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Fish and invertebrate bycatch and discards in New Zealand jack mackerel trawl fisheries from 2002–03 until 2013–14

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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 rate and level of fish bycatch and discards in the jack mackerel trawl fishery for each fishing year from 2002–03 to 2013–14. Separate estimates, along with estimates of precision, were made for three general categories of catch and discards; all QMS species combined, all non-QMS species combined, and all invertebrate species combined. In addition, estimates were made of the annual bycatch of spiny dogfish and a range of other individual species.

A ratio estimator, based on the observed bycatch or discards per tow, 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 unobserved tows in each stratum, as determined from commercial catch-effort data, and added to observed amounts to estimate the annual bycatch and discard levels in the target jack mackerel trawl fishery as a whole. Multi-step bootstrap methods, taking into account the effect of auto-correlation between tows for the same observed vessel and area stratum, were used to quantify variability and calculate confidence intervals around annual bycatch and discard estimates. In addition to the ratio-based estimates, a statistical model incorporating the same covariates (area and depth) was used to provide independent estimates of bycatch levels (but not discards) for QMS species, non-QMS species, invertebrate species, and spiny dogfish.

Since 1991–92, jack mackerel (three species combined) have accounted for about 75% of the total estimated catch weight recorded by observers in the target trawl fishery. The remainder of the observed catch was comprised mainly of four QMS species; barracouta (13% of total catch weight), blue mackerel (3.4%), frostfish (3.4%), and redbait (2.5%). Non-QMS invertebrate species made up only a very small fraction of the overall catch (less than 0.1%), with cnidarians (mainly jellyfish) the main group caught.

The ratio-based method and the statistical model produced very similar estimates of bycatch in each of the species categories examined, with the main difference being the slightly smaller confidence intervals obtained using the statistical model. Total annual bycatch in the jack mackerel trawl fishery ranged from about 6650 t in 2010–11 to a high of about 16 500–18 800 t (depending on model type) in 2005–06, with a slight decreasing trend over time. The majority of bycatch comprised QMS species with annual estimates ranging from about 6500 t to 14 100 t, slightly decreasing over time. Annual catches of non-QMS species also decreased slightly over time, ranging from 130 t to 2700 t. Spiny dogfish bycatch (20–320 t per year) and invertebrate species bycatch (less than 1 t in most years) increased slightly over time. None of these increasing or decreasing trends were statistically significant.

Estimated total annual discards ranged from about 80 t to 400 t and showed no trend over time. The contribution of QMS species (0–304 t per year) and non-QMS species (40–300 t per year) to total discards was similar overall, although QMS species discards were more variable. Estimates of spiny dogfish and invertebrate species discards were similar to the bycatch estimates for these species. Discards of jack mackerel species were low (0–17 t per year) but showed a significant increasing trend (due to an increase in non-zero discards) during the most recent five years. Other species categories did not show significant trends.

The level of annual discards in the jack mackerel trawl fishery between 2002–03 and 2013–14, calculated as a fraction of the target species catch, ranged from 0.003 kg to 0.013 kg of discarded fish

for every 1 kg of jack mackerel caught. This fraction is similar to that seen in the southern blue whiting fishery, and lower than in all other offshore fisheries for which estimates are available.

The annual catch of the 45 most commonly caught individual bycatch species was estimated using the same procedures (ratio method) as for the combined species categories, and trends examined. A total of 13 species showed a decreasing trend and 8 species an increasing trend in bycatch *levels* over time. Trends in bycatch *rates* of the main bycatch species were also examined and compared with trends from published values of relative biomass from the west coast South Island trawl survey time series. There were few strong trends identified, and little correlation between bycatch rates and estimated biomass.

1. INTRODUCTION

The Ministry for Primary Industries (MPI) National Deepwater 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 Quota Management System (QMS). The first four years of the programme have produced assessments of the scampi (*Metanephrops challengeri*), arrow squid (*Nototodarus* spp.), and hoki/hake/ling trawl fisheries (Anderson 2012, 2013, Ballara & O'Driscoll 2015); and the ling (*Genypterus blacodes*) bottom longline fishery (Anderson 2014). The jack mackerel (*Trachurus* spp.) trawl fishery is the subject of this report.

The three species of jack mackerel (*T. novaezelandiae*, *T. declivis*, and *T. murphyi*) have different but overlapping distributions within New Zealand waters. The yellowtail jack mackerel (*T. novaezelandiae*) is found mainly shallower than 150 m and in water warmer than 13˚ C (generally north of 42˚ S). The greenback jack mackerel (*T. declivis*) is mainly found in deeper (to about 300 m) and colder water (less than 16˚ C), north of about 45˚ S. The slender jack mackerel (*T. murphyi*) lives to at least 500 m deep and has a wide latitudinal range (from the equator to at least 40˚ S).

Jack mackerel support an important finfish fishery for New Zealand; in 2015 export amounts were second by weight after hoki (*Macruronus novaezelandiae*), and annual earnings (about NZ$45M) were third after hoki and orange roughy (*Hoplostethus atlanticus*) (http://www.seafoodnewzealand.org.nz/). A purse seine fishery dominates jack mackerel landings in the Bay of Plenty and east Northland (JMA 1) where recent annual landings have been 8000–12 000 t, with only a small amount (less than 5%) taken as bycatch in trawl fisheries (Ministry for Primary Industries 2015). The much larger target trawl fishery is concentrated mostly off the west coast of the lower half of North Island but also operates further south as far as Greymouth and on the Stewart-Snares shelf and parts of the Chatham Rise (JMA 3 and JMA 7), with annual landings of 30 000–40 000 t. Vessels in this fishery generally use mid-water trawl gear in relatively shallow water (75–150m) and the gear tends to be towed on or near the seabed.

Since 2002–03, over 90% of the annual trawl catch has been taken by Ukrainian foreign charter vessels, mainly processing fish to a dressed state. A fishery of this size has considerable potential for catching and discarding non-target species with no commercial value. These may be species for which there is no economic market or they may be marketable species which are not kept because of damage (crushing in the codend or factory line and deterioration of flesh quality from processing delays), hold space limitations, or because they are of unwanted or sub-legal size. Fish can also be discarded without ever reaching the deck of the boat, when dead or dying fish are forced through the meshes of the net while fishing (unseen mortality) or as a result of a mechanical or other failure or an intentional release of fish from the cod-end, during gear retrieval.

Reported landings of jack mackerel in 2013–14 were 50 388 t, the highest level since records began in 1931. In the previous ten years landings have fluctuated between 37 000 t and 48 000 t (Ministry for Primary Industries 2015).

Observer data have previously shown that jack mackerel species account for about 70% of the total catch in the target trawl fishery, with the principal bycatch species identified as barracouta (*Thyrsites atun*), blue mackerel (*Scomber australasicus*), frostfish (*Lepidopus caudatus*), redbait (*Emmelichthys nitidus*), and arrow squid (*Nototodarus* spp) (Anderson 2007).

The most recent analyses of bycatch and discards in the jack mackerel trawl fishery, covering the periods 1998–99 to 2000–01 (Anderson 2004) and 2001–02 to 2004–05 (Anderson 2007), used a tow duration-based estimator derived from observer records to calculate annual totals for the entire fleet. The earliest analysis (Anderson et al. 2000) used a target species catch-based estimator and covered the 1990–91 to 1997–98 period. These reports estimated total annual bycatch in the jack mackerel trawl fishery for the combined period (1990–91 to 2004–05) to have ranged from about 4500 t to about 15 500 t and total annual discards from about 90 t to about 1900 t (declining over time). Annual estimates of the rate of discarding ranged from 0.01–0.06 kg of discards for every 1 kg of jack mackerel caught. In this assessment, revised estimates of annual bycatch and discards were made for the 2002–03 to 2004–05 period and new estimates were made for the period 2005–06 to 2013–14, using a revised estimator, and the methods used in previous work were built on by examining temporal trends in more detail.

This report was prepared as an output from the MPI 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-5

1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded in the jack mackerel 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 jack mackerel trawl fishery.

3. To compare any trends apparent in bycatch rates in the jack mackerel 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 prep), and repeated here for JMA only.

After subsequent discussions between project and MPI staff the following refinements and extensions to the objectives were agreed.

a. In addition to ratio-based estimates, include the production of model-based estimates of bycatch (but not discards) using the methodology developed under MPI project ENV201301 (Development of model-based estimates of fish bycatch). The two estimation methods (ratio and model-based) will use the same set of predictors so as to allow maximum comparability between estimates.

b. As originally specified, estimates will be made for the species groups QMS, NONQMS and INV but separate estimates will now also be made for the QMS species spiny dogfish (SPD). The QMS species group will be adjusted to match the year-of-entry of individual species in the QMS system.

c. To update estimates of bycatch and discards (ratio-based method) for only the fishing years since 2002–03. This date coincides with the introduction of observer logbooks (and the possibility to re-assign discard information to individual tows), stability of fleet composition, and will minimize issues with improvements in taxonomic identification and the associated introduction of finer resolution MPI 3-letter taxon codes.

d. Conduct a cross-validation exercise with the final models by withholding subsets of the data to test against model predictions.
e. Conduct a comparative analysis of ratio and model-based bycatch estimates, and discuss the relative merits of each method in the presentation and final report.

This additional work was completed under MPI project SEA2014-01 "Additional analyses under DAE2010-02E (Jack Mackerel Fishery)".

2. METHODS

2.1 Definition of terms

For this study *non-target fish species catch* is equivalent to *bycatch*, defined by McCaughran (1992) as all fish caught that were not the stated target species for that tow (jack mackerel species in this case), whether or not they were discarded. *Discarded catch* (or *discards*) is defined as "all the fish, both target and non-target species, which are returned to the sea whole as a result of economic, legal, or personal considerations" (McCaughran 1992). *Discarded catch* in this report includes estimates of any fish lost from the net at the surface. Estimates of total *non-target catch*, if required, can be obtained from this report by adding target species *discards* to total *bycatch*.

2.2 Observer data

MPI observers have been making detailed tow by tow records of catch by species or species group for a portion of the jack mackerel trawl 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, as well as the capacity of vessels to accommodate additional personnel. It has therefore not always been possible to achieve a representative or random spread of observer effort in each fishery (see Section 3.1 for more details). Observer coverage in the jack mackerel trawl fishery has varied through time but has been relatively high in most years. In the first decade of the observed fishery, from 1990–91 to 1999–2000, annual observer coverage typically represented about 20% of the total target species catch from the fishery although dropping as low as 8.6% in 1991–92. Coverage was also low (about 10% or less) during the three years from 2001–02 to 2003–04, but in the last ten years coverage has increased substantially – from a minimum of 25.8% in 2006–07 to 94.9% in 2012–13.

For the 24 year period as a whole, there has been a large amount of observer data collected, representing nearly 16 000 tows, by 72 vessels, and 32.6% of the total trawl catch of jack mackerel. However, this period has seen substantial changes in the commercial fleet, with a reduction in the number and variability of the vessels operating, so that the current fishery is now dominated by about 7 large (105 m) vessels which are mainly Ukrainian registered. Some changes in recording and databasing of observer data also occurred in the early 2000s, at about the same time that the fleet shrunk to its current size and composition, with the result that discard information could more readily be assigned to individual tows and improvements in taxonomic identification became possible with the introduction of a range of finer resolution 3-letter MPI codes. For these reasons the decision was made by members of the Aquatic Environment Working Group to restrict the current analysis to the 2002–03 to 2013–14 period (represented by nearly 11 000 observed tows), as this corresponds to a period of greater consistency in fishery characteristics and fishery data.

2.1.1 Data preparation and grooming

For the analysis of the jack mackerel trawl fishery, a dataset was prepared from the MPI observer database *cod*, based on all observed trawls targeting jack mackerel for the entire period from 1990–91 to 2013–14. This dataset contains a complete set of catch by species for all relevant trawls. Catches in various categories that were not relevant to this analysis were removed from the initial extract; e.g., seaweed, birds, marine mammals, reptiles, and rubbish.

All records in the observer dataset were run through a set of checks and operations to ensure consistency, to correct or aid correction of erroneous values where possible, to remove records with missing values in critical fields if necessary, and to derive additional variables with the potential to describe patterns in variability of bycatch and discards.

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 70 km, approximately the 99th 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, otherwise positions were determined from median imputation. Trawl distances were then recalculated from a combination of the corrected positions and values derived from the recorded duration and trawling speed. Records with missing position data that could not be resolved were removed from the dataset.

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 (about 2% of tows). 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 less than 3.5 knots or greater than 6.5 knots (about 1.2% 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. About 89% of observed tows were recorded as MW (midwater trawls), and these were on average 60 m above the seabed. About 71% of the observed trawls 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 very rare in this fishery, occurring in only 12 observed tows and in total accounting for less than 0.1% of the estimated greenweight at the surface.

The criteria used to identify erroneous records across a range of fields, and their frequency in the observer data, are given in Table 1. Through the use of the grooming processes described above there was no need to delete any data, so the analysis was therefore based on records of all observed target tows available for the period.

Observer data were available from 72 vessels ranging in length from 55 to 105 m. No vessel or company is identified in this report, and alpha-numeric codes are used to differentiate between vessels where necessary.

Table 1: Criteria used to identify likely errors in the observer data, and the number of records that met those criteria. Records were corrected as described in the text above, and none were deleted.

Criterion	Number of records	Percentage of records
Start/finish time missing or identical	45	0.3
Start/finish position missing or identical	50	0.3
Tows longer than 70 km or data missing	245	1.5
Tow speed missing or > 6.5 knots	195	1.2
Gear path in relation to bottom missing	549	3.3
Gear path in relation to changes in direction missing	970	5.9
Start depth missing	1 256	7.6
End depth missing	5 314	32.4
Fish lost at subsurface missing	11	0.1
Fish lost at surface missing	12	0.1

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. To be able to use the discard information from processing groups comprising more than one tow, species discard weights in these groups were re-assigned to individual tows based on their respective contribution to the total estimated catch for the group. Data from groups that comprised more than 10 tows were not included owing to increasing uncertainty in discard quantities actually contributed by each tow.

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

- QMS: All QMS species combined, excluding jack mackerels. The composition of this category expanded over time as species were added to the QMS; observers recorded 67 QMS species in total, excluding jack mackerels
- non-QMS: All non QMS species combined, excluding invertebrates. The composition of this category contracted over time as species were added to the QMS; observers recorded 197 species which were non-QMS species at some time
- INV: All non-QMS invertebrate species combined; observers recorded 98 INV species or species groups in total
- SPD: spiny dogfish (*Squalus acanthias*)
- Individual species (bycatch only)

The above abbreviations (QMS, non-QMS, and INV) are used throughout the remainder of this report along with standard MPI species code (see http://marlin.niwa.co.nz). Bycatch and discards were estimated separately for each of the combined species categories and for SPD.

Summaries of the observed catch and percentage discarded of individual species, broad taxa, and species categories are tabulated in Appendices 1–3.

2.2 Commercial fishing return data

Catch-effort, daily processed, and landed data were requested from the MPI catch-effort database "warehou" as extract 9881. The data consist of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of jack mackerel (MPI codes JMA, JMM, JMD, or JMN) between 1 October 1989 and 30 September 2014. 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 excluded high seas versions of these forms. Data are analysed by fishing year (1 October to 30 September), referred to as, for example, 1991 for the 1990–91 fishing year. Data were groomed for errors using simple checking and imputation algorithms developed in the statistical software package 'R' (R Core Team 2015). 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. These records, representing 64 824 tows, were assigned to the areas defined in Figure 1 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 tow or group of tows the total catch (as well as the catch of the target species) is recorded, unless it is outside of the top five species by weight and therefore generally small. 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 had been common; for example only a quarter of the catch of the main bycatch species (spiny dogfish) 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 were recorded, it is not possible to properly estimate the bycatch of individual species or groups of species.

2.3 Stratification

In addition to providing estimates of annual bycatch and discards for each of the major offshore fisheries, it has become particularly useful to also be able to make summaries for all these fisheries across standardised fishery areas. Area has proven to be a critical predictor of bycatch and discard rates for all offshore fisheries including the jack mackerel fishery (Anderson 2007). For this reason strata used in the analysis were limited to fishing year and area, and a standardised area stratification was adopted for this purpose based as defined in the 2015 Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2016) (Figure 1).

Each record in the observer and commercial effort datasets was assigned to an area based on Figure 1. The target jack mackerel trawl fishery is mainly confined to four areas (WCNI, WCSI, CHAT, and STEW) and there were few commercial trawls and no observed trawls in KERM, NORTH, COOK, or SUBA. For the purposes of bycatch and discard calculations, all records from outside of the four main fishery areas were combined into a single OTHR category. The number of observed trawls in each area over the 24 years is shown in Table 2.

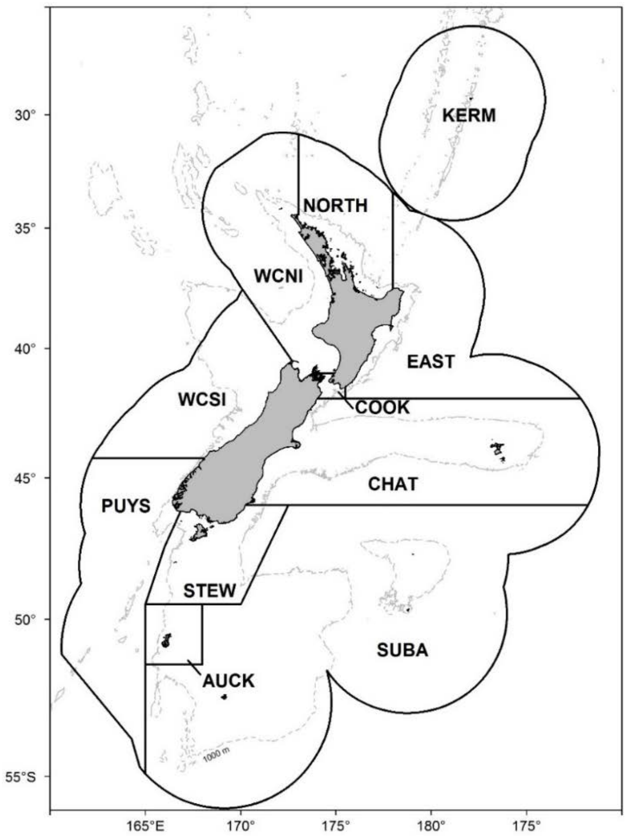

Figure 1: Standardised assessment areas for estimation of total non-protected fish and invertebrate bycatch in offshore fisheries.

Table 2: Number of observed trawls targeting jack mackerel by area (see Figure 1 for area boundaries) and fishing year. Note: there were no observed target jack mackerel trawls in areas KERM, NORTH, COOK, or SUBA.

	AUCK	CHAT	EAST	PUYS	STEW	WCNI	WCSI	All areas
1990–91	0	2	0	0	37	256	27	322
1991–92	0	0	0	0	6	283	70	359
1992–93	0	153	0	1	62	322	57	595
1993–94	0	43	0	0	3	449	156	651
1994–95	0	4	0	0	16	389	6	415
1995–96	16	92	0	0	51	121	19	299
1996–97	0	11	0	0	92	165	89	357
1997–98	0	9	0	0	253	217	41	520
1998–99	0	22	1	0	205	100	260	588
1999–00	1	22	0	0	371	72	30	496
2000–01	1	32	0	0	173	126	66	398
2001–02	0	85	0	0	117	111	39	352
2002–03	0	27	0	0	42	225	43	337
2003–04	0	0	0	0	3	145	10	158
2004–05	0	1	0	0	9	526	19	555
2005–06	0	55	0	0	2	605	8	670
2006–07	0	16	0	0	0	595	170	781
2007–08	0	23	0	0	5	696	79	803
2008–09	0	2	0	0	25	643	89	759
2009–10	0	11	0	0	45	702	34	792
2010–11	0	23	0	0	63	469	35	590
2011–12	0	52	0	0	86	1 275	81	1 494
2012–13	0	216	0	0	92	1 424	155	1 887
2013–14	0	281	0	0	106	1 557	193	2 137
All years	18	1 182	1	1	1 864	11 472	1 776	16 314

2.4 Calculation of bycatch and discards

2.4.1 Ratio method

For each species category, the observed weights of catch and discards were summed within each stratum. From this, the discard rate, $\widehat{DR}$, and bycatch rate, $\widehat{BR}$ were derived, with the following forms,

$$\widehat{DR}_s = \frac{\sum_{i=1}^{m_s} d_i}{m_s} \qquad \text{and} \qquad \widehat{BR}_s = \frac{\sum_{i=1}^{m_s} b_i}{m_s}$$

where *m* tows were sampled from stratum *s*, b_i is the weight of the catch from the *i*th tow sampled, d_i the weight of the discarded catch from the *i*th tow sampled.

Using this rate estimator, estimates of $\widehat{BR}_s$ and $\widehat{DR}_s$ were derived for each stratum in each fishing year and variances were estimated by a multi-step bootstrapping procedure that allowed for correlation between tows within individual vessels, following the method of Anderson & Smith (2005). Specific rates were calculated for each fishing year/strata with 25 records or more. For strata with fewer than 25 records in the year, additional records were taken from the adjacent two years (the previous and subsequent year) or single year if at the start or end of the series. If there were still fewer than 25 records the next two adjacent years were included, and this process was continued until 25 records or more were available. The rate calculated was then multiplied by the total number of unobserved tows in that fishing year and stratum from commercial catch records for the target jack mackerel trawl fishery, to estimate total unobserved bycatch $\widehat{B}$ and discards $\widehat{D}$.

$$(1) \qquad \widehat{B} = \sum_j \widehat{BR}_j \times M_j \quad \text{and} \quad \widehat{D} = \sum_j \widehat{DR}_j \times M_j$$

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

The total unobserved bycatch and discards was then added to the observed amounts to obtain total values for the entire target fishery. To obtain a 95% confidence interval for the unobserved bycatch and discards that takes into account vessel to vessel differences, variability in the total amount of fishing effort between vessels, and allows for correlation between tows by the same vessel, 1000 bootstrap samples were generated from the tows within each cell using a three-step sequential sampling procedure.

First a vessel was chosen at random, then a bootstrap sample was taken of the tows from that vessel that were in the cell. These steps were repeated until the *effective* number of tows was approximately equal to the *effective* number of observed tows for the cell. The effective number of vessels in the bootstrap sample was then calculated. If this was within 5% of the effective number of observed vessels in the cell, then the bootstrap sample was accepted. Otherwise a new bootstrap sample was drawn, and the process repeated until 1000 samples in all had been accepted for each cell.

The *effective* number of tows and the *effective* number of vessels used in this procedure were calculated from the effort (number of tows) and reflected the contributions to the variance of the bycatch/discard rate from the variance of the bycatch/discards and the covariance between pairs of bycatch/discard values for the same vessel 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 $\widehat{B}$ or $\widehat{D}$. An empirical distribution for the total was obtained by summing the bootstrap estimates across all strata within a fishing year, and the 95% confidence interval was obtained from the 2.5% and 97.5% quantiles.

Bootstrapping procedures were carried out using the statistical software package R (R Core Team, 2015).

2.4.2 Statistical modelling of bycatch data

The statistical model was constructed around similar covariates to those used by the ratio method, so as to facilitate comparison, these being area and year. Since this was an illustrative exercise, only the bycatch data were modelled.

The bycatch data are characterised by a large number of zero catches, particularly for the invertebrates. We therefore constructed a model of the bycatch (y) in kilogram units per observed tow using a zero-inflated statistical distribution:

$$f(y_i|z_i,\boldsymbol{\gamma},x_i,\boldsymbol{\beta}) = f_{zero}(0|z_i,\boldsymbol{\gamma}).I(y_i) + (1 - f_{zero}(0|z_i,\boldsymbol{\gamma}))f_{count}(y_i|x_i,\boldsymbol{\beta})$$

where $f_{zero}(0|z_i,\boldsymbol{\gamma}) = \pi$ is the binomial probability of obtaining a zero catch, $f_{count}(y_i|x_i,\boldsymbol{\beta})$ is the probability of observed value y, and $I(y)$ is an indicator function equal to one for a zero catch and zero otherwise (Zeileis et al. 2008). The regression equations for the binomial probability and expected value respectively can be written as:

$$logit(\pi_i) = z_i'\boldsymbol{\gamma}$$

$$\mu_i = (1-\pi_i)\exp(x_i'\boldsymbol{\beta})$$

Parameterisation of the model therefore involves estimation of the coefficient vectors $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ for observed bycatch values y, and regressors x and z, which in this case was achieved using the R-package **pscl** (Jackman 2008). The $f_{count}(y_i|x_i,\boldsymbol{\beta})$ distribution was specified as a negative binomial for the QMS, SPD and total bycatch, but a Poisson for non-QMS and INV — due to these latter cases having uninformative data for purposes of estimating the over-dispersion.

For both model components, we estimated coefficients for year and area effects (with a zero intercept term), which allowed us to predict the total bycatch per strata for a specified degree of commercial effort E in area strata a and year strata t:

$$\log(y_{a,t}^{total}) = \hat{\beta}_a + \hat{\beta}_t + \log\left(1 - \frac{\exp(\hat{\gamma}_a + \hat{\gamma}_t)}{1+\exp(\hat{\gamma}_a + \hat{\gamma}_t)}\right) + \log(E_{a,t})$$

If any strata contained no data, which was true for some areas, the regression coefficients could not be estimated and were therefore set to zero for predictive purposes (i.e. equal to the intercept term). The total bycatch per year was simply a summation across areas:

$$y_t^{total} = \sum_a y_{a,t}^{total}$$

To yield an estimate of uncertainty, we employed a bootstrap procedure in which the observer data were sampled at random with replacement within each year-area strata combination. The model was refitted to each bootstrap sample of the data and the bycatch predicted using the revised coefficients and commercial effort data. Confidence intervals could then be obtained as the 95% quantiles of the resultant distribution of values of either $y_{a,t}^{total}$ or y_t^{total}.

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 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 produced. 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 (indicating no trend) was tested.

2.6 Comparison of trends in bycatch rates with data from trawl surveys

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

The two major trawl survey time-series for middle-depth species (the Chatham Rise series (O'Driscoll et al. 2011) and the sub-Antarctic series (Bagley et al. 2013)) have very little spatial and depth overlap with the jack mackerel trawl fishery. However, there is a partial overlap between the jack mackerel fishery and the west coast South Island inshore trawl survey time-series. Four of the survey strata, in depths of 100–400 m (strata 2, 6, 8, and 9), match closely with the WCSI strata of the present analysis. Biomass estimates for the main bycatch species within these strata were assembled from published accounts of the six surveys that took place between 2002–03 and 2013–14 (Stevenson 2004, 2006, 2007a, 2012, MacGibbon & Stevenson 2013, Stevenson & MacGibbon 2015). Although the survey trawl gear and vessel power differs from that used in the commercial jack mackerel trawl fishery, and the survey is limited to bottom trawling while most of the trawls in the commercial fishery are midwater, the comparison may be useful if strong increases or decreases in bycatch rates evident from the observer data are mirrored in the survey data.

Comparisons were made graphically, by plotting annual levels of observed catch rates for the main bycatch species alongside survey biomass estimates for the six surveys conducted during the 2002–03 to 2013–14 period, and the correlation (Pearson correlation coefficient) between the corresponding elements of the two series was calculated.

2.7 Annual bycatch by individual species

For Objective 4, annual bycatch rates for individual QMS and non-QMS species (fish and invertebrates) in the jack mackerel trawl fishery were calculated from observer records for the period 2002–03 to 2013–14. The species considered were limited to the top 25 QMS species, top 25 non-QMS species, and top 5 invertebrate species, by recorded weight. For this exercise non-informative species codes (e.g., FIS, unidentified fish; UNI, unidentified; and MIX, mixed fish) were ignored. These codes were used for less than 0.01% of the total observed catch for the period.

Annual species specific bycatch rates were multiplied by the annual effort (number of tows) in the fishery 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. Precision was estimated using the same bootstrapping procedure and stratification used for the combined species categories also as described in Section 2.4.

An indication of whether the bycatch of each species increased, decreased, or stayed relatively unchanged over time was calculated in the form of a slope coefficient for a loglinear regression fitted to the data. These slopes are provided only as a simple indicator of general changes over time, as the relationships may be non-linear and some trends may be strongly influenced by changes in observer recording of species over time.

3. RESULTS

3.1 Distribution and representativeness of observer data

The spatial distribution of target trawl fishing effort for jack mackerel between 1 October 1990 and 30 September 2012 is shown for all commercial tows and all observed tows in Figures 2 and 3.

