Ministry for Primary Industries
Manatū Ahu Matua

Fish and invertebrate bycatch and discards in New Zealand scampi fisheries from 1990–91 until 2009–10

New Zealand Aquatic Environment and Biodiversity Report No. 100.

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ISSN 1179-6480 (online)

ISBN 978-0-478-40086-1 (online)

September 2012

New Zealand Government

Growing and Protecting New Zealand

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Anderson, O.F. (2012). Fish and invertebrate bycatch and discards in New Zealand scampi fisheries from 1990–91 until 2009–10.

***New Zealand Aquatic Environment and Biodiversity Report No. 100.* 65 p.**

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 scampi trawl fishery for each fishing year from 1990–91 to 2009–10. Separate estimates were made for several categories of catch and discards; all QMS species combined, all non-QMS species combined, all invertebrate species combined, javelinfish, and all other rattail species combined.

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

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

For the 20 years of the fishery examined here, scampi accounted for about 17% of the total estimated catch recorded by observers. The remainder of the observed catch comprised mainly non-commercial rattail species (29%) (more than half of which comprised the single species javelinfish), and the QMS species sea perch (8%), ling (7%), and hoki (6%). In addition, stargazer, dark ghost shark, deepsea flathead, and red cod each accounted for about 2% of the total catch. Invertebrate species combined (excluding scampi) accounted for about 5% of the total catch. These mostly comprised crustaceans (2.2%) and echinoderms (1.6%).

Bycatch rates were highly variable among years and areas, but rates of both QMS and non-QMS species bycatch tended to be highest on the Chatham Rise, and lowest around the Aucklands Islands fishery. In contrast, bycatch rates of invertebrates were higher around the Auckland Islands than on the Chatham Rise. Discard rates, while also highly variable, followed a similar pattern to rates of bycatch, although discard rates of non-QMS species were naturally relatively much higher than those of QMS species.

Total annual bycatch since 1990–91 ranged from about 2100 t to 9200 t and, although highly variable, has shown a significant decline over the past 20 years – driven mainly by a decline in the bycatch of QMS species. Annual bycatch has generally been an even mixture of QMS and non-QMS species, with invertebrate species (though showing a significant increase over time) accounting for only about 7% of the total bycatch for the whole period. Rattails (split evenly between javelinfish and all other species combined) accounted for 30–80% of the annual non-QMS bycatch. Comparison of bycatch rates with relative biomass estimates from trawl surveys to test for similarity of trends over time was possible for the Chatham Rise and Auckland Islands fishery areas, but these were inconclusive.

The estimation of discards based on observed discard rates is complicated by the practice of legal discarding of QMS species when an observer is present as well as possible alteration of discarding behaviour when no observer is present, leading to an unknown level of bias.

Total annual discards ranged from 6790 t in 1995–96 to 1430 t in 2005–06 and, although showing a general decrease since 2001–02, there was no significant trend in overall discard levels since 1990–91. Discards were dominated by non-QMS species (overall about 75%) followed by QMS species (16%) and invertebrates (9%). Rattail species accounted for nearly 60% of the non-QMS discards and about 45% of all discards. Discards of both invertebrates and rattails increased significantly over the 20-year period as a whole. In addition to rattails, other species frequently discarded (those in the top ten species bycatch categories by weight and greater than 50% discarded) were sea perch, deepsea flatheads, and spiny dogfish.

Statistical analysis of trends in the estimates showed that there has been a significant decrease in the bycatch of both QMS species and all species combined over time, but no associated decrease in discard levels. For invertebrate species, there was a significant increase over time in the level of both bycatch and discards. Discarding, but not bycatch, also increased over time for rattails.

The rate of annual discards in the scampi fishery, calculated as a fraction of the catch of the target species, has increased since the previous assessment from an average of 3.5 kg of discarded fish for every 1 kg of scampi caught in the years before 2005–06, to an average of 4.2 kg in the four years since. This rate of discarding is high compared to other deepwater Tier 1 species examined in New Zealand (0.005 kg for southern blue whiting to 0.35 kg for ling longline) but less than the 9 kg estimated for Scotland’s Clyde Sea *Nephrops norvegicus* scampi fishery.

1. INTRODUCTION

The Ministry for Primary Industries deepwater 10-year plan includes the following Environment Outcome related management objective: MO2.4. Identify and avoid or minimise adverse effects of deepwater and middle-depth fisheries on incidental bycatch species. This project addresses this objective by quantifying the level of bycatch of species or groups of species not managed separately in the QMS system. Significant changes in the relative catch of a species can be used to infer changes in abundance (though these may be due to other causes, such as changes in fishing practices). Bycatch species identified in this way as being in decline can be monitored and remedial action planned. The scampi (*Metanephrops challengeri*) trawl fishery is assessed in this first year of the programme, to be followed in subsequent years by each of the other six Ministry for Primary Industries Tier 1 fisheries, in the following order:

- squid (*Nototodarus* spp.) trawl,
- ling (*Genypterus blacodes*) bottom longline,
- hoki (*Macruronus novaezelandiae*)/hake (*Merluccius australis*)/ling trawl,
- jack mackerel (*Trachurus* spp.) trawl,
- southern blue whiting (*Micromesistius australis*) trawl, and
- orange roughy (*Hoplostethus atlanticus*)/oreo (Oreosomatidae) trawl.

The New Zealand scampi fishery is small but valuable, with total reported trawl catches in 2008–09 of about 600 t and export earnings in 2008 of NZ$11M (http://www.fish.govt.nz). Annual catches were restricted by a mixture of individual and competitive catch limits before the introduction of this species into the QMS in 2004–05. The main scampi fisheries are in the Bay of Plenty, off the Wairarapa coast, around the Chatham Rise, and in the Sub-Antarctic, in depths of 300–500 m (Ministry of Fisheries 2011). Because of the small size and high value of this species, target catch tends to be outweighed by non-target catch — frequently non-QMS species of low or no commercial value which are likely to be discarded. The commercial scampi fishing industry are very conscious of the large bycatch in this fishery and various gear trials have been carried out, both in New Zealand and overseas, to attempt to minimise this (Hartill et al. 2006).

Scampi vessels are mainly 20–40 m long and use otter trawls, usually rigged with double or triple nets towed together using a sled between them to maintain net shape. This arrangement allows a wider total net width to be trawled, while minimising the headline height and therefore also unwanted bycatch. The exact configuration of each trawl deployed (i.e. the number of nets) is not recorded sufficiently well to allow this effect to be examined. Doorspread can be used to model the variation in trawl configuration (and even estimate the number of nets used) but this is rarely recorded by observers (less than 5% of the time). Wingspread may be recorded more often; this was shown by Baird et al. (2011) to have remained constant over time in the scampi fishery, though tow duration and distance have increased.

The first analysis of bycatch and discards in the scampi trawl fishery used a trawl duration-based estimator and provided annual estimates of bycatch and discards from 1990–91 to 2000–01 (Anderson 2004). The second analysis used the same estimator and generated annual estimates of bycatch and discards from 1999–2000 to 2005–06 (Ballara & Anderson 2009). In this assessment new estimates are provided for all years from 1990–91 to 2009–10, using a revised estimator and building on methods used in previous work on bycatch and discards by examining temporal trends in more detail and making explicit comparisons of the results with relative abundance estimates from trawl surveys where possible.

Total annual bycatch in the scampi fishery for the period 1990–91 to 2005–06 ranged from about 3000 t to 8000 t, compared with annual estimated scampi catches of 800–1000 t (Anderson 2004, Ballara & Anderson 2009). The main non-QMS bycatch species were various species of rattails, and spiny dogfish. Total annual discard estimates ranged from about 1500 t to 5100 t. The rate of discarding fell from about 3.5 kg of discards for every 1 kg of scampi landed (average for the 1990–91 to 2000–01 period) to about 2.5 kg of discards for every 1 kg of scampi landed (average for the 1999–2000 to 2005–06 period). This was considerably lower than estimated for the Clyde Sea (Scotland) scampi (*Nephrops* *norvegicus*) fishery, using similar fishing gear, where the equivalent average discard rate was 9 kg (Bergmann et al. 2002). Interestingly, discards returned to the sea in the North Sea scampi fishery were shown to have a positive effect on marine scavenger populations, including seabirds, crabs, and starfish (Catchpole et al. 2006).

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

Overall objective:

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

Specific objectives for year-1

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

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

2. METHODS

2.1 Observer data

Ministry for Primary Industries observers have made detailed records of catch and discards by species or species group, for each trawl or (frequently for discards) group of trawls, for a portion of the scampi fleet in each year since 1990–91. The allocation of observers on commercial vessels takes into account a range of data collection requirements and compliance issues for multiple fisheries. It has therefore not always been possible to achieve an even or random spread of observer effort in each fishery. Annual coverage has been variable in the scampi fishery, with less than 8% of the total catch observed in 7 of the 20 years (and only 3.9% in 2004–05) but greater than 14% observed in 6 years. Recent coverage, since the end of the last review period (2005–06) has been typical, ranging from 7.0–12.2%.

Overall, there is a considerable amount of observer data available for this analysis, with about 140–800 observed trawls annually.

2.1.1 Data preparation and grooming

Two datasets were prepared from the Ministry for Primary Industries observer databases *obs* and *cod*, based on all observed trawls targeting scampi since 1990–91, one comprising bycatch data and the other discard data. The *cod* database, which superseded the older *obs* database, was used to construct the bycatch dataset as this contains a complete set of catch by species for all relevant trawls. The discard dataset required data from both *obs* and *cod* to produce a complete set of discards by species for the years required, because of the lack of linkage in *cod* between processing data and station data in records from before about mid 2007. The *obs* database has this linkage, but contains no relevant data after April 2008. Observers assess discards as part of their examination of the processing of the catch to the various product states and may, for convenience when the catch from consecutive trawls gets mixed onboard, summarise this processing across two or more trawls. In these cases a unique link between the discards by species and the station data cannot be made, and is therefore of limited use in this analysis. Therefore, the dataset produced was restricted to those trawls for which the processing data were assessed independently.

A total of 8124 observed trawls targeting scampi was extracted and used in the analysis of bycatch. Because of variability in the recording of fish processing data, there were fewer observed trawls (5777) available for the analysis of discards – see below. Data grooming was carried out in the same way for each dataset.

Trawl distance was calculated from the recorded start and finish positions. Records in which a start or finish position was missing, or where the calculated distance was more than 50 km, about 1% of all records, were identified and groomed using median imputation. This process substitutes the missing/dubious value with an approximate one calculated from the median latitude or longitude for other trawls by the same vessel on the same day. Trawl distances were then recalculated from a combination of the corrected positions and values derived from the recorded duration and trawling speed.

Trawl durations were derived from the difference between the start and finish times, less the period (recorded by observers) between those times when the net was not fishing, e.g., when the net was lifted off the bottom to avoid foul ground, brought to the surface during turning, or was temporarily left hanging in the water due to equipment malfunction. These trawl durations were then cross-checked with estimates based on the recorded fishing speed and calculated trawl distance. Missing fishing speed values and speeds greater than 4 knots (about 1.5% of the records) were substituted with values estimated by median imputation.

Fishing depth was calculated from the average of the recorded start and finish net depths where possible. For the records where one or both of these values was not recorded (11% of all records) bottom depth was taken from the remaining value or from the seabed depth (average of start and finish values where possible). Less than 1% of trawls were recorded as not being on the seabed at all times, and only 4 trawls were coded as midwater trawling — probably in error. Most trawls (85%) followed a straight line or constant depth contour, 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 should differ only if fish are lost from the net, either at or below the surface. Such losses may 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 recorded as lost fish (presumed dead) and included in the discards for 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 rare in this fishery, occurring in only seven tows, with an average of about 360 kg of lost fish per tow.

Each record was assigned to an area (see Figure 1), based on natural breaks in the fishery, known stock divisions, or management areas. A few records fell outside these defined areas, but were retained in the analysis and designated as area “OTHER”. These are the same areas defined by Ballara & Anderson (2009) for the previous review. The number of trawls observed in each area over the 20 years is shown in Table 1.

Observer data were available from 20 vessels ranging in length from 20 to 64 m. No vessel or company is identified in this report, and alpha-numeric codes are used to differentiate between vessels where necessary.

