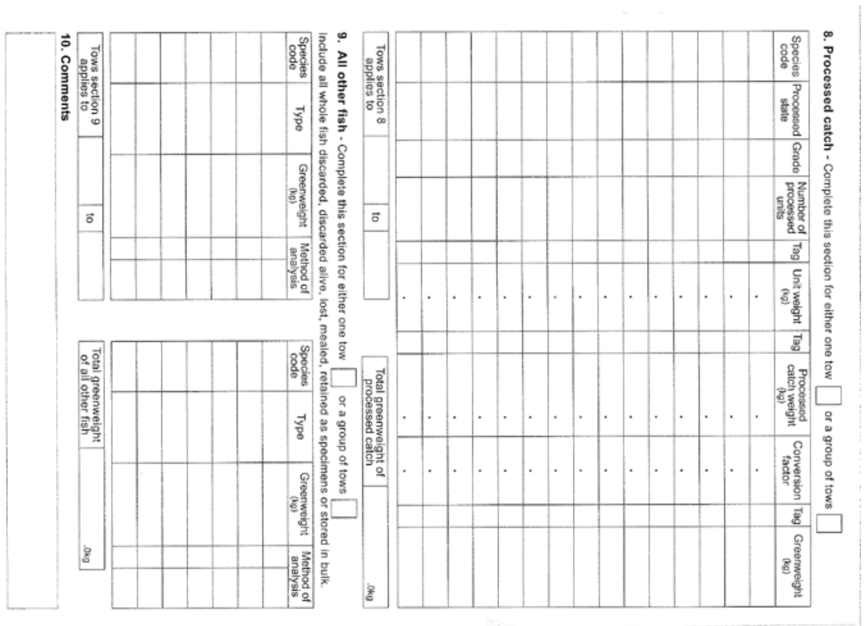
7. Greenweight catch

Eyeball estimate of greenweight at surface	Eyeball estimate of greenweight on board	Subsurface losses	Surface losses	Non-fish bycatch?	Benthic materials?
.0kg	.0kg			Y N U	Y N U

Species code	Greenweight (kg)	Method of analysis	Species code	Greenweight (kg)	Method of analysis	Species code	Greenweight (kg)	Method of analysis

Biological sampling: Number of species sampled

Sum of greenweights .0kg



8. Processed catch - Complete this section for either one tow ☐ or a group of tows ☐

Species code	Processed state	Grade	Number of processed units	Tag	Unit weight (kg)	Tag	Processed catch weight (kg)	Conversion factor	Tag	Greenweight (kg)

Tows section 8 applies to ____ to ____

Total greenweight of processed catch .0kg

9. All other fish - Complete this section for either one tow ☐ or a group of tows ☐

Include all whole fish discarded, discarded alive, lost, mealed, retained as specimens or stored in bulk.

Species code	Type	Greenweight (kg)	Method of analysis	Species code	Type	Greenweight (kg)	Method of analysis

Tows section 9 applies to ____ to ____

Total greenweight of all other fish .0kg

10. Comments

Appendix 11: Arrow squid trawl fishery. Total annual bycatch estimates (t) (with estimated c.v.s in parentheses) for individual species, based on observer catch rates. Species are ordered by decreasing total catch. The slope of a regression through the data points is shown in parentheses alongside each species code. See http://marlin.niwa.co.nz for species code definitions).