Observer coverage has been well spread over the spatial extent of this fishery, particularly around the four main fisheries on the west coast of the North and South Islands (areas WCNI and WCSI), the western Chatham Rise (CHAT), and the Stewart-Snares shelf (STEW) (Figure 2). Observer sampling was more limited in the minor commercial jack mackerel fisheries around the Auckland Islands (AUCK), the Eastern Chatham Rise, Cook Strait (COOK), Northland (NRTH), sub-Antarctic (SUBA), and the Puysegur Banks (PUYS). These smaller fisheries, especially in COOK and EAST, were fished by small vessels (Table 3a, 3b) which typically could not accommodate an observer on board. Observer coverage was notably more extensive in recent years (Figure 3), with the spread of observer coverage closely matching that of the commercial fishery as a whole. As the fleet in the four main fishery areas comprised mainly large vessels, catch and effort data were mostly recorded on forms with positional data, and observers could generally be accommodated. Vessels that were not observed at any time throughout the period only accounted for 8–12% of the total effort in these fisheries (Table 3a).This percentage decreased to less than 5% when considering the recent period only (Table 3b).

Table 3a: ALL years: summary statistics for the jack mackerel trawl fishery, by area, for the period 1990–91 to 2013–14, including observer coverage and aspects of data quality (e.g. number of tows with positional data).

		Total effort			
Area	Median vessel length (m)	Number of tows	Percent of tows observed	Percent of tows with position data	Percent of tows by vessels never observed
WCNI	104.5	40 174	28.6	99.7	10.7
WCSI	104.4	10 035	17.7	99.7	12.4
STEW	104.5	7 405	25.2	100.0	8.2
CHAT	104.4	6 933	17.0	98.8	6.0
COOK	41.7	111	0.0	73.2	100.0
PUYS	91.9	62	1.6	98.4	9.7
AUCK	101.4	34	52.9	0.0	26.5
EAST	21.2	24	4.2	58.3	79.2
NORTH	18.0	22	0.0	68.2	95.5
SUBA	103.0	2	0.0	50.0	0.0

Table 3b: Recent years: summary statistics for the jack mackerel trawl fishery, by area, for the period 2002–03 to 2013–14, including observer coverage and aspects of data quality (e.g. number of tows with positional data).

		Total effort			
Area	Median vessel length (m)	Number of tows	Percent of tows observed	Percent of tows with position data	Percent of tows by vessels never observed
WCNI	104.5	23 783	37.3	99.7	1.1
WCSI	104.5	2 282	40.1	99.7	4.6
STEW	104.5	1 767	40.0	98.8	3.7
CHAT	104.5	1 031	46.4	100.0	1.5
COOK	42.0	22	0.0	73.2	100.0
NORTH	29.8	5	0.0	68.2	80.0
EAST	62.9	2	0.0	58.8	50.0
PUYS	104.5	1	0.0	98.4	0.0
SUBA	104.5	1	0.0	50.0	0.0
AUCK	–	0	–	–	–

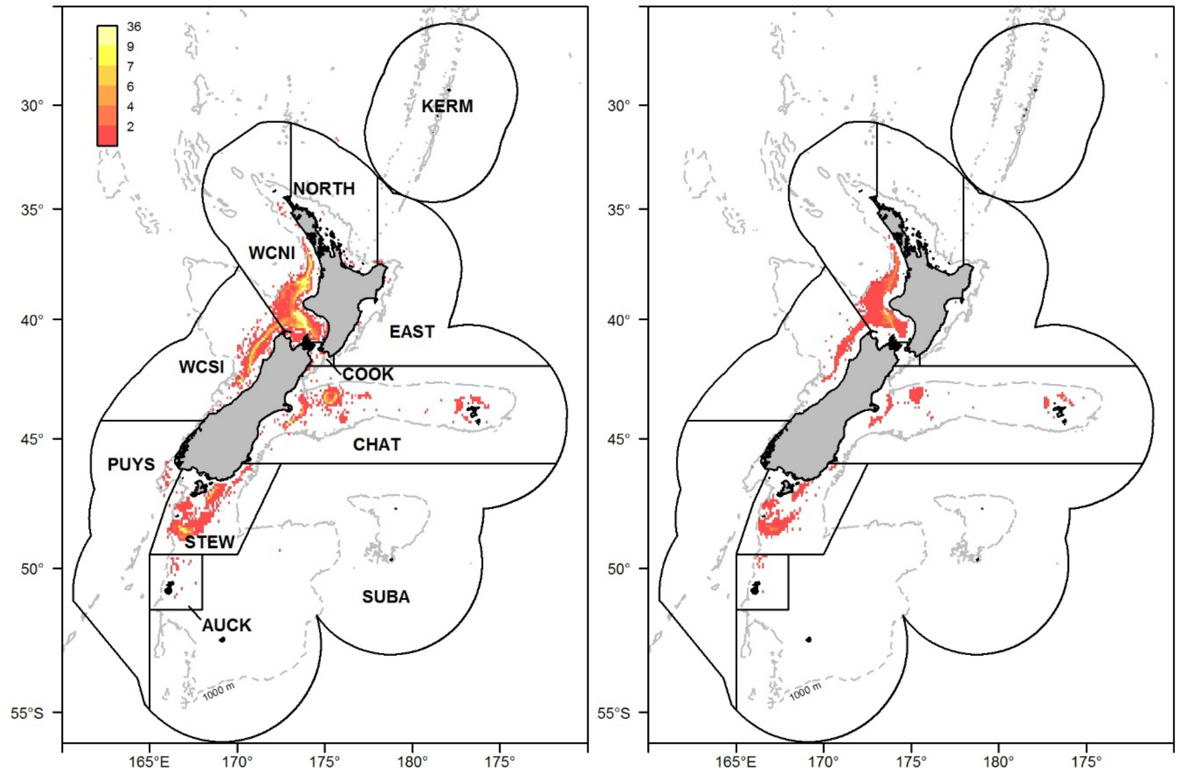

Figure 2: Density plots showing the distribution of all commercial tows with recorded position data targeting jack mackerel (left) and all tows recorded by observers on vessels targeting jack mackerel (right), for 1990–91 to 2013–14. The legend indicates the average number of tows per year in each 0.1˚ cell; solid lines mark the boundary of the EEZ and areas used in the analyses; dashed lines indicates the approximate 1000 m isobaths.

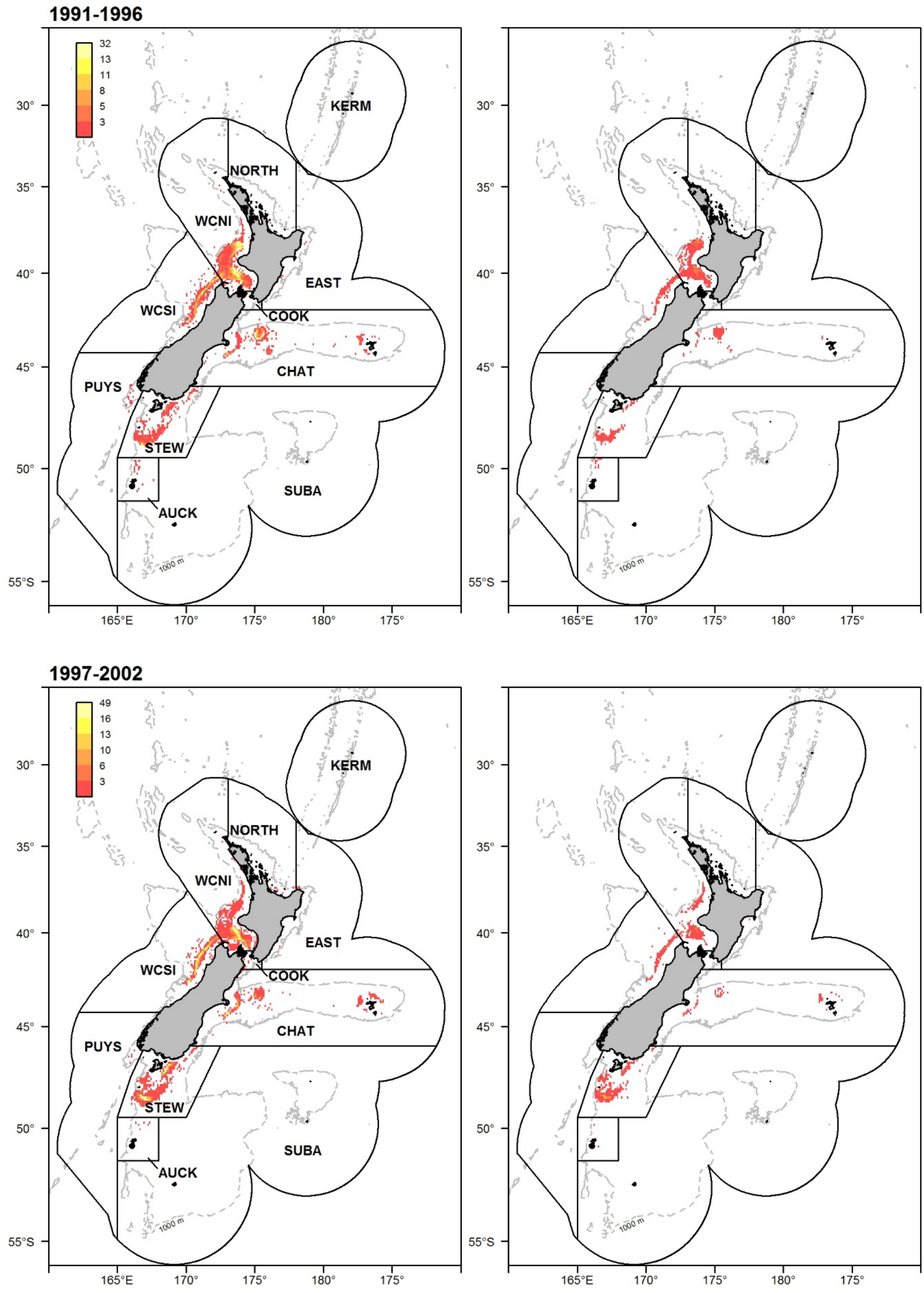

Figure 3: Density plots showing the distribution of all commercial tows with recorded position data targeting jack mackerel (left) and all tows recorded by observers on vessels targeting jack mackerel (right), by blocks of years. In the titles, 1991 = fishing year 1990–91, thus panel 1991–1996, for example, represents fishing years 1990–91 to 1995–96. The legend indicates the average number of tows per year in each 0.1˚ cell. See Figure 2 caption for more details.

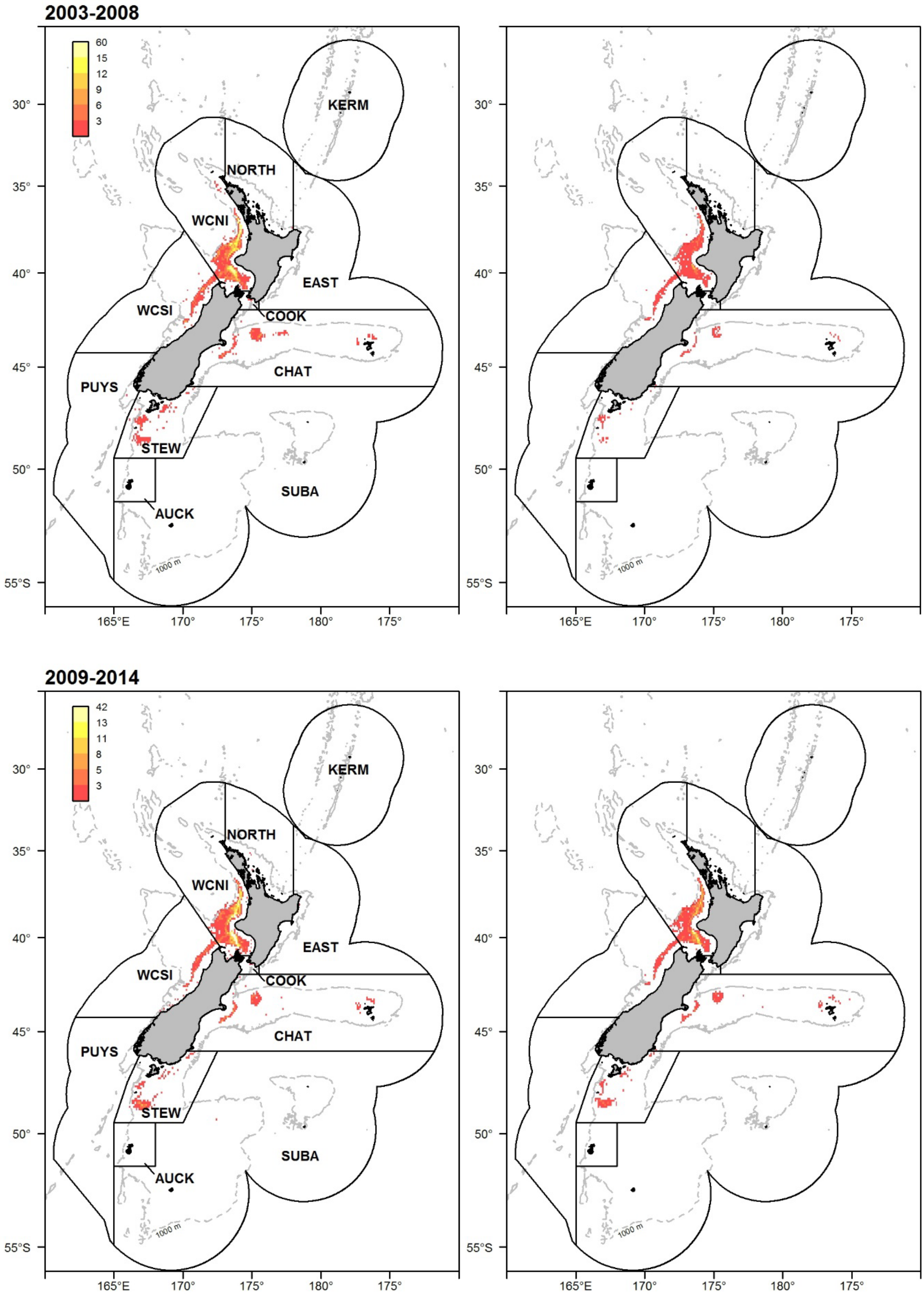

Figure 3—*Continued*

To more objectively assess the spatial observer coverage, a comparison of the latitude and longitude of observed tows with all commercial tows recorded with position data was produced using density plots (Figure 4).

The spread of observed tows across the spatial extent of the fishery was well matched to the spread of commercial tows throughout much of the 24-year period with data, particularly in the period since 2002–03 (Figure 4). There was some over and under sampling of the key fishery areas in earlier years, especially between 1993–94 and 1995–96 and between 1999–2000 and 2001–02, but when considering the whole history of the observed fishery the spatial spread of sampling has been almost perfectly matched to the commercial effort (Figure 4).

There was a high level of inter-annual variability in the spatial distribution of fishing effort before 2002–03, but very little since (Figure 4). In particular, operating procedures for jack mackerel trawlers in the WCNI region (north of 40˚ 30' S), introduced in 2008 to reduce the likelihood of captures of common dolphins, have had no discernible effect on the distribution of fishing effort. These procedures include avoiding the shooting of nets when dolphins are observed and discourage the shooting or hauling of nets between the hours of 2.30am and 4.30am (Deepwater Group 2014).

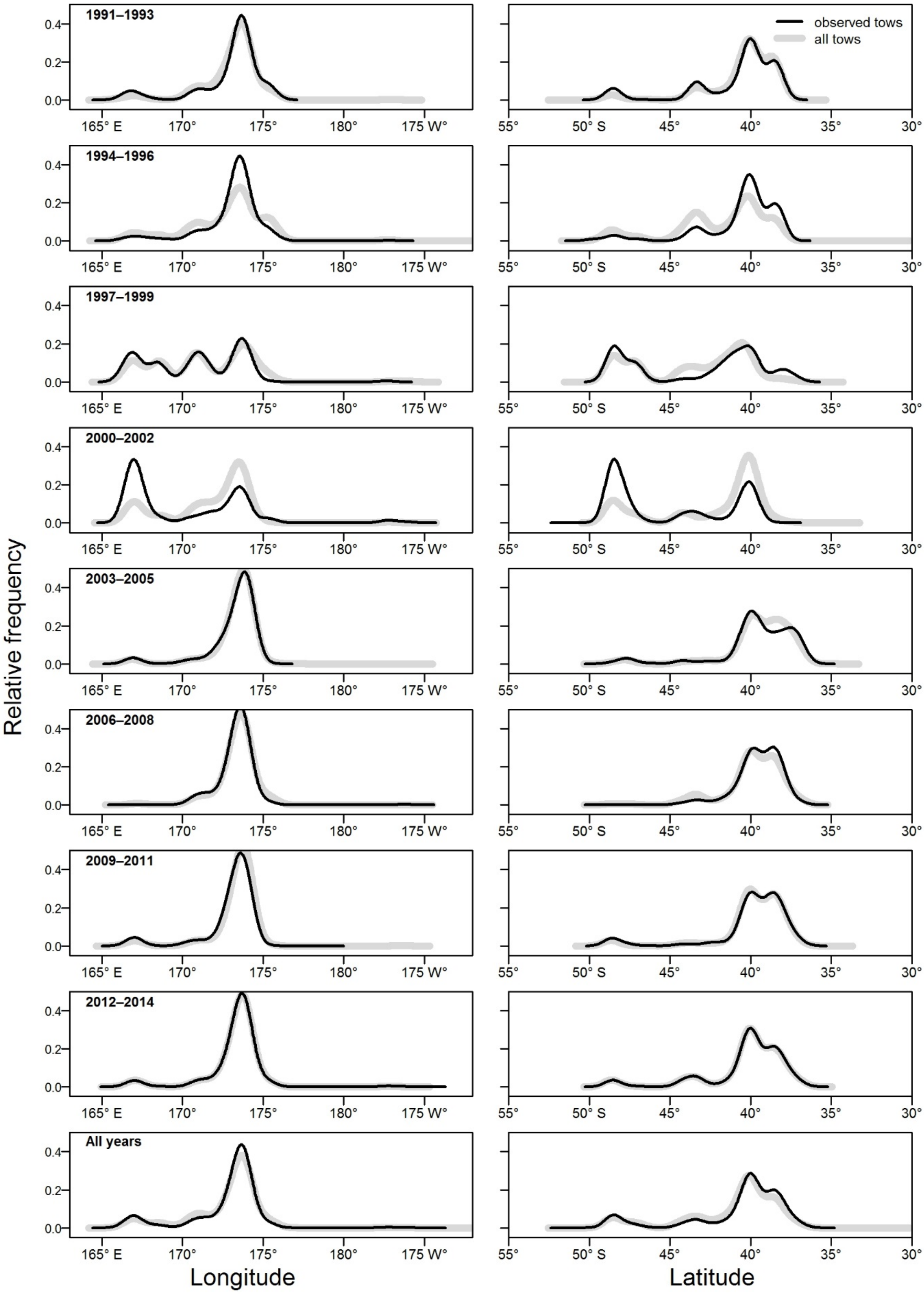

Figure 4: Comparison of start positions (latitude and longitude) of observed tows with those of all commercial tows in the jack mackerel trawl fishery, by blocks of three fishing years and for all years combined, for the period 1990–91 to 2013–14. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Observer coverage of the jack mackerel fishery began in 1990. The annual number of observed tows since then has ranged from 158 to 2137 with a very high level of coverage occurring in the most recent three years but otherwise mostly at a level of 300–800 tows per year (Table 4). The number of vessels observed in each year ranged from 6 to 14 (equivalent to 20–70% of the fleet and increasing over time as the fleet size contracted), with the lowest levels in the 2000s. The fraction of trips observed each year also increased over time, especially in the last three years when the number of observed trips doubled or tripled. The observed number of tows accounted for more than 10% of the total in all but one year (2003–04), and the percentage of catch observed was similarly high. These percentages have been steadily increasing since 2002–03, reaching a peak of 95% (by catch) in 2012–13.

Table 4: Summary of effort and estimated catch in the target trawl fishery for jack mackerel, for observed tows and overall, by fishing year. Trips include those with any recorded targeting of jack mackerel.

Fishing year	Number of tows		Number of vessels		Number of trips		Jack mackerel total catch (t)		Percentage observed	
	Obs	All	Obs	All	Obs	All	Obs	All	Catch	Tows
1990–91	322	1 916	13	46	15	129	2 117	11 083	19.1	16.8
1991–92	359	3 358	9	48	10	121	1 912	22 310	8.6	10.7
1992–93	595	3 399	13	41	16	105	5 065	23 487	21.6	17.5
1993–94	651	3 497	14	36	17	101	3 935	18 807	20.9	18.6
1994–95	415	3 191	9	40	9	116	2 172	17 785	12.2	13.0
1995–96	299	2 754	9	38	11	123	2 328	15 290	15.2	10.9
1996–97	357	2 613	12	39	13	141	3 501	16 374	21.4	13.7
1997–98	520	4 160	10	39	12	164	4 991	24 422	20.4	12.5
1998–99	588	3 801	10	41	13	164	4 697	22 585	20.8	15.5
1999–00	496	2 292	12	27	14	88	2 975	13 253	22.4	21.6
2000–01	398	1 941	14	29	26	86	2 921	15 694	18.6	20.5
2001–02	352	3 002	7	23	13	99	2 454	23 423	10.5	11.7
2002–03		3 060	7	23	12	89	2 312	26 119	8.9	11.0
2003–04	158	2 381	6	16	7	62	2 132	26 826	7.9	6.6
2004–05	554	2 492	9	17	14	58	8 990	33 351	27.0	22.2
2005–06	670	2 765	7	15	13	58	8 245	30 071	27.4	24.2
2006–07	781	2 693	8	18	17	79	7 919	30 713	25.8	29.0
2007–08	803	2 620	9	16	22	77	10 579	33 381	31.7	30.6
2008–09	759	2 136	9	15	23	71	10 846	27 712	39.1	35.5
2009–10	792	2 383	9	20	16	68	9 239	29 945	30.9	33.2
2010–11	590	1 874	7	13	14	52	8 789	28 554	30.8	31.5
2011–12	1 494	1 957	8	11	33	63	22 385	28 096	79.7	76.3
2012–13	1 887	2 119	11	14	51	69	29 505	31 087	94.9	89.1
2013–14	2 137	2 414	10	14	54	69	30 685	34 377	89.3	88.5
All years	16 314	64 818	72	182	428	2 189	190 696	584 745	32.6	25.2

Comparisons made between vessel sizes in the commercial fleets and the observed portion showed that although a wide size range of vessels have operated in this fishery, from about 12 t GRT (Gross Register Tonnage) to over 6000 t, most fishing is by a core group vessels of a very similar size (4300–4500 t, Figure 5). This core group of vessels was well covered by observers, both across all years of the observed fishery and during the recent period (since 2002–03), with no evidence of over- or under-sampling.

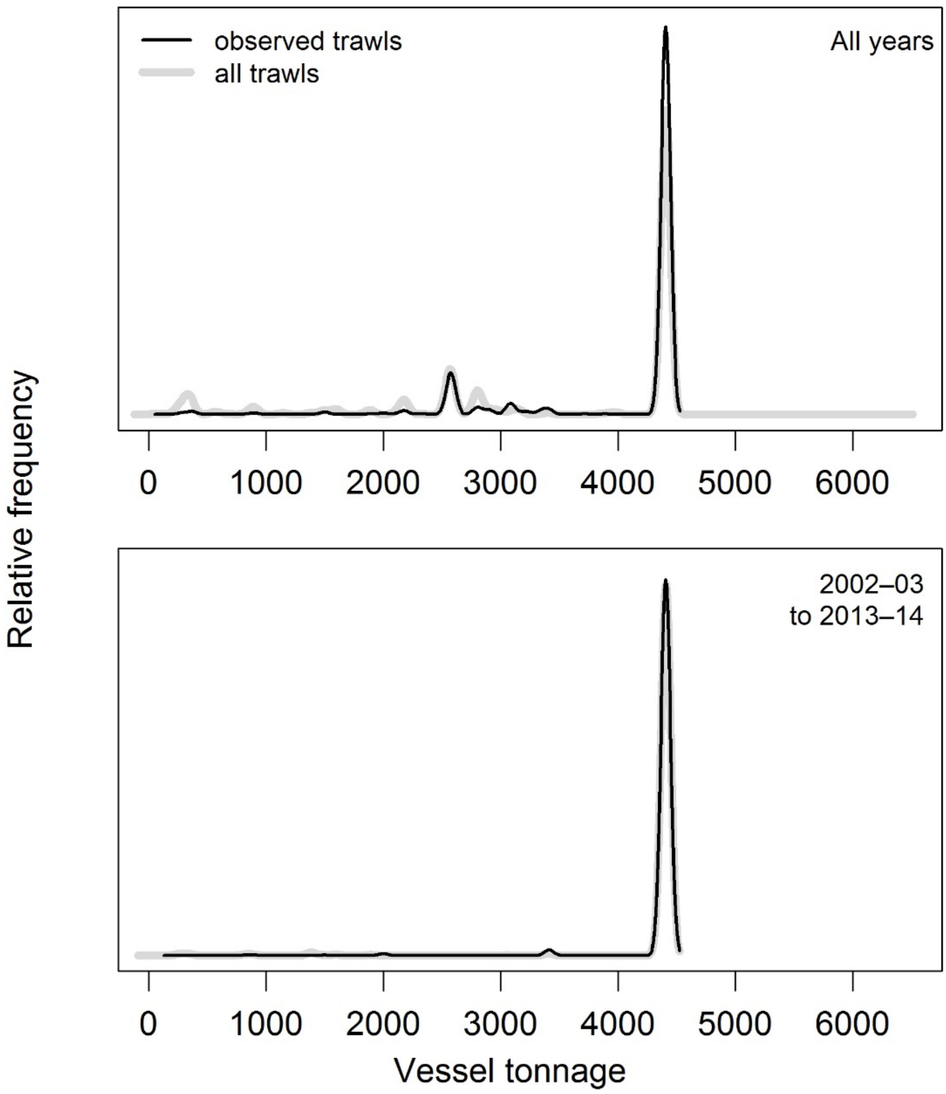

Figure 5: Comparison of vessel sizes (Gross Register Tonnage) in observed tows versus all recorded commercial tows, for all years (top) and for the years 2002–03 to 2013–14 (bottom), in the jack mackerel trawl fishery. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Although commercial fishing for jack mackerel can be successfully undertaken at any time of the year, there has tended to be lower levels of effort in November, February, and May in most years (Figure 6). Observer coverage has tended to be less spread out in most years, but the concentration of effort has varied from year to year so that for the period as a whole the temporal spread of observer coverage across the fishing year is very similar to the commercial fishery as a whole. The very high levels of observer coverage in recent years are evident in Figure 6, especially 2012–13 and 2013–14, with closely overlapping density traces.