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

	AUCK	CHAL	CHAT	NRTH	OTHR	PUYS	WAIR	WCSI	All areas
1990–91	0	0	3	175	0	0	173	0	351
1991–92	260	0	109	88	1	25	64	0	547
1992–93	146	0	140	8	0	8	100	0	402
1993–94	273	0	327	3	3	0	191	0	797
1994–95	50	0	153	40	0	0	157	0	400
1995–96	66	0	60	56	0	0	90	0	272
1996–97	224	0	0	39	3	0	52	0	318
1997–98	154	0	84	36	3	0	21	0	298
1998–99	23	0	103	30	4	0	322	0	482
1999–00	71	0	89	82	0	0	169	0	411
2000–01	84	0	34	0	8	0	138	0	264
2001–02	160	16	123	41	1	0	242	2	585
2002–03	150	0	326	0	0	3	32	0	511
2003–04	166	0	236	5	0	0	0	0	407
2004–05	0	0	76	51	0	0	15	0	142
2005–06	118	2	97	114	0	0	0	0	331
2006–07	100	0	151	93	0	0	30	0	374
2007–08	92	0	183	144	0	0	101	0	520
2008–09	60	0	203	88	0	0	37	0	388
2009–10	91	0	106	123	0	0	27	0	347
All years	2 288	18	2 603	1 216	23	36	1 961	2	8 147

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 during sorting and processing. In order to examine how discard levels varied with fishing depth, area, season, etc., either these variables can be summarised over all trawls within each processing group, or processing groups representing more than one trawl can be disregarded. In this case the latter approach was adopted (which avoids also having to account for the effects of differences in discard variability between groups with one tow and groups with multiple tows), therefore disregarding about 27% of the available discard data—spread fairly evenly across all years and areas of the fishery. An examination was made to investigate whether the practice of combining multiple tows into single groups was related to the level of discards per tow, e.g., discards being tallied and recorded only when several small amounts had been accumulated. This showed that although mean discards per tow was slightly greater for groups comprising a single tow (704 $kg.tow^{-1}$) there was no trend with increasing numbers of tows per group (2 tows per group, 591 $kg.tow^{-1}$; 3 tows per group, 531 $kg.tow^{-1}$; 4 tows per group, 617 $kg.tow^{-1}$).

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

- All current Quota Management System species combined, excluding SCI (QMS). Observers recorded 41 QMS species in total, excluding scampi.
- All non-QMS species combined, excluding invertebrates (non-QMS).
- All non-QMS invertebrate species combined (INV)
- Javelinfish (*Lepidorhynchus denticulatus*) (JAV) a non-QMS fish species.
- All other rattails (Macrouridae) (RAT) a non-QMS fish group. This potentially includes some javelinfish as they are a member of the Macrouridae usually identifiable to species.

The catch and discarding of rattails and javelinfish were examined separately as they were found to be the main bycatch species in this fishery. The above abbreviations (QMS, non-QMS, INV, JAV, and RAT) are used throughout the remainder of this report. Bycatch and discards were estimated separately for each of the combined species categories. Summaries of the observed catch and percentage discarded of individual species and species groups are tabulated in Appendices 1–3.

2.2 Commercial fishing return data

Catch records from commercial fishing returns were obtained from Ministry for Primary Industries catch-effort databases for all trawls in which scampi was the stated target species, for the period 1 October 1990 to 30 September 2010. This included all fishing recorded on Trawl Catch Effort Returns (TCERs), Trawl Catch, Effort and Processing Returns (TCEPRs), and Catch, Effort and Landing Returns (CELRs). Data were groomed for errors using simple checking and imputation algorithms developed in the statistical software package 'R' (Ihaka & Gentleman 1996). Tow positions, trawl distance and duration, fishing speed, and depths, were all groomed in this manner, primarily employing median imputation and range checks to identify and deal with missing or unlikely values and outliers (Table 2).

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

Field (range)	CEL	TCE	BOTH
Missing/outlying start longitude (< 157° E or < 167° W)	–	25	–
Missing/outlying end longitude (< 157° E or < 167° W)	–	54	–
Missing/outlying start latitude (< 157° E or < 167° W)	–	11	–
Missing/outlying end latitude (<24° S or >58° S)	–	41	–
Calculated distance missing or > 100 km	–	1 038	–
Missing/outlying gear depths (<160 m or > 615 m)	–	–	497
Missing/outlying bottom depths (<160 m or > 615 m)	–	–	2 318
Missing/outlying fishing duration (>13.3 h)	4	674	–
Missing/outlying fishing speed (<1.2 or > 4.0 knots)	–	164	–

Records were assigned to the areas defined in Figure 1, as was done for the observer data, using the recorded position coordinates.

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

2.3 Analysis of factors influencing discards and bycatch

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

Each species category (QMS, non-QMS, INV, JAV and RAT) was examined separately and normal and, where appropriate, binomial mixed-effect regression models constructed. Binomial regression models were used only where there was a large proportion of zero values in the data. This combined approach enabled an examination of factors influencing both the *probability* and the *level* of a bycatch or discard. The response variable in the binomial models comprised a binomial vector assigned "0" if no bycatch/discard was recorded and "1" otherwise. The response variable in the normal models was the log of the bycatch/discards of the species group.

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

2.4 Calculation of discard and bycatch ratios

For each species category, the observed weights of catch and discards were summed within each stratum determined from regression analysis. Similarly, the target species catches and trawl durations were summed within strata. From this, the "discard ratio", $\hat{D}_{\cdot}$, was derived. Initially, three versions of the ratio were calculated for several subsets of the data, one based on the total catch of the target species (scampi), one on the total trawl duration, and one on the number of trawls. The estimators had the following form,

$$\hat{DR}_{catch} = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} l_i} \quad , \quad \hat{DR}_{duration} = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} t_i} \quad \text{and} \quad \hat{DR}_{n.trawls} = \frac{\sum_{i=1}^{m} d_i}{m}$$

where m trawls were sampled from a stratum; d_i is the weight of discarded catch from the ith trawl sampled; l_i is the weight of scampi caught in the ith trawl sampled; and t_i is the duration of the ith trawl. Variances of these estimates were calculated using standard bootstrap techniques. This involved sampling at random (with replacement) 1000 sets of ratios based on each of the above formulas, each set being the length of the number of records (i.e., 8124 for bycatch, and 5777 for discards). This resulted in 1000 estimates of $\hat{D}_{\cdot}$ from which variances and confidence intervals were calculated. A comparison of the three estimators was then made by examining the ratio variances produced, and the estimator which consistently produced the lowest variance was chosen for all further calculations.

This bootstrap method of estimating variance makes the assumption that all trawls were sampled with equal probability. Random assignment of observers to trawls did not occur, with some vessels receiving no observer coverage, but a wide range of vessels and vessel sizes was observed, and the spread of observed trawl positions compared with all recorded trawl positions (see Figure 1) showed that the main fishing grounds were covered reasonably well.

Once the best estimator was chosen, estimates of $\hat{D}$ were derived for each stratum in each fishing year and variances estimated by a more sophisticated bootstrapping procedure that allowed for correlation of discards between trawls within an observed trip. Separate ratios were calculated only for fishing year/stratum combinations with 100 records or more. Where there were fewer than 100 records, overall ratios based on all strata in the fishing year were substituted. And for years with fewer than 200 records across all strata, an overall ratio based on all years for the stratum was substituted. The discard ratio calculated for each cell was then multiplied by either the total estimated catch of the target species, total trawl duration, or number of trawls in the cell (depending on the version of the estimator chosen), from commercial catch records, to estimate total discards $\hat{D}$:

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

where L_j is the total catch of scampi, T_j the total trawl duration, and M_j the number of trawls, in fishing year/strata cell j.

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

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

The effective number of trawls and the effective number of trips was calculated from the effort (catch, duration, or number of trawls) and reflected the contributions to the variance of the discard rate $\hat{D}$ from the variance of the discards and the covariance between pairs of discards within the same trip and cell. Matching a bootstrap sample to the cell on these criteria ensured that the variation in the bootstrap sample estimate matched the sampling variation of $\hat{D}$. An empirical distribution for the total discards was obtained by totalling the bootstrap estimates across the strata within a fishing year, and the 95% confidence interval was obtained from the 2.5% and 97.5% quantiles.

Bycatch estimates were calculated in a similar same manner to discards. Bootstrapping was carried out using the statistical software package R (Ihaka & Gentleman 1996).

2.5 Analysis of temporal trends in bycatch and discards

Annual estimates of the amount of bycatch and discards in each species category and overall, with confidence intervals, were plotted for the whole time-series. A weighted linear regression was performed on these data, with lognormal errors. The weighting used was the inverse of the CV^2, designed to give greater weighting to points with a smaller CV. The regressions lines thus calculated were fitted to the plots and the significance of the difference of the slopes of these lines from a slope of zero (i.e. no trend) was tested.

A similar approach was used to examine trends in the rates of bycatch and discarding in each species category and stratum.

2.6 Comparison of trends in bycatch with data from trawl surveys

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

The Chatham Rise hoki and middle depth species trawl survey time series provides a useful set of data for estimating the abundance of QMS and non-QMS fish species, as well as invertebrates, in an important sector of the scampi fishery. This annual survey has been running since 1992, and overlaps with area CHAT in this analysis (Figure 1). The survey comprises the following depth strata; 200–400 m, 400–600 m, 600–800 m and, in some years, 800–1000 m. The scampi fishery operates within the shallower two strata.

The trawl survey of middle depth species in the Southland and Sub-Antarctic areas also overlaps with the scampi fishery. This time series began in 1991 and includes a stratum (stratum 6, 300–600 m), which encompasses the Auckland Islands scampi fishery.

Although these surveys use substantially different trawl gear to the commercial scampi fishery, and the Chatham Rise survey has been rejected for use as an alternative relative abundance index for scampi (Ian Tuck, NIWA, unpublished results), the catch composition for other species (fish in particular) may be sufficiently similar to allow a worthwhile comparison of survey abundance estimates with observed bycatch rates to be made.

For the relevant strata within each survey in these two time series, the biomass of each species in each category was estimated using the swept area method of Francis (1981, 1989) and the formulae in Vignaux (1994) as implemented in the NIWA custom software SurvCalc (Francis & Fu 2010). Biomass and coefficients of variation (CV) were calculated for these species by strata, and combined. The catchability coefficient (1.0) and other settings were held at the same values as specified in the reports from these trawl surveys (e.g., O’Driscoll et al. 2011, Stevens et al. 2011, Bagley et al. (in press)).

Annual survey biomass estimates within each species category were then compared graphically with the equivalent median catch rates from the observer data for the same area, and the correlation between the two time series was determined using graphical techniques and statistical tests. More rigorous statistical comparisons, for example using resampling methods to estimate correlation significance, were considered not appropriate due to the differences in stratification between the surveys and this analysis.

3. RESULTS

3.1 Distribution and representativeness of observer data

The positions of all observed trawls in the target scampi fishery between 1 October 1991 and 30 September 2010 are shown, along with all trawls recorded with position data on commercial fishing returns from the same period, in Figures 1 and 2.

For the 20-year period as a whole, observer coverage included all the major scampi fisheries, with observed trawls well spread over the Auckland Islands, western and eastern Chatham Rise, Wairarapa coast, and Bay of Plenty regions (Figure 1). A few small gaps in coverage are visible, especially on the central Chatham Rise and west coast South Island, but these represent relatively minor scampi fisheries—annual landings from the west coast South Island scampi fishery are usually less than 1 t, and commercial scampi fishing on the central Chatham Rise has only developed since 2004–05 (Tuck 2009). Scattered targeting of scampi has occurred in appropriate depths throughout much of the EEZ, but few areas outside of the main scampi fisheries were observed.

Some differences in commercial effort and observer coverage within time periods are apparent: targeted fishing for scampi on the west coast South Island, Challenger Plateau, and Northland decreased over time; observer coverage and commercial effort has been highly variable in the small Puysegur fishery; observer coverage on the Challenger Plateau was almost entirely limited to the 2000–01 to 2004–05 period; and there was no observer coverage on the eastern Chatham Rise in 1995–96 to 1999–2000 (Figure 2).