	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
BAR(0)	8220(16)	7010(31)	6220(11)	2650(21)	1250(17)	6380(12)	990(22)	1420(14)	6960(16)	3880(11)	10200(12)	7930(16)	3740(23)	5250(26)	3480(19)	5700(20)	850(30)	3750(18)	2410(23)	3220(20)	2880(19)
SWA(0.1)	250(28)	150(45)	780(49)	640(130)	360(68)	100(47)	1780(29)	2090(23)	3350(23)	970(14)	2150(12)	2390(24)	5280(25)	3190(14)	3170(40)	2020(19)	11280(31)	570(13)	1000(22)	790(13)	710(24)
SPD(0)	420(39)	710(36)	570(39)	1600(16)	120(41)	10(39)	340(41)	210(29)	2230(43)	430(47)	1850(16)	3170(21)	2660(18)	800(20)	2220(39)	860(24)	3410(28)	290(20)	530(27)	840(29)	510(27)
JMA(-0.2)	1530(46)	420(34)	1680(27)	560(47)	350(35)	3520(19)	4190(20)	610(30)	670(44)	970(26)	500(29)	2240(21)	10(22)	140(39)	190(48)	170(33)	20(82)	110(64)	110(41)	410(35)	60(91)
RCO(0)	360(40)	310(33)	280(46)	820(35)	480(29)	160(41)	80(23)	140(82)	980(29)	530(32)	600(23)	480(14)	1890(15)	470(26)	1190(20)	610(24)	370(17)	950(21)	230(30)	660(27)	1160(20)
JMM(-0.2)	130(100)	540(49)	2050(53)	160(59)	100(36)	4560(26)	260(52)	190(47)	1280(66)	60(63)	230(31)	90(44)	10(69)	20(41)	20(71)	70(91)	0(–)	80(92)	10(87)	310(55)	0(–)
WAR(0)	900(48)	1280(46)	2260(24)	40(56)	0(–)	150(102)	460(82)	10(104)	230(59)	560(32)	610(20)	80(36)	60(63)	710(37)	100(50)	690(57)	640(30)	20(53)	90(42)	180(60)	170(61)
NCB(0.5)	0(–)	0(–)	0(–)	110(92)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	50(98)	0(–)	410(21)	1970(21)	950(26)	1380(22)	1360(21)	1010(16)	620(23)
HOK(0)	120(25)	40(58)	740(39)	700(114)	100(29)	110(14)	170(20)	260(34)	490(55)	40(36)	370(82)	560(20)	200(20)	30(28)	370(72)	380(47)	1260(31)	120(19)	250(28)	310(28)	500(21)
RBT(0)	40(112)	90(64)	150(59)	10(62)	0(–)	0(–)	150(54)	1210(39)	400(73)	570(42)	290(27)	750(39)	100(18)	410(44)	430(47)	70(42)	70(82)	80(83)	40(122)	130(61)	10(51)
RAT(0.1)	110(47)	10(30)	100(50)	60(42)	20(51)	10(17)	70(29)	30(46)	230(43)	130(37)	510(18)	410(24)	500(13)	30(40)	960(29)	340(19)	380(25)	90(25)	110(24)	70(19)	220(16)
CRB(-0.1)	50(63)	0(–)	30(79)	40(60)	40(26)	40(25)	410(39)	260(37)	40(53)	40(32)	200(29)	360(23)	630(18)	1180(34)	130(55)	20(38)	20(37)	80(63)	0(–)	0(–)	0(–)
LIN(0.1)	30(72)	30(57)	150(47)	90(29)	90(53)	0(–)	20(47)	40(57)	320(58)	20(29)	120(29)	210(20)	290(18)	110(58)	190(27)	200(24)	290(20)	50(41)	90(40)	90(38)	340(23)
GSH(0.1)	10(63)	0(–)	30(64)	20(53)	10(73)	0(–)	10(54)	10(57)	70(44)	30(52)	360(45)	420(34)	330(18)	20(49)	300(38)	40(44)	630(29)	10(57)	10(42)	40(59)	80(27)
STU(-0.1)	30(23)	80(26)	120(34)	190(47)	70(63)	240(10)	170(48)	10(26)	60(90)	50(15)	40(28)	20(19)	10(26)	10(22)	680(35)	40(24)	10(28)	40(33)	30(41)	20(62)	20(34)
RBM(-0.1)	160(20)	30(92)	410(29)	10(17)	30(23)	140(28)	150(25)	20(60)	20(27)	20(59)	270(14)	180(31)	70(38)	10(17)	80(36)	70(38)	40(37)	10(22)	0(–)	0(–)	10(24)