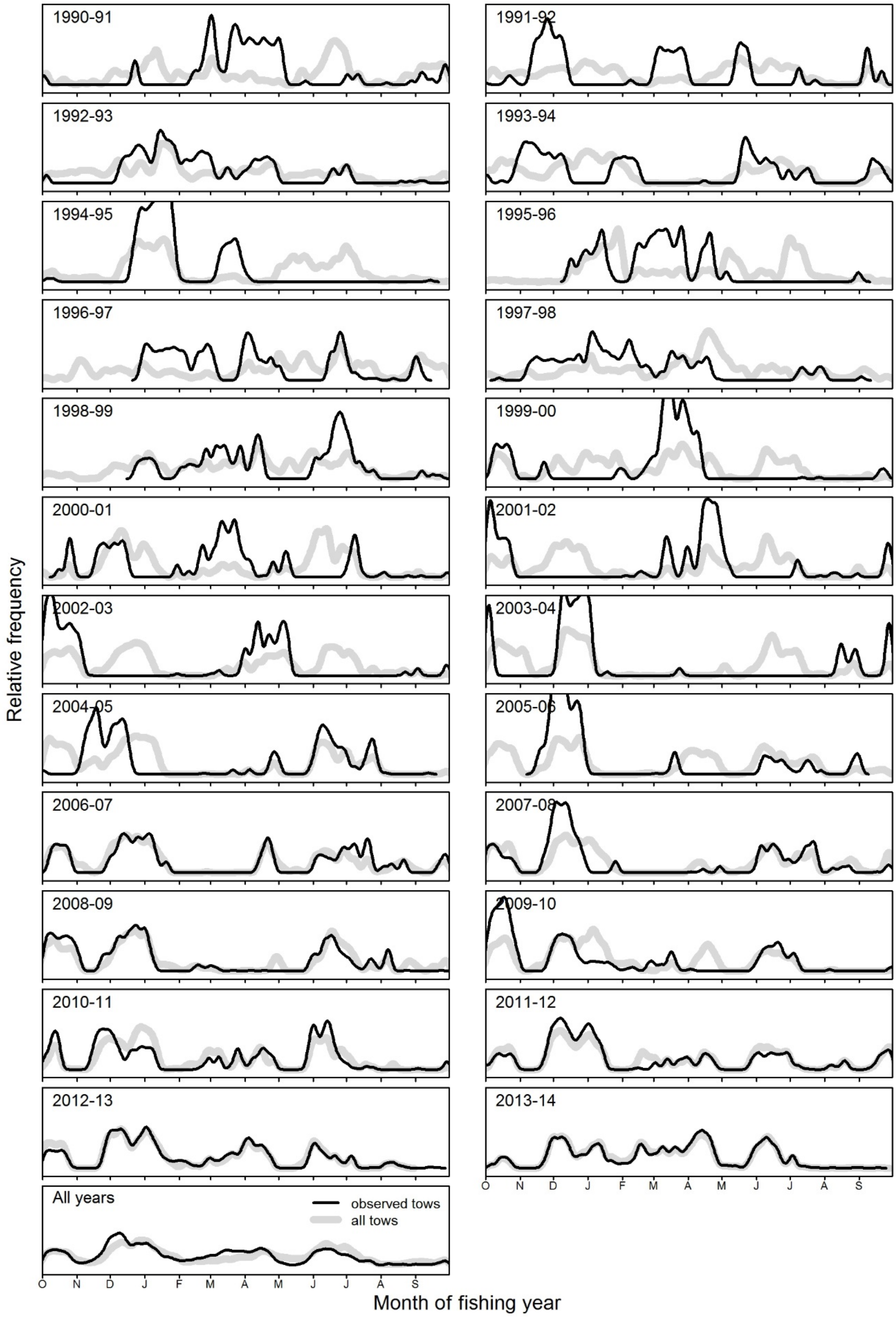

Figure 6: Comparison of the temporal spread of observed tows with all recorded commercial tows for 1992–93 to 2013–14, and for all fishing years combined. The relative frequency of the numbers of tows was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Bycatch data

3.2.1 Overview of raw bycatch data

More than 320 bycatch species or species groups were identified by observers in the jack mackerel target trawl fishery, most being non-commercial species, including invertebrate species, caught in low numbers (see summaries in Appendices 1–3). Jack mackerel species accounted for about 75% of the total estimated catch from all observed tows targeting jack mackerel between 1 Oct 2002 and 30 Sep 2014. The main bycatch species by weight were the QMS species barracouta (*Thyrsites atun*) (13%), blue mackerel (*Scomber australasicus*) (3.4%), frostfish (*Lepidopus caudatus*) (3.4%), and redbait (*Emmelichthys nitidus*) (2.5%). Observers recorded very little discarding of these species, but two thirds of spiny dogfish (the eighth most common bycatch species, 0.25% of the catch) were discarded (Figure 7). Although a QMS species since October 2004, spiny dogfish can legally be returned to the sea, dead or alive, under Schedule 6 of the Fisheries Act 1996. Other bycatch species with notable levels of discards included kingfish (*Seriola lalandi*), porcupine fish (*Allomycterus jaculiferus*), sunfish (*Mola mola*), and thresher sharks (*Alopias vulpinus*) (Figure 7). When combined into broader taxonomic groups, osteichthid fish other than tuna, rattails, and billfish contributed the most bycatch (20.4% of the total catch) and only 1% these were discarded. Tuna species accounted for a further 3.7% of the catch and these were also mostly retained. Sharks and dogfish were the next largest group (0.4% of the catch); about half of these were discarded. Of the invertebrates, only molluscs (mostly arrow squid) were caught in substantial amounts and these were mostly retained. About 13 t of cnidarians, sponges, and echinoderms were caught, and almost all were discarded (see Appendix 3 for more details).

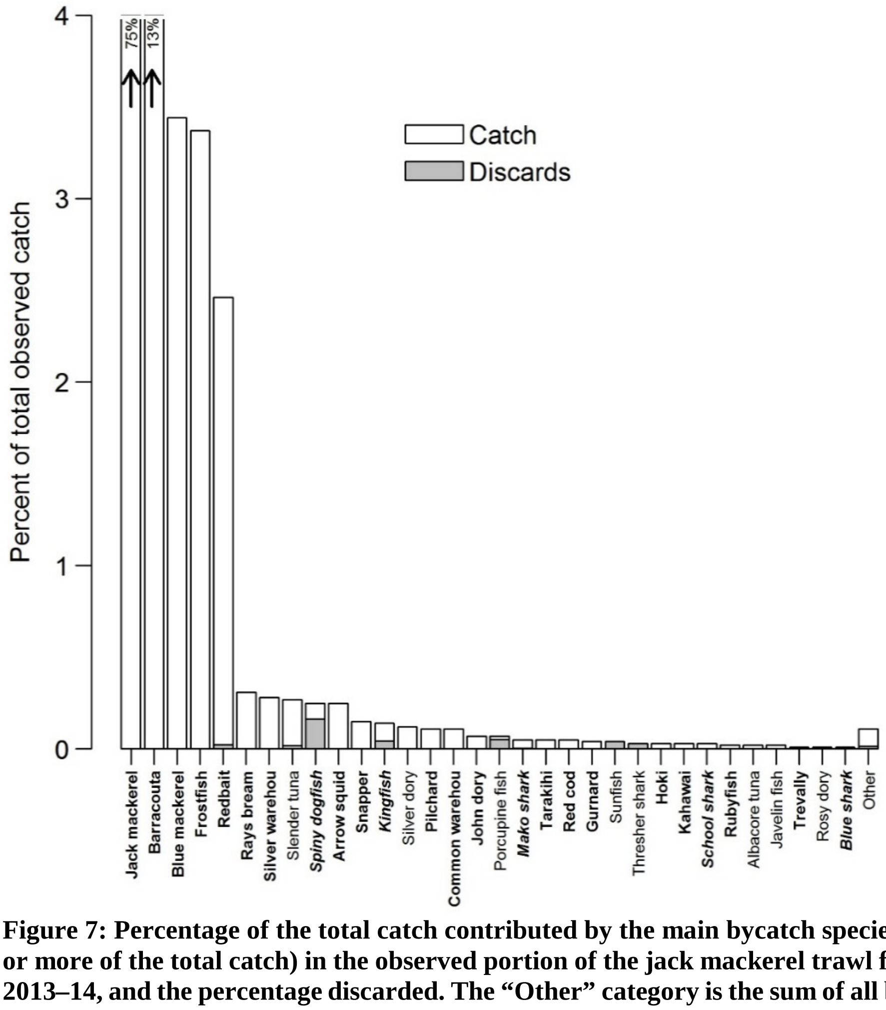

Figure 7: Percentage of the total catch contributed by the main bycatch species (those representing 0.01% or more of the total catch) in the observed portion of the jack mackerel trawl fishery between 2002–03 and 2013–14, and the percentage discarded. The “Other” category is the sum of all bycatch species representing less than 0.01% of the total catch. Names in bold are QMS species, names in italics are QMS species which can be legally discarded under Schedule 6 of the Fisheries Act (1996).

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 tow (plotted on a log scale) with respect to other relevant available variables, including depth, duration, vessel, fishing year, area, nationality, and net type (Figures 8–10). Plots were prepared separately for each time period (1990–91 to 2013–14 and 2002–03 to 2013–14) and species category (QMS species, non-QMS species, and ALL species).

For the 1990–91 to 2013–14 period, total bycatch per tow was highly variable, ranging from 0 t to 164 t (Figure 8a). Fishing was mostly in depths of 50–200 m, with very little effort beyond 250 m, and there is a very slight indication of increasing total bycatch with increasing fishing depth. Most tows were less than 5 hours in duration but longer tows were frequent and some were longer than 12 h. There was an indication of increasing total bycatch with increasing duration. There were some differences in total bycatch rates between vessels, with more variability among the shorter vessels than the longer vessels, but no evidence of any other size related pattern. There was no obvious change in total bycatch rates from year to year through the series. Bycatch rates were slightly lower in area WCSI than in other areas, and Russian vessels had slightly lower rates than vessels of other nations. Net type had a small influence as well, with midwater trawls producing lower overall bycatch than bottom trawls. Separate analysis of the recent period (2002–03 to 2013–14) indicated mostly similar patterns: the number of vessels with more than 50 tows was reduced to nine and bycatch rates were very even among them except for slightly lower rates for the largest vessel; the lower bycatch rates in the west coast fisheries is more pronounced; and Korean vessels have the highest bycatch rates (Figure 8b).

Patterns of bycatch for QMS species in relation to these variables differed somewhat to those for total bycatch, for the 1990–91 to 2013–14 period (Figure 9a). There was a slight negative relationship between net depth and QMS bycatch and more variability between vessels. The obvious increase in QMS bycatch over time will be largely due to the regular introduction of species to the QMS during the period, and this may have also affected patterns shown for other variables, for example with changing relative effort over time among vessels and nations. There is little apparent difference in QMS bycatch between net types. For the 2002–03 to 2013–14 period vessel bycatch rates of QMS species were very similar, and QMS species composition had stabilised and there was no apparent trend over time (Figure 9b).

Bycatch of non-QMS species show similar patterns to QMS species with respect to net depth and duration, and similar variability among vessels. The temporal trend is the reverse, however, as the number of species comprising this category has reduced over time (Figure 10a), although it stabilises during the more recent period (Figure 10b). Non-QMS species bycatch is substantially lower for midwater nets than for bottom nets for the 1990–91 to 2013–14 period, but this is far less evident for the 2002–03 to 2013–14 period.

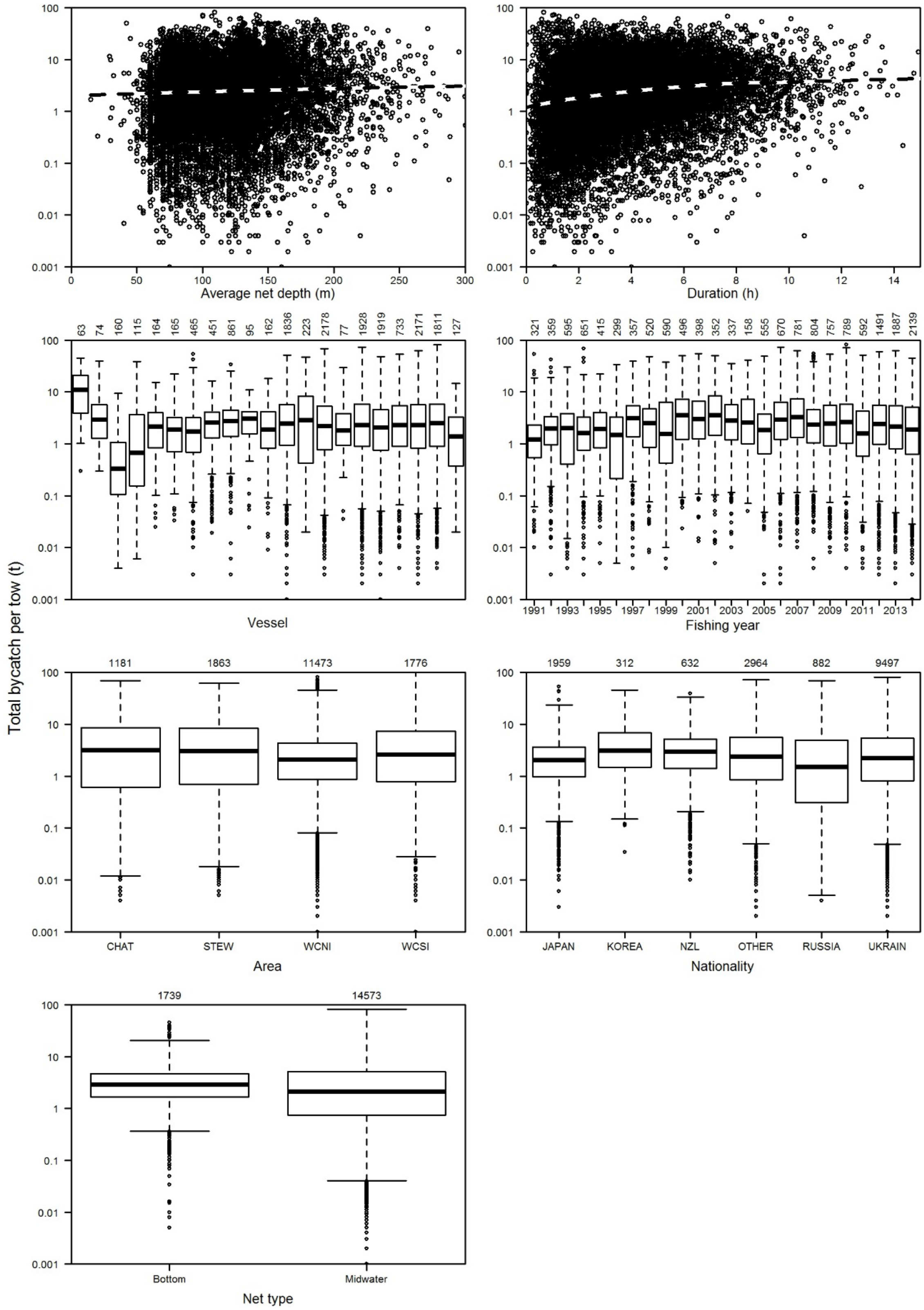

Figure 8a: ALL YEARS: total observed bycatch (all species) in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. The dashed lines in the top panels represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots 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 records (tows) associated with that level of the variable. In the vessel plot, vessels are ordered by size, from shortest to longest. Vessels, areas, and nationalities represented by fewer than 50 records are not plotted. Average depth is the average of the start and finish depths of the tow. See Figure 1 for area codes.

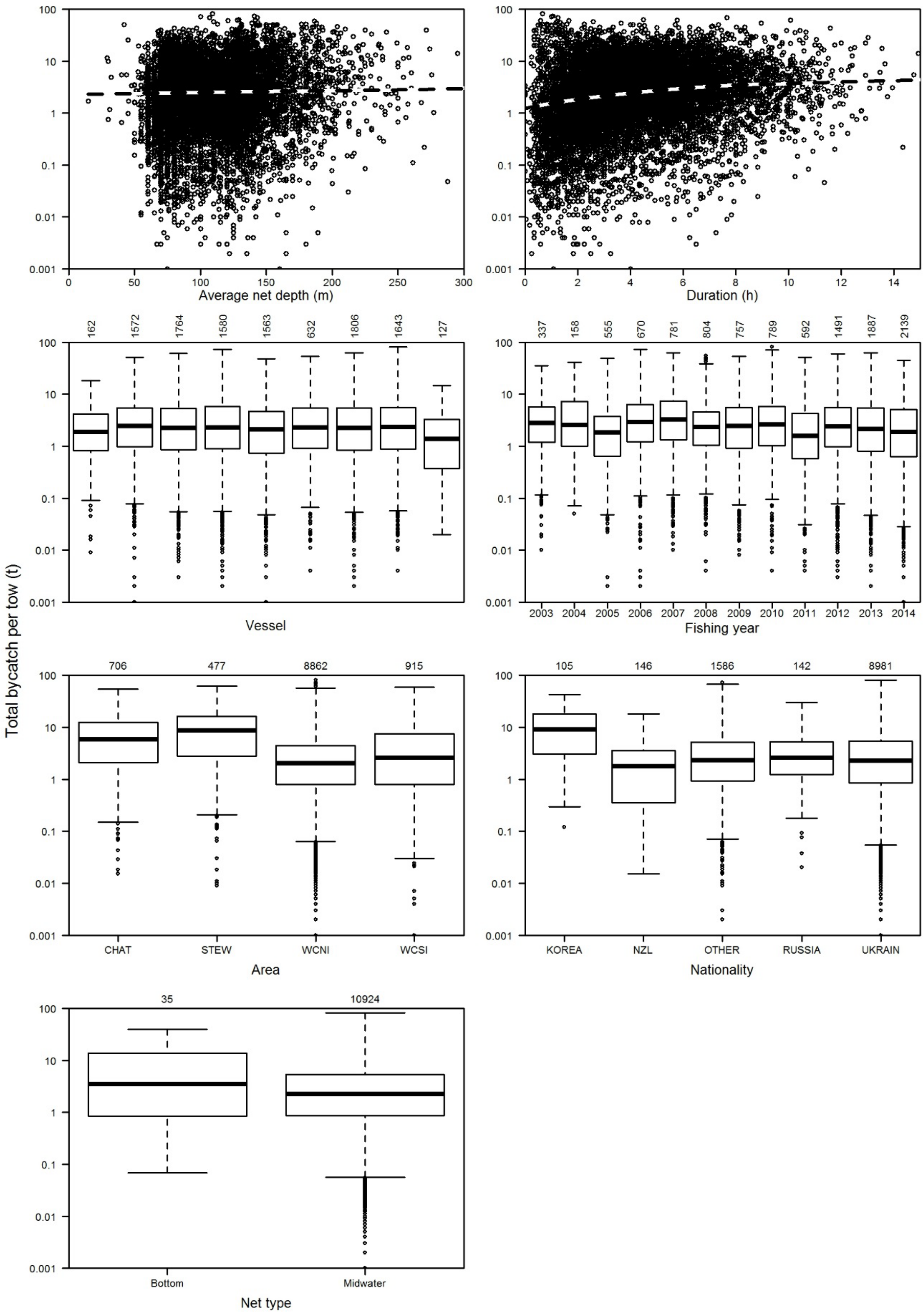

Figure 8b: 2002–03 to 2013–14 only: total observed bycatch (all species) in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8a for further details.

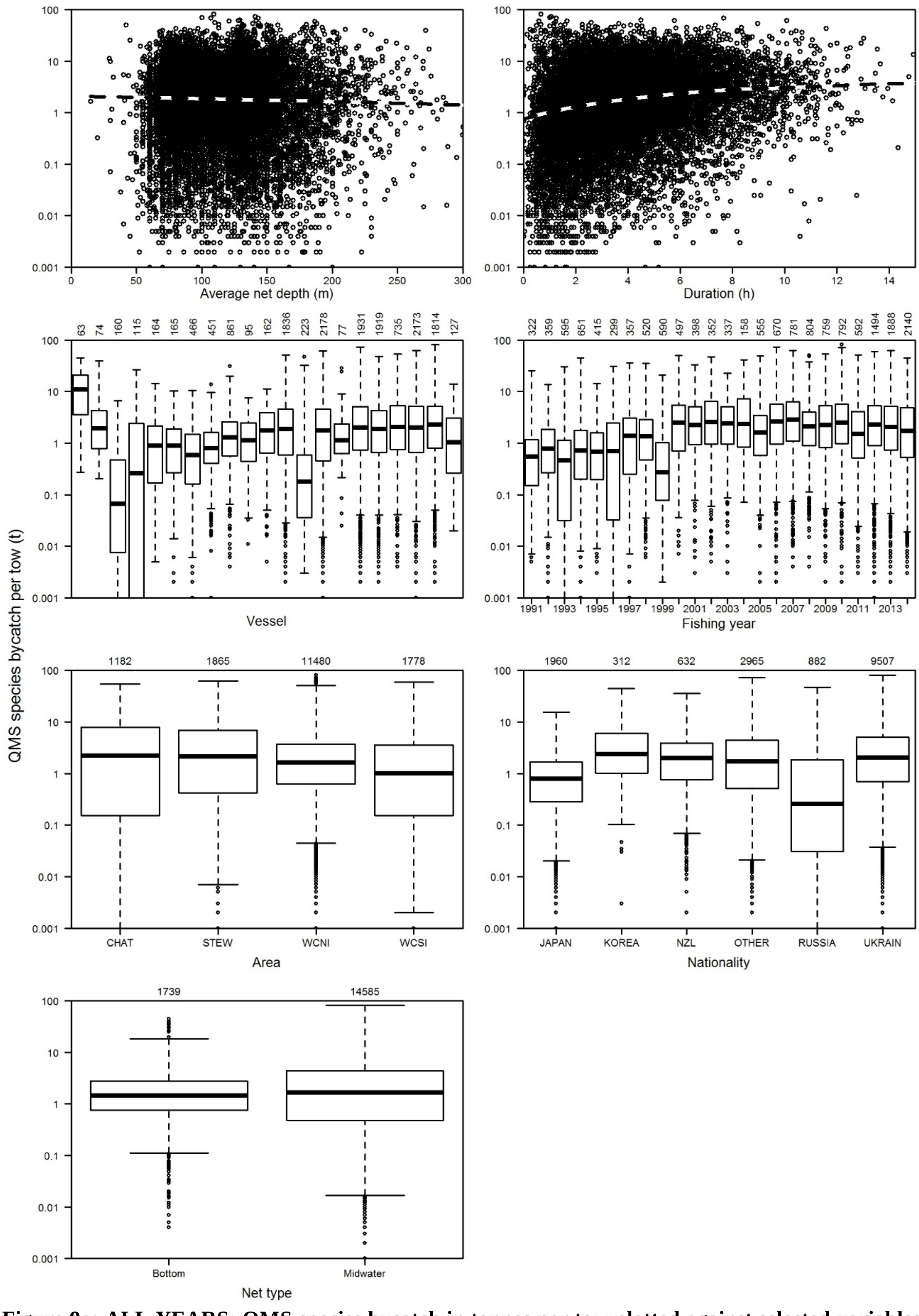

Figure 9a: ALL YEARS: QMS species bycatch in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8a for further details.

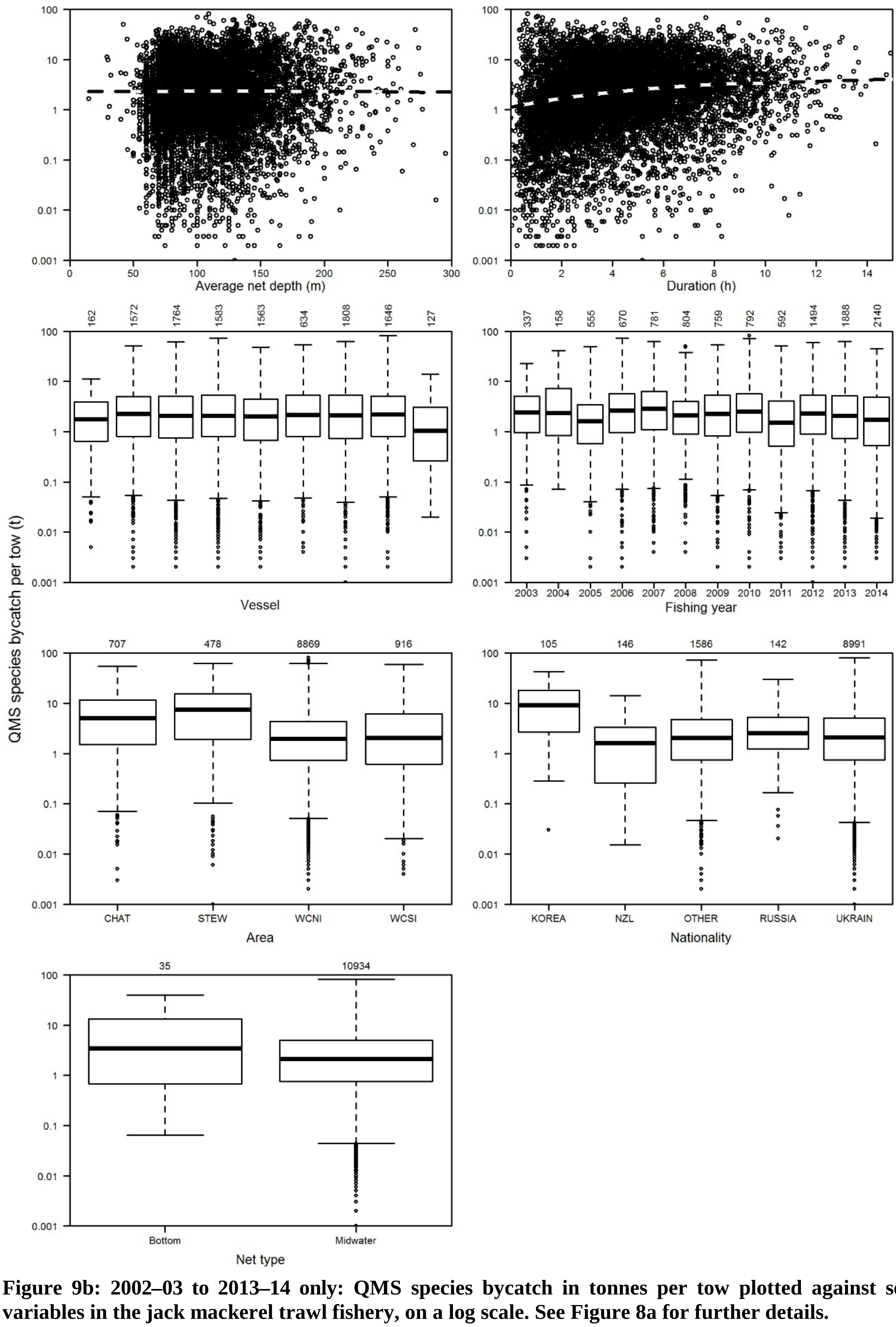

Figure 9b: 2002–03 to 2013–14 only: QMS species bycatch in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8a for further details.

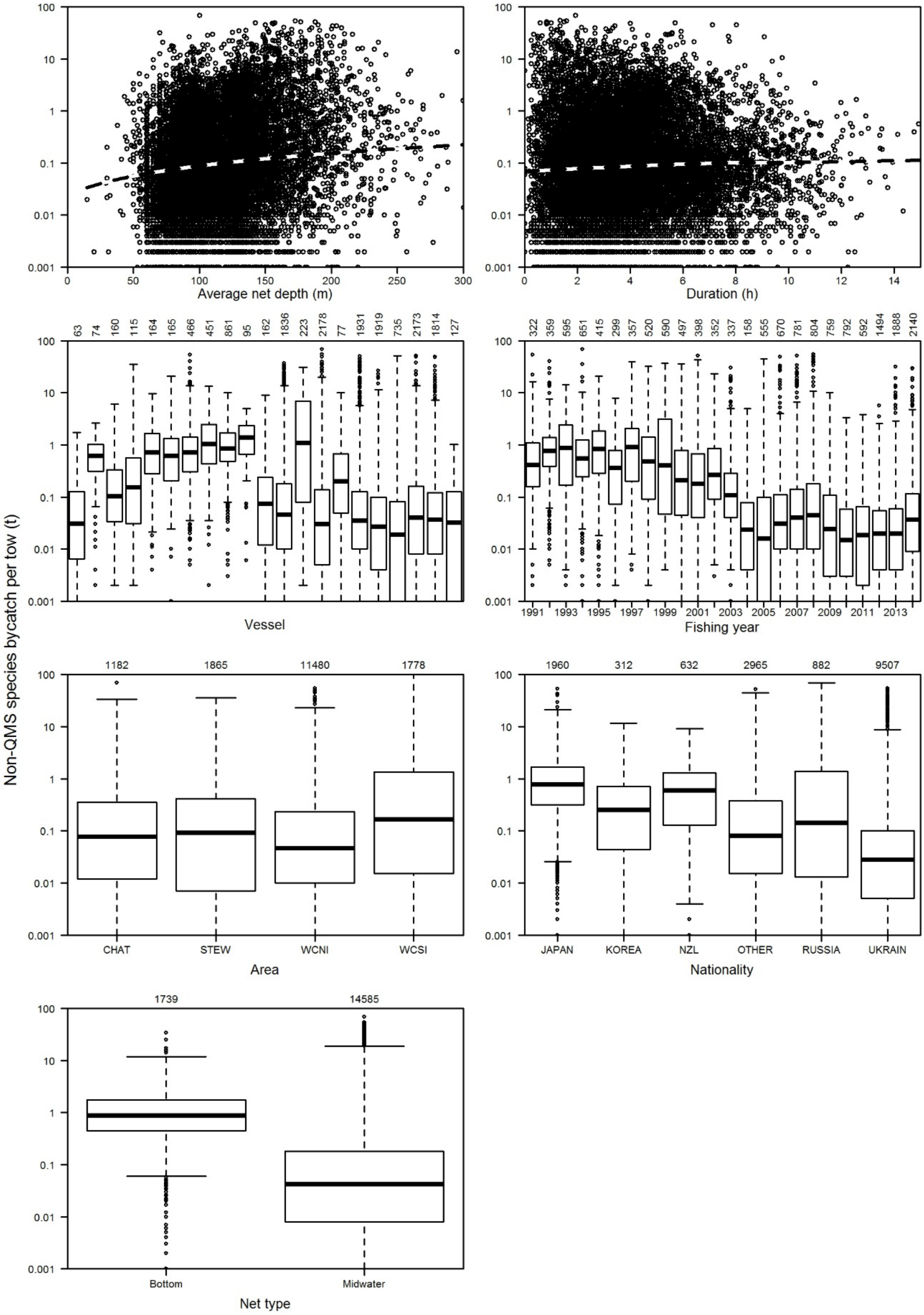

Figure 10a: ALL years: Non-QMS species bycatch in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8a for further details.