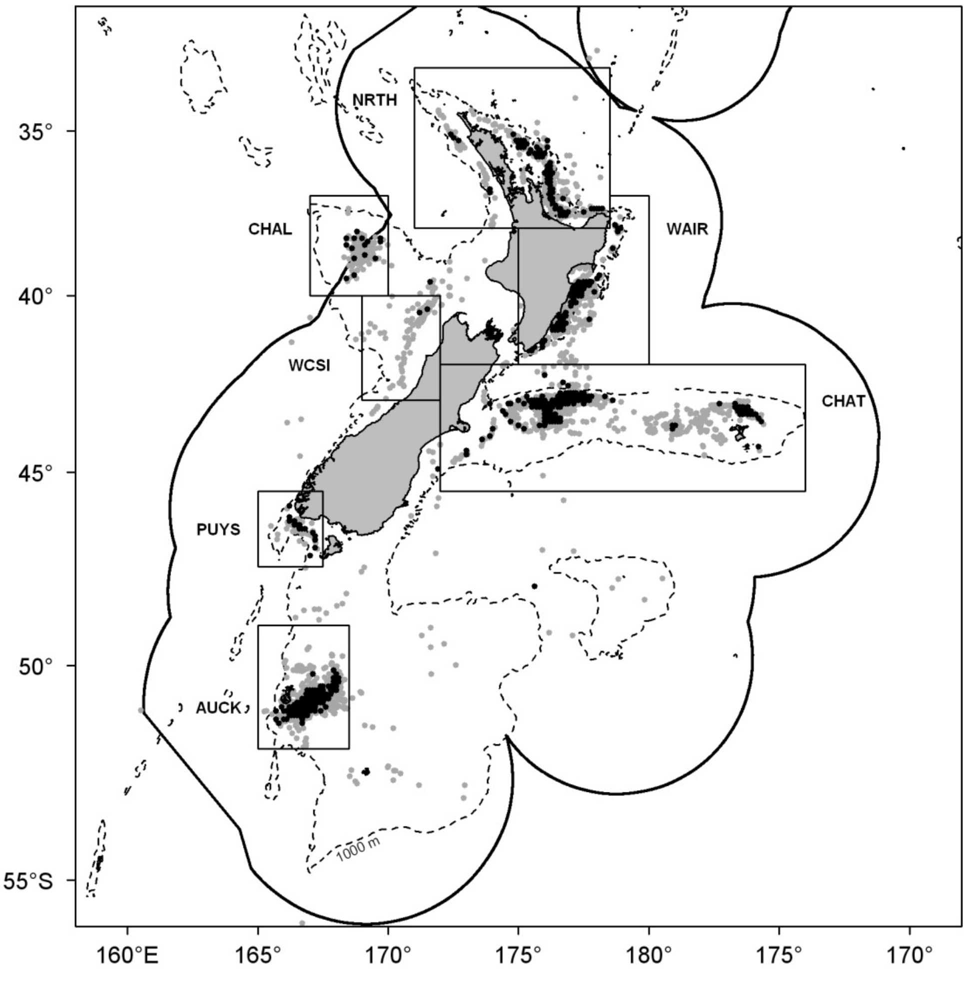

Figure 1: Distribution of trawl positions recorded by observers on vessels targeting scampi (black dots), and all commercial trawls with position data targeting scampi (grey dots) for 1990–91 to 2009–10. Area divisions used in the analyses are shown: NRTH, North; CHAL, Challenger Plateau; WAIR, Wairarapa; WCSI, west coast South Island; CHAT, Chatham Rise; PUYS, Puysegur; AUCK, Auckland Islands.

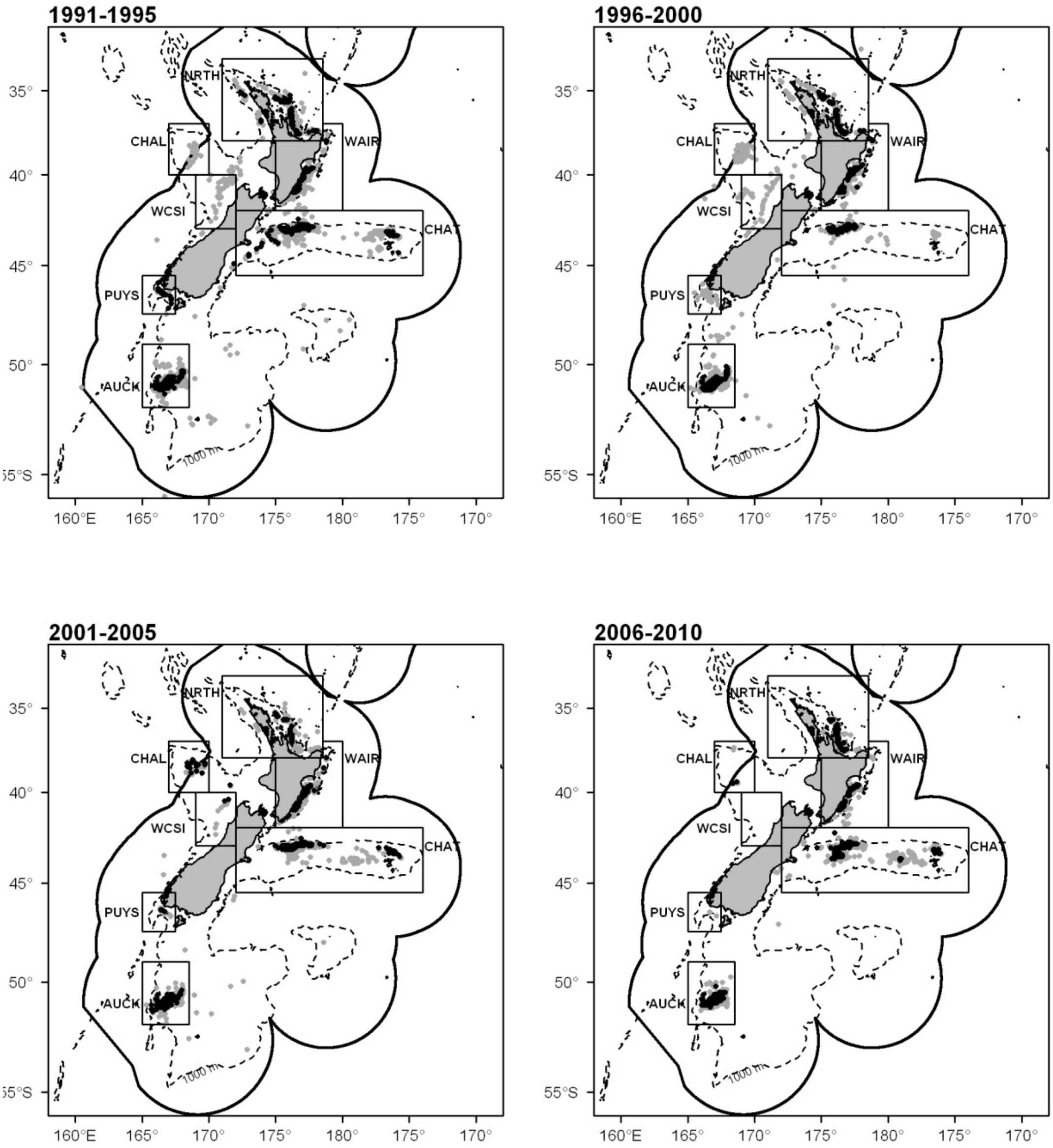

Figure 2: Distribution of trawl positions recorded by observers on vessels targeting scampi (black dots), and all commercial trawls with position data targeting scampi (grey dots) by blocks of years. Area divisions used in the analyses are shown. In the titles, 1991= fishing year 1990–91, etc.

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

The spread of observed trawls over the longitudinal and latitudinal extent of the fishery was well matched to that of the entire commercial fishery throughout much of the last two decades. This match was least perfect during the 2000–01 to 2004–05 period in which the northern Wairarapa and southern and eastern Bay of Plenty regions were poorly covered; and in 2005–06, when observer coverage was relatively low again in the northern Wairarapa and also in southern parts of the Chatham Rise. Observer sampling was intermittent in the small fishery at the eastern end of the Chatham Rise, with none after 2006–07.

In the years since 2005–06 observer coverage was matched better to commercial effort and, when all years are considered together, overall observer coverage is shown to have neither oversampled nor undersampled substantially at any range of longitude or latitude.

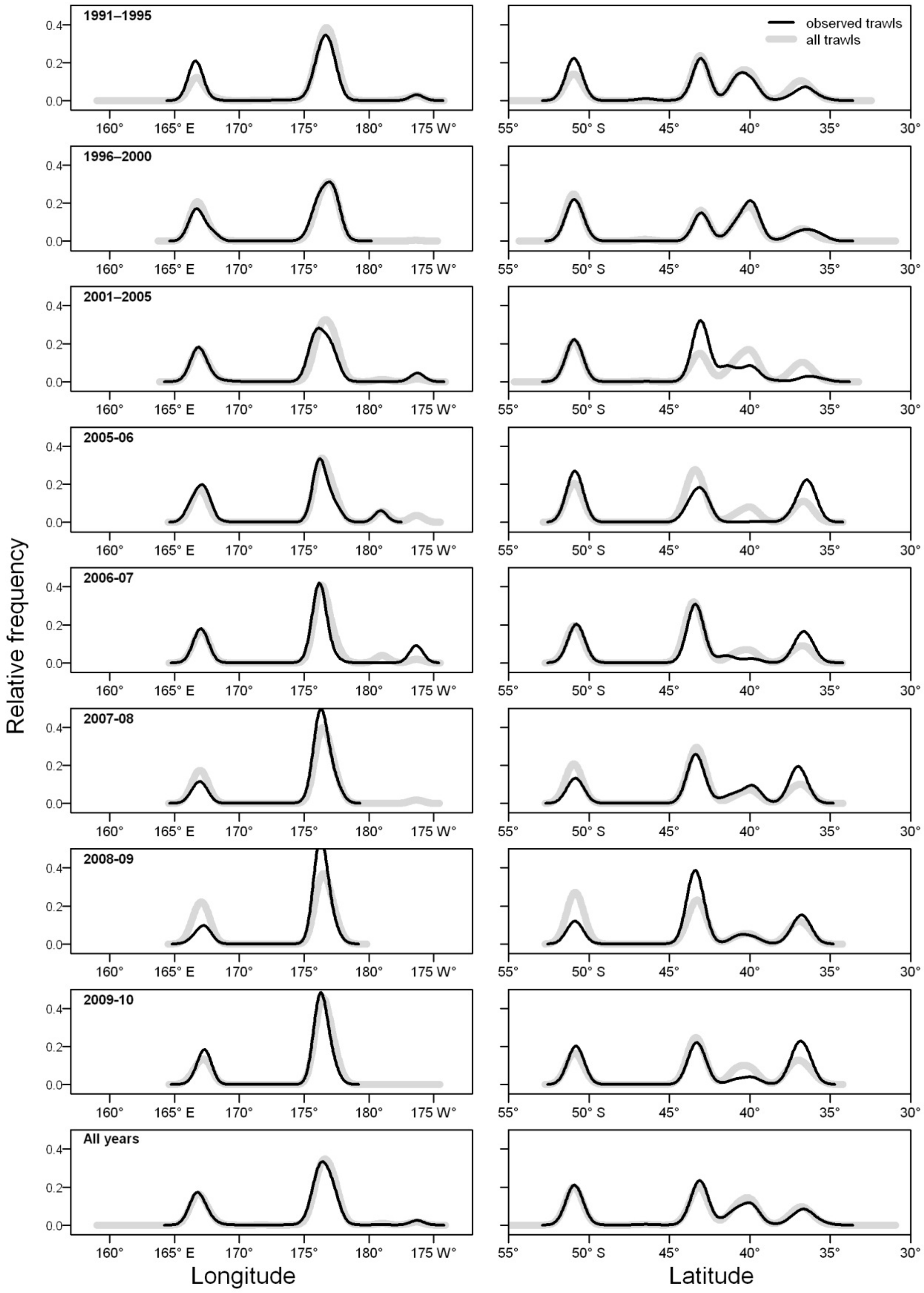

Figure 3: Scampi target fishery. Comparison of start positions (latitude and longitude) of observed trawls with those of all commercial trawls. Fishing years 1990–91 to 2004–2005 are shown in 5-year blocks, fishing years 2005–06 to 2009–10 are shown by year and, in the bottom panel, all 20 fishing years are shown combined. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

The annual number of observed trawls in the scampi fishery ranged from 142 to 797, but was over 300 trawls in 16 of the 20 years (Table 3). The number of vessels observed in each year ranged from 3 to 8 (equivalent to 33–66% of the fleet) and was very constant, being at 5 or 6 vessels through 14 of the 20 years. The number of trips observed annually fluctuated over time, from a low of 3 in 2004–05 to a high of 14 in 1993–94 and 2001–02. Although in some years the observed catch accounted for less than 10% of the total catch (minimum of 3.9% in 2004–05) in most years coverage was greater than 10% and for the 20 years as a whole was 11.2%.

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

Fishing year	Number of trawls		Number of vessels		Number of trips		Total scampi catch (t)		Percentage observed (%)	
	observed	all	observed	all	observed	all	observed	all	catch	trawls
1990–91	351	3 791	6	12	7	97	34	432	7.9	9.3
1991–92	547	5 319	7	14	7	111	153	799	19.1	10.3
1992–93	402	5 156	5	12	7	103	93	856	10.9	7.8
1993–94	797	5 090	7	11	14	90	131	908	14.4	15.7
1994–95	400	3 667	6	9	9	85	143	825	17.3	10.9
1995–96	272	3 369	3	9	4	69	66	846	7.8	8.1
1996–97	318	3 531	5	10	6	76	87	875	9.9	9.0
1997–98	298	3 407	6	11	7	81	90	903	10.0	8.7
1998–99	482	4 138	6	11	7	108	134	947	14.1	11.6
1999–00	411	4 664	6	11	8	118	100	912	11.0	8.8
2000–01	264	4 961	5	11	6	126	48	912	5.3	5.3
2001–02	585	6 642	7	15	14	187	113	887	12.7	8.8
2002–03	511	5 129	8	19	8	148	136	783	17.4	10.0
2003–04	407	3 554	6	17	6	62	117	674	17.4	11.5
2004–05	142	4 585	3	9	3	83	32	829	3.9	3.1
2005–06	331	4 862	6	9	6	79	60	794	7.6	6.8
2006–07	374	5 086	6	10	8	80	54	768	7.0	7.4
2007–08	520	4 802	5	11	8	87	62	607	10.2	10.8
2008–09	388	3 973	5	9	5	63	67	550	12.2	9.8
2009–10	347	4 170	5	8	6	60	48	629	7.6	8.3
All years	8 147	89 896	20	30	141	1 876	1 770	15 734	11.2	9.1

Comparisons made between vessel sizes in the commercial fleets and the observed portion (Figure 4) showed that the full range of vessel sizes was covered by observers. Total vessel effort formed roughly into four size groups; the great majority of the total effort was by vessels less than 250 t, with only a small amount of effort by vessels in size groups of around 500 t, 650 t, and 1900 t. Each of these size groups were covered by observers, although the two larger size groups were slightly oversampled.