SDO(0.5)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(19)	90(42)	420(19)	30(63)	440(48)	80(46)	20(42)	40(35)	90(94)	70(40)	90(40)
TAR(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(52)	10(88)	0(–)	280(30)	750(33)	0(–)	160(38)	0(–)	40(50)	0(–)	0(–)	0(–)	0(–)
SPE(0.1)	10(53)	20(67)	20(75)	0(–)	10(45)	0(–)	0(–)	10(45)	30(40)	0(–)	300(101)	60(30)	180(19)	20(35)	180(42)	10(60)	70(48)	0(–)	0(–)	20(64)	40(31)
STA(0.1)	20(30)	20(42)	40(66)	20(24)	20(48)	0(–)	10(30)	10(14)	60(50)	20(23)	30(18)	90(21)	140(14)	20(30)	60(25)	50(21)	180(14)	20(17)	20(25)	50(16)	50(23)
JAV(0.2)	0(–)	0(–)	20(58)	0(–)	0(–)	0(–)	0(–)	0(–)	60(52)	0(–)	50(115)	120(54)	30(27)	10(110)	50(59)	120(40)	410(54)	10(28)	10(69)	10(73)	20(51)
JMD(-0.1)	500(86)	70(59)	0(–)	0(–)	40(122)	10(50)	40(66)	0(–)	80(74)	0(–)	50(74)	20(66)	0(–)	0(–)	30(95)	20(75)	0(–)	0(–)	0(–)	20(53)	0(–)
HAP(0.1)	10(67)	0(–)	20(48)	10(64)	60(29)	10(41)	0(–)	20(21)	30(25)	30(18)	60(12)	90(19)	110(11)	60(20)	150(17)	40(23)	40(13)	20(31)	30(61)	50(21)	20(25)
GSC(0.4)	0(–)	0(–)	0(–)	0(–)	10(32)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(61)	50(20)	180(29)	60(21)	70(22)	140(30)	70(20)	210(17)
SKI(-0.1)	100(14)	120(76)	70(42)	20(39)	30(49)	0(–)	10(30)	10(22)	10(24)	0(–)	0(–)	120(25)	240(12)	10(20)	40(31)	10(47)	10(24)	0(–)	0(–)	0(–)	10(94)
BSK(0.2)	0(–)	0(–)	0(–)	30(144)	0(–)	0(–)	0(–)	0(–)	80(80)	90(36)	290(104)	10(122)	120(37)	30(125)	0(–)	0(–)	100(35)	20(91)	10(155)	0(–)	20(114)
SSK(0)	10(57)	10(35)	30(77)	10(41)	10(52)	0(–)	10(49)	0(–)	140(49)	20(41)	50(21)	70(29)	160(21)	30(51)	40(22)	20(37)	110(33)	10(51)	0(–)	0(–)	10(24)
WWA(0)	0(–)	20(86)	10(108)	10(82)	0(–)	0(–)	0(–)	10(73)	20(58)	70(52)	90(52)	50(23)	150(29)	50(51)	10(57)	10(30)	190(50)	0(–)	10(91)	20(98)	20(48)
SCH(0.1)	0(–)	10(33)	0(–)	0(–)	0(–)	0(–)	10(42)	0(–)	20(28)	10(52)	30(16)	50(23)	90(20)	10(40)	70(37)	30(19)	20(20)	20(22)	10(30)	20(25)	40(32)
FRO(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(86)	0(–)	30(110)	90(34)	100(42)	0(–)	80(65)	10(74)	100(72)	0(–)	0(–)	0(–)	0(–)
PAD(-0.4)	50(37)	10(73)	20(77)	0(–)	40(62)	60(42)	50(76)	90(41)	40(84)	10(32)	40(48)	10(81)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
RSK(0.2)	0(–)	0(–)	20(80)	0(–)	10(55)	0(–)	0(–)	0(–)	20(148)	0(–)	0(–)	0(–)	0(–)	80(86)	50(27)	30(22)	60(28)	20(31)	20(24)	40(19)	70(18)
NCA(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	20(63)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	80(42)	90(87)	0(–)	0(–)	150(79)	0(–)	0(–)	0(–)	0(–)
SSI(0.3)	0(–)	0(–)	0(–)	0(–)	20(106)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(19)	0(–)	30(26)	20(49)	150(28)	50(65)	10(30)	0(–)	10(14)