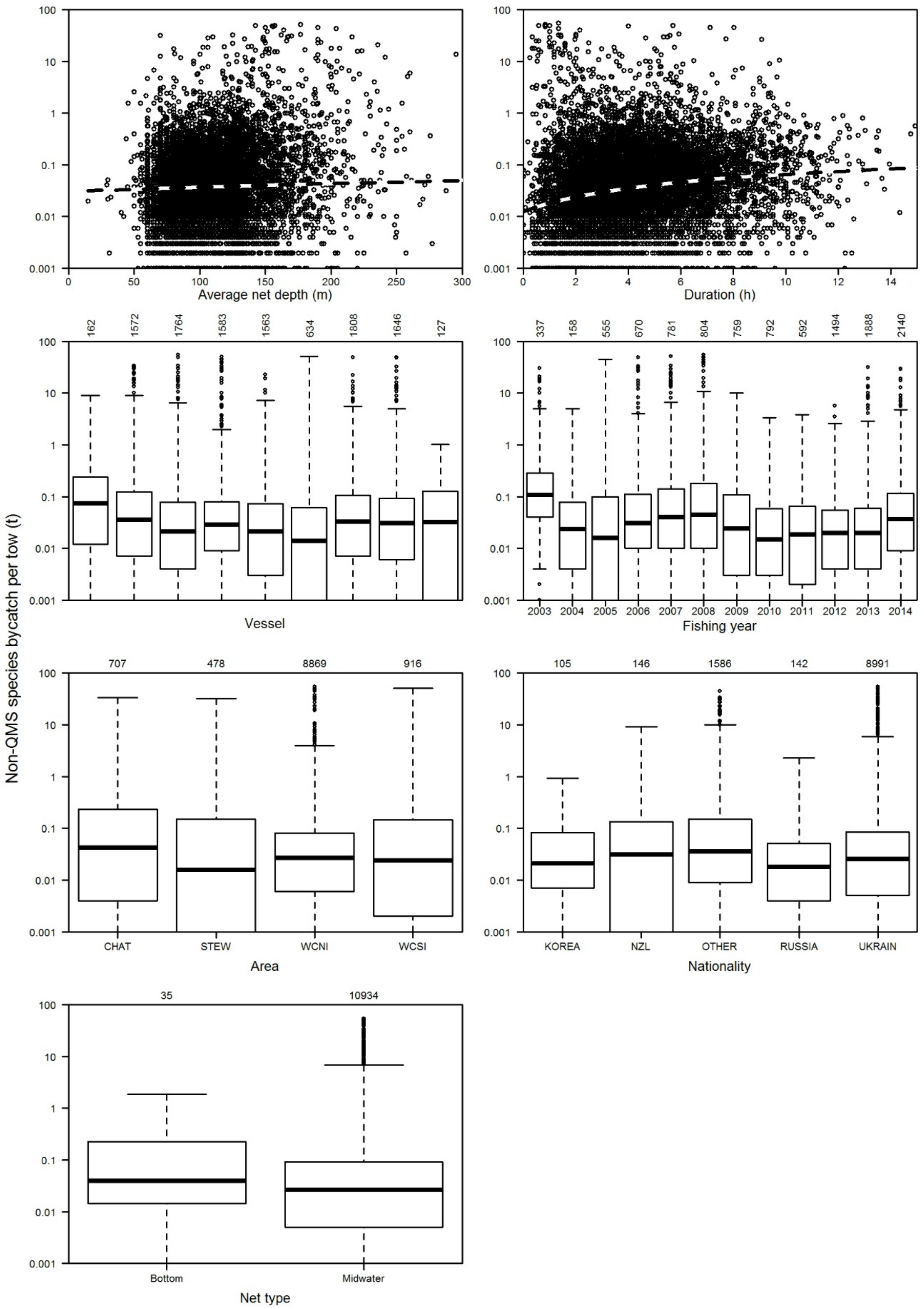

Figure 10b: 2002–03 to 2013–14 only: Non-QMS species bycatch in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8a for further details.

3.3 Discard data

3.3.1 Overview of raw discard data

The individual fish species most discarded in the jack mackerel trawl fishery was spiny dogfish, a species introduced into the QMS in October 2004 and at the same time added to the 6th schedule of the Fisheries Act 1996, allowing it to be legally discarded (dead or alive) at sea (see also Section 3.5.5 for a discussion of observer-authorised QMS species discards). Spiny dogfish was also the eighth most common fish bycatch species and an estimated 66% of the 499 t observed catch was discarded (Figure 7, Appendix 1). Of the seven most common fish bycatch species, observers recorded discarding only for redbait (1% discarded) and slender tuna (*Allothunnus fallai*) (7% discarded). Higher levels of discarding (reaching 100% in some cases) were recorded for less frequently caught, low value non-QMS species such as porcupine fish (*Allomycterus jaculiferus*) sunfish (*Mola mola*), and thresher shark (*Alopias vulpinus*) (Appendix 1). Surprisingly, observers reported discarding of 31% of the tenth most common bycatch species, kingfish (*Seriola lalandi*), although this was only added to the QMS in October 2003 and much of the discarding will have preceded this date.

The most commonly caught invertebrate species was arrow squid (*Nototodarus* spp.) and observers did not report any discarding of this species. Other invertebrates were caught in relatively small amounts, with jellyfish (12.7 t, 0.01% of the total catch) shown to have been 94% discarded (but likely to have been 100% in reality). Catches of octopus were usually retained, but the other main invertebrate bycatch taxa (the shrimp *Acanthephyra quadrispinosa*, sea pens (Pennatulacea), anemones, and sponges) were all fully discarded.

The variability in the level of discards per tow for QMS species, non-QMS species and all species combined, with respect to some of the available variables are explored in Figures 11–13. The level of total discards from 1990–91 to 2013–14 was highly variable, ranging from 0 to 35 t per tow (Figure 11a). The quantity of total discards, QMS discards, and non-QMS discards was either constant or decreased slightly with increasing net depth, and increased slightly with longer duration tows. Total discards per tow varied among vessels and tended to be less for larger vessels; total discards per tow was highly variable before 2003–04 but since then has been more constant at a level of about 10–20 kg. Median values of total discards are extremely low for some levels of the variables examined, due to large numbers of zero discards (42% overall), but higher discard rates are shown for area WCNI, and Korean vessels (Figure 11a and 11b). Where meal processing plants are used, rates of total discard, QMS discards, and non-QMS discards are all lowered.

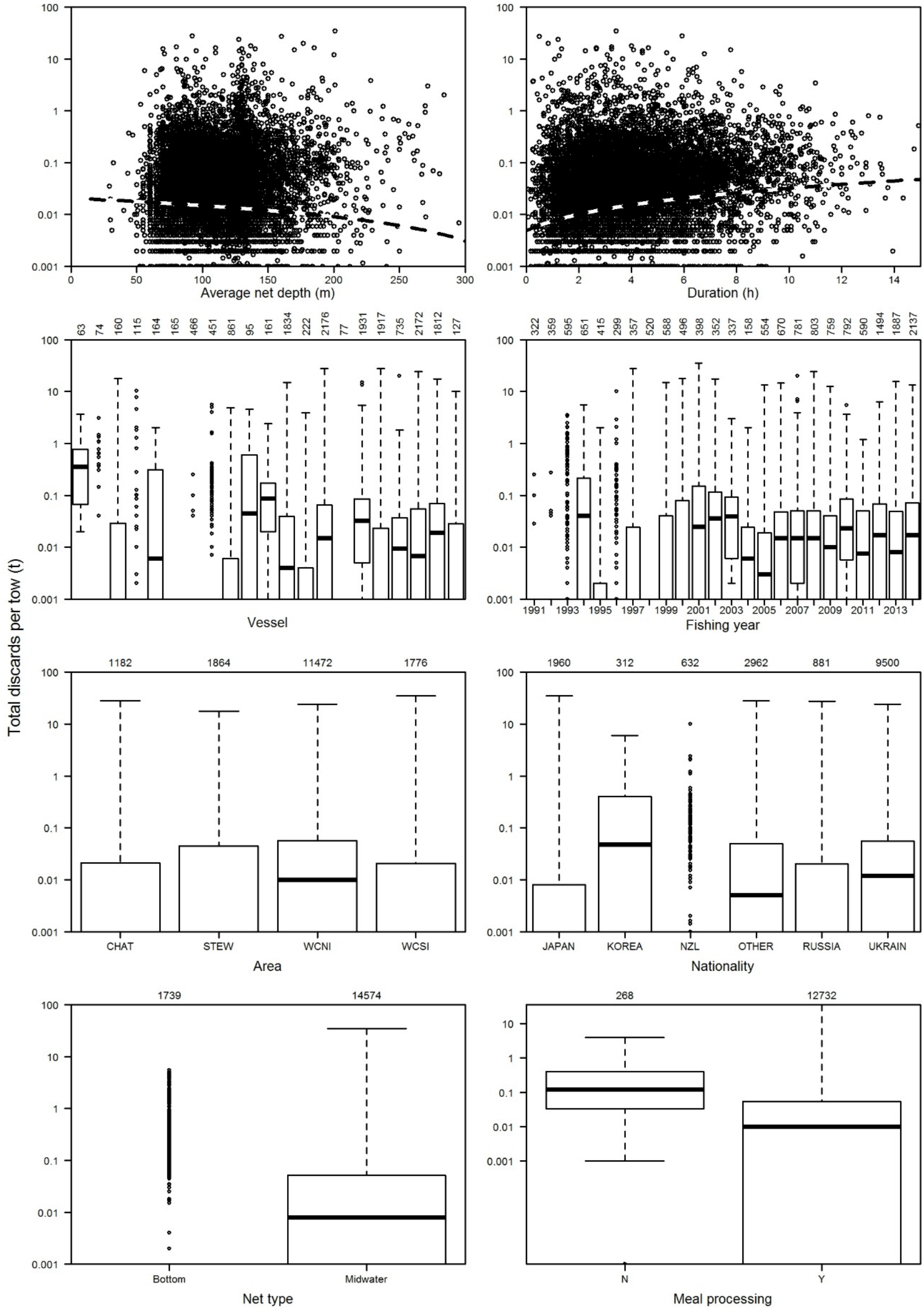

Figure 11a: ALL YEARS: total observed discards (all species) in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

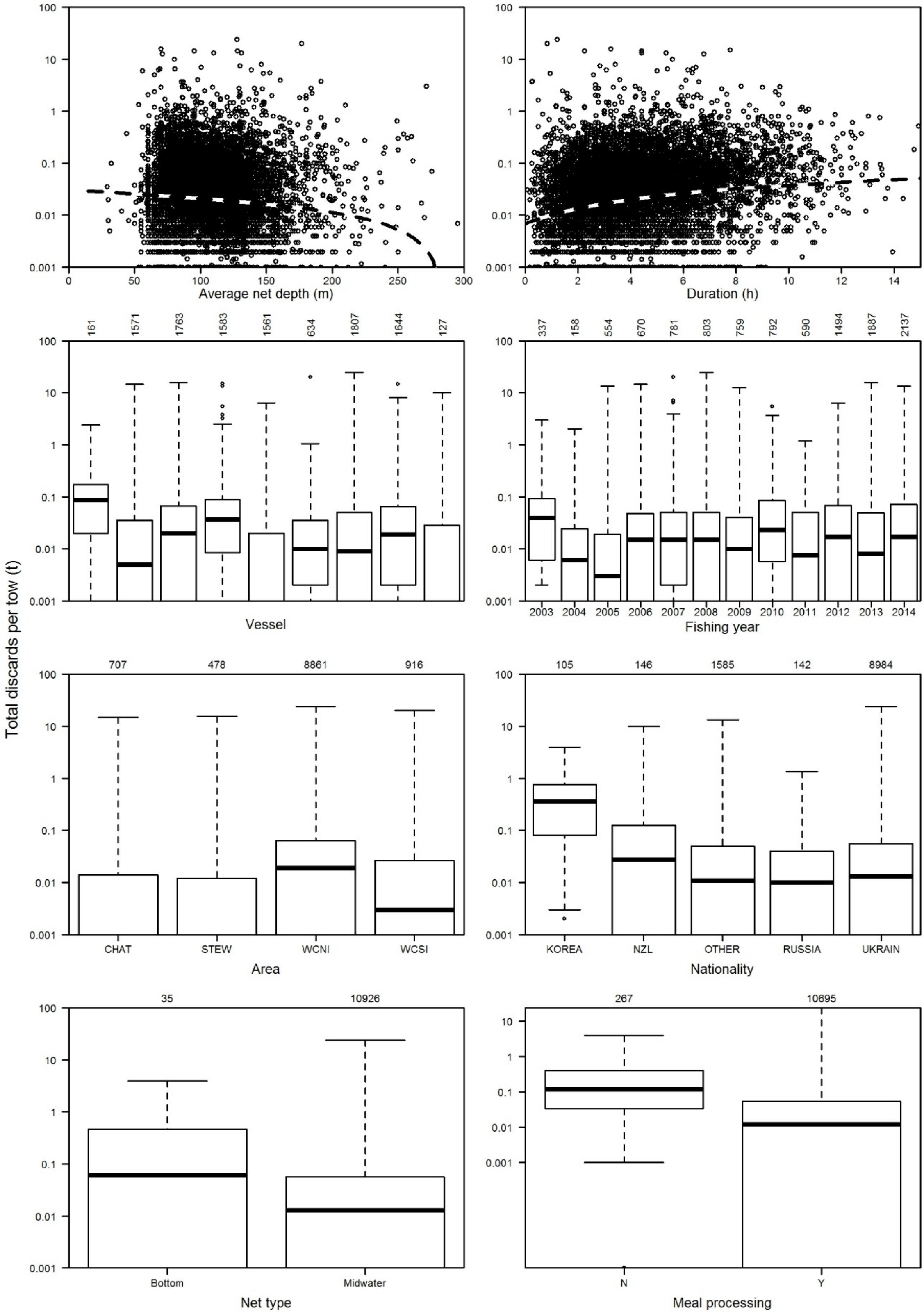

Figure 11b: 2002–03 to 2013–14 only: total observed discards (all species) in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

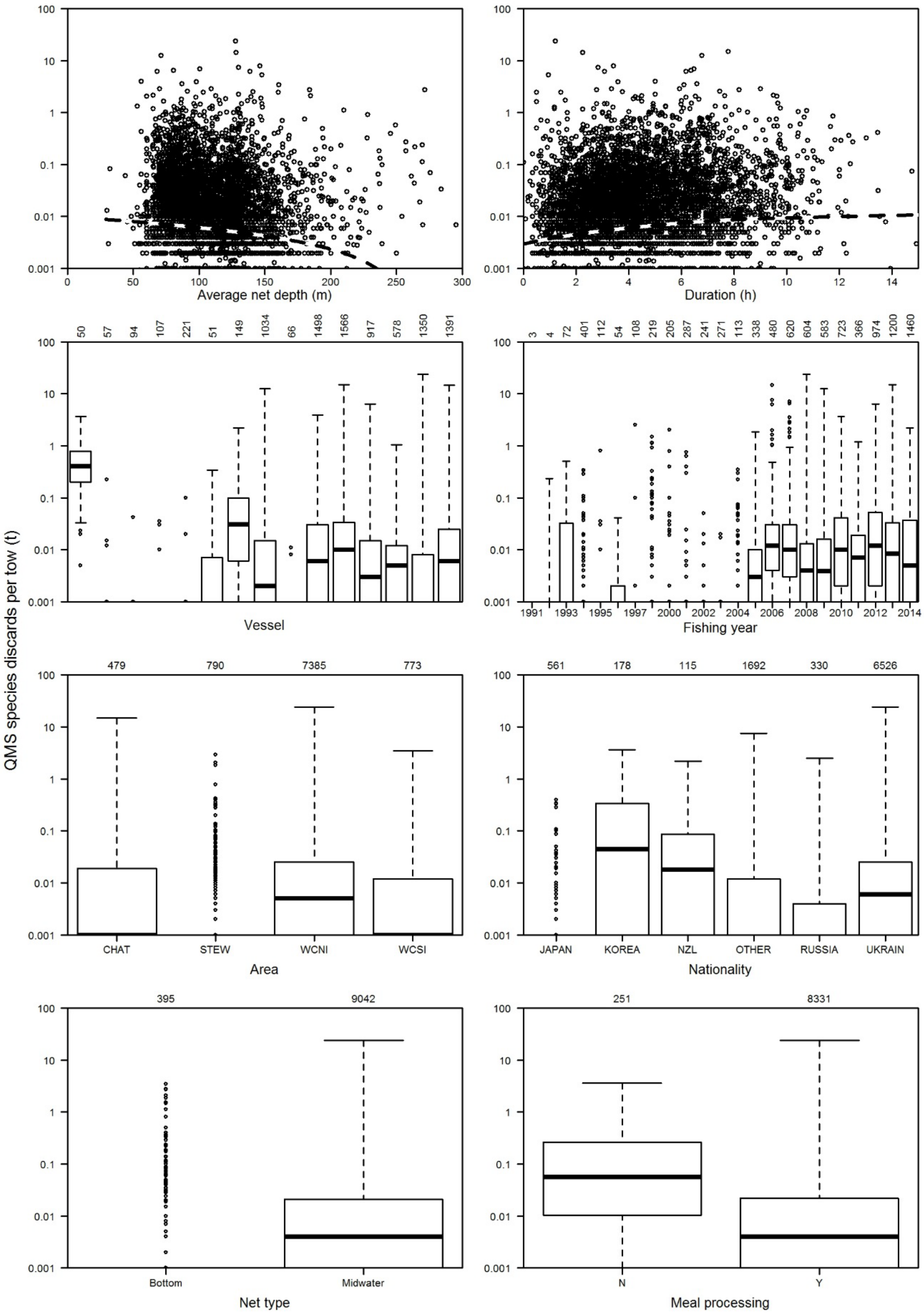

Figure 12a: ALL YEARS: QMS species discards in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

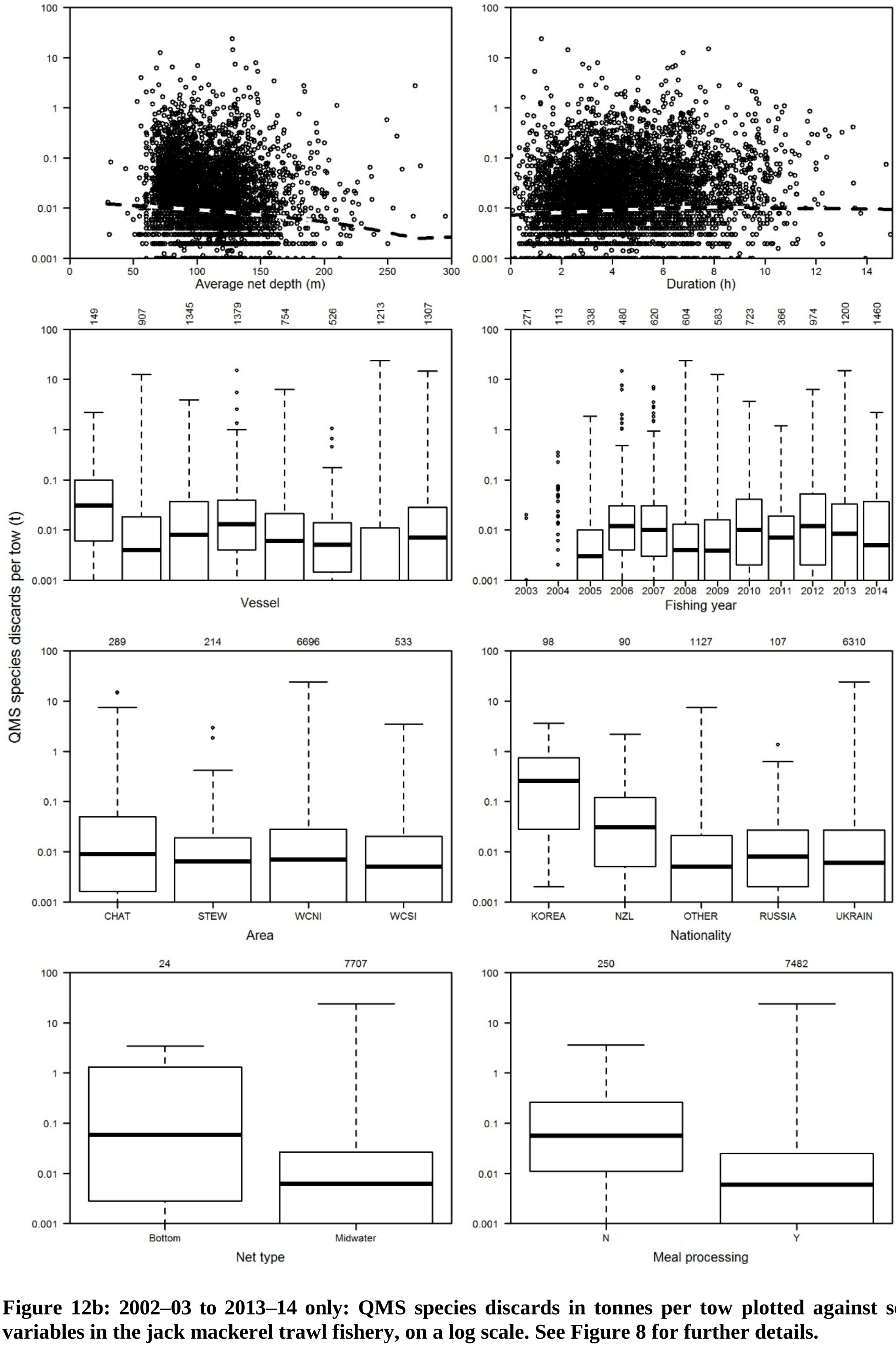

Figure 12b: 2002–03 to 2013–14 only: QMS species discards in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

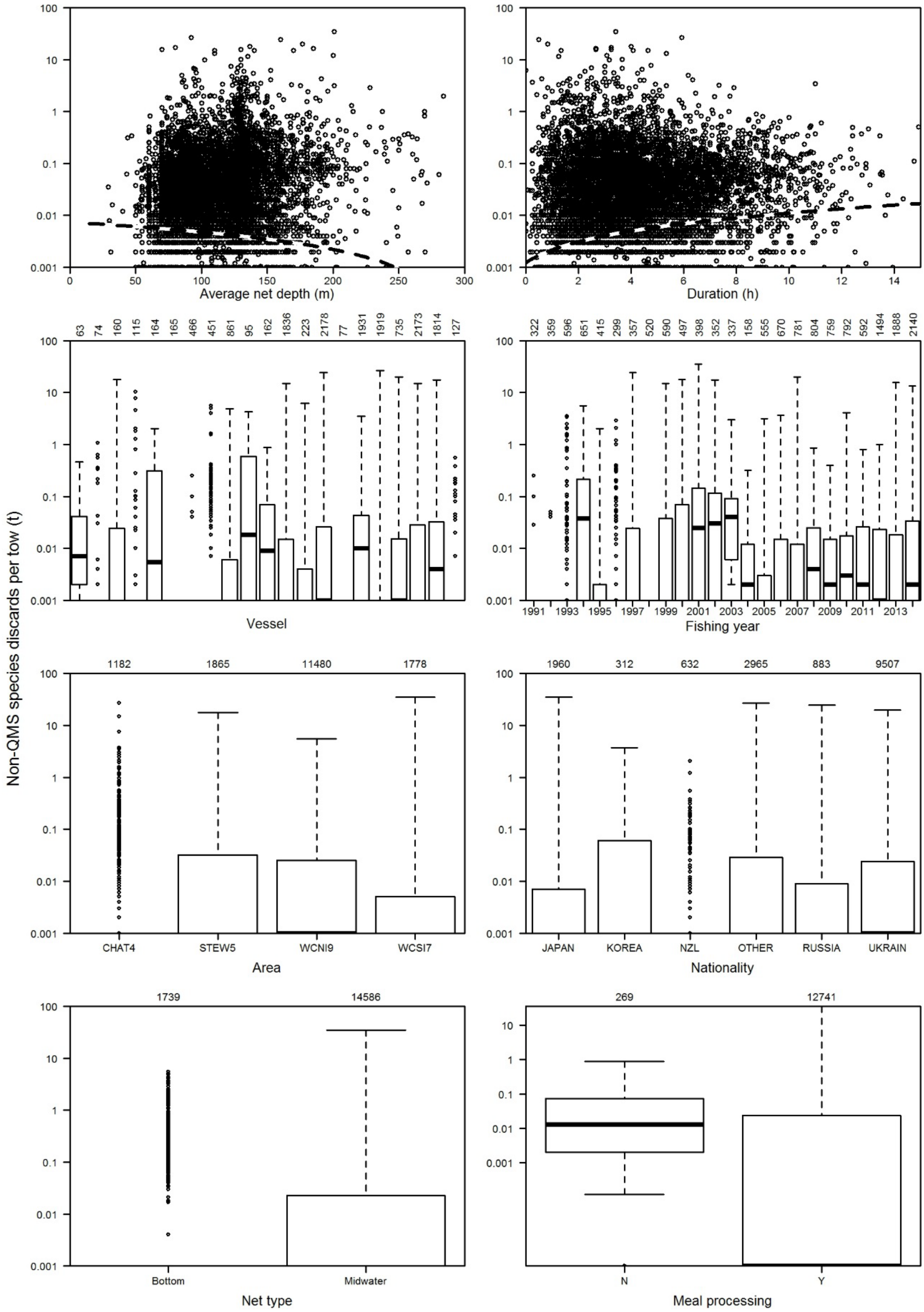

Figure 13a: ALL YEARS: Non-QMS species discards in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

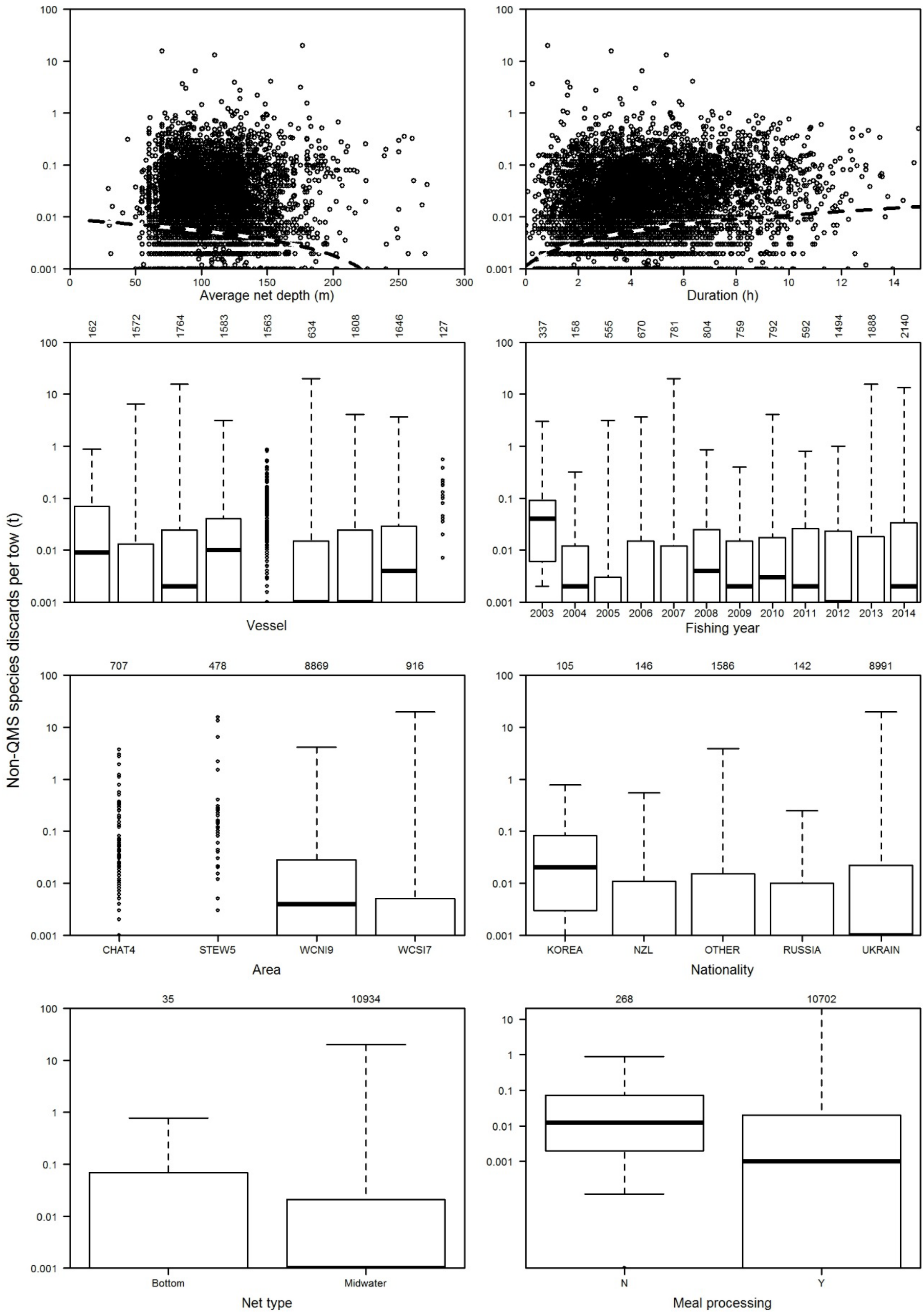

Figure 13b: 2002–03 to 2013–14 only: Non-QMS species discards in tonnes per tow plotted against selected variables in the jack mackerel trawl fishery, on a log scale. See Figure 8 for further details.