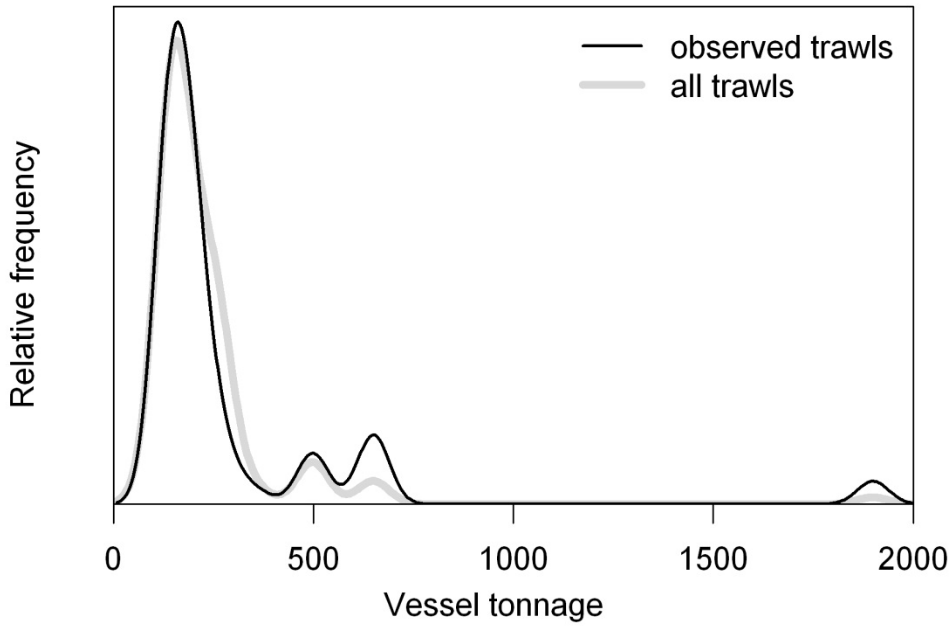

Figure 4: Comparison of vessel sizes (gross registered tonnage) in observed trawls versus all recorded commercial trawls for the period 1 October 1990 to 30 September 2010. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

Comparison of the distribution of fishing depths between the observed tows and all commercial tows shows good correspondence (Figure 5). The distribution of fishing depths shows a strongly bimodal distribution, with one mode centred on 350–400 m and another on 450–500 m. A closer examination of the data showed that the deeper mode is strongly associated with the Auckland Islands fishery, where fishing took place mainly in 400–500 m.

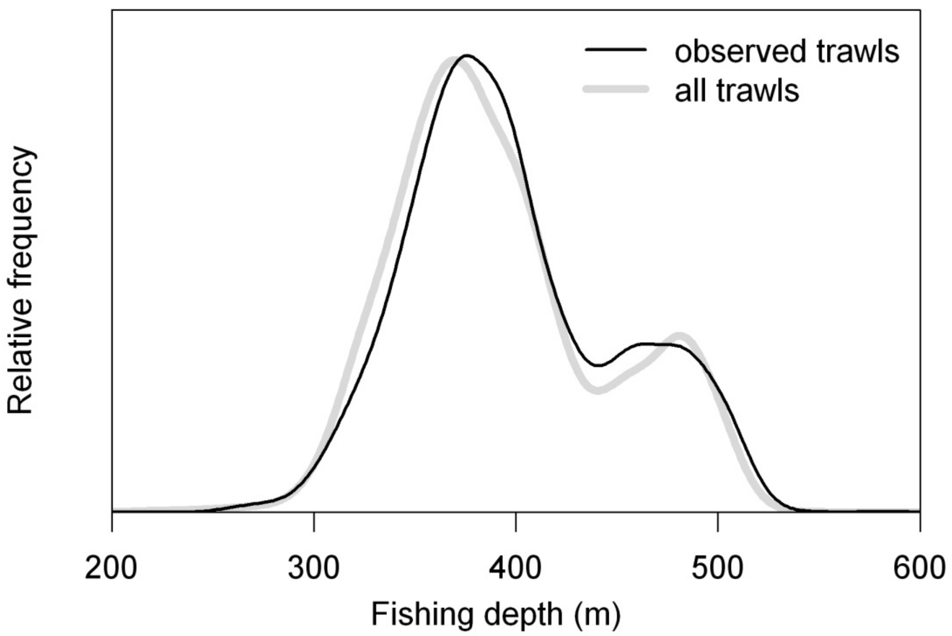

Figure 5: Comparison of fishing depth in observed trawls versus all recorded commercial trawls for the period 1 October 1990 to 30 September 2010. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

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

The plots show that commercial fishing for scampi took place right through the year in each of the 20 years examined. This effort was spread quite evenly across the year in most years, although in several years there was relatively more effort at the beginning of the year, especially in 2002–03 and 2003–04 so that, over all 20 years, there is on average a slight but steady decline in effort throughout the year (this is mostly due to the fishery in the AUCK area, where fishing is more concentrated into the first half of the year, but effort is also slightly higher in the first few months of the fishing year in the other main areas, CHAT, WAIR, and NRTH). Observer effort was much less evenly spread throughout the year; in some years (e.g., 1990–91, 2002–03, and 2003–04) restricted to just the beginning or end of the year, and in others (e.g., 1994–95 and 2006–07) spread across several trips spanning most of the year. For all years combined, the spread of observer effort was reasonably well matched to the spread of commercial effort, except for slight oversampling in October–December and undersampling in the following few months.

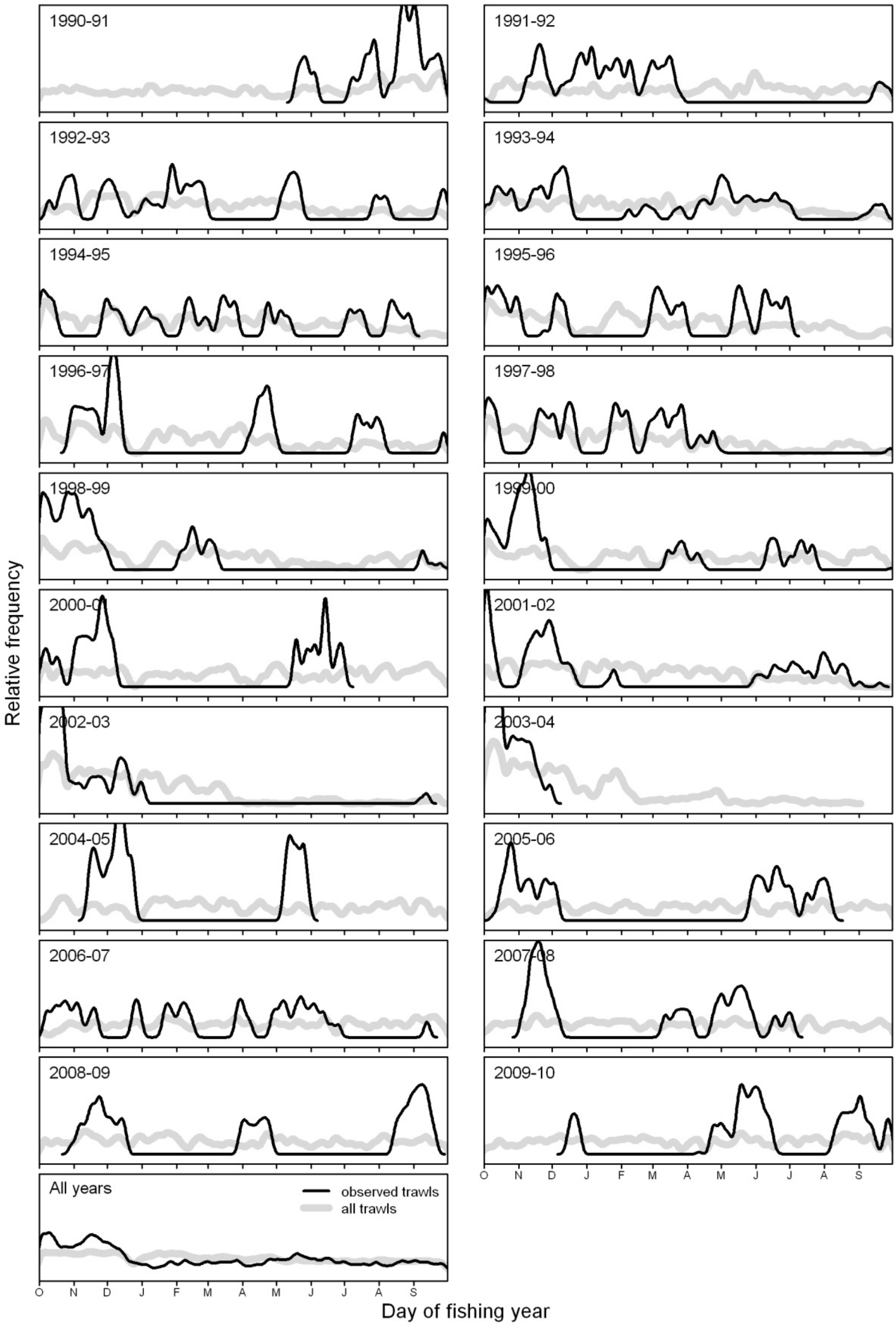

Figure 6: Scampi fishery: Comparison of the temporal spread of observed trawls with all recorded commercial trawls for 1990–91 to 2009–10, and for all fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.

3.2 Selection of ratio estimators

In the previous reviews of bycatch and discards in this fishery (Anderson 2004, Ballara & Anderson 2009), a trawl duration-based ratio estimator was chosen over a scampi catch-based estimator for all calculations of bycatch and discards, after comparing CVs from various sets of trial data. In more recent assessments of bycatch and discards, in other fisheries (e.g., Ballara et al. 2010, Anderson 2011), a "per trawl" ratio estimator was used after trials showed it to produce consistently lower CVs. This estimator was also examined here for the scampi fishery, alongside the scampi catch and trawl duration forms of the estimator. Although these trials resulted in very small CVs for each form of the estimator, the "per trawl" form produced consistently lower CVs than the two other forms of the estimator (Table 4). Therefore, the "per trawl" form of the ratio estimator was selected for all discard and bycatch calculations.

Table 4: Comparison of ratio estimators.

Bycatch/discards	Species category	Estimator	Bycatch ratio	CV (%)
Bycatch	QMS	Scampi catch	2.08	1.14
	QMS	Trawl duration	36.4	1.13
	QMS	Catch per trawl	452	1.07
	NONQMS	Scampi catch	2.44	1.30
	NONQMS	Trawl duration	88.7	1.32
	NONQMS	Catch per trawl	530	1.25
	INV	Scampi catch	0.30	2.14
	INV	Trawl duration	10.8	2.06
	INV	Catch per trawl	64.7	1.97
Discards	QMS	Scampi catch	0.51	2.48
	QMS	Trawl duration	17.2	2.41
	QMS	Discards per trawl	107	2.37
	NONQMS	Scampi catch	2.42	1.56
	NONQMS	Trawl duration	81.7	1.58
	NONQMS	Discards per trawl	507	1.51
	INV	Scampi catch	0.26	2.87
	INV	Trawl duration	8.9	2.54
	INV	Discards per trawl	55.3	2.69

3.3 Bycatch data

3.3.1 Overview of raw bycatch data

Over 450 species or species groups were identified as bycatch by observers in the scampi target fishery, most being non-commercial species, including invertebrate species, caught in low numbers (see Appendices 1–3). Scampi accounted for about 17% of the total estimated catch from all observed trawls targeting scampi since 1 October 1990. The main bycatch species or species groups were javelinfish (16%), other (unidentified) rattails (13%), sea perch (*Helicolenus* spp.) (8.4%), ling (7.5%), and hoki (6.1%). The first three of these bycatch groups were mostly discarded (Figure 7). Of the other invertebrate groups, unidentified crabs (1.1%) and unidentified starfish (0.8%) were observed in the greatest amounts. When combined into broader taxonomic groups, bony fish (excluding rattails) contributed the most to total bycatch (40%), followed by rattails (29%), rays and skates (3.5%), sharks and dogfish (2.3%), crustaceans (2.2%), chimaeras (2.0%), echinoderms (1.6%), and cnidarians (0.6%). A large percentage of the bycatch in these groups was discarded, and was only less than 85% for bony fish (excluding rattails) (33%), rays and skates (67%), and chimaeras (28%). In the calculations for Appendices 1–3, discards of species or species groups expected to have been 100% discarded in this fishery, e.g., starfish, or hagfish (*Eptatretus cirrhatus*), sometimes came to slightly less than this suggesting (most likely incorrectly) that some were retained. This is due to the "destination" being assumed to be “retained” rather than “discarded” when this field was missing on the observer forms—a correct assumption in most, but not all, cases.