Appendix 11—*continued*

	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
POS(0.1)	0(–)	10(42)	10(28)	0(–)	0(–)	10(33)	10(26)	20(25)	30(20)	20(13)	30(24)	50(23)	20(17)	10(28)	10(32)	10(35)	20(37)	0(–)	0(–)	10(22)	10(24)
WIT(0.2)	10(20)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(32)	0(–)	10(22)	0(–)	20(22)	10(33)	40(26)	10(10)	40(26)	0(–)	10(14)	10(10)	10(17)
CAR(0.3)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	30(29)	0(–)	30(18)	10(75)	10(22)	10(40)	50(17)	0(–)	10(24)	10(32)	40(35)
SBW(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	100(97)	0(–)	0(–)	0(–)	0(–)	30(139)	0(–)	0(–)	0(–)	10(45)	0(–)	0(–)	10(37)
SPI(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(41)	10(93)	0(–)	20(41)	0(–)	10(32)	80(62)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
SPO(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	30(131)	0(–)	0(–)	0(–)	0(–)	0(–)	100(85)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
MAK(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	10(37)	10(77)	20(39)	20(36)	10(55)	40(86)	0(–)	10(47)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BWS(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	90(31)	10(14)	0(–)	0(–)	0(–)	10(14)	0(–)	0(–)	0(–)	0(–)	0(–)
FHD(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(17)	0(–)	100(28)	0(–)	0(–)	0(–)	0(–)
JMN(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	110(93)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
PIG(0.3)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(14)	0(–)	20(43)	10(28)	10(28)	10(24)	10(33)	10(14)	30(20)
BCO(0.2)	0(–)	0(–)	10(73)	0(–)	0(–)	0(–)	10(47)	0(–)	0(–)	0(–)	10(41)	0(–)	10(50)	10(54)	0(–)	0(–)	20(40)	0(–)	0(–)	0(–)	30(53)
HPB(-0.1)	20(38)	30(39)	30(31)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(68)	0(–)	10(65)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BCD(0.3)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(44)	0(–)	0(–)	60(37)	10(32)	0(–)	10(14)
GON(0.3)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(14)	10(17)	10(17)	10(24)	10(24)	10(20)	10(22)	10(28)	10(20)
HAK(0)	0(–)	0(–)	10(58)	0(–)	0(–)	0(–)	0(–)	0(–)	70(67)	0(–)	0(–)	0(–)	10(17)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
LDO(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(56)	10(30)	0(–)	0(–)	0(–)	10(17)	0(–)	60(26)	0(–)	0(–)	0(–)	0(–)
SSC(-0.2)	0(–)	0(–)	30(92)	50(88)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
CBE(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	50(96)	0(–)	0(–)	0(–)	20(93)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
CDO(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	30(66)	40(68)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
RDO(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(97)	0(–)	0(–)	0(–)	0(–)	0(–)	50(92)	10(59)
BEL(0.2)	0(–)	0(–)	0(–)	10(160)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(104)	10(37)	0(–)	0(–)	0(–)	0(–)	0(–)	10(89)	0(–)	0(–)	20(57)
OCT(0.1)	0(–)	0(–)	0(–)	10(24)	0(–)	0(–)	0(–)	0(–)	20(49)	0(–)	0(–)	0(–)	10(17)	0(–)	10(33)	0(–)	0(–)	0(–)	0(–)	0(–)	10(10)
TOA(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(14)	0(–)	0(–)	10(22)	20(18)	0(–)	10(10)	0(–)	10(20)
GUR(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	40(49)	10(36)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BSH(-0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	40(85)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
COF(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	40(87)	0(–)	0(–)	0(–)	0(–)
SQI(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(160)	0(–)	0(–)	20(86)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
LAN(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(75)	10(85)	0(–)	0(–)	10(59)
STN(0.1)	0(–)	10(28)	0(–)	0(–)	0(–)	10(36)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(28)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BAS(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(32)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BBE(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(50)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BYS(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	20(82)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
GFL(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(106)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(10)
MDO(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(26)	0(–)	0(–)	0(–)	0(–)	10(66)	0(–)	0(–)	0(–)	0(–)
ONG(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(86)	0(–)	10(56)	0(–)
OPE(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(212)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(126)	0(–)

Appendix 11—*continued*

	1990–91	1991–92	1992–93	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
QSC(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(89)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(41)
SKA(-0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(37)	0(–)	0(–)	0(–)	0(–)	10(44)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
SNA(0)	0(–)	0(–)	0(–)	10(97)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(183)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
THR(-0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(24)	10(66)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
YCO(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(17)	0(–)	10(17)	0(–)	0(–)	0(–)	0(–)
ASR(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(22)	0(–)	0(–)	0(–)	0(–)
BGZ(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(46)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BRA(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(95)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
BTH(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(58)	0(–)	0(–)	0(–)	0(–)
BYX(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(51)	0(–)	0(–)	0(–)	0(–)
CON(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(122)
CRA(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(99)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
CRU(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(68)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
DSK(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(40)	0(–)	0(–)	0(–)	0(–)
DSP(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(46)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
EEX(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(69)
FLA(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(40)	0(–)	0(–)	0(–)	0(–)	0(–)
GMU(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(147)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
GSP(0.2)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(53)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
JFI(-0.1)	10(58)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
JGU(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(52)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
LSK(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(22)	0(–)	0(–)	0(–)	0(–)
MOK(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(39)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
SCD(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(87)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
SHA(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(75)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
SNI(0)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(82)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)
WPS(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(86)	0(–)	0(–)	0(–)	0(–)	0(–)
WSQ(0.1)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	0(–)	10(30)	0(–)	0(–)	0(–)	0(–)