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. For the ratio method the variance associated with these estimates was calculated using the bootstrap procedure described in Section 2.4. Average bycatch rates across all areas in each year were calculated to apply to the small amount of fishing effort in areas outside of the four main areas.

This process can also provide some insight as to how bycatch rates vary between the different regions of the jack mackerel trawl 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 calculation of bycatch ratios for several year/area combinations borrowed data from adjacent years, as described in Section 2.4. The total number of years of data required for each stratum is shown in Table 5. In most years there were sufficient observer data from the west coast fisheries to avoid borrowing data from other years, but in areas CHAT and STEW records from the two adjacent years were frequently required, especially in the earlier part of the time series. In the worst instances, low coverage in area STEW in the mid-2000s required accumulating data from 5 or 7 years to meet the target of 25 records (Table 5).

Table 5: Number of years of observer data required to provide more than 25 records for bycatch and discard rate calculations.

Fishing year	Area			
	CHAT	STEW	WCNI	WCSI
2002–03	1	1	1	1
2003–04	3	3	1	3
2004–05	3	5	1	3
2005–06	1	7	1	3
2006–07	3	5	1	1
2007–08	3	3	1	1
2008–09	3	1	1	1
2009–10	3	1	1	1
2010–11	3	1	1	1
2011–12	1	1	1	1
2012–13	1	1	1	1
2013–14	1	1	1	1

Median bycatch rates of QMS species were consistently highest in STEW (about 7500–12 000 kg/tow), and in most years were lowest in WCNI (2500–6000 kg/tow) (Figure 14). Bycatch rates of non-QMS species were always lower than QMS species, and highly variable, ranging from about 20–3500 kg/tow; rates were highest in CHAT and WCSI up until 2008–09, when they decreased substantially in each area. This decrease was likely to have been associated with the introduction of redbait (*Emmelichthys nitidis*), one of the main non-QMS bycatch species, into the QMS in 2009. Although this shift resulted in a decrease in non-QMS catch rates in CHAT and WCSI in the following years, this was not fully matched by increases in QMS catch rates in these areas (especially WCSI). This is because for unknown reasons the total reported catch of redbait (across all fisheries) in the first two years after introduction into the QMS dropped to around a quarter to a third of that prior to introduction – although it has subsequently increased to about two-thirds (Ministry for Primary Industries 2015). Bycatch rates of invertebrate species were very low (below 1 kg/tow) in most years and areas, but were over 30 kg/tow in 2003–04 in WCNI and about 15 kg/tow in 2012–13 in CHAT.

Linear regression models were used to identify areas and species categories with significant trends in bycatch rates, with the models weighted by $1/n$, where n is the number of years of observer records combined to achieve a minimum of 25 records (see Table 5). Despite this weighting the calculated trends are partially influenced by these combinations and are presented as only a general indicator of temporal changes in bycatch rates. Results indicated a mixture of increasing and decreasing bycatch rates over time in the QMS and non-QMS species categories, with significant decreasing trends ($p<0.01$) identified for non-QMS species in CHAT and WCSI. Regressions showed increasing trends for invertebrate species in all areas, significantly so in STEW where the rate of invertebrate bycatch rose from less than 1 g per tow before 2006–07 to a mean of about 160 g per tow after 2009–10 (Table 6).

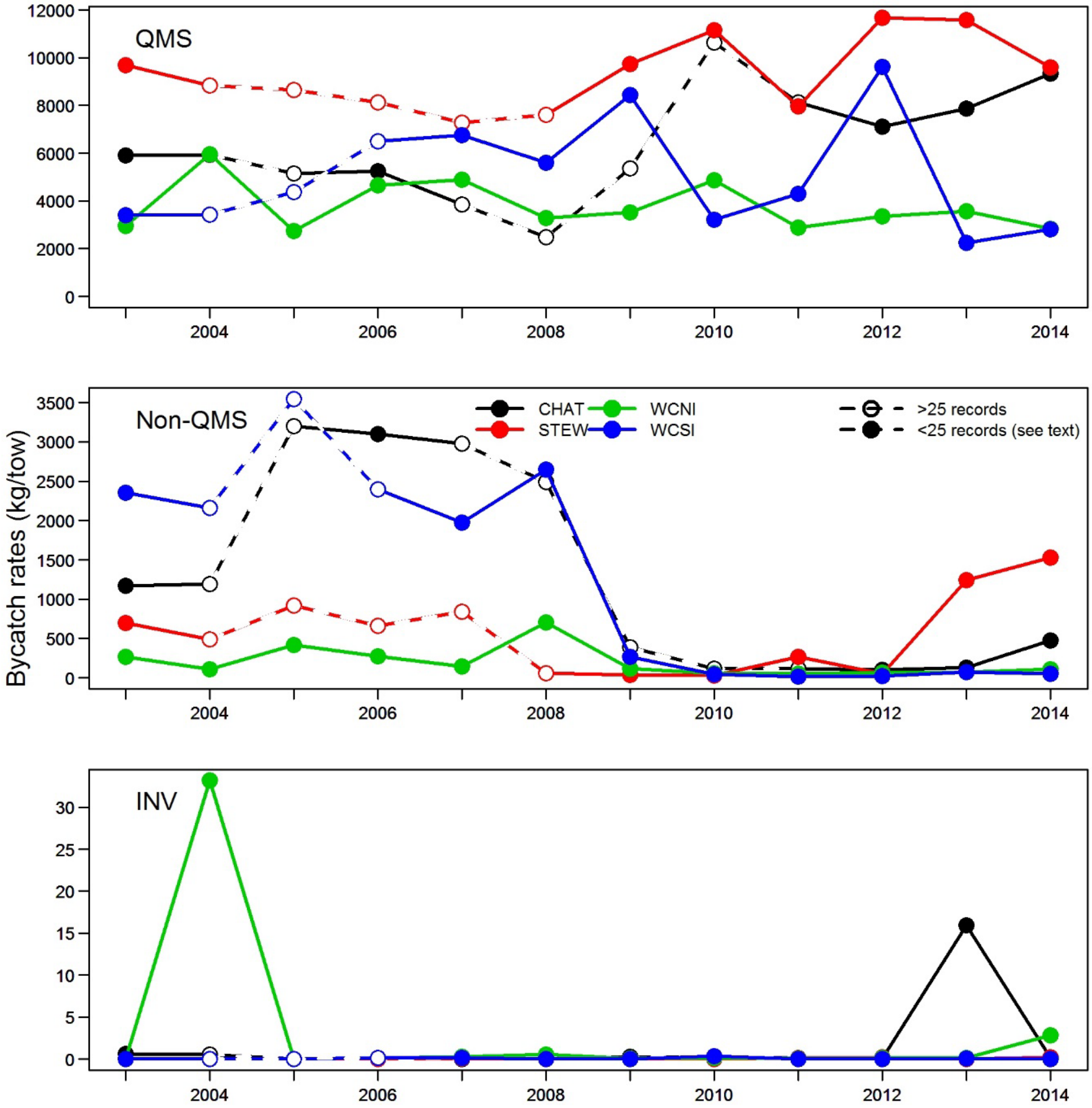

Figure 14: Annual bycatch rates by species category and areas used for stratification, in the jack mackerel trawl fishery. Bycatch rates are the median of the bootstrap sample of 1000. Filled dots and solid lines indicate periods during which there were sufficient observed trawls (over 25) to calculate an individual discard rate for the area, otherwise dots are unfilled and lines are dashed and discard rates were calculated using additional records from between 3 and 7 adjacent years (average 3.5, see Table 5) as required to obtain at least 25 records.

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 0.01 (generally considered highly significant) are shown in bold.

Species category	Area	Slope	*p*
QMS	CHAT	0.049	0.041
QMS	STEW	0.014	0.269
QMS	WCNI	-0.021	0.361
QMS	WCSI	-0.023	0.608
Non-QMS	**CHAT**	**-0.250**	**0.007**
Non-QMS	STEW	0.006	0.965
Non-QMS	WCNI	-0.136	0.040
Non-QMS	**WCSI**	**-0.499**	**0.001**
Invertebrates	CHAT	0.393	0.200
Invertebrates	**STEW**	**0.755**	**<0.001**
Invertebrates	WCNI	0.024	0.895
Invertebrates	WCSI	0.422	0.157

3.4.2 Annual bycatch levels

Total estimated annual bycatch in each species category, for the two estimation methods, is shown in Tables 7a and 7b, and Figure 15. There were only small differences in the estimated bycatch between methods, and no consistent direction in these small differences was evident (Figure 15). The main difference between methods was in the size of the confidence intervals around the estimates, usually smaller for the statistical model method.

The estimated annual bycatch of QMS species ranged from a low of about 6500 t (in 2010–11) to a high of about 14 100 t (in 2003–04). Although QMS bycatch is variable from year to year, there is a slight decreasing trend over time (Figure 15, Table 7a). The majority of the total QMS bycatch (about 75% overall) is caught in area WCNI in each year (Tables 8a and 8b). The remainder is split fairly evenly between the three other main fishery areas, but in differing proportions from year to year. Areas outside of the four main fisheries account for 20 t or less of QMS bycatch in all years except 2006–07 (60 t).

The estimated annual bycatch of non-QMS species was much lower than that of QMS species in each year, ranging from 130 t (in 2010–11 and 2011–12) to about 2700 t (in 2007–08) (Tables 9a and 9b). In line with the pattern in bycatch rates shown for non-QMS species (see Figure 14) total annual bycatch in this category sharply decreases after 2007–08 (Table 7a), as a result of the introduction of the main component of this category (redbait) into the QMS (see Section 3.4.1). In contrast to QMS bycatch, area WCNI accounts for only about 45% of the total non-QMS bycatch over all years. The remainder is fairly evenly split between WCSI and CHAT, with non-QMS bycatch in STEW accounting for only about 6–12% overall (depending on the model), although catches have been relatively higher there in the last few years (Tables 9a and 9b).

Invertebrate species were only a very small component of the total annual bycatch, amounting to less than 1 t in all but three years when estimated using the ratio method (Table 7a). The 2003–04 fishing year was an exception to this, with an estimated 75 t of invertebrate species caught. Estimated bycatch of invertebrate species was zero or close to zero in most areas in most years, the exception being a catch of about 70 t in WCNI in 2003–04 (Tables 10a and 10b). Inspection of the raw observer data shows that this high level of invertebrate catch stems from several observations of large catches of jellyfish off the North Island west coast in the summer of 2003–04.
Bycatch of spiny dogfish ranged from 20–30 t to 210–320 t per year (depending on model type), and over all years accounted for about 1% of the total bycatch (Figure 15, Tables 7a and 7b). Spiny dogfish were

caught in all areas, but the highest catches were in WCNI and CHAT (Tables 11a and 11b). There was no obvious trend in catches over time in any separate area or in all areas combined.

Total bycatch (all categories combined) shows a similar pattern to QMS species bycatch as it was dominated by that category, but the sharp drop in non-QMS bycatch in the latter half of the time series slightly intensifies the trend of decreasing bycatch seen in QMS species (Figure 15). Total annual bycatch ranged from a low of about 6650 t in 2010–11 to a high of about 16 500–18 800 t (depending on model type) in 2005–06. The total bycatch estimates of Anderson (2007) are similar to the current estimates for 2004–05 but somewhat lower for the previous two years, with confidence intervals not overlapping for 2003–04 (Figure 15). Total bycatch is weakly correlated with jack mackerel landings (correlation coefficient = 28%), but highly correlated with effort (correlation coefficient = 73%) as may be expected with effort having decreased in this fishery between 2005–06 and 2010–11. Total bycatch is greatest in WCNI in each year, this area accounting for about 70% of the total bycatch across all years. The remaining component of total bycatch is fairly evenly split among the three other main areas, in varying ratios over time (Tables 12a and 12b). Total bycatch from outside these main areas is negligible, generally less than 55 t.

Table 7a: Estimates of total annual bycatch rounded to the nearest 10 t (except for invertebrates, rounded to the nearest tonne) in the jack mackerel trawl fishery for the species categories QMS, non–QMS, invertebrates, SPD, and overall, based on the RATIO METHOD; 95% confidence intervals in parentheses.

	QMS		Non-QMS		INV		SPD		Total bycatch	
2002–03	11150	(9700–12770)	1920	(1250–2980)	0	(0–0)	170	(130–240)	13070	(10950–15750)
2003–04	14100	(8980–18070)	430	(250–710)	75	(5–185)	20	(10–40)	14600	(9230–18960)
2004–05	7280	(6400–8280)	1390	(860–2600)	0	(0–0)	70	(40–130)	8670	(7260–10880)
2005–06	13930	(11370–17620)	2560	(1610–3750)	0	(0–0)	320	(110–660)	16490	(12980–21370)
2006–07	13900	(12650–15270)	1540	(1210–1910)	0	(0–0)	200	(120–340)	15440	(13860–17180)
2007–08	9110	(8070–10390)	2680	(1700–4100)	0	(0–0)	80	(50–120)	11790	(9770–14490)
2008–09	9270	(8370–10210)	300	(250–380)	0	(0–0)	70	(50–160)	9570	(8620–10590)
2009–10	12460	(9940–16010)	150	(120–190)	0	(0–0)	110	(80–170)	12610	(10060–16200)
2010–11	6530	(5720–7350)	130	(110–170)	0	(0–0)	90	(50–260)	6660	(5830–7520)
2011–12	8930	(8690–9190)	130	(120–150)	0	(0–0)	130	(110–160)	9060	(8810–9340)
2012–13	9090	(9000–9200)	300	(290–320)	4	(4–4)	110	(110–110)	9390	(9290–9520)
2013–14	9640	(9510–9800)	550	(530–570)	4	(4–4)	100	(100–100)	10190	(10040–10370)

Table 7b: Estimates of total annual bycatch (t) in the jack mackerel trawl fishery for the species categories QMS, non–QMS, invertebrates, SPD, and overall, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	QMS		Non–QMS		INV		SPD		Total bycatch	
2002–03	11006	(9716–11928)	1717	(1092–2642)	0	(0–1)	163	(119–214)	12897	(11517–14338)
2003–04	14450	(10899–17431)	250	(131–401)	73	(5–159)	32	(15–50)	14907	(11974–17661)
2004–05	7109	(6351–7906)	1180	(707–1867)	0	(0–0)	68	(42–94)	8352	(7290–9374)
2005–06	16728	(14993–18399)	2775	(1816–3740)	1	(0–2)	145	(93–204)	18775	(16956–20906)
2006–07	14859	(13679–16357)	1630	(1141–2126)	1	(0–3)	209	(118–322)	16303	(14966–17579)
2007–08	9954	(8985–10851)	2570	(1730–3601)	2	(1–3)	54	(42–70)	12611	(11489–13993)
2008–09	9538	(8654–10466)	333	(262–443)	0	(0–0)	89	(35–169)	9860	(8932–10567)
2009–10	12898	(11605–14482)	136	(112–163)	0	(0–1)	106	(75–147)	13126	(11569–14528)
2010–11	6467	(5735–7371)	123	(95–148)	0	(0–0)	106	(35–241)	6632	(5926–7503)
2011–12	8832	(8356–9301)	154	(126–179)	0	(0–0)	120	(102–143)	9032	(8430–9617)
2012–13	9054	(8536–9671)	292	(213–370)	4	(0–11)	113	(91–141)	9413	(8862–9914)
2013–14	9280	(8581–9900)	527	(425–644)	5	(3–8)	114	(89–140)	9805	(9188–10451)

Table 8a: Estimates of annual QMS species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the RATIO method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	1100	(780–1460)	1950	(1400–2450)	6730	(5560–8290)	1300	(880–1760)	10	(10–10)	11150	(9700–12770)
2003–04	70	(40–90)	320	(210–440)	13450	(8360–17320)	270	(210–340)	0	(0–0)	14100	(8980–18070)
2004–05	50	(20–80)	440	(290–590)	6350	(5500–7370)	400	(270–590)	10	(0–10)	7280	(6400–8280)
2005–06	2360	(1240–4550)	680	(410–970)	9680	(7800–13000)	1090	(890–1340)	20	(20–30)	13930	(11370–17620)
2006–07	380	(200–690)	160	(60–250)	10450	(9240–11790)	2810	(2490–3250)	60	(50–80)	13900	(12650–15270)
2007–08	430	(250–670)	80	(50–120)	7210	(6210–8430)	1360	(870–1830)	20	(20–30)	9110	(8070–10390)
2008–09	380	(190–720)	760	(630–930)	6280	(5590–6940)	1830	(1320–2400)	0	(0–0)	9270	(8370–10210)
2009–10	570	(410–770)	800	(730–920)	10810	(8380–14400)	230	(190–360)	20	(20–30)	12460	(9940–16010)
2010–11	600	(500–720)	930	(620–1300)	4460	(3800–5150)	520	(320–720)	10	(10–20)	6530	(5720–7350)
2011–12	870	(740–1070)	1650	(1550–1760)	5330	(5190–5460)	1060	(950–1200)	10	(10–10)	8930	(8690–9190)
2012–13	1700	(1700–1700)	1080	(1080–1080)	5920	(5830–6040)	380	(370–400)	10	(10–10)	9090	(9000–9200)
2013–14	2860	(2800–2920)	1140	(1110–1170)	5010	(4900–5170)	620	(610–650)	10	(10–10)	9640	(9510–9800)

Table 8b: Estimates of annual QMS species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	1307	(1142–1456)	1716	(1513–1924)	6469	(5745–7097)	1500	(1272–1684)	14	(12–16)	11006	(9716–11928)
2003–04	157	(120–194)	673	(523–835)	13001	(9807–15615)	619	(473–763)	0	(0–0)	14450	(10899–17431)
2004–05	60	(52–70)	429	(370–505)	6266	(5523–6955)	348	(303–390)	7	(6–8)	7109	(6351–7906)
2005–06	5049	(4452–5726)	1191	(1025–1375)	9411	(8379–10424)	1032	(888–1183)	45	(40–51)	16728	(14993–18399)
2006–07	1326	(1174–1502)	319	(283–374)	10309	(9519–11351)	2772	(2465–3074)	133	(118–151)	14859	(13679–16357)
2007–08	1437	(1259–1626)	140	(121–161)	7227	(6548–7862)	1110	(983–1250)	41	(37–46)	9954	(8985–10851)
2008–09	651	(569–767)	936	(830–1066)	6810	(6193–7428)	1141	(980–1291)	0	(0–0)	9538	(8654–10466)
2009–10	646	(564–732)	1077	(944–1282)	10687	(9598–12002)	451	(394–505)	36	(33–42)	12898	(11605–14482)
2010–11	505	(429–583)	1019	(876–1203)	4459	(3937–5054)	469	(405–542)	14	(12–16)	6467	(5735–7371)
2011–12	1094	(998–1212)	1536	(1412–1684)	5664	(5327–5958)	529	(473–577)	9	(8–10)	8832	(8356–9301)
2012–13	1782	(1639–1970)	873	(779–981)	5605	(5245–5994)	785	(694–865)	8	(8–9)	9054	(8536–9671)
2013–14	2219	(2023–2438)	1050	(936–1179)	5133	(4688–5516)	871	(773–960)	7	(7–8)	9280	(8581–9900)

Table 9a: Estimates of annual non-QMS species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the RATIO method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	220	(100–390)	140	(60–320)	610	(320–1080)	910	(420–1850)	0	(0–0)	1920	(1250–2980)
2003–04	10	(10–30)	20	(0–50)	240	(110–480)	150	(70–300)	0	(0–0)	430	(250–710)
2004–05	30	(10–50)	40	(10–130)	980	(480–2160)	320	(130–650)	0	(0–0)	1390	(860–2600)
2005–06	1380	(600–2400)	90	(40–200)	570	(260–1140)	460	(290–660)	10	(0–10)	2560	(1610–3750)
2006–07	370	(190–570)	20	(0–80)	310	(230–400)	830	(590–1130)	20	(10–30)	1540	(1210–1910)
2007–08	390	(90–1020)	0	(0–0)	1570	(820–2750)	670	(350–1130)	10	(0–10)	2680	(1700–4100)
2008–09	30	(10–90)	0	(0–0)	210	(190–250)	60	(40–110)	0	(0–0)	300	(250–380)
2009–10	10	(0–10)	0	(0–0)	140	(120–190)	0	(0–10)	0	(0–0)	150	(120–190)
2010–11	10	(0–10)	30	(20–50)	90	(70–120)	0	(0–0)	0	(0–0)	130	(110–170)
2011–12	10	(10–30)	10	(10–30)	110	(110–120)	0	(0–0)	0	(0–0)	130	(120–150)
2012–13	30	(30–30)	120	(120–120)	140	(130–160)	10	(10–10)	0	(0–0)	300	(290–320)
2013–14	150	(140–150)	190	(170–210)	190	(190–200)	10	(10–10)	0	(0–0)	550	(530–570)

Table 9b: Estimates of annual non-QMS species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	220	(128–355)	458	(280–643)	564	(335–851)	473	(245–787)	2	(2–4)	1717	(1092–2642)
2003–04	4	(2–8)	25	(11–43)	191	(101–314)	30	(15–51)	0	(0–0)	250	(131–401)
2004–05	14	(7–25)	139	(65–228)	880	(505–1492)	146	(81–233)	2	(1–3)	1180	(707–1867)
2005–06	1005	(627–1560)	361	(182–518)	1010	(660–1344)	389	(217–567)	9	(6–14)	2775	(1816–3740)
2006–07	170	(105–271)	63	(34–97)	718	(500–978)	663	(439–913)	17	(11–27)	1630	(1141–2126)
2007–08	475	(304–680)	70	(38–107)	1324	(898–1919)	687	(440–1023)	14	(9–20)	2570	(1730–3601)
2008–09	27	(18–40)	57	(35–78)	160	(122–220)	89	(61–120)	0	(0–0)	333	(262–443)
2009–10	10	(6–13)	24	(15–31)	90	(73–115)	12	(9–17)	0	(0–0)	136	(112–163)
2010–11	11	(7–16)	35	(23–45)	57	(41–73)	20	(13–28)	0	(0–0)	123	(95–148)
2011–12	22	(15–32)	46	(30–62)	65	(52–80)	20	(14–27)	0	(0–0)	154	(126–179)
2012–13	68	(46–97)	50	(29–72)	118	(83–156)	56	(39–77)	0	(0–0)	292	(213–370)
2013–14	142	(105–189)	102	(57–153)	177	(140–219)	105	(73–136)	0	(0–1)	527	(425–644)

Table 10a: Estimates of annual INVERTEBRATE species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the RATIO method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	0.12	(0.02–0.02)	0.00	(0–0)	0.11	(0.01–0.01)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2003–04	0.00	(0–0)	0.00	(0–0)	74.71	(4.81–184.81)	0.00	(0–0)	0.00	(0–0)	75	(5–185)
2004–05	0.00	(0–0)	0.00	(0–0)	0.01	(0.01–0.01)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2005–06	0.00	(0–0)	0.00	(0–0)	0.41	(0.11–0.11)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2006–07	0.00	(0–0)	0.00	(0–0)	0.60	(0.2–0.2)	0.04	(0.04–0.04)	0.00	(0–0)	0	(0–0)
2007–08	0.00	(0–0)	0.00	(0–0)	1.35	(0.45–0.45)	0.01	(0.01–0.01)	0.00	(0–0)	0	(0–0)
2008–09	0.00	(0–0)	0.01	(0.01–0.01)	0.17	(0.07–0.07)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2009–10	0.01	(0.01–0.01)	0.00	(0–0)	0.43	(0.13–0.13)	0.03	(0.03–0.03)	0.00	(0–0)	0	(0–0)
2010–11	0.00	(0–0)	0.01	(0.01–0.01)	0.14	(0.04–0.04)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2011–12	0.01	(0.01–0.01)	0.02	(0.02–0.02)	0.17	(0.17–0.17)	0.00	(0–0)	0.00	(0–0)	0	(0–0)
2012–13	3.61	(3.61–3.61)	0.01	(0.01–0.01)	0.26	(0.26–0.26)	0.02	(0.02–0.02)	0.00	(0–0)	4	(4–4)
2013–14	0.06	(0.06–0.06)	0.02	(0.02–0.02)	4.95	(4.35–4.35)	0.01	(0.01–0.01)	0.00	(0–0)	4	(4–4)

Table 10b: Estimates of annual INVERTEBRATE species bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–1)
2003–04	2	(0–6)	0	(0–1)	70	(5–155)	0	(0–2)	0	(0–0)	73	(5–159)
2004–05	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2005–06	0	(0–1)	0	(0–0)	0	(0–1)	0	(0–0)	0	(0–0)	1	(0–2)
2006–07	0	(0–1)	0	(0–0)	1	(0–2)	0	(0–0)	0	(0–0)	1	(0–3)
2007–08	0	(0–2)	0	(0–0)	1	(1–2)	0	(0–0)	0	(0–0)	2	(1–3)
2008–09	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2009–10	0	(0–0)	0	(0–0)	0	(0–1)	0	(0–0)	0	(0–0)	0	(0–1)
2010–11	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2011–12	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2012–13	2	(0–7)	0	(0–0)	2	(0–4)	0	(0–0)	0	(0–0)	4	(0–11)
2013–14	2	(0–4)	0	(0–0)	3	(1–5)	0	(0–0)	0	(0–0)	5	(3–8)

Table 11a: Estimates of annual spiny dogfish (SPD) bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the RATIO method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	50	(18–108)	11	(2–32)	106	(81–151)	1	(0–0)	0	(0–0)	170	(130–240)
2003–04	3	(0–10)	3	(0–10)	17	(11–31)	0	(0–0)	0	(0–0)	20	(10–40)
2004–05	4	(0–10)	6	(2–12)	56	(23–103)	1	(0–0)	0	(0–0)	70	(40–130)
2005–06	251	(45–585)	8	(0–20)	53	(36–76)	3	(0–20)	1	(0–0)	320	(110–660)
2006–07	43	(16–106)	3	(0–10)	130	(69–259)	14	(7–37)	2	(0–0)	200	(120–340)
2007–08	35	(13–73)	1	(0–0)	37	(22–52)	2	(1–1)	0	(0–0)	80	(50–120)
2008–09	7	(0–20)	6	(4–14)	55	(35–145)	1	(0–0)	0	(0–0)	70	(50–160)
2009–10	4	(1–11)	1	(1–1)	106	(75–165)	1	(1–1)	0	(0–0)	110	(80–170)
2010–11	11	(2–32)	0	(0–0)	86	(50–240)	0	(0–0)	0	(0–0)	90	(50–260)
2011–12	34	(15–65)	2	(1–1)	84	(78–88)	5	(4–4)	0	(0–0)	130	(110–160)
2012–13	30	(30–30)	3	(3–3)	79	(78–78)	1	(1–1)	0	(0–0)	110	(110–110)
2013–14	14	(13–13)	1	(1–1)	83	(83–83)	1	(1–1)	0	(0–0)	100	(100–100)

Table 11b: Estimates of annual spiny dogfish (SPD) bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	37	(22–59)	8	(4–15)	112	(84–155)	6	(3–10)	0	(0–0)	163	(119–214)
2003–04	0	(0–1)	0	(0–0)	31	(15–49)	0	(0–0)	0	(0–0)	32	(15–50)
2004–05	1	(0–1)	1	(0–1)	66	(41–91)	0	(0–1)	0	(0–0)	68	(42–94)
2005–06	65	(33–100)	2	(1–4)	76	(55–103)	2	(1–3)	1	(0–1)	145	(93–204)
2006–07	34	(17–61)	1	(1–3)	158	(89–247)	11	(5–19)	3	(2–7)	209	(118–322)
2007–08	13	(8–19)	0	(0–0)	39	(31–51)	1	(1–2)	0	(0–1)	54	(42–70)
2008–09	10	(4–22)	2	(1–4)	75	(29–144)	2	(1–3)	0	(0–0)	89	(35–169)
2009–10	9	(5–15)	3	(1–5)	92	(64–129)	1	(1–2)	0	(0–0)	106	(75–147)
2010–11	14	(5–36)	4	(1–11)	86	(27–192)	1	(1–3)	0	(0–1)	106	(35–241)
2011–12	27	(17–40)	6	(3–12)	85	(72–99)	2	(1–3)	0	(0–0)	120	(102–143)
2012–13	37	(23–55)	3	(2–6)	71	(61–83)	2	(1–3)	0	(0–0)	113	(91–141)
2013–14	42	(27–63)	3	(1–5)	67	(52–80)	2	(1–2)	0	(0–0)	114	(89–140)