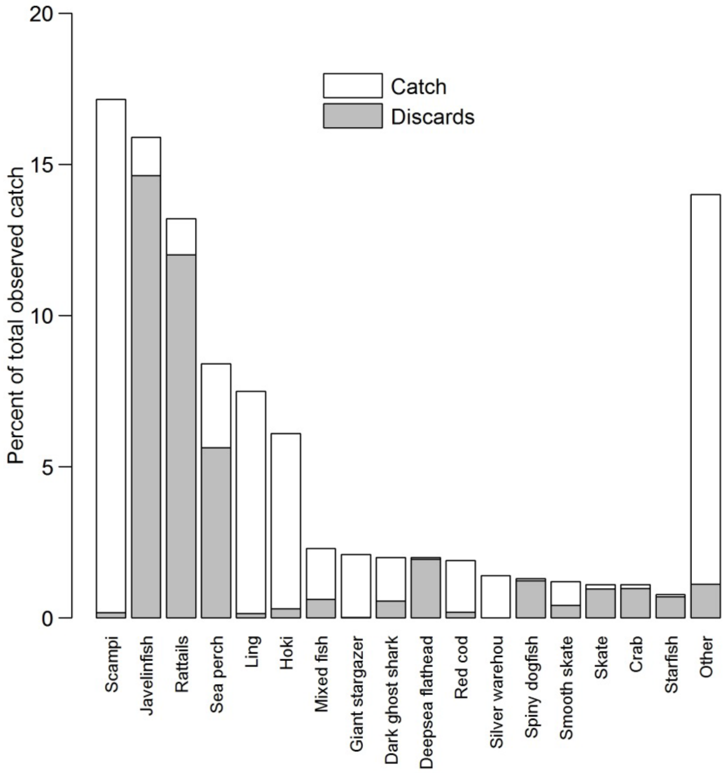

Figure 7: Percentage of the total catch contributed by the main bycatch species (those representing 1% or more of the total catch) in the observed portion of the scampi fishery, and the percentage discarded. The “Other” category is the sum of all other bycatch species (fish and invertebrates) representing less than 1% of the total catch.

Many invertebrates, in particular corals, echinoderms, and crustaceans, were identified to species, especially in the more recent records. This is due to improving knowledge of the New Zealand marine invertebrate fauna, both in general and specifically by fisheries scientists and observers, the use of invertebrate identification guides (e.g. Tracey et al. 2011a) which have become available to observers, and also dedicated observer benthic collections in selected deepwater fisheries (including scampi) between 2007–08 and 2009–10 (Tracey et al. 2011b). See Appendices 1 and 2 for a list of the main observed bycatch species and Appendix 3 for a summary by higher taxonomic group.

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

Total bycatch was highly variable between trawls, ranging from 0–11 t (Figure 8). Trawls were mostly 3–9 h long, with a median of 6.1 h. Bycatch per trawl showed little variation with increasing trawl duration, but a fitted line to these data indicated a slight decrease in bycatch for longer duration tows which was most marked for QMS species (Figure 9). This may be because the typically more abundant QMS species (especially in this instance hoki) are more likely than the less abundant, non-commercial, species to be caught in large amounts from short tows. Trawling was mostly at an average bottom depth of 300–500 m, with a median of 390 m. Total bycatch decreased very slightly with increasing bottom depth for QMS species and overall, but not for non-QMS species (Figure 10). Mean bycatch of QMS species decreased from about 480 kg per trawl at 300 m to about 250 kg per trawl at 500 m.

There was substantial variation in bycatch between the 18 vessels represented by more than 50 records, with total bycatch medians ranging from about 375 kg per trawl to 1525 kg per trawl, QMS bycatch medians from about 125 kg per trawl to about 790 kg per trawl, and non-QMS bycatch medians from about 173 kg per trawl to about 657 kg per trawl. There was a slight indication of lower QMS species bycatch in later years than in earlier years, with median values for the most recent five years all lower than any earlier values. This pattern was not seen in non-QMS species.

There were some substantial differences in bycatch levels in each catch category between the six main areas examined, although the values shown for areas PUYS (Puysegur) and CHAL (Challenger Plateau) were based on only a few records. For the other four areas, median bycatch in each catch category was lowest in AUCK (Auckland Islands) and NRTH, and highest in CHAT (Chatham Rise), with WAIR (Wairarapa) intermediate in value. There were relatively small variations in bycatch between months in each species category, with no indication of any seasonal pattern or trend.

The great majority of records were associated with domestic vessels, and the few records from Australian registered vessels showed a very similar level of bycatch to New Zealand vessels in each category. For most of the observer records the trawl was recorded as comprising a single net; where more than one net was recorded the QMS species bycatch was substantially less; and although the non-QMS species bycatch was also less with two nets, with three nets it was greater than with a single net. However, this result may be slightly misleading and may be the result of inconsistent recording of this detail of the fishing gear by observers, as the use of multiple nets by scampi vessels is likely to be more frequent than is suggested by these figures. According to Hartill et al. (2006) most vessels tow triple trawl rigs and the remainder tow double-rigged nets.

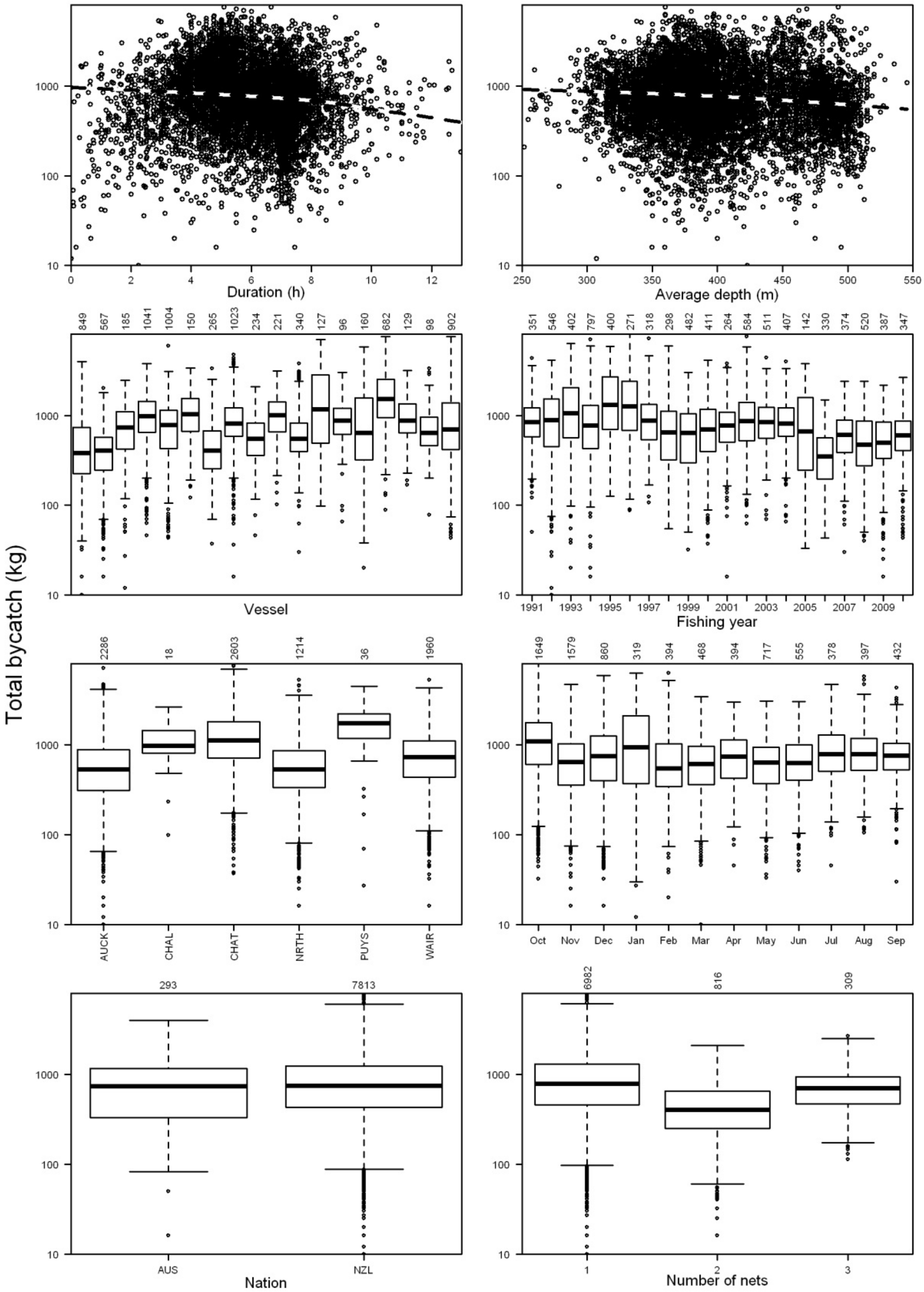

Figure 8: Total bycatch (all species) per trawl plotted against selected variables in the scampi target fishery. Total bycatch is plotted on a log scale. The dashed lines in the top panels represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted. The numbers above the plots indicate the number of records associated with that level of the variable. In the vessel plot, vessels are ordered by size, from shortest to longest; and vessels represented by fewer than 50 records were not plotted. Average depth is the average of the start and finish gear depth. NZL, New Zealand; AUS, Australia. See Figure 1 for area codes.

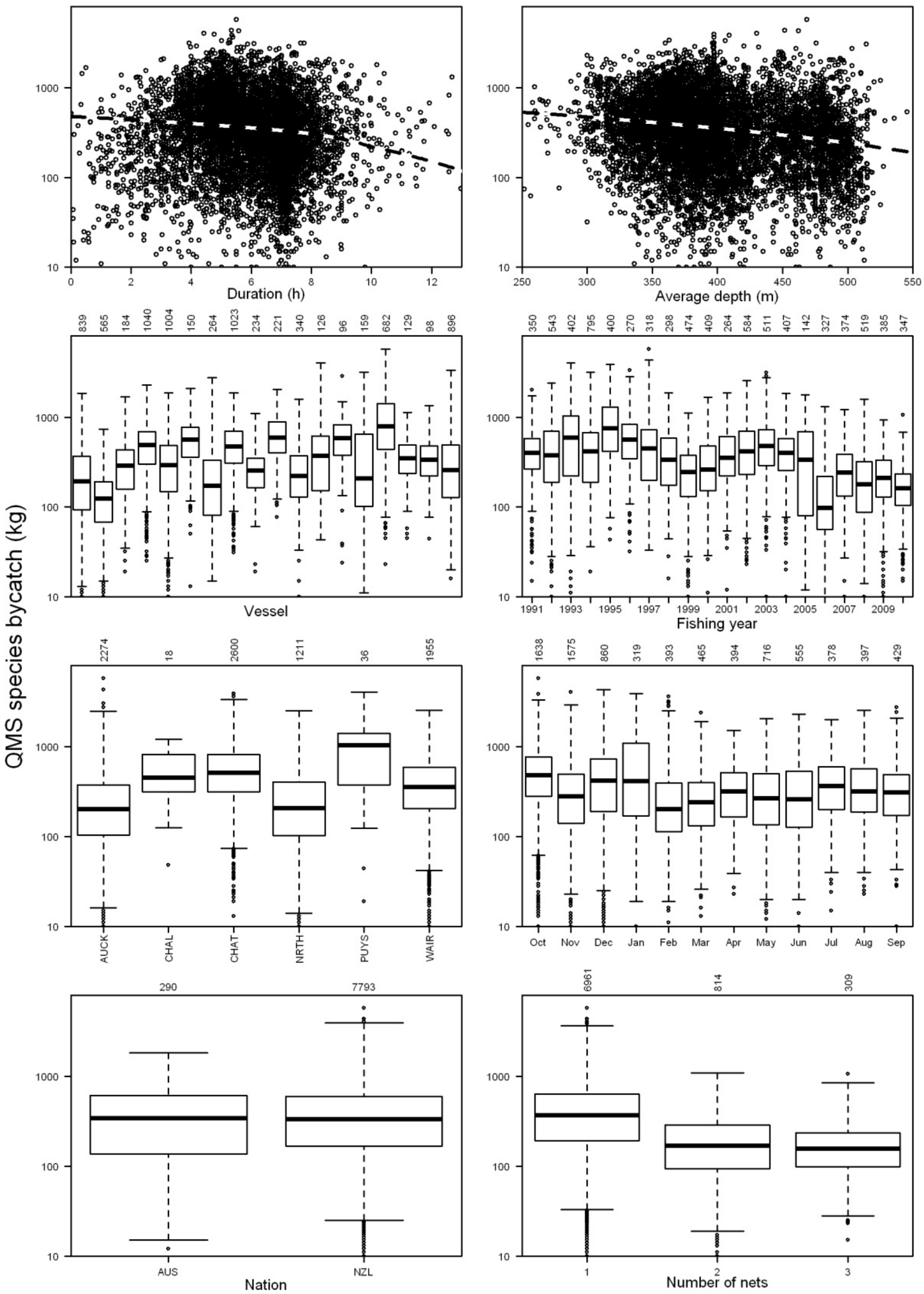

Figure 9: QMS species bycatch per trawl plotted against selected variables in the scampi target fishery. See Figure 8 for further details.

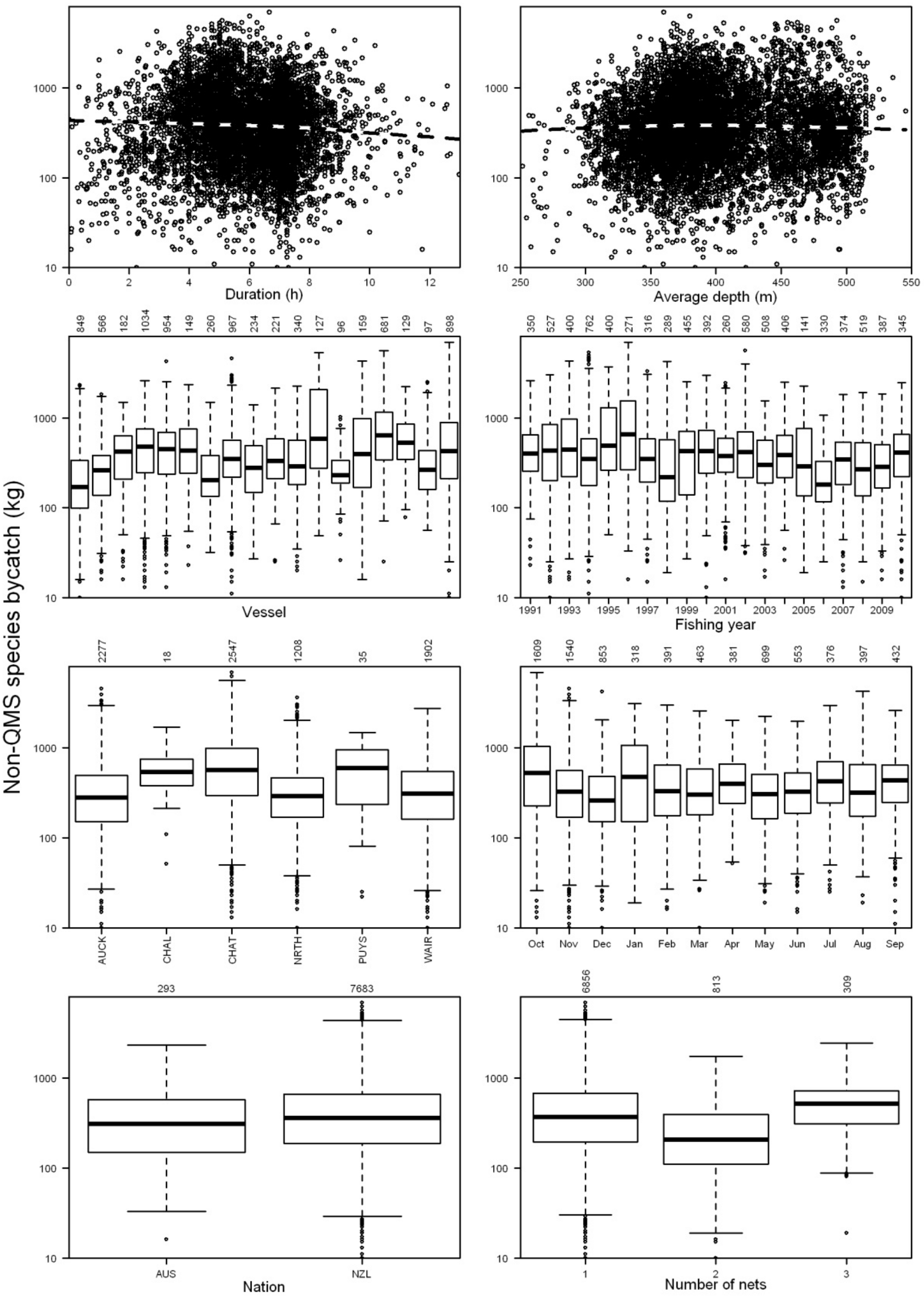

Figure 10: Non-QMS species bycatch per trawl plotted against selected variables in the scampi target fishery. See Figure 8 for further details.

3.3.2 Regression modelling and stratification of bycatch data

The dependent variable in the LME models was the bycatch ratio, expressed as the log of catch (kg) per trawl. There was a substantial fraction of records with no bycatch of invertebrate species, javelinfish, and other rattails, and so for these groups both log-linear and binomial models were constructed. This enabled identification of factors affecting both the level and likelihood of invertebrate bycatch. For QMS and non-QMS species categories the fraction of records with no bycatch was less than 3%, and so binomial models were not constructed.

In each of the models (except for JAV binomial) *area* was the most influential variable, and generally *duration* was the next most important variable (Table 5). The variables *start time*, *fishing year*, *depth*, *month*, and *tonnage* each had some influence in at least one of the models.

Although trawl duration clearly has an influence on catch rates in each species category, the quantity of available observer data in this relatively small fishery is such that it would be impractical to attempt a calculation of bycatch estimates based on multiple strata. Therefore due to the consistent influence of area in each of the bycatch categories, this variable alone was used to stratify all bycatch calculations, as it was for most of the species categories examined in earlier assessments of this fishery (Anderson 2004, Ballara & Anderson 2009).

Table 5: Summary of LME modelling of bycatch in the scampi trawl fishery. The numbers denote the order in which the variable entered the model. *fyr* = fishing year.

Species cat.	Model type							Variable
		area	*duration*	*start time*	*fyr*	*depth*	*month*	*tonnage*
QMS	Normal	1	3	2	4	5	6	7
Non-QMS	Normal	1	2	3	6	4	5	–
INV	Normal	1	2	4	6	7	3	–
INV	Binomial	1	2	4	–	5	–	–
JAV	Normal	1	4	5	6	2	3	–
JAV	Binomial	2	–	–	3	4	1	–
RAT	Normal	1	3	2	5	7	4	8
RAT	Binomial	1	4	3	–	–	2	5

3.4 Discard data

3.4.1 Overview of raw discard data

Javelinfish was the individual species most caught and most discarded in the scampi fishery, according to observer records. There are many species of rattails likely to be caught within the depth range and location of the scampi fisheries (see Anderson et al. 1998) and very frequently these are not identified beyond the code RAT (rattail) by observers. Hence unspecified rattails were the next most caught and discarded group recorded. One or two other rattail species were individually recorded by observers, and together rattail species (family Macrouridae) accounted for nearly 30% of the catch. Most of this catch was discarded.

Sea perch were also a major component of the catch and, despite having been in the QMS since 1998, a large fraction over time have been discarded. These are a relatively low value fish and it is likely that they were more frequently discarded prior to 1998. After this, sea perch can only have been discarded when an observer was present and given approval. Records of such approvals are provided in observer trip reports (but not in any electronic database) and examination of a selection of these showed that sea perch were frequently discarded on observed trips—in two cases over seven tonnes for the trip.

Other significant components of the catch that were frequently discarded included “mixed fish” (code MIX used when no species identification was made), dark ghost shark (*Hydrolagus novaezelandiae*), and deepsea flathead (*Hoplichthys haswelli*) (Appendix 1). Dark ghost shark (1998) (and smooth skate, 2003) also joined the QMS during the period being examined, and while the level of discarding may also have decreased after their entry, the amounts involved are likely to have been minor as the catch of these species was usually retained. Discard approval records in the selection of trip reports examined showed some discarding of dark ghost shark but at a much lower level than sea perch (10–300 kg per trip).

Few of the major invertebrate bycatch species were retained with any frequency, and most were 80–100% discarded (Appendix 2).

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

The level of total discards was highly variable between trawls, ranging from 0–8.5 t (Figure 11). The quantity of discards decreased only slightly with trawl duration for QMS species (Figure 12), and even less so for non-QMS species (Figure 13) and overall. Similarly, discards decreased with increasing depth for QMS species, from a mean of about 110 kg at 300 m to about 37 kg at 500 m, but depth had no discernible influence on non-QMS species or overall discards.

There was substantial variation in discards between vessels represented by more than 50 records, with total discard medians ranging from about 90 kg per trawl to about 840 kg per trawl, QMS discard medians from about 15 kg per trawl to about 140 kg per trawl, and non-QMS discard medians from about 30 kg per trawl to about 630 kg per trawl. There was considerable variation in discard rates between years in each species category, but no indication of any trends over time.

There were some substantial differences in discard levels in each catch category between the six main areas examined, even when disregarding the extreme values shown for areas PUYS (Puysegur) and CHAL (Challenger Plateau), which were based on only a few records. Median discards in each species category were lowest in AUCK and highest in CHAT. There were relatively small variations in discards between months in each species category, with no indication of any seasonal pattern or trend.

The few records from Australian registered vessels showed a very similar level of total discards to New Zealand vessels, but slightly higher QMS species discards and slightly lower non-QMS species discards. The number of nets making up the trawl had no discernable influence on discards of QMS species but, for non-QMS species and overall, two nets resulted in slightly less discards and three nets slightly more. But see Section 3.3.1 regarding the validity of these data.

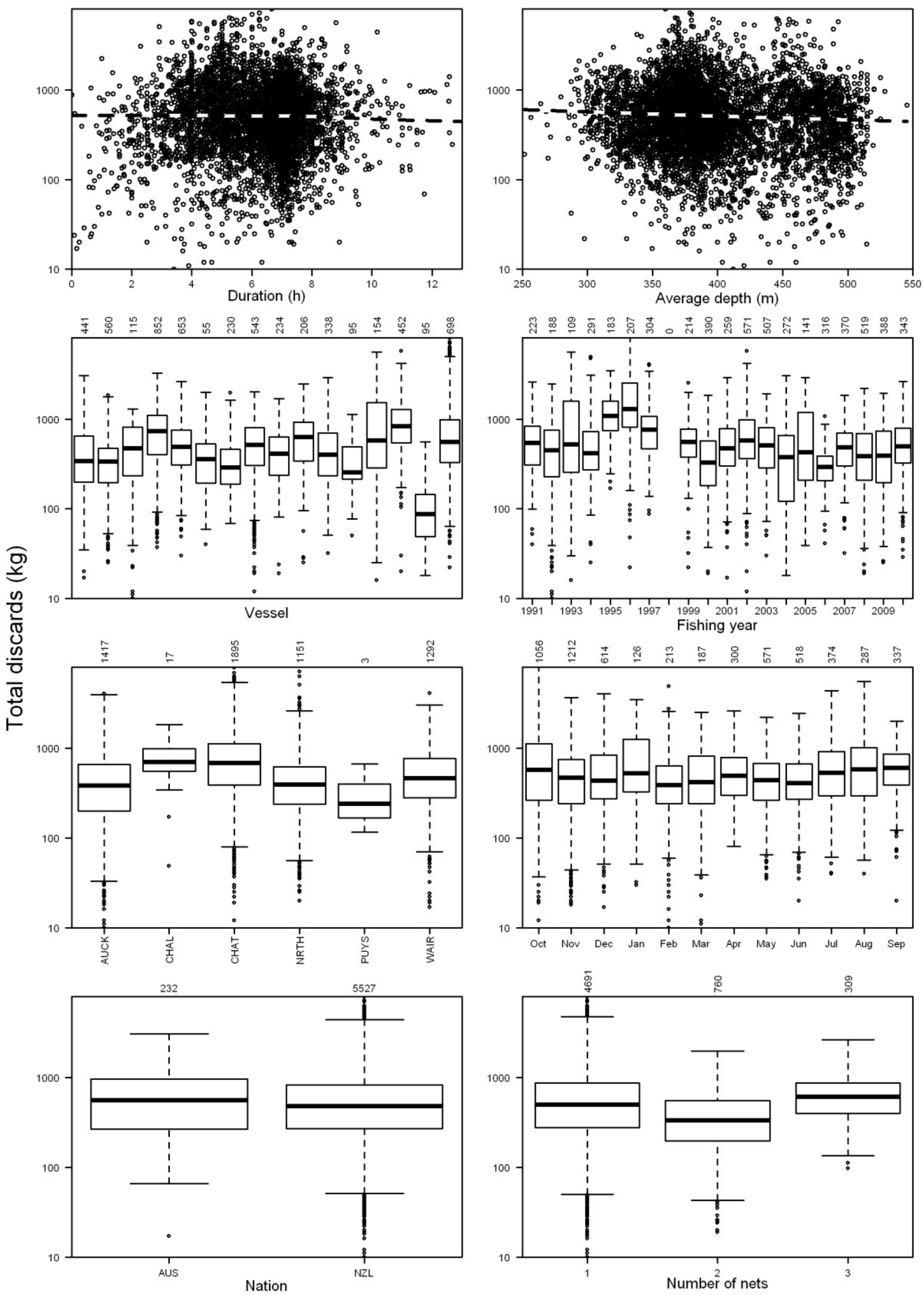

Figure 11: Total discards (all species) per trawl plotted against selected variables in the scampi target fishery. Total discards is plotted on a log scale. The dashed lines in the top panels represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5 times the interquartile range, and outliers individually plotted. The numbers above the plots indicate the number of records associated with that level of the variable. In the vessel plot, vessels are ordered by size, from shortest to longest; and vessels represented by fewer than 50 records were not plotted. Average depth is the average of the start and finish gear depth. NZL, New Zealand; AUS, Australia. No data for 1997–98 due to linkage error in database tables. See Figure 1 for area codes.