Table 12a: Estimates of TOTAL annual bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the RATIO method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	1313	(884–1854)	2095	(1456–2766)	7338	(5878–9368)	2204	(1294–3604)	13	(10–10)	13070	(10950–15750)
2003–04	78	(50–120)	339	(212–492)	13765	(8468–17978)	423	(282–642)	0	(0–0)	14600	(9230–18960)
2004–05	71	(34–134)	481	(300–720)	7330	(5985–9535)	723	(399–1239)	7	(0–10)	8670	(7260–10880)
2005–06	3738	(1841–6951)	771	(452–1172)	10252	(8059–14139)	1551	(1183–2003)	32	(20–40)	16490	(12980–21370)
2006–07	749	(387–1257)	179	(60–330)	10755	(9469–12189)	3646	(3082–4382)	79	(60–110)	15440	(13860–17180)
2007–08	825	(336–1686)	81	(52–122)	8785	(7030–11180)	2028	(1224–2964)	32	(20–40)	11790	(9770–14490)
2008–09	403	(198–808)	764	(626–926)	6486	(5773–7183)	1887	(1355–2505)	0	(0–0)	9570	(8620–10590)
2009–10	580	(409–779)	799	(726–916)	10942	(8492–14582)	237	(189–369)	23	(20–30)	12610	(10060–16200)
2010–11	613	(507–737)	963	(640–1350)	4547	(3865–5265)	527	(320–720)	12	(10–20)	6660	(5830–7520)
2011–12	886	(744–1094)	1661	(1556–1786)	5437	(5300–5580)	1059	(949–1199)	8	(10–10)	9060	(8810–9340)
2012–13	1736	(1736–1736)	1191	(1191–1191)	6057	(5960–6200)	392	(380–410)	7	(10–10)	9390	(9290–9520)
2013–14	3005	(2940–3070)	1333	(1278–1378)	5208	(5091–5371)	636	(619–659)	7	(10–10)	10190	(10040–10370)

Table 12b: Estimates of TOTAL annual bycatch (t) in the jack mackerel trawl fishery, by standard area, based on the STATISTICAL MODEL method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR		TOTAL	
2002–03	1549	(1340–1738)	2063	(1823–2339)	7366	(6565–8192)	1902	(1602–2149)	16	(14–18)	12897	(11517–14338)
2003–04	168	(133–206)	723	(560–894)	13310	(10725–15744)	706	(553–856)	0	(0–0)	14907	(11974–17661)
2004–05	73	(63–83)	527	(446–603)	7292	(6346–8183)	452	(378–520)	8	(7–9)	8352	(7290–9374)
2005–06	5771	(5080–6530)	1369	(1204–1564)	10312	(9335–11488)	1271	(1122–1470)	52	(46–59)	18775	(16956–20906)
2006–07	1476	(1310–1652)	360	(320–399)	11015	(9996–11887)	3304	(3000–3677)	147	(131–165)	16303	(14966–17579)
2007–08	1859	(1642–2100)	183	(161–212)	8975	(8110–10079)	1540	(1353–1733)	53	(47–60)	12611	(11489–13993)
2008–09	685	(606–766)	996	(870–1104)	6891	(6297–7366)	1287	(1113–1412)	0	(0–0)	9860	(8932–10567)
2009–10	677	(579–780)	1144	(963–1276)	10760	(9455–11962)	506	(430–577)	39	(33–45)	13126	(11569–14528)
2010–11	528	(469–607)	1081	(924–1251)	4484	(3991–5082)	524	(454–602)	15	(13–17)	6632	(5926–7503)
2011–12	1139	(1031–1239)	1622	(1450–1768)	5674	(5327–6038)	588	(520–650)	9	(8–10)	9032	(8430–9617)
2012–13	1885	(1713–2042)	935	(854–1017)	5696	(5337–6026)	889	(782–967)	9	(8–10)	9413	(8862–9914)
2013–14	2378	(2194–2573)	1135	(1020–1232)	5281	(4920–5644)	1003	(894–1113)	8	(7–8)	9805	(9188–10451)

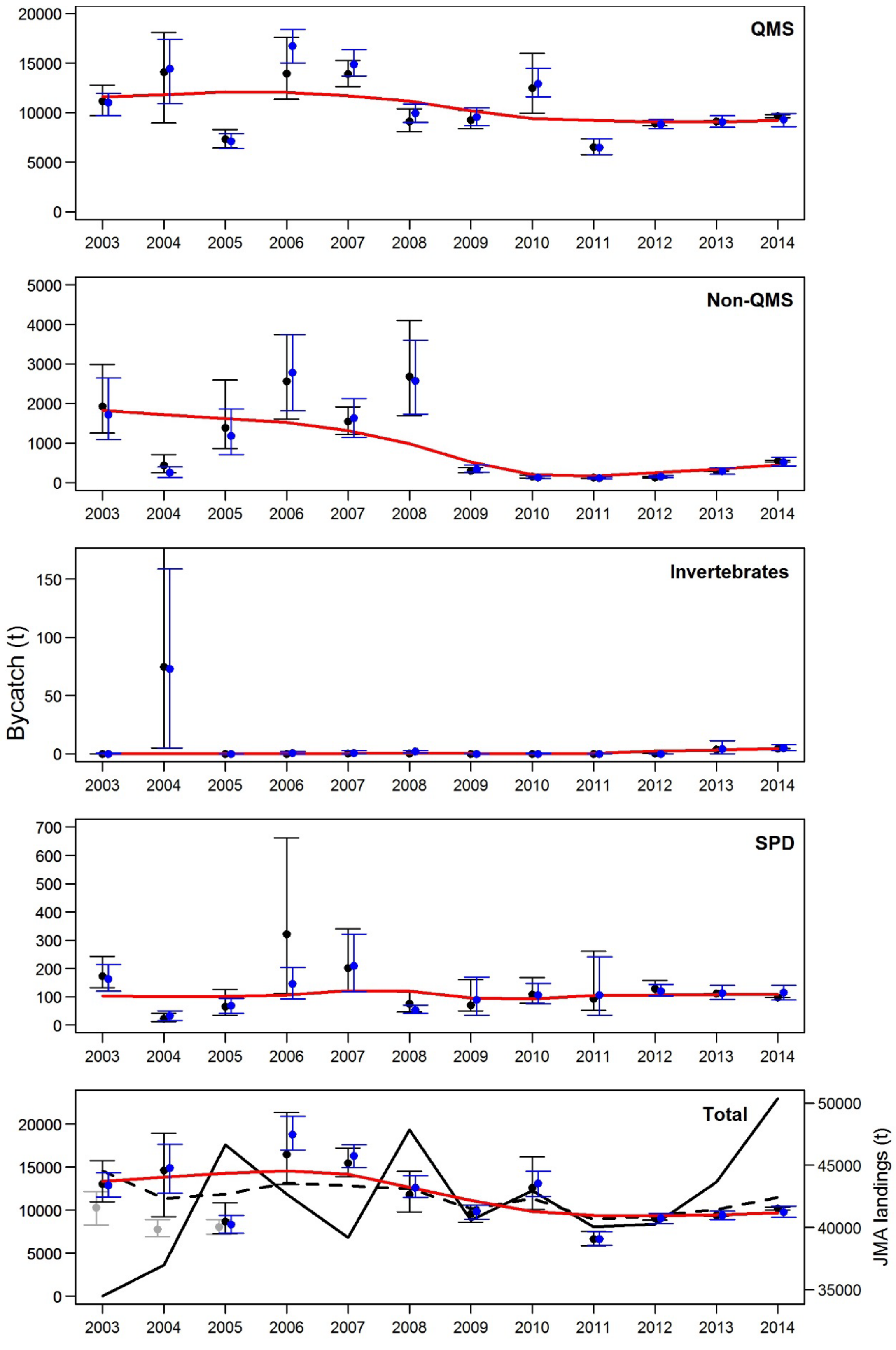

Figure 15: Annual estimates of bycatch in the jack mackerel trawl fishery, for QMS species, non-QMS species, invertebrates, and overall (Total) for 2002–03 to 2013–14: black dots, ratio method; blue dots, statistical model method. Also shown (in grey on the 'Total' panel) are earlier estimates of total bycatch calculated for 2002–03 to 2004–05 (from Anderson 2007). 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 landings of jack mackerels, and the dashed line shows annual effort (number of tows), scaled to have mean equal to that of total bycatch.

Total annual bycatch calculated directly from commercial catch records (by summing the difference between the recorded total catch and jack mackerel catch for each trawl (TCP and TCE type forms) or group of trawls (CEL type forms)) was lower than the observer data-based estimate in 9 of the 12 years examined, but only outside of the 95% confidence intervals of the observer data-based estimates in 5 of the 12 years (Figure 16, Table 13). Overall, the total catch record-based annual bycatch for the 21-year period was about 89% of the observer data-based bycatch and the general pattern over time was similar between the two estimates, with a correlation of about 80%.

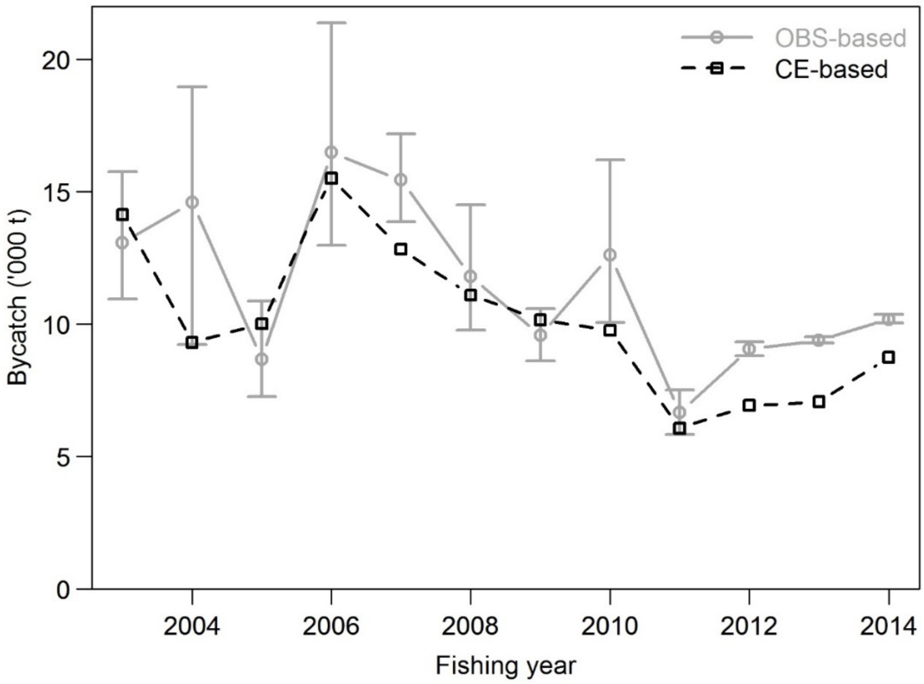

Figure 16: Total annual bycatch in the jack mackerel trawl fishery from scaled up observer catch rates (OBS-based, ratio method) and commercial catch effort records (CE-based).

Table 13: Total annual bycatch estimates for the jack mackerel trawl fishery, based on catch effort records, compared with the ratio method observer-based estimates. Estimates are derived by summing the difference between the recorded total catch and jack mackerel catch for each trawl (TCP and TCE type forms) or group of trawls (CEL type forms).

Fishing year	Total bycatch (t)	% of observer-based estimate
2002–03	14 150	108
2003–04	9 400	64
2004–05	10 016	116
2005–06	15 540	94
2006–07	12 861	83
2007–08	11 134	94
2008–09	10 258	107
2009–10	9 766	77
2010–11	6 077	91
2011–12	7 009	77
2012–13	7 066	75
2013–14	8 760	86

3.4.3 Trends in annual bycatch

Slope values from the linear regressions on bycatch levels over time indicate that bycatch decreased over time in the QMS and non-QMS species categories and increased for spiny dogfish and invertebrates. None of these trends were significant (Table 14). Although changes in annual bycatch in these species categories may not necessarily be strongly linear these regressions are useful, in conjunction with the locally weighted polynomials fitted to the plots in Figure 15, for highlighting any short or long term trends.

Table 14: Summary of results of linear 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 0.01 (generally considered highly significant) are shown in bold.

Species category	Slope	*p*
QMS	-0.029	0.189
Non-QMS	-0.202	0.030
Invertebrate	0.140	0.520
Spiny dogfish	0.017	0.780
Total	-0.041	0.066

3.4.4 Cross-validation

A cross-validation exercise was performed to investigate the predictive ability of the statistical modelling approach. This involved fitting the model to a subset of the observer data, and using the model fit to predict the total observed bycatch, which is of course known.

For the cross-validation we used the total observer bycatch data (i.e. QMS, non-QMS and INV combined), deleted 10% of the data at random across the whole data set, refitted the model, and compared model-based predictions of the total bycatch by year and area to the actual observer data. This was repeated for 10 random samples from the data with non-overlapping deletions. The results of this procedure are shown in Figure 17, indicating that the model is able to accurately reproduce the empirical estimates, and is robust to small random reconfigurations of the data used during the model fit.

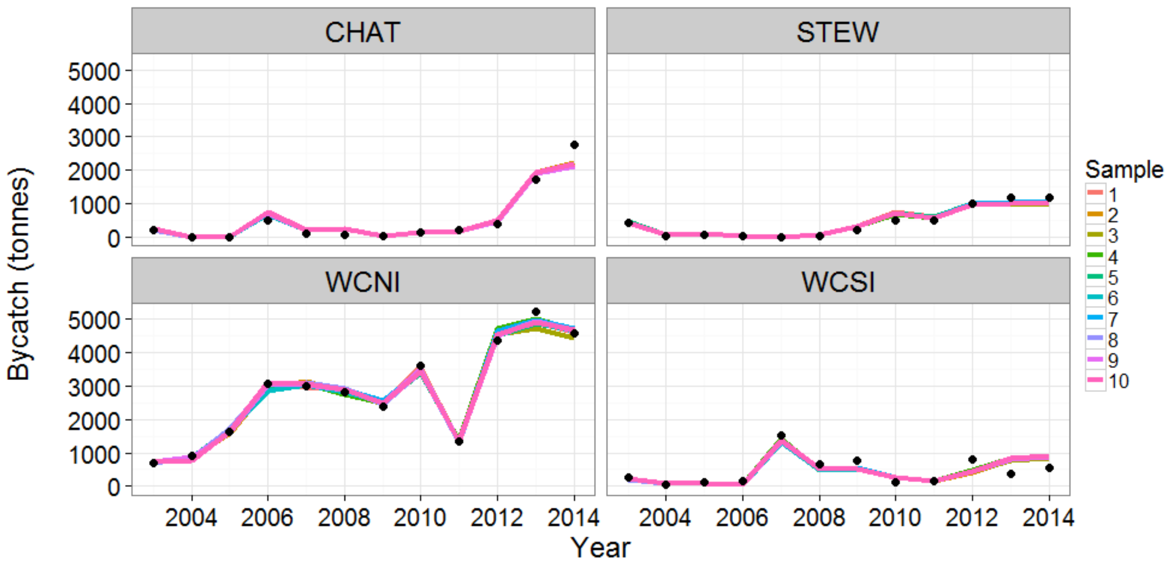

Figure 17: Results of a cross validation exercise for total observer bycatch showing the empirical bycatch values (points) and predictions (lines) from each of ten data subsamples with non-overlapping deletions of 10% of the observer data.

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. For the ratio method, the variance associated with the discard estimates was calculated using the bootstrap methods described in Section 2.4. Average discard rates across all areas in each year were calculated to apply to the small amount of fishing effort in areas outside of the four main areas. As with bycatch, the limited spread of observer effort required discard rates for several year/area combinations to include data from adjacent years, as described in Section 2.4 and detailed in Table 5.

Median discard rates of jack mackerel were generally very low, mostly close to zero and less than 10 kg per tow in all years and areas except for STEW in 2012–13 (Figure 18). Values greater than zero were restricted to the latter half of the time period (2009–10 to 2013–14).

Discard rates of QMS species ranged from close to zero (in all areas in 2002–03) to a maximum of slightly over 500 kg per tow (in CHAT in 2004–05 and 2005–06). Apart from these few years in CHAT, discard rates were mostly similar among areas and were generally below 100 kg per tow.

Discard rates of non-QMS species were generally similar to those of QMS species, mostly being less than 100 kg per tow, but occasionally higher, with a maximum of about 400 kg per tow estimated for 2002–03 and 2003–04 in CHAT. Aside from these two high values, there was no obvious overall difference in discard rates between areas.

Discard rates for invertebrates are virtually identical to bycatch for this group (see Figure 15), because most invertebrates were discarded. As with bycatch, patterns of invertebrate discard rates may have been influenced by changes in observer recording practices over time.

Regression modelling was used to examine trends in discard rates in the same way (and with the same limitations) as described for bycatch (see Section 3.4.1). Results indicated increasing discard rates over time in all areas for the JMA and QMS species category, but significantly so only for JMA in WCSI (Table 15). For the non-QMS and INV species categories there was a mixture of increasing and decreasing rates over time, with a significant (decreasing) trend only for non-QMS species in CHAT.

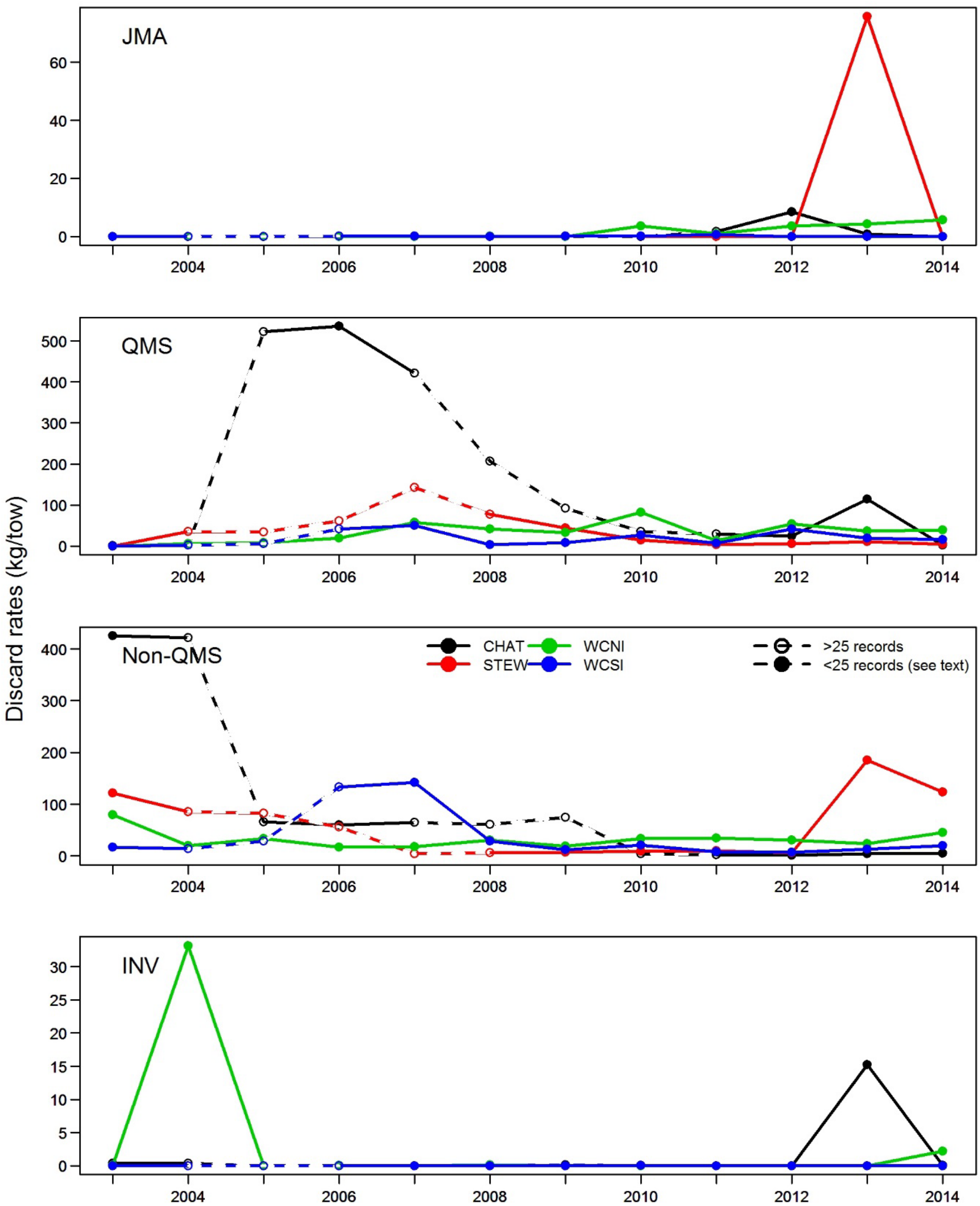

Figure 18: Annual discard rates by species category and areas used for stratification, in the jack mackerel trawl fishery. Discard rates are the median of the bootstrap sample of 1000. Filled dots and solid lines indicate periods during which there were sufficient observed trawls (over25) to calculate an individual discard rate for the area, otherwise dots are unfilled and lines are dashed and discard rates were calculated using additional records from between 3 and 7 adjacent years (average 3.5, see Table 5) as required to obtain at least 25 records.

Table 15: 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 0.01 (generally considered highly significant) are shown in bold.

Species category	Area	Slope	*p*
JMA	CHAT	0.680	0.058
JMA	STEW	0.427	0.327
JMA	**WCNI**	**1.263**	**<0.001**
JMA	WCSI	0.024	0.943
QMS	CHAT	0.008	0.962
QMS	STEW	0.620	0.064
QMS	WCNI	0.593	0.049
QMS	WCSI	0.708	0.023
NONQMS	**CHAT**	**-0.466**	**<0.001**
NONQMS	STEW	-0.032	0.809
NONQMS	WCNI	<0.001	0.994
NONQMS	WCSI	-0.104	0.193
INV	CHAT	0.095	0.797
INV	STEW	0.186	0.379
INV	WCNI	-0.423	0.244
INV	WCSI	-0.118	0.646

3.5.2 Annual discard levels

Total estimated annual discards in each species category, for the ratio estimation method only, are shown in Table 16 and Figure 19. Discards of jack mackerel were generally very low, less than 20 t per year in all years, and virtually non-existent between 2002–03 and 2008–09. The highest levels of target species discards were all in the five most recent years examined. Discarding of jack mackerel was mostly restricted to area WCNI, with non-zero estimates in other areas restricted to only one year in each of CHAT and STEW (Table 17).

Discards of QMS species were highly variable, ranging from zero in 2002–03 to 304 t three years later, and less than 100 t in each of the last four years examined (Table 18). The fitted line in Figure 19 shows no clear trend in discard levels over time. Discarding of QMS species was greatest in area WCNI, where annual estimates were typically 20–100 t; high levels were occasionally also shown for CHAT (e.g. 244 t in 2005–06) but were highly variable and less than 10 t in most years. In other areas, QMS discards were almost always below 10 t per year.

Discards of non-QMS species were less variable than discards of QMS species, with a range of about 40–300 t per year, but at a similar overall level (Table 19). Figure 19 does not show any clear trend in non-QMS species discards over time. As with QMS species, discards of non-QMS species were greatest in area WCNI where they were remarkably consistent (35–80 t in all but the 2002–03 fishing year). Annual discards were occasionally high in CHAT, STEW, and WCSI, but in most years were below 10 t per year.

Annual discards of invertebrates match the estimates of bycatch for this group (as almost all of the catch in this category is discarded), and were virtually zero in most years but with a high estimate for 2003–04 of 75 t, restricted to area WCNI (Table 20).

Spiny dogfish were consistently discarded in each year, with annual levels ranging from 25 t to 306 t. Higher levels of SPD discards (over 100 t) were limited to the first half of the period examined (Table 21). Estimated SPD discard estimates are similar to estimated bycatch for most years (compare Table 16 to Tables 7a and 7b) but are substantially lower in the four most recent years examined, suggesting improving utilisation of this species. Discards of spiny dogfish are greatest in areas WCNI and CHAT, where they are occasionally over 100 t per year; in other areas SPD discards are mostly less than 10 t per year.

Estimates of total annual discards were relatively constant, ranging from about 80–400 t per year, with little evidence of a trend over time (Table 22). The estimates for 2002–03 to 2004–05 match closely to those of Anderson (2007) for the same years, with strongly overlapping confidence intervals (Figure 19). As seen for the separate species categories, total discards were also greatest in area WCNI (ranging from 76 t to 183 t per year) and were also occasionally high, but also variable, in CHAT and WCSI

Table 16: Estimates of total annual discards (rounded to the nearest 1 t) in the jack mackerel trawl fishery for the species categories JMA, QMS, non-QMS, invertebrates, SPD, and overall, based on observed discard rates; 95% confidence intervals in parentheses.

	JMA		QMS		Non-QMS		Invertebrate		SPD		Total discards	
2002–03	0	(0–0)	0	(0–1)	297	(234–368)	0	(0–0)	168	(117–237)	297	(234–369)
2003–04	0	(0–0)	16	(6–29)	53	(36–75)	75	(9–170)	25	(15–39)	144	(52–274)
2004–05	0	(0–5)	30	(20–46)	86	(55–150)	0	(0–0)	28	(17–45)	116	(75–201)
2005–06	0	(0–0)	304	(105–695)	90	(45–201)	0	(0–0)	306	(97–716)	394	(150–896)
2006–07	0	(0–0)	207	(122–346)	108	(67–189)	0	(0–0)	199	(108–346)	315	(189–535)
2007–08	0	(0–0)	133	(73–296)	87	(65–112)	0	(0–1)	64	(38–99)	220	(138–409)
2008–09	0	(0–0)	79	(54–165)	42	(34–52)	0	(0–0)	68	(43–154)	121	(87–217)
2009–10	8	(3–20)	186	(111–324)	77	(55–116)	0	(0–0)	81	(54–116)	272	(169–461)
2010–11	2	(1–6)	25	(20–33)	57	(34–80)	0	(0–0)	17	(13–22)	84	(55–120)
2011–12	7	(6–13)	95	(87–101)	50	(47–53)	0	(0–0)	60	(54–65)	152	(140–166)
2012–13	17	(16–22)	97	(93–103)	67	(66–69)	3	(3–3)	63	(60–66)	185	(178–198)
2013–14	11	(10–16)	76	(73–81)	102	(99–109)	4	(4–6)	40	(37–45)	194	(185–211)

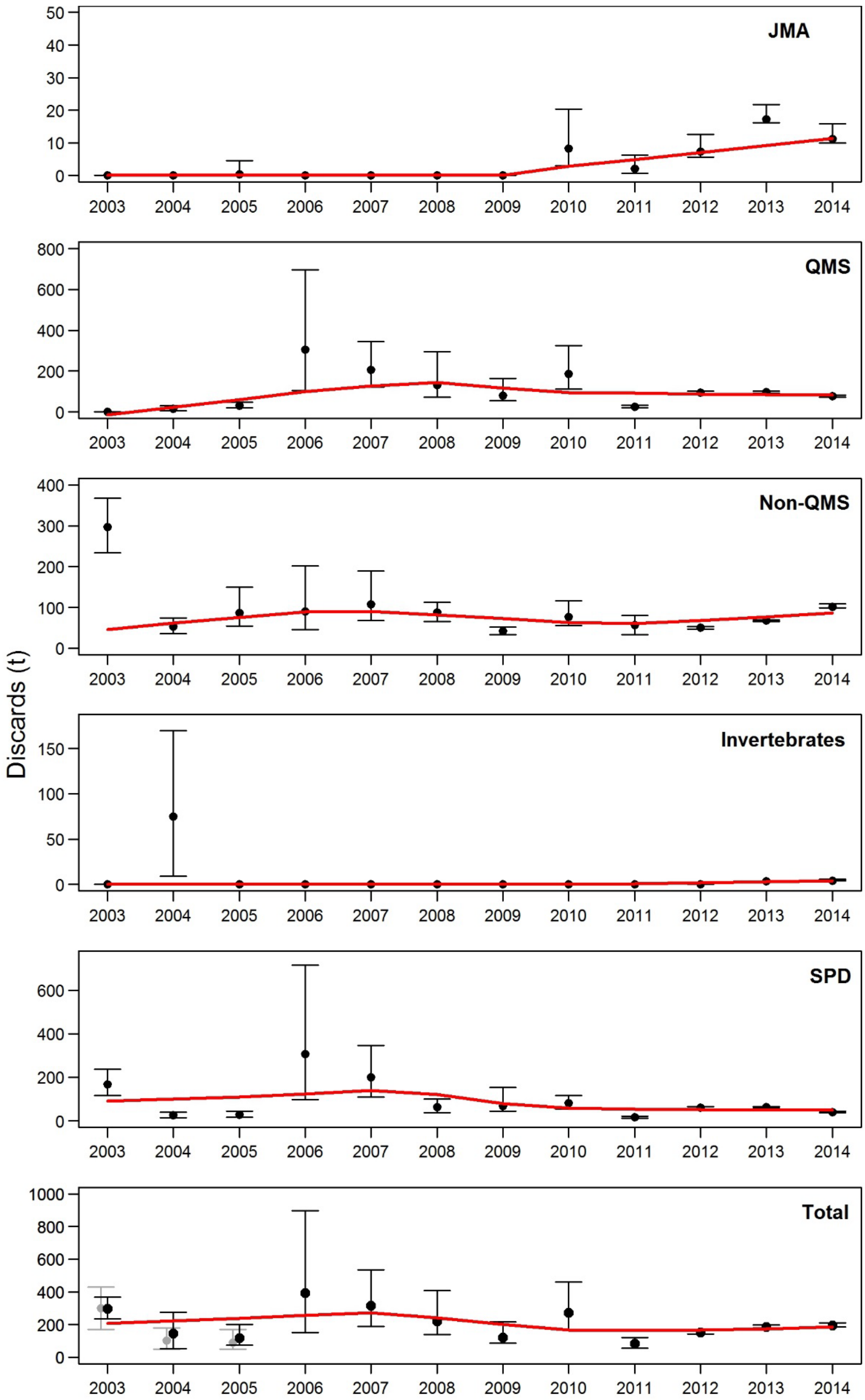

Figure 19: Annual estimates of discards in the jack mackerel trawl fishery, for jack mackerels (JMA), QMS species, non-QMS species, invertebrates, spiny dogfish (SPD), and overall (Total) for 2002–03 to 2013–14. Also shown (in grey on the 'Total' panel) are earlier estimates of total discards calculated for 2002–03 to 2004–05 (from Anderson 2007). Error bars indicate 95% confidence intervals. The red lines show the fit of a locally-weighted polynomial regression to annual discards.