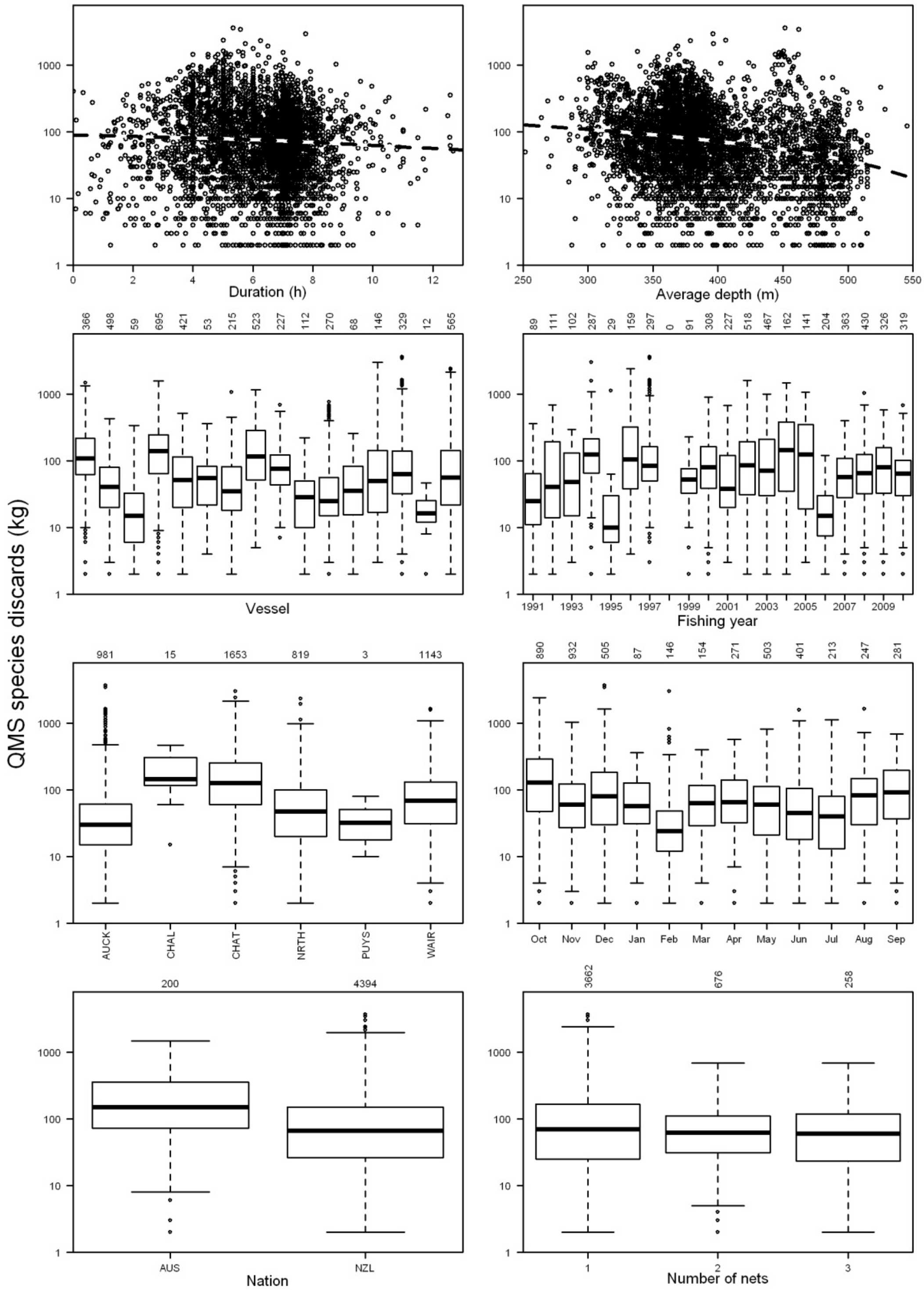

Figure 12: QMS species discards per trawl plotted against selected variables in the scampi target fishery. See Figure 11 for further details.

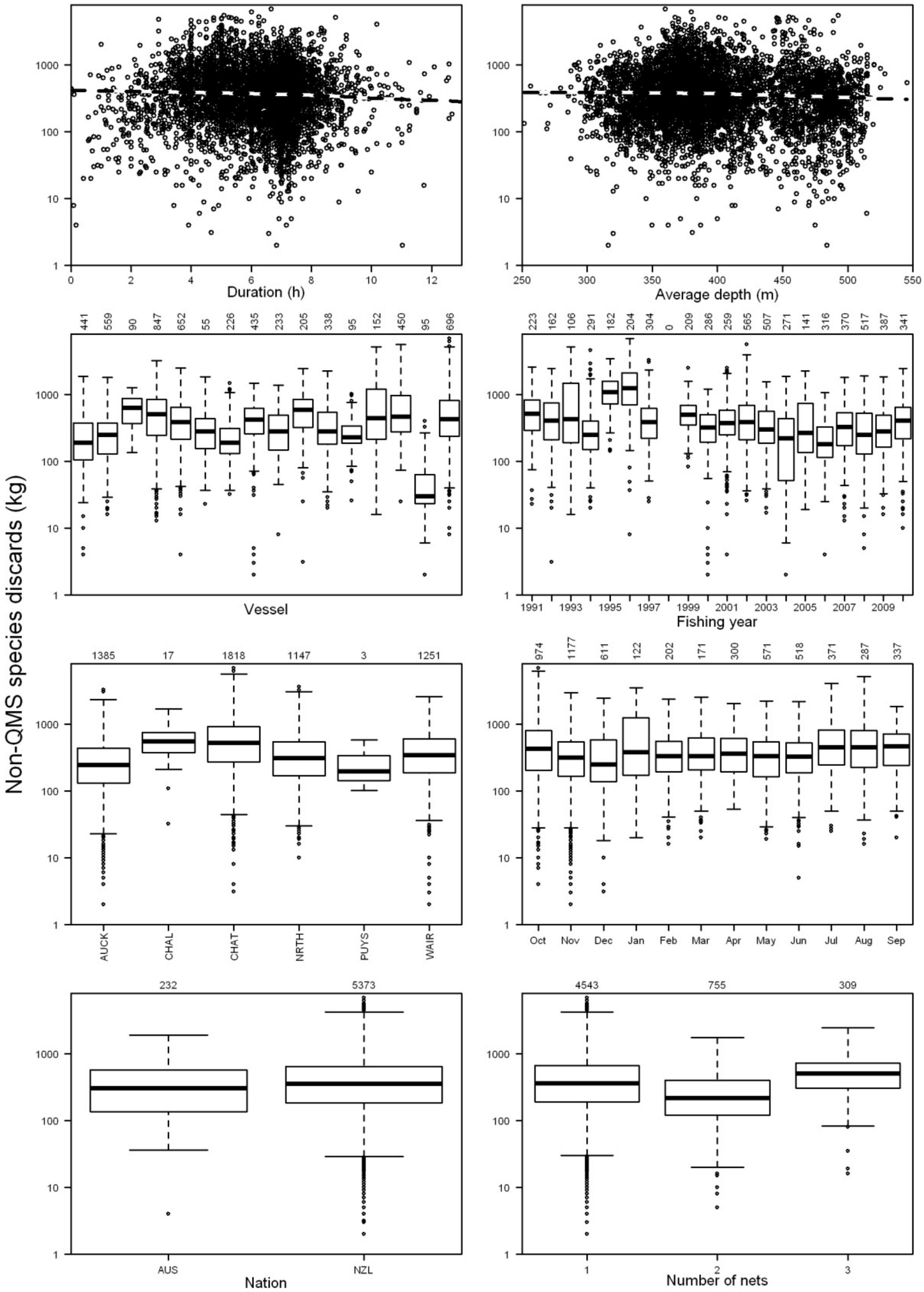

Figure 13: Non-QMS species discards per trawl plotted against selected variables in the scampi target fishery. See Figure 11 for further details.

3.4.2 Regression modelling and stratification of discard data

The dependent variable in the discard LME models was the discard ratio, expressed as the log of discards (kg) per trawl. Both log-linear and binomial models were run for each species category except non-QMS, for which the fraction of records with no discards was very low (about 2.5%).

In four of the five lognormal models and in the invertebrate binomial model *area* was the most influential variable, but it had less significant influence in each of the other binomial models (Table 6). As it was for bycatch *duration* was also an important predictor in most discard models, and several other variables, mainly *start time*, *depth*, *month*, and *fishing year* contributed to some extent in the other models. The variable *depth*, in particular, was highly influential in the QMS binomial model, and *fishing year* was important in the binomial rattail models.

For the same reasons that *area* was used as the sole stratification in the calculation of bycatch estimates, and to be consistent with those calculations, this variable alone was used in the discard calculations. As *area* was usually consistent among tows within the unused processing groups—those comprising more than one tow—it may have been possible to incorporate discard data from these processing groups into the analysis. However, this was not done due to the difficulty of accounting for differences in the variance of discard rates between groups with differing numbers of tows.

Table 6: Summary of LME modelling of discards in the scampi trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fyr*, fishing year, *head_ht*, headline height.

Species cat.	Model type								Variable
		area	*duration*	*start time*	*fyr*	*depth*	*month*	*tonnage*	*head_ht*
QMS	Normal	1	3	4	6	2	5	–	–
QMS	Binomial	–	2	3	–	1	–	4	5
Non-QMS	Normal	3	1	2	8	4	5	7	6
INV	Normal	1	2	3	–	–	6	–	5
INV	Binomial	1	–	–	3	–	2	–	–
JAV	Normal	1	2	4	–	3	5	7	–
JAV	Binomial	4	3	–	1	2	–	–	–
RAT	Normal	1	4	2	–	5	3	–	7
RAT	Binomial	3	5	–	1	–	4	2	–

3.5 Estimation of bycatch

3.5.1 Bycatch rates

Bycatch rates by area and year were calculated for each species category from the observer data, using the "per trawl" form of the bycatch ratio as described in section 3.2. The median bycatch rate and its variance were calculated using the bootstrap methods described in section 2.4.

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

Median bycatch rates of QMS species, although highly variable, were highest in CHAT in each year (ignoring years in which there were insufficient data to calculate a separate rate for this area) and generally lower in AUCK. This is not surprising as the Chatham Rise scampi fishery overlaps with several major middle-depth fisheries, including those for hoki and ling. Bycatch rates of non-QMS species were also generally higher in CHAT than in other areas in most years but were also highly variable, with especially high rates in 1995–96 and 2001–02. A similar level of variability was apparent in invertebrate bycatch rates, but in this case rates tended to be higher in AUCK than in other areas, and lower in CHAT.

Bycatch rates of rattails (excluding javelinfish) was greatest in CHAT in most years, peaking at about 900 kg per tow in 1994–95. In other years rattail bycatch in this and other areas was almost entirely below 400 kg per tow and generally 100–200 kg per tow. Bycatch rates of javelinfish were at a similar level to those of other rattails combined, varying between about 100 kg per tow and 400 kg per tow, and generally highest in CHAT where the peak bycatch rate was about 600 kg per tow in 2001–02.

A significant negative trend in bycatch rates over time, identified by regression modelling, was shown for QMS species in NRTH and WAIR, for non-QMS species in WAIR, and for javelinfish in WAIR; a positive trend was shown for invertebrate species in CHAT (Table 7).