Table 17: Estimates of annual target species discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2003–04	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2004–05	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2005–06	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2006–07	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2007–08	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2008–09	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2009–10	0	(0–0)	0	(0–0)	8	(3–23)	0	(0–0)	0	(0–0)
2010–11	0	(0–0)	0	(0–0)	2	(1–11)	0	(0–0)	0	(0–0)
2011–12	2	(1–1)	0	(0–0)	6	(5–15)	0	(0–0)	0	(0–0)
2012–13	0	(0–0)	8	(8–8)	9	(8–18)	0	(0–0)	0	(0–0)
2013–14	0	(0–0)	0	(0–0)	11	(10–20)	0	(0–0)	0	(0–0)

Table 18: Estimates of annual QMS species discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2003–04	0	(0–0)	1	(0–10)	14	(1–31)	0	(0–0)	0	(0–0)
2004–05	4	(0–10)	4	(2–12)	21	(15–35)	1	(0–0)	0	(0–0)
2005–06	244	(45–635)	5	(0–20)	43	(33–63)	7	(0–30)	1	(0–0)
2006–07	46	(16–96)	3	(0–10)	127	(59–259)	22	(10–60)	2	(0–0)
2007–08	34	(13–73)	1	(0–0)	98	(45–245)	1	(0–0)	1	(0–0)
2008–09	6	(0–20)	6	(4–14)	64	(36–146)	2	(1–1)	0	(0–0)
2009–10	3	(1–11)	1	(1–1)	181	(109–319)	2	(1–1)	0	(0–0)
2010–11	2	(1–1)	0	(0–0)	20	(16–26)	1	(0–0)	0	(0–0)
2011–12	3	(1–1)	1	(1–1)	86	(79–89)	4	(3–3)	0	(0–0)
2012–13	28	(28–28)	1	(1–1)	64	(55–65)	4	(4–4)	0	(0–0)
2013–14	1	(1–1)	1	(1–1)	70	(62–72)	3	(3–3)	0	(0–0)

Table 19: Estimates of annual non-QMS species discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	79	(32–142)	25	(5–55)	183	(149–219)	7	(1–11)	0	(0–0)
2003–04	5	(0–10)	3	(0–10)	45	(33–63)	1	(0–0)	0	(0–0)
2004–05	1	(0–0)	4	(0–10)	78	(47–147)	2	(0–10)	0	(0–0)
2005–06	27	(4–124)	5	(0–10)	35	(20–50)	22	(1–61)	0	(0–0)
2006–07	6	(0–20)	0	(0–0)	37	(30–50)	62	(27–137)	1	(0–0)
2007–08	12	(3–23)	0	(0–0)	68	(52–92)	7	(2–12)	0	(0–0)
2008–09	5	(0–10)	0	(0–0)	33	(32–42)	3	(1–1)	0	(0–0)
2009–10	0	(0–0)	0	(0–0)	75	(55–115)	2	(1–1)	0	(0–0)
2010–11	0	(0–0)	2	(1–1)	54	(26–76)	1	(0–0)	0	(0–0)
2011–12	0	(0–0)	1	(1–1)	48	(49–49)	1	(1–1)	0	(0–0)
2012–13	1	(1–1)	23	(23–23)	41	(35–45)	2	(2–2)	0	(0–0)
2013–14	2	(2–2)	16	(14–24)	80	(80–80)	6	(5–5)	0	(0–0)

Table 20: Estimates of annual INVERTEBRATE species discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	0	(0.01–0.01)	0	(0–0)	0	(0.01–0.01)	0	(0–0)	0	(0–0)
2003–04	0	(0–0)	0	(0–0)	75	(4.81–164.81)	0	(0–0)	0	(0–0)
2004–05	0	(0–0)	0	(0–0)	0	(0.01–0.01)	0	(0–0)	0	(0–0)
2005–06	0	(0–0)	0	(0–0)	0	(0.05–0.05)	0	(0–0)	0	(0–0)
2006–07	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2007–08	0	(0–0)	0	(0–0)	0	(0.13–0.13)	0	(0.01–0.01)	0	(0–0)
2008–09	0	(0–0)	0	(0–0)	0	(0.02–0.02)	0	(0–0)	0	(0–0)
2009–10	0	(0–0)	0	(0–0)	0	(0.02–0.02)	0	(0.01–0.01)	0	(0–0)
2010–11	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2011–12	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2012–13	3	(3.41–3.41)	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–0)
2013–14	0	(0.01–0.01)	0	(0–0)	4	(3.89–3.89)	0	(0.01–0.01)	0	(0–0)

Table 21: Estimates of annual spiny dogfish (SPD) discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	52	(18–108)	11	(2–32)	98	(70–140)	1	(0–0)	0	(0–0)
2003–04	3	(0–10)	3	(0–10)	18	(11–31)	0	(0–0)	0	(0–0)
2004–05	4	(0–10)	6	(2–12)	17	(4–34)	0	(0–0)	0	(0–0)
2005–06	253	(45–665)	8	(0–20)	40	(32–52)	3	(0–20)	1	(0–0)
2006–07	45	(16–96)	3	(0–10)	130	(58–278)	11	(6–36)	2	(0–0)
2007–08	35	(13–63)	1	(0–0)	25	(18–38)	0	(0–0)	0	(0–0)
2008–09	7	(0–20)	6	(4–14)	50	(32–132)	1	(0–0)	0	(0–0)
2009–10	3	(1–1)	1	(1–1)	76	(45–115)	1	(1–1)	0	(0–0)
2010–11	2	(1–1)	0	(0–0)	14	(14–14)	0	(0–0)	0	(0–0)
2011–12	2	(1–1)	1	(1–1)	54	(43–63)	4	(3–3)	0	(0–0)
2012–13	25	(25–25)	1	(1–1)	36	(31–41)	0	(0–0)	0	(0–0)
2013–14	1	(1–1)	0	(0–0)	38	(34–44)	0	(0–0)	0	(0–0)

Table 22: Estimates of TOTAL annual discards in the jack mackerel trawl fishery, by standard area, based on the ratio method; 95% confidence intervals in parentheses.

	CHAT		STEW		WCNI		WCSI		OTHR	
2002–03	80	(32–142)	25	(5–55)	183	(149–219)	7	(1–11)	0	(0–0)
2003–04	5	(0–10)	4	(0–20)	133	(39–259)	1	(0–0)	0	(0–0)
2004–05	5	(0–10)	7	(2–22)	98	(62–182)	3	(0–10)	0	(0–0)
2005–06	271	(49–759)	10	(0–30)	77	(53–113)	29	(1–91)	1	(0–0)
2006–07	52	(16–116)	3	(0–10)	165	(89–309)	84	(37–197)	3	(0–0)
2007–08	47	(16–96)	1	(0–0)	166	(97–337)	7	(2–12)	1	(0–0)
2008–09	11	(0–30)	7	(4–14)	97	(68–188)	5	(2–2)	0	(0–0)
2009–10	3	(1–11)	2	(1–1)	264	(167–457)	4	(2–2)	0	(0–0)
2010–11	3	(1–1)	2	(1–1)	76	(43–113)	1	(0–0)	0	(0–0)
2011–12	4	(2–2)	3	(2–2)	140	(133–153)	5	(4–4)	0	(0–0)
2012–13	32	(32–32)	32	(32–32)	113	(98–128)	7	(6–6)	0	(0–0)
2013–14	3	(3–3)	17	(15–25)	165	(156–176)	9	(8–8)	0	(0–0)

3.5.3 Trends in annual discards

Positive slopes in the linear regressions on discard levels over time indicate that discards of jack mackerels and other QMS species generally increased, while negative slopes indicate that discards of non-QMS, spiny dogfish, and invertebrate species generally decreased. These trends were significant, however, only for jack mackerels (Table 23).

Table 23: 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 0.01 (generally considered highly significant) are shown in bold.

Species category	Slope	*p*
JMA	**0.942**	**<0.001**
QMS	0.259	0.104
Non-QMS	-0.061	0.160
Invertebrate	-0.099	0.754
Spiny dogfish	-0.067	0.384
Total	-0.033	0.426

3.5.4 Discard information from Catch Landing Returns

The disposal of all catch taken by vessels in the jack mackerel trawl 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-QMS)
M	QMS species returned to sea (those in Part 6A of the Fisheries (Reporting) Regulations 2001, this code currently only applies to 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 (i.e., spiny dogfish).

A summary of this information is made 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 trawling trips on which jack mackerel was the primary landed species (over 75% by weight). This approximation is based on the fraction of jack mackerel catches on observed trips and is necessary as CLR returns relate to the catch from several days or from whole trips rather than from individual tows and may relate to more than one target fishery.

Recorded accidental losses of fish ranged from 0–151 t per year and discarding of non-QMS species ranged from 16–606 t per year (Table 24). Annual accidental losses were highly variable and although there was no strong trend over time the highest annual totals tended to be at the beginning and end of the period examined. Annual reported non-QMS discards were also highly variable, reaching a maximum of 636 t in 1997–98, but have been below 100 t since 2004–05 when spiny dogfish became a QMS species and are subsequently accounted for in Table 24 under destination type M. Destination types J, and X are more recent codes, introduced in 2013–14 and 2007–08 respectively to account for other QMS species that can be legally discarded. The total discards calculated from CLR data do not closely match those estimated from observer records (varying from 9% to 250% of the observer based estimates per year), most likely due to the approximations used in the former.

Table 24: Summary of discard and loss weights (t) by destination type and fishing year, from jack mackerel trawl fishery Catch Landing Returns. A, Accidental loss; D, Discarded (Non-QMS); J, Observer authorised discards; 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 but including species with size limits, e.g. red cod); –, code not used.

	Destination type						
	A	D	J	M	X	Total	% of observer-based estimate
1990–91	–	59	–	–	–	59	N/A
1991–92	3	44	–	–	–	47	N/A
1992–93	50	299	–	–	–	349	N/A
1993–94	27	354	–	–	–	381	N/A
1994–95	76	146	–	–	–	222	N/A
1995–96	70	174	–	–	–	244	N/A
1996–97	46	606	–	–	–	652	N/A
1997–98	2	636	–	–	–	638	N/A
1998–99	11	352	–	–	–	363	N/A
1999–00	1	127	–	–	–	128	N/A
2000–01	0	258	–	–	–	258	N/A
2001–02	6	564	–	–	–	570	N/A
2002–03	0	211	–	–	–	211	71
2003–04	12	110	–	–	–	122	85
2004–05	16	59	–	67	–	142	122
2005–06	1	16	–	20	–	37	9
2006–07	2	44	–	92	0	138	44
2007–08	–	46	–	39	1	86	39
2008–09	20	51	–	80	2	153	126
2009–10	2	58	–	121	8	189	69
2010–11	38	54	–	28	3	123	146
2011–12	22	82	–	84	14	202	133
2012–13	151	97	–	166	48	462	250
2013–14	15	88	83	66	27	279	144

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 and, since 1 October 2013, on CLR forms (see Section 3.5.4). 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 have been incorporated into this study) is that usually the records relate to the combined discards from several fishing events, or the entire trip, and reconciling these data with the catch from individual tows would be difficult.

Observer authorised discarding clearly has the potential to bias estimation of discards which are based on observed discard ratios. Ideally such discards would be ignored in the calculation of these ratios 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 ratio of zero and imply zero discarding of (non-Schedule 6, or fish smaller then MLS) QMS species in the unobserved portion of the fishery. The annual QMS species discard estimates presented in this report therefore make the assumption that the level of discarding of QMS species not listed in Schedule 6 and MLS of the Fisheries Act 1996 is unaffected by the presence of an observer on the vessel.

3.6 Discards as a fraction of catch in the jack mackerel trawl fishery

Annual discard estimates in the jack mackerel trawl fishery were divided by the estimated annual trawl catch of jack mackerel and the total annual bycatch (Table 25).

The annual discard fraction (kilograms of discards/kilograms of jack mackerel catch) ranged from 0.003 in 2004–05 and 2010–11 to 0.13 in 2005–06, with an overall value for the 12-year period of 0.007. Although variable from year to year, the discard fraction has tended to be lower in recent years. The fraction of the total bycatch discarded has ranged from 0.010 to 0.024 and shown no pattern over time.

Table 25: Estimated annual jack mackerel catch (t), total bycatch (t), and total discards (t) in the target jack mackerel trawl fishery; discard fraction (kg of total discards per kg of jack mackerel caught); and discards as a fraction of bycatch.

Fishing year	Jack mackerel estimated catch	Total bycatch	Total discards	Discard fraction	Discards/ bycatch
2002–03	26 119	13 072	297	0.011	0.023
2003–04	26 826	14 602	144	0.005	0.010
2004–05	33 351	8 669	116	0.003	0.013
2005–06	30 071	16 486	394	0.013	0.024
2006–07	30 713	15 439	315	0.010	0.020
2007–08	33 381	11 793	220	0.007	0.019
2008–09	27 712	9 573	121	0.004	0.013
2009–10	29 945	12 606	272	0.009	0.022
2010–11	28 554	6 662	84	0.003	0.013
2011–12	28 096	9 058	152	0.005	0.017
2012–13	31 087	9 387	185	0.006	0.020
2013–14	34 377	10 188	194	0.006	0.019

3.7 Annual bycatch by individual species in the jack mackerel trawl fishery

A table of annual bycatch estimates for the most commonly caught individual species (the top 25 QMS, top 25 non-QMS, and top 5 invertebrate species observed, with at least 1 t of bycatch in at least one year), and regression slopes indicating general trends in abundance, is given in Appendix 4. Based on these estimates, the most commonly caught bycatch species over the entire commercial fishery were (in decreasing order) barracouta (BAR), blue mackerel (EMA), frostfish (FRO), redbait (RBT), blue warehou (WAR), and arrow squid (SQU). Of the 45 bycatch species examined, 13 have shown a significant decrease in catch over time, and 8 an increase in catch over time (the remaining species showing no change at the 1% level of significance). Among the species showing significant declines were capro dory (*Capromimus abbreviatus*, CDO), hoki (HOK), and leatherjacket (*Meuschenia scaber*, LEA) (Figure 20). Species showing significant increases included albacore tuna (*Thunnus alalunga*, ALB), kahawai (*Arripis trutta*, ATT), and slender tuna (*Allothunnus fallai*, STU).

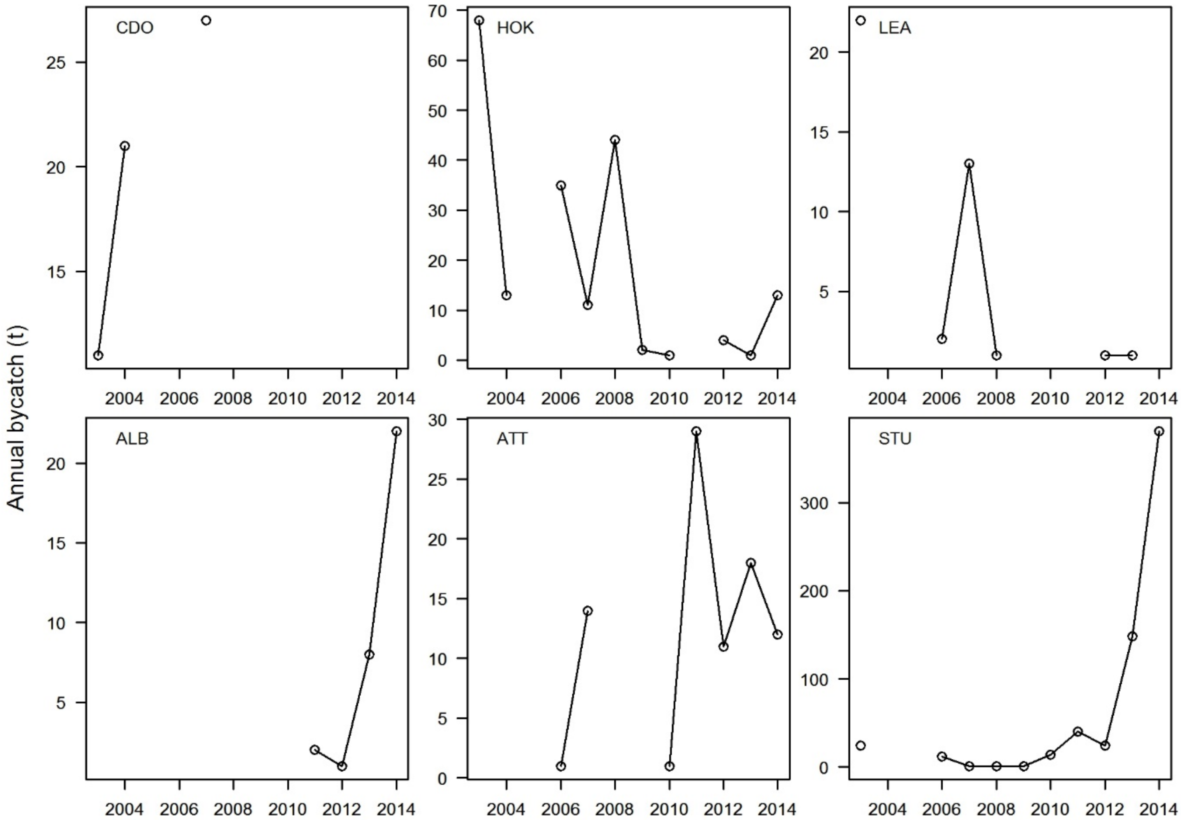

Figure 20: Annual bycatch estimates in the jack mackerel trawl fishery for the species which have shown the greatest decrease (top) and greatest increase (bottom) between 2002–03 and 2013–14. See text above for explanation of the species codes. Note: the scale changes on the y-axis between plots; lines are joined only where there are data points for consecutive years (no data point = no observed catch).

3.7.1 Comparison of trends in individual species bycatch with trawl survey time series

The time series of west coast South Island surveys is designed to monitor adult abundance of the five target species: giant stargazer (STA), red cod (RCO), red gurnard (GUR), spiny dogfish (SPD), and tarakihi (NMP), but analysis of survey results have shown that it may also provide useful indices for monitoring hoki (HOK), school shark (SCH), barracouta (BAR), and john dory (JDO) (Stevenson 2007b).

There is little evidence from these trawl surveys to support the temporal pattern in bycatch rates derived from the observer data for most of the main bycatch species (Figure 21). For most species the calculated correlation between the two series was either negative (spiny dogfish, hoki, red gurnard, red cod, school shark, arrow squid (SQU), and tarakihi), or very low (barracouta). For two species, frostfish (FRO) and john dory (JDO), the pattern of observed bycatch rate was more closely matched by the survey biomass estimates, with correlations between series of 55–57%. For both of these species biomass estimates from the most recent survey are low compared with previous surveys, so continued monitoring of this trend is recommended.

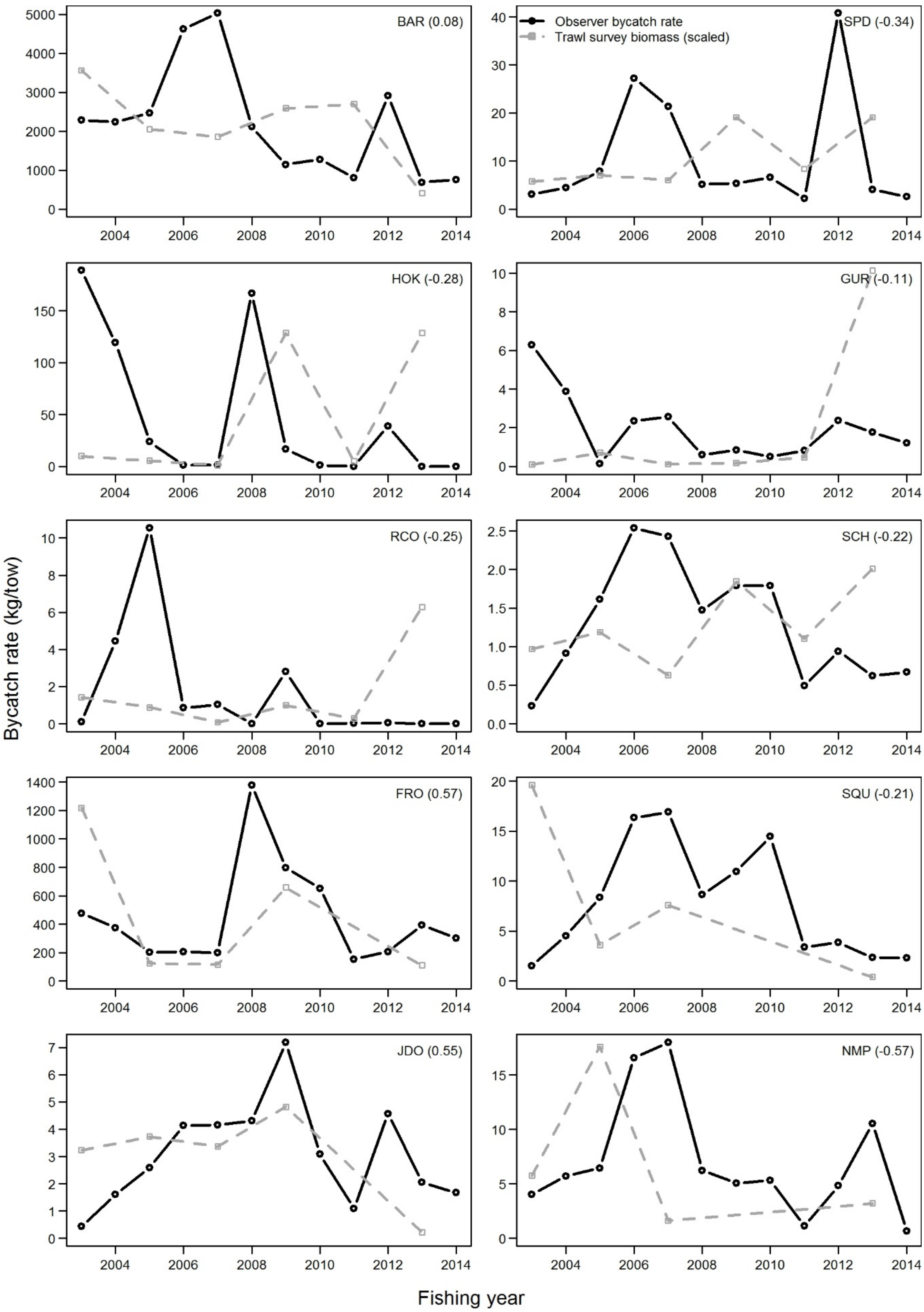

Figure 21: Comparison of observed bycatch rates of individual species in the WCSI stratum (black solid lines) with estimated biomass from equivalent strata in the west coast South Island inshore trawl survey time-series (grey dashed lines). The survey series are scaled to have the same mean as the observed bycatch rates. Note: survey data were not available in some years for the species in the bottom four panels. See text for explanation of species codes; correlation coefficients shown in parentheses.

4. SUMMARY AND DISCUSSION

The annual estimates of bycatch and discards in the jack mackerel 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. In particular, no attempt is made to account for any difference in fishing and processing behaviour that might exist between the observed and unobserved sectors of the fishery. The available information on such differences is largely anecdotal and not easily incorporated into this sort of analysis.

The level of observer coverage in the jack mackerel trawl fishery over the 12-year period covered has been higher than most of the other offshore fisheries for which bycatch and discard levels are assessed. The level of observer coverage in the fishery for this period has averaged 41% of the total estimated target species catch, the same level as in the southern blue whiting fishery during at least the first part of this period (Anderson 2008), and over 75% since 2011–12. Observer coverage in the orange roughy, oreo, and arrow squid fisheries has been about 30–35% during this same period, with lower coverage achieved in the hoki/hake/ling trawl fishery (22%), ling longline fishery (11%), and scampi fishery (10%) (Anderson 2009, 2011, 2012, 2013, Ballara & O'Driscoll 2015).

The distribution of observer effort has been fairly representative of total commercial effort across the range of available fishery parameters. The major fisheries off the west coasts of the North and South Islands, the Stewart-Snares Shelf, and the Chatham Rise were all well sampled by observers in most years; the main vessels and vessel sizes operating in the fishery all received appropriate coverage; and other aspects such as fishing depth and the latitudinal and longitudinal spread of observer effort were well matched to the total commercial effort, especially within the most recent 12 years which were the focus of this report.

The selection of area as the primary variable for stratification of the analyses was a choice made in order to align the outputs from this analysis with those from each of the other offshore fisheries that are examined under this programme. Conveniently, the standardised areas applied closely match the natural divisions in the jack mackerel fishery, and area has shown to be a primary driver of variability in bycatch and discard rates in this and other fisheries. However, the limited amount of data available precluded using additional variables (such as tow type or meal plant usage) that may have influenced bycatch and discard rates.

The results presented here show that when the same covariates are used (namely time and area) the ratio- and model-based methods give similar predictions of the bycatch, with comparable confidence intervals (Figure 15). The expected accuracy of the model-based approach is supported by the results of the cross-validation exercise (Figure 17), which shows not only that the empirical values can be reproduced by the model, but that this predictive ability is, to some extent, robust to the exact data used The accuracy of these predictions could be improved by using additional covariate data applied in the context of the model-based approach, which is not necessarily true for the ratio-based method, and we therefore advocate the former approach for future work.

Estimation of bycatch and discards focussed on three broad categories of catch; QMS species, non-QMS species, and invertebrates. These categories do not match the "commercial" and "non-commercial" species categories previously assessed in this fishery. Nor do they match the QMS and non-QMS species categories used in analyses of other fisheries as here for the first time the allocation of species to these categories took into account the species date of entry into the QMS, altering the composition of these categories from year to year. These categorisations limited the comparison of results from earlier analyses of the jack mackerel fishery with those from the current study to estimates of total bycatch and total discards, for the three years in which the studies overlap. The repeated estimates of total annual bycatch and discards for these years (for both the ratio and the statistical model method) were very similar to the earlier estimates in most cases, especially for discards. The small differences observed are likely to be due to slight differences in data grooming methods and the revised procedure used for dealing with data poor strata.

Nine of the top ten bycatch species are QMS species, and therefore direct controls exist to limit their overall catch. Of the main bycatch species, spiny dogfish is the only one which is regularly discarded, despite being a QMS species with some commercial value. A separate assessment of the bycatch and discards of spiny dogfish estimated that between 20% and 100% of the 20–320 t caught each year was discarded, and the raw observer data showed an overall discard rate of 66% for this species. Spiny dogfish are also a major component of the bycatch and discards in the arrow squid, scampi, hoki, hake, ling, and southern blue whiting trawl fisheries, and the ling longline fishery (Anderson 2007, 2009, 2012, 2013, 2014, Ballara & O'Driscoll 2015), and much of the total annual catch of this species has historically been discarded due to its low commercial value (Manning et al. 2004). Despite this, there is no evidence that spiny dogfish abundance has declined, and stock sizes may have actually increased in some areas (Ministry for Primary Industries 2015).

The most abundant observed non-QMS bycatch species were slender tuna and silver dory, but at only 0.27% and 0.12% of the total observed catch, respectively, these were a fairly insignificant part of the catch in this fishery. Despite being non-QMS species with low economic value, discards of both species were less than 10%, probably due to the high use of meal plants in this fishery.

Excluding the QMS arrow squid, which account for 0.25% of the total catch, bycatch of invertebrates in the jack mackerel trawl fishery is very low compared to most trawl fisheries, with jellyfish the only taxon with a total observed catch of greater than 1 t. This low invertebrate catch is likely to be directly related to the widespread use of midwater trawl gear in this fishery, which generally does not contact the seafloor where many invertebrates dwell.

Trends in bycatch and discards of QMS species and non-QMS species are difficult to interpret due to the requirement that these categories take into account the date of entry into the QMS, but bycatch of both species categories (and total bycatch) declined slightly over time, although not significantly in any case and the decline was not substantial. Despite the decreasing catch of QMS species over time, discards increased slightly, although again not significantly. The only significant trend identified was for discards of the target species, the result of greater levels of discarding between 2009–10 and 2013–14. Total bycatch determined from commercial catch-effort records was similar in most years to the observer-based estimates, and also showed a decreasing trend. This similarity is in contrast to other offshore fisheries examined, e.g. the scampi trawl fishery and the ling longline fishery (Anderson 2012, 2014), where the catch effort based estimates are typically half or less than the observer based estimates, but is comparable to the similarity between estimates in the arrow squid and hoki/hake/ling trawl fisheries (Anderson 2013, Ballara & O'Driscoll 2015).

The rate of discarding in the jack mackerel fishery was very low for the 2002–03 to 2013–14 period, with values of 0.003– 0.013 kg of discards per kilogram of jack mackerel caught. This current rate is similar to average rates in the southern blue whiting (0.005 kg) fishery, and lower than those in the oreo (0.03 kg), orange roughy (0.04 kg), arrow squid (0.06 kg), hoki, hake, ling (0.06 kg), and scampi (4.2 kg) trawl fisheries; and the ling longline fishery (0.3 kg) (Anderson 2009, 2011, 2012, 2013, 2014, Ballara & O'Driscoll 2015).
The estimation of bycatch levels for a wide range of individual species in the jack mackerel trawl fishery (under Objective 4) has provided an initial overview of the level of annual catch and enabled the highlighting of taxa where catch has changed over time, possibly inferring a change in abundance. Comparisons of bycatch rate estimates for the combined QMS species, non-QMS species, and invertebrate species categories from this study with relative abundance estimates from time series of research surveys were not practical due to limited spatial and bathymetric overlap, and differences in trawl gear. However, graphical comparisons were made for a few of the main individual catch species common to the jack mackerel trawl fishery and the west coast South Island trawl survey time series. Although these comparisons showed a moderate level of agreement for two species (frostfish and john dory) there was no

obvious increasing or decreasing trend for either species over the 12 years examined, and other species showed negative correlations between series – indicating that the comparisons may not be reliable.

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APPENDICES

Appendix 1: Observed FISH catch and discards. 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 jack mackerel trawl fishery from 1 Oct 2002 to 30 Sep 2014. Records are ordered by decreasing percentage of catch. Codes in bold are QMS species (as of 1 October 2013); codes in italics are Schedule 6 QMS species (i.e., can legally be returned to the sea).

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae*	88 169	44.03	0
JMD	Greenback jack mackerel	*Trachurus declivis*	41 105	20.53	0
BAR	Barracouta	*Thyrsites atun*	25 857	12.91	0
JMN	Yellowtail jack mackerel	*Trachurus novaezelandiae*	17 150	8.56	0
EMA	Blue mackerel	*Scomber australasicus*	6 879	3.44	0
FRO	Frostfish	*Lepidopus caudatus*	6 745	3.37	0
RBT	Redbait	*Emmelichthys nitidus*	4 917	2.46	1
JMM	Slender jack mackerel	*Trachurus murphyi*	4 061	2.03	0
RBM	Rays bream	*Brama brama*	612	0.31	0
SWA	Silver warehou	*Seriolella punctata*	568	0.28	0
STU	Slender tuna	*Allothunnus fallai*	535	0.27	7
SPD	Spiny dogfish	*Squalus acanthias*	499	0.25	66
SNA	Snapper	*Pagrus auratus*	297	0.15	0
KIN	Kingfish	*Seriola lalandi*	273	0.14	31
SDO	Silver dory	*Cyttus novaezealandiae*	239	0.12	1
PIL	Pilchard	*Sardinops sagax*	228	0.11	0
WAR	Common warehou	*Seriolella brama*	225	0.11	0
JDO	John dory	*Zeus faber*	147	0.07	0
POP	Porcupine fish	*Allomycterus jaculiferus*	137	0.07	77
MAK	Mako shark	*Isurus oxyrinchus*	99	0.05	7
NMP	Tarakihi	*Nemadactylus macropterus*	94	0.05	0
RCO	Red cod	*Pseudophycis bachus*	93	0.05	0
GUR	Gurnard	*Chelidonichthys kumu*	86	0.04	0
SUN	Sunfish	*Mola mola*	83	0.04	100
THR	Thresher shark	*Alopias vulpinus*	64	0.03	99
HOK	Hoki	*Macruronus novaezelandiae*	57	0.03	0
ATT	Kahawai	*Arripis trutta*	57	0.03	0
SCH	School shark	*Galeorhinus galeus*	55	0.03	1
RBY	Rubyfish	*Plagiogeneion rubiginosum*	45	0.02	0
ALB	Albacore tuna	*Thunnus alalunga*	35	0.02	0
JAV	Javelin fish	*Lepidorhynchus denticulatus*	33	0.02	0
TRE	Trevally	*Pseudocaranx georgianus*	28	0.01	0
RDO	Rosy dory	*Cyttopsis roseus*	25	0.01	0
BWS	Blue shark	*Prionace glauca*	17	0.01	15
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	17	0.01	1
HAP	Hapuku	*Polyprion oxygeneios*	14	0.01	0
RAT	Rattails	Macrouridae	12	0.01	4
SWO	Broadbill swordfish	*Xiphias gladius*	12	0.01	5
POS	Porbeagle shark	*Lamna nasus*	10	<0.01	22
CDO	Capro dory	*Capromimus abbreviatus*	9	<0.01	0
ERA	Electric ray	*Torpedo fairchildi*	9	<0.01	19
OPE	Orange perch	*Lepidoperca aurantia*	8	<0.01	1
LDO	Lookdown dory	*Cyttus traversi*	8	<0.01	0
LEA	Leatherjacket	*Meuschenia scaber*	8	<0.01	0
RSK	Rough skate	*Zearaja nasuta*	7	<0.01	2
EGR	Eagle ray	*Myliobatis tenuicaudatus*	7	<0.01	15
BEN	Scabbardfish	*Benthodesmus* spp.	7	<0.01	0
RSO	Gemfish	*Rexea solandri*	6	<0.01	0
SSI	Silverside	*Argentina elongata*	5	<0.01	5
GSH	Ghost shark	*Hydrolagus novaezealandiae*	5	<0.01	2
LIN	Ling	*Genypterus blacodes*	5	<0.01	1
SPE	Sea perch	*Helicolenus* spp.	5	<0.01	0
DEA	Dealfish	*Trachipterus trachypterus*	4	<0.01	1
SSK	Smooth skate	*Dipturus innominatus*	4	<0.01	4
STR	Stingray		4	<0.01	39
RHY	Common roughy	*Paratrachichthys trailli*	4	<0.01	2
GIZ	Giant stargazer	*Kathetostoma giganteum*	3	<0.01	1

Appendix 1 — *Continued*

ELE	Elephant fish	*Callorhinchus milii*	2	<0.01	0
BWH	Bronze whaler shark	*Carcharhinus brachyurus*	2	<0.01	78
SKJ	Skipjack tuna	*Katsuwonus pelamis*	2	<0.01	0
CBE	Crested bellowsfish	*Notopogon lilliei*	2	<0.01	0
JGU	Spotted gurnard	*Pterygotrigla picta*	2	<0.01	0
HAK	Hake	*Merluccius australis*	2	<0.01	0
ANC	Anchovy	*Engraulis australis*	2	<0.01	1
PRO	*Protomyctophum* spp	*Protomyctophum* spp.	1	<0.01	0
BRA	Short-tailed black ray	*Dasyatis brevicaudata*	1	<0.01	29
HPB	Hapuku & bass	*Polyprion oxygeneios* & *P. americanus*	1	<0.01	0
SEV	Broadnose sevengill shark	*Notorynchus cepedianus*	1	<0.01	58
SPO	Rig	*Mustelus lenticulatus*	1	<0.01	5
LAN	Lantern fish	Myctophidae	1	<0.01	19
WRA	Longtailed stingray	*Dasyatis thetidis*	1	<0.01	17
STM	Striped marlin	*Tetrapturus audax*	1	<0.01	100
BEM	Blue marlin	*Makaira mazara*	1	<0.01	100
RUD	Rudderfish	*Centrolophus niger*	1	<0.01	1
MDO	Mirror dory	*Zenopsis nebulosa*	1	<0.01	0
STN	Southern bluefin tuna	*Thunnus maccoyii*	1	<0.01	0
BPE	Butterfly perch	*Caesioperca lepidoptera*	1	<0.01	0
DMA	Malayan lanternfish	*Diaphus malayanus*	1	<0.01	0
CUC	Cucumber fish	*Paraulopus nigripinnis*	1	<0.01	42
BKM	Black marlin	*Makaira indica*	1	<0.01	100
CAR	Carpet shark	*Cephaloscyllium isabellum*	1	<0.01	79
SHA	Shark		1	<0.01	10
PHO	Lighthouse fish	*Phosichthys argenteus*	<1	<0.01	0
BNS	Bluenose	*Hyperoglyphe antarctica*	<1	<0.01	14
FOR	*Forsterygion* spp	*Forsterygion* spp.	<1	<0.01	0
NSD	Northern spiny dogfish	*Squalus griffini*	<1	<0.01	70
RAY	Rays	Torpedinidae, Dasyatidae, Myliobatidae, Mobulidae	<1	<0.01	36
SRH	Silver roughy	*Hoplostethus mediterraneus*	<1	<0.01	0
BYS	Alfonsino	*Beryx splendens*	<1	<0.01	0
WWA	White warehou	*Seriolella caerulea*	<1	<0.01	0
BNE	Scabbard fish	*Benthodesmus elongatus*	<1	<0.01	0
BIG	Bigeye tuna	*Thunnus obesus*	<1	<0.01	0
PIG	Pigfish	*Congiopodus leucopaecilus*	<1	<0.01	61
MOK	Moki	*Latridopsis ciliaris*	<1	<0.01	0
BAS	Bass groper	*Polyprion americanus*	<1	<0.01	0
MOO	Moonfish	*Lampris guttatus*	<1	<0.01	5
FTU	Frigate tuna	*Auxis thazard*	<1	<0.01	0
SPP	Splendid perch	*Callanthias spp.*	<1	<0.01	0
OFH	Oilfish	*Ruvettus pretiosus*	<1	<0.01	44
UFISH	Unidentified fish		<1	<0.01	0

Appendix 2: Observed INVERTEBRATE bycatch and discards. Species codes, common and scientific names, estimated catch, percentage of total catch, and overall percentage discarded of all invertebrate species or species groups by weight from observer records for the jack mackerel trawl fishery from 1 Oct 2002 to 30 Sep 2014. Records are ordered by decreasing percentage of catch. Codes in bold are QMS species; codes in italics are Schedule 6 QMS species (can legally be returned to the sea).

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	496	0.25	0
JFI	Jellyfish		12.7	0.01	94
OCT	Octopus	*Pinnoctopus cordiformis*	0.8	<0.01	9
AQU	*Acanthephyra quadrispinosa*	*Acanthephyra quadrispinosa*	0.1	<0.01	100
PTU	Sea pens	Pennatulacea	0.1	<0.01	100
HMT	Deepsea anemone	Hormathiidae	0.1	<0.01	100
CRM	Airy finger sponge	*Callyspongia* cf *ramosa*	0.07	<0.01	46
ONG	Sponges	Porifera	0.07	<0.01	100
PRK	Prawn killer	*Ibacus alticrenatus*	0.05	<0.01	33
MNI	Munida unidentified	*Munida* spp.	0.05	<0.01	100
OCO	*Octopus* spp.	*Octopus* spp.	0.04	<0.01	26
ELP	Gill biter	*Elthusa propinqua*	0.04	<0.01	3
NCB	Smooth red swimming crab	*Nectocarcinus bennetti*	0.03	<0.01	100
HDF	Feathery hydroids	Leptomeduseae & Anthoathecatae (excl. Stylasteridae)	0.03	<0.01	100
BSQ	Broad squid	*Sepioteuthis australis*	0.03	<0.01	4
SLG	Sea slug	*Scutus breviculus*	0.03	<0.01	100
SFI	Starfish	Asteroidea & Ophiuroidea	0.02	<0.01	100
OCP	Octopod		0.02	<0.01	14
HTH	Sea cucumber	Holothurian unidentified	0.02	<0.01	5
ENE	Gill biter or tongue biter, isopod	*Elthusa neocytta*	0.02	<0.01	100
ARN	Paper nautilus	*Argonauta nodosa*	0.02	<0.01	31
WSQ	Warty squid	*Onykia* spp.	0.02	<0.01	40
URP	*Uroptychus* spp	*Uroptychus* spp.	0.02	<0.01	100
TLA	Encrusting polyps, coral	*Telestula* spp.	0.01	<0.01	100
EGA	*Euciroa galatheae*	*Euciroa galatheae*	0.01	<0.01	23
PSI	Geometric star	*Psilaster acuminatus*	0.01	<0.01	40
GOC	Gorgonian coral	Gorgonacea	0.01	<0.01	100
VSQ	Violet squid	*Histioteuthis* spp.	0.01	<0.01	100
GAS	Gastropods	Gastropoda	0.01	<0.01	14
HYA	Floppy tubular sponge	*Hyalascus* sp.	0.01	<0.01	100
DWO	Deepwater octopus	*Graneledone* spp.	0.01	<0.01	100
COB	Black coral	Antipatharia	0.01	<0.01	100
SPN	Sea pen		0.01	<0.01	100
TSQ	*Todarodes filippovae*	*Todarodes filippovae*	0.01	<0.01	100
CRB	Crab		0.01	<0.01	100
CBD	Coral rubble - dead		0.01	<0.01	100
SLL	Slipper lobsters	Scyllaridae	0.01	<0.01	40
HDR	Hydroid	Hydrozoa	<0.01	<0.01	100
SMO	Cross-fish	*Sclerasterias mollis*	<0.01	<0.01	100
ZDL	Salp	*Doliolum* sp.	<0.01	<0.01	100
OPL	Opheliids	Opheliidae	<0.01	<0.01	100
CPH	Cephalopoda	Cephalopoda	<0.01	<0.01	100
EZE	Yellow octopus	*Enteroctopus zealandicus*	<0.01	<0.01	100
OPI	Umbrella octopus	*Opisthoteuthis* spp.	<0.01	<0.01	100
QSC	Queen scallop	*Zygochlamys delicatula*	<0.01	<0.01	100
PNE	*Proserpinaster neozelanicus*	*Proserpinaster neozelanicus*	<0.01	<0.01	67
KWH	Knobbed whelk	*Austrofucus glans*	<0.01	<0.01	100
CRN	Sea lily, stalked crinoid		<0.01	<0.01	100
EEX	*Enypniastes eximia*	*Enypniastes eximia*	<0.01	<0.01	100
CRU	Crustacea		<0.01	<0.01	100
FUN	*Funchalia* spp	*Funchalia* spp.	<0.01	<0.01	100
PAD	Paddle crab	*Ovalipes catharus*	<0.01	<0.01	100
FQU	Rope-like sea pen	*Funiculina quadrangularis*	<0.01	<0.01	100
SLO	Spanish lobster	*Arctides antipodarum*	<0.01	<0.01	77
POL	Polychaete	Polychaeta	<0.01	<0.01	100
FMA	*Fusitriton magellanicus*	*Fusitriton magellanicus*	<0.01	<0.01	100
TPS	Topshell	Trochidae	<0.01	<0.01	100

Appendix 2 — *Continued*

GLM	Green-lipped mussel	*Perna canaliculus*	<0.01	<0.01	100
MSB	Blue mussel	*Mytilus galloprovincialis*	<0.01	<0.01	100
VKI	*Veprichlamys kiwaensis*	*Veprichlamys kiwaensis*	<0.01	<0.01	100
ASR	Asteroid (starfish)		<0.01	<0.01	100
OPH	Ophiuroid (brittle star)		<0.01	<0.01	100
RGR	*Radiaster gracilis*	*Radiaster gracilis*	<0.01	<0.01	100
ZOR	Rat-tail star	*Zoroaster* spp.	<0.01	<0.01	100
EUP	Euphausiid e.g. *Euphausia*		<0.01	<0.01	100
GSC	Giant spider crab	*Jacquinotia edwardsii*	<0.01	<0.01	100
DIR	Pagurid	*Diacanthurus rubricatus*	<0.01	<0.01	100
LCO	Dwarf swimming crab	*Liocarcinus corrugatus*	<0.01	<0.01	100
NCA	Hairy red swimming crab	*Nectocarcinus antarcticus*	<0.01	<0.01	100
GLS	Glass sponges	Hexactinellida	<0.01	<0.01	100
PNN	Feathery sea pens	*Pennatula* spp.	<0.01	<0.01	100
SUA	Fleshy club sponge	*Suberites affinis*	<0.01	<0.01	100
THO	Bottlebrush coral	*Thouarella* spp.	<0.01	<0.01	100
CIC	Orange frond sponge	*Crella incrustans*	<0.01	<0.01	100
PHW	*Psammocinia* cf *hawere*	*Psammocinia* cf *hawere*	<0.01	<0.01	100
ACS	Smooth deepsea anemones	Actinostolidae	<0.01	<0.01	100
BOO	Bamboo coral	*Keratoisis* spp.	<0.01	<0.01	100
COU	Coral (unspecified)	Alcyonacea, Gorgonacea, Scleractinia, Antipatharia, & Stylasteridae	<0.01	<0.01	100
SOC	Soft coral	Alcyonacea	<0.01	<0.01	100
TLO	Encrusting long polyps, coral	*Telesto* spp.	<0.01	<0.01	100
CTN	*Calliostoma turnerarum*	*Calliostoma turnerarum*	<0.01	<0.01	100
WHE	Whelks		<0.01	<0.01	100
BHE	*Bathypectinura heros*	*Bathypectinura heros*	<0.01	<0.01	100
CRI	Sea lilies	Crinoidea	<0.01	<0.01	100
PGN	Hermit crab	*Pagurus novizealandiae*	<0.01	<0.01	100
DSO	Demosponges	Demospongiae	<0.01	<0.01	100
NEE	*Nemertesia elongata*	*Nemertesia elongata*	<0.01	<0.01	100
VOL	Volute	Volutidae	<0.01	<0.01	100
BIV	Bivalves unidentified	Bivalvia	<0.01	<0.01	100

Appendix 3: Observed bycatch by species group. Estimated catch, percentage of total catch, and overall percentage discarded from observer records for the jack mackerel trawl fishery from 1 Oct 2002 to 30 Sep 2014.

Group	Observed catch (t)	% of catch	% discarded
Invertebrates			
Molluscs	497	0.25	<1
Cnidaria	13	0.01	94
Crustaceans	0.4	<0.01	6
Echinoderms	0.1	<0.01	100
Sponges	0.1	<0.01	74
Elasmobranchs			
Sharks & dogfish	751	0.38	54
Rays & skates	35	0.02	16
Chimaeras	7	<0.01	1
Other fish			
Fish (other)	40938	20.44	1
Tuna	7453	3.72	1
Rattails	46	0.02	1
Billfish	15	0.01	22

Appendix 4: Jack mackerel trawl fishery. Total annual bycatch estimates (t) by fishing year (with estimated 95% CIs in parenthesis) for individual species (based on the top 25 QMS, top 25 Non-QMS, and top 5 INV species observed, with at least 1 t of bycatch in at least one year). 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 Appendices 1 or 2, or http://marlin.niwa.co.nz for species code definitions).

	2002–03		2003–04		2004–05		2005–06		2006–07		2007–08		2008–09		2009–10		2010–11		2011–12		2012–13		2013–14	
BAR(0)	8330	(7060–9860)	8327	(3577–11777)	3005	(2525–3575)	9010	(7260–11280)	9247	(7827–10637)	4802	(3822–5832)	4522	(3922–5252)	6991	(5191–10541)	3398	(2938–3948)	4788	(4658–4928)	4561	(4471–4651)	5504	(5394–5634)
EMA(0)	757	(567–1007)	3824	(2454–5594)	1743	(1083–2623)	1321	(711–2681)	2213	(1553–3293)	1781	(1301–2311)	1681	(1321–2151)	2839	(1839–4369)	1261	(791–2001)	958	(878–1038)	1118	(1078–1168)	1029	(979–1139)
FRO(0)	900	(750–1090)	1409	(1009–1999)	1847	(1547–2167)	1707	(1417–1997)	1470	(1110–1770)	1781	(1511–2111)	1248	(1108–1438)	1514	(1334–1694)	971	(801–1141)	1499	(1449–1559)	1532	(1492–1562)	1118	(1088–1158)
RBT(0)	1463	(743–2493)	301	(111–601)	1173	(613–2353)	2372	(1452–3562)	1348	(998–1708)	2582	(1562–3912)	1313	(843–1863)	383	(263–793)	359	(179–539)	881	(741–1051)	929	(929–939)	760	(740–800)
SWA(0.1)	137	(37–317)	20	(0–50)	30	(0–90)	811	(131–2491)	138	(28–398)	29	(9–69)	92	(2–392)	120	(60–290)	99	(29–199)	196	(106–366)	125	(125–125)	121	(111–131)
SQU(-0.1)	245	(105–385)	53	(23–93)	94	(44–144)	255	(195–345)	302	(162–482)	119	(79–179)	66	(46–146)	114	(74–164)	44	(34–64)	83	(73–93)	91	(81–91)	61	(51–61)
SPD(0)	172	(122–252)	22	(12–42)	65	(35–115)	331	(111–711)	201	(111–341)	76	(46–116)	69	(49–169)	103	(63–153)	102	(52–262)	124	(104–154)	109	(109–109)	93	(93–93)
RBM(0.1)	34	(14–64)	10	(10–20)	40	(20–60)	58	(28–118)	33	(23–53)	34	(14–64)	67	(37–137)	13	(3–13)	14	(14–24)	3	(3–3)	242	(242–242)	338	(328–348)
WAR(-0.1)	350	(180–570)	51	(21–91)	90	(40–160)	72	(32–162)	12	(2–12)	15	(5–25)	51	(31–71)	16	(6–36)	16	(6–36)	26	(16–26)	23	(23–23)	75	(65–75)
SDO(-0.2)	114	(84–144)	33	(13–73)	117	(67–197)	105	(85–145)	127	(87–167)	89	(59–149)	96	(76–116)	33	(33–43)	13	(3–13)	19	(19–29)	21	(21–21)	17	(17–17)
SNA(0.1)	11	(11–21)	86	(6–236)	92	(32–212)	30	(10–80)	28	(18–48)	77	(37–167)	48	(28–78)	75	(45–115)	57	(27–137)	99	(89–109)	58	(48–58)	48	(38–48)
STU(0.5)	24	(4–74)	0.1	(0–0)	0.1	(0–0)	12	(2–52)	1	(1–11)	1	(1–1)	1	(1–1)	14	(4–24)	40	(30–60)	24	(14–44)	148	(148–148)	381	(361–401)
KIN(0.1)	11	(1–21)	21	(11–51)	56	(26–116)	24	(14–44)	46	(26–126)	47	(27–97)	29	(19–29)	61	(41–91)	29	(19–39)	61	(61–71)	53	(43–53)	95	(95–105)
PIL(0)	34	(14–84)	32	(2–102)	13	(3–43)	28	(8–58)	13	(3–13)	46	(16–106)	14	(4–14)	16	(6–36)	0.1	(0–0)	51	(41–71)	64	(54–74)	102	(92–112)
JDO(0)	44	(34–64)	11	(11–21)	27	(17–47)	28	(18–38)	55	(35–75)	29	(19–39)	30	(20–30)	44	(24–64)	27	(7–37)	37	(27–37)	31	(31–41)	19	(19–19)
POP(0)	45	(35–55)	11	(11–11)	12	(2–12)	28	(18–38)	29	(29–39)	30	(20–40)	16	(16–16)	47	(37–87)	16	(16–26)	38	(38–38)	27	(27–37)	23	(23–23)
GUR(-0.1)	100	(80–150)	10	(0–10)	13	(13–23)	27	(17–37)	28	(18–38)	17	(17–27)	13	(3–13)	29	(19–39)	14	(14–14)	13	(13–23)	13	(13–13)	18	(18–18)
NMP(0.2)	34	(24–44)	0.1	(0–10)	1	(1–11)	14	(14–24)	42	(32–52)	29	(19–39)	16	(16–16)	28	(18–38)	14	(14–24)	14	(14–14)	13	(13–13)	23	(23–33)
HOK(-0.2)	68	(8–248)	13	(3–43)	0.1	(0–10)	35	(5–125)	11	(1–21)	44	(14–124)	2	(2–12)	1	(1–11)	0.1	(0–0)	4	(4–14)	1	(1–1)	13	(13–13)
THR(0)	22	(12–32)	21	(11–31)	27	(17–57)	1	(1–11)	13	(13–13)	15	(15–25)	14	(4–14)	14	(4–14)	27	(17–37)	7	(7–7)	10	(10–10)	13	(13–13)
SUN(0.2)	0.1	(0–10)	10	(0–20)	13	(3–23)	14	(14–24)	14	(4–24)	30	(20–50)	3	(3–13)	13	(3–13)	14	(4–24)	11	(11–11)	8	(8–8)	32	(32–42)
SCH(0.1)	24	(14–34)	0.1	(0–10)	13	(13–23)	14	(4–24)	14	(14–14)	15	(15–25)	14	(4–14)	14	(4–14)	2	(2–12)	9	(9–9)	11	(11–11)	9	(9–9)
MAK(0.4)	0.1	(0–0)	0.1	(0–10)	12	(2–12)	12	(2–12)	1	(1–1)	13	(3–23)	14	(4–24)	1	(1–11)	1	(1–11)	7	(7–7)	33	(33–53)	44	(44–64)
TRE(0.1)	0.1	(0–0)	107	(7–277)	1	(1–11)	2	(2–22)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–11)	0.1	(0–0)	6	(6–6)	8	(8–8)	2	(2–2)
RCO(0.4)	1	(1–11)	0.1	(0–0)	1	(1–11)	11	(1–21)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	0.1	(0–10)	2	(2–12)	14	(4–24)	24	(24–24)	67	(57–67)
ATT(0.5)	0.1	(0–20)	0.1	(0–0)	0.1	(0–0)	1	(1–11)	14	(4–44)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	29	(9–59)	11	(11–11)	18	(18–28)	12	(12–12)
JFI(0)	0.1	(0–0)	75	(5–165)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	3	(3–3)	4	(4–4)
CDO(-0.4)	11	(1–31)	21	(11–41)	0.1	(0–0)	0.1	(0–0)	27	(7–67)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)
RDO(0.1)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	53	(33–113)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	0.1	(0–0)	0.1	(0–0)
LEA(-0.2)	22	(12–32)	0.1	(0–0)	0.1	(0–0)	2	(2–12)	13	(3–23)	1	(1–1)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–1)	0.1	(0–0)
ALB(0.5)	0.1	(0–0)	0.1	(0–10)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	2	(2–12)	1	(1–1)	8	(8–8)	22	(22–32)
JAV(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	32	(32–62)	0.1	(0–0)
SCG(0.2)	0.1	(0–10)	0.1	(0–0)	12	(2–22)	1	(1–11)	1	(1–11)	1	(1–1)	1	(1–1)	1	(1–11)	1	(1–1)	4	(4–4)	2	(2–2)	3	(3–3)
OPE(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	11	(1–21)	0.1	(0–0)	0.1	(0–0)	0.1	(0–10)	1	(1–11)	1	(1–1)	0.1	(0–0)	1	(1–1)	4	(4–4)
RAT(0.3)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	5	(5–5)	1	(1–1)	5	(5–5)
ERA(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	0.1	(0–0)	1	(1–1)	1	(1–1)	0.1	(0–0)	0.1	(0–0)	2	(2–2)	2	(2–2)	2	(2–2)
EGR(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	0.1	(0–0)	2	(2–12)	1	(1–1)	1	(1–1)	0.1	(0–0)	1	(1–1)	1	(1–1)	1	(1–1)
GSH(0.3)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	3	(3–3)	1	(1–1)
RSO(0.1)	1	(1–11)	0.1	(0–10)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–1)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–1)
SPE(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	3	(3–3)
SSI(0.2)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–1)	2	(2–2)
SKJ(0.1)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	2	(2–2)
GIZ(0.2)	0.1	(0–10)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	1	(1–1)
RHY(0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–10)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	1	(1–1)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)
SKA(0)	0.1	(0–10)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)	0.1	(0–0)