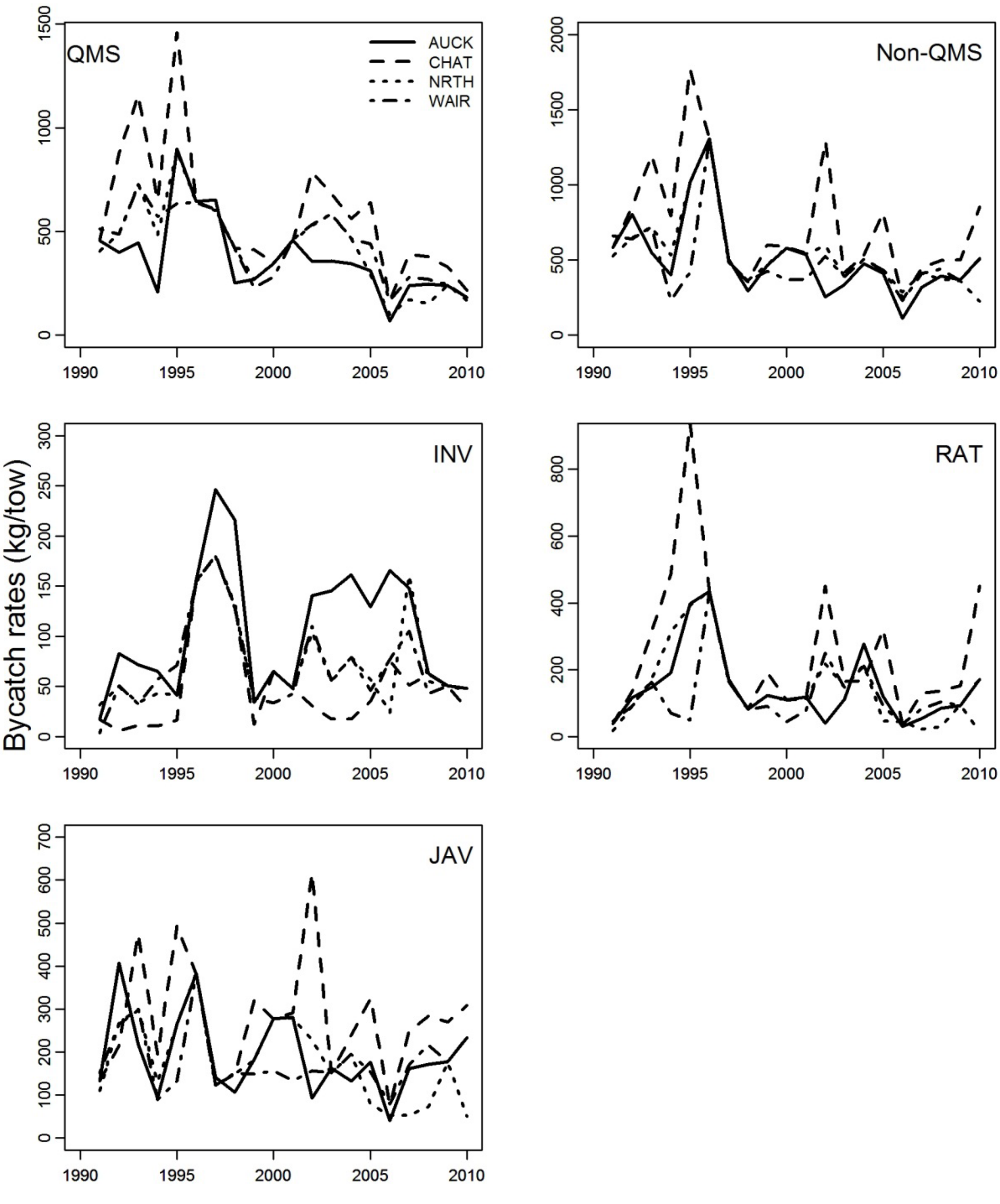

Figure 14: Annual bycatch rates by species category and areas used for stratification, in the scampi trawl fishery. Bycatch rates are the median of the bootstrap sample of 1000.

Table 7: Summary of results of regression analyses for trends in annual bycatch rates, by species category and area. The *p* values indicate how significantly the slopes differed from zero. Those results where p values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Area	Slope	*p*
QMS	AUCK	0.014	0.734
QMS	CHAT	-0.022	0.467
QMS	**NRTH**	**-0.057**	**0.011**
QMS	**WAIR**	**-0.099**	**0.000**
NONQMS	AUCK	0.025	0.544
NONQMS	CHAT	0.000	0.991
NONQMS	NRTH	-0.031	0.084
NONQMS	**WAIR**	**-0.070**	**0.003**
Invertebrates	AUCK	0.075	0.124
Invertebrates	**CHAT**	**0.110**	**0.019**
Invertebrates	NRTH	0.021	0.371
Invertebrates	WAIR	-0.016	0.614
Rattails	AUCK	0.035	0.498
Rattails	CHAT	0.023	0.596
Rattails	NRTH	-0.063	0.055
Rattails	WAIR	-0.038	0.232
Javelinfish	AUCK	0.060	0.246
Javelinfish	CHAT	0.034	0.290
Javelinfish	NRTH	-0.048	0.055
Javelinfish	**WAIR**	**-0.053**	**0.018**

3.5.2 Annual bycatch levels

The total annual bycatch in each species category was estimated by multiplying the ratios calculated from observer data for each area/year stratum by the total number of trawls in the commercial target scampi fishery for the equivalent stratum, as described in Section 2.4. Precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Tables 8 and 9, Figures 15 and 16). For a breakdown of the annual bycatch by area for each species category refer to Appendices 8–13.

Bycatch of QMS species followed a roughly cyclical pattern between 1990–91 and 2003–04, reaching peaks in 1992–93 (4370 t) and 2001–02 (3470 t) and lows in 1990–91 (1790 t) and 1998–99 (1240 t), which were strongly related to the annual variability in fishing effort (Figure 15). Bycatch in this category declined steadily after the 2001–02 peak, and by the most recent year examined, 2009–10, had fallen to 790 t (Table 8). The estimates for the years 1999–2000 to 2005–06 are very similar to those estimated for QMS species for this period by Ballara & Anderson (2009), with confidence intervals overlapping in all but one year (2005–06). The earliest study of bycatch in the scampi fishery (Anderson 2004) used different species categories to those used in the two subsequent assessments, and therefore no useful comparisons of results are possible.

A similar pattern of increasing and decreasing bycatch over time was seen also for non-QMS species (Figure 15). Annual levels of non–QMS bycatch were also similar to those of QMS species, ranging from 1020 t in 2005–06 to 4530 t in 1992–93 (Table 8). Estimates made by Ballara & Anderson (2009) for 1999–2000 to 2005–06 were again quite similar to those from this study, with confidence intervals (mostly narrower again in the present study) overlapping in all but 2005–06.

Invertebrate species were a much smaller component of the total bycatch, ranging between 60 t and 720 t per year (Table 8). Unspecified species of rattails, combined with the easily identified javelinfish, accounted for 30–80% of the non-QMS bycatch (Table 9). These two groups of rattails were caught in similar amounts overall, and annually followed the same cyclical pattern shown for bycatch of QMS and non-QMS categories, and commercial effort (Figure 16).

Total bycatch (all categories combined) peaked in 1992–93 at 9050 t and was high again in 2001–02 (when overall effort was at its highest level); since then there has been a general decline, with the lowest total annual bycatch (2090 t) occurring in 2005–06 (Table 8). The total bycatch estimates of Ballara & Anderson (2009) are mostly very similar to those of the present study, particularly for the middle three years, with confidence intervals overlapping in each year (Figure 15). There is no persistent difference in the estimates from the two studies, with some values for equivalent years smaller in the earlier study, while others are higher, and there is a difference between studies of only 3% in the total bycatch for the seven year period as a whole.

The variation in bycatch levels over time shows only a slight correspondence with the reported landings of scampi; total bycatch and reported landings were both high in the first few years of the series, and both have been generally decreasing since the early 2000s, but there is little relationship outside of these periods and the statistical correlation is low (36%). A similar overall correlation is shown between total annual bycatch and annual effort (35%), despite a very close correlation for the eight years between 1997–98 and 2004–05 (95%).

Table 8: Estimates of total annual bycatch (rounded to the nearest 10 t) in the scampi trawl fishery for the species categories QMS, non–QMS, invertebrates, and overall, based on observed catch rates; 95% confidence intervals in parentheses.

	QMS		Non-QMS		Invertebrate		Total bycatch	
1990–91	1 790	(1 240–2 190)	2 320	(1 990–3 030)	60	(40–100)	4 170	(3 270–5 320)
1991–92	3 320	(2 880–3 840)	4 000	(3 310–4 860)	200	(80–380)	7 520	(6 270–9 080)
1992–93	4 370	(3 330–6 650)	4 530	(3 020–6 610)	150	(60–250)	9 050	(6 410–13 510)
1993–94	2 500	(2 030–3 000)	2 600	(1 570–3 930)	210	(70–420)	5 310	(3 670–7 350)
1994–95	3 700	(2 880–4 550)	4 050	(2 900–5 120)	150	(110–200)	7 900	(5 890–9 870)
1995–96	2 170	(1 770–2 370)	4 390	(2 170–4 780)	520	(110–630)	7 080	(4 050–7 780)
1996–97	2 190	(720–3 420)	1 740	(1 410–2 120)	720	(330–1 050)	4 650	(2 460–6 590)
1997–98	1 240	(740–1 660)	1 140	(500–1 930)	540	(150–900)	2 920	(1 390–4 490)
1998–99	1 240	(830–1 610)	2 080	(920–3 120)	130	(70–230)	3 450	(1 820–4 960)
1999–00	1 510	(930–2 440)	2 390	(1 300–4 190)	250	(80–540)	4 150	(2 310–7 170)
2000–01	2 270	(1 780–2 830)	2 360	(1 770–3 520)	230	(190–280)	4 860	(3 740–6 630)
2001–02	3 470	(2 700–4 470)	3 770	(2 750–5 850)	700	(490–1 020)	7 940	(5 940–11 340)
2002–03	2 770	(2 090–3 620)	1 930	(1 350–2 550)	360	(150–560)	5 060	(3 590–6 730)
2003–04	1 580	(1 230–1 980)	1 770	(1 380–2 180)	340	(150–600)	3 690	(2 760–4 760)
2004–05	2 070	(1 590–2 660)	2 620	(2 030–3 250)	300	(200–420)	4 990	(3 820–6 330)
2005–06	630	(360–930)	1 020	(720–1 280)	440	(270–660)	2 090	(1 350–2 870)
2006–07	1 540	(1 310–1 810)	2 060	(1 660–2 470)	510	(360–660)	4 110	(3 330–4 940)
2007–08	1 380	(960–1 750)	2 120	(1 470–2 790)	290	(240–330)	3 790	(2 670–4 870)
2008–09	1 070	(720–1 400)	1 630	(1 230–2 020)	200	(170–270)	2 900	(2 120–3 690)
2009–10	790	(690–940)	2 340	(1 860–2 950)	160	(140–200)	3 290	(2 690–4 090)

Table 9: Estimates of total annual bycatch (rounded to the nearest 10 t) in the scampi trawl fishery for the species categories RAT and JAV, based on observed catch rates; 95% confidence intervals in parentheses.

	RAT		JAV	
1990–91	140	(80–180)	520	(360–680)
1991–92	590	(400–840)	1 430	(1 000–1 920)
1992–93	1 160	(400–2 020)	1 860	(1 160–2 940)
1993–94	1 400	(550–2 790)	660	(360–950)
1994–95	1 770	(1 070–2 450)	1 090	(700–1 700)
1995–96	1 460	(310–1 680)	1 290	(600–1 460)
1996–97	580	(410–830)	460	(250–750)
1997–98	280	(140–460)	470	(120–900)
1998–99	550	(240–840)	850	(370–1 260)
1999–00	410	(210–720)	1 110	(460–2 100)
2000–01	500	(320–740)	1 140	(750–2 050)
2001–02	1 460	(1 000–2 220)	1 390	(920–2 150)
2002–03	720	(350–1 140)	790	(650–940)
2003–04	790	(590–1 040)	640	(450–830)
2004–05	810	(540–1 130)	940	(770–1 170)
2005–06	190	(130–240)	290	(210–470)
2006–07	450	(300–620)	940	(680–1 240)
2007–08	480	(280–690)	1 000	(560–1 460)
2008–09	460	(270–640)	820	(580–1 090)
2009–10	960	(670–1 440)	910	(590–1 200)

Total annual bycatch calculated directly from commercial catch records (by comparing total catch with the catch of the target species in each trawl or group of trawls, depending on form type) was considerably lower than the observer data-based estimate in every year (Table 10). The similarity in these estimates has, however, increased over time. Before 2000–01 the catch-effort records-based estimate was between 11% and 28% of the observer data-based estimate but since then they have been greater than 30% and over 60% in a few years. This is most likely an indication that recording of bycatch on catch-effort forms has improved in this fishery over time, but using catch-effort data as a reliable estimate of total bycatch is not yet feasible.

Table 10: Total annual bycatch estimates for the scampi fishery, based on catch effort records, compared with the observer-based estimates. Estimates are derived by summing the difference between the recorded total catch and scampi catch for each trawl (TCE) or group of trawls (CEL).

Fishing	Total bycatch (t)	% of observer-based
1990–91	629	15
1991–92	1 148	15
1992–93	1 331	14
1993–94	1 091	21
1994–95	875	11
1995–96	677	10
1996–97	723	15
1997–98	534	18
1998–99	885	26
1999–00	1 168	28
2000–01	1 493	31
2001–02	2 587	33
2002–03	3 038	60
2003–04	2 327	63
2004–05	1 794	36
2005–06	1 578	76
2006–07	1 777	43
2007–08	1 860	49
2008–09	1 136	39
2009–10	1 555	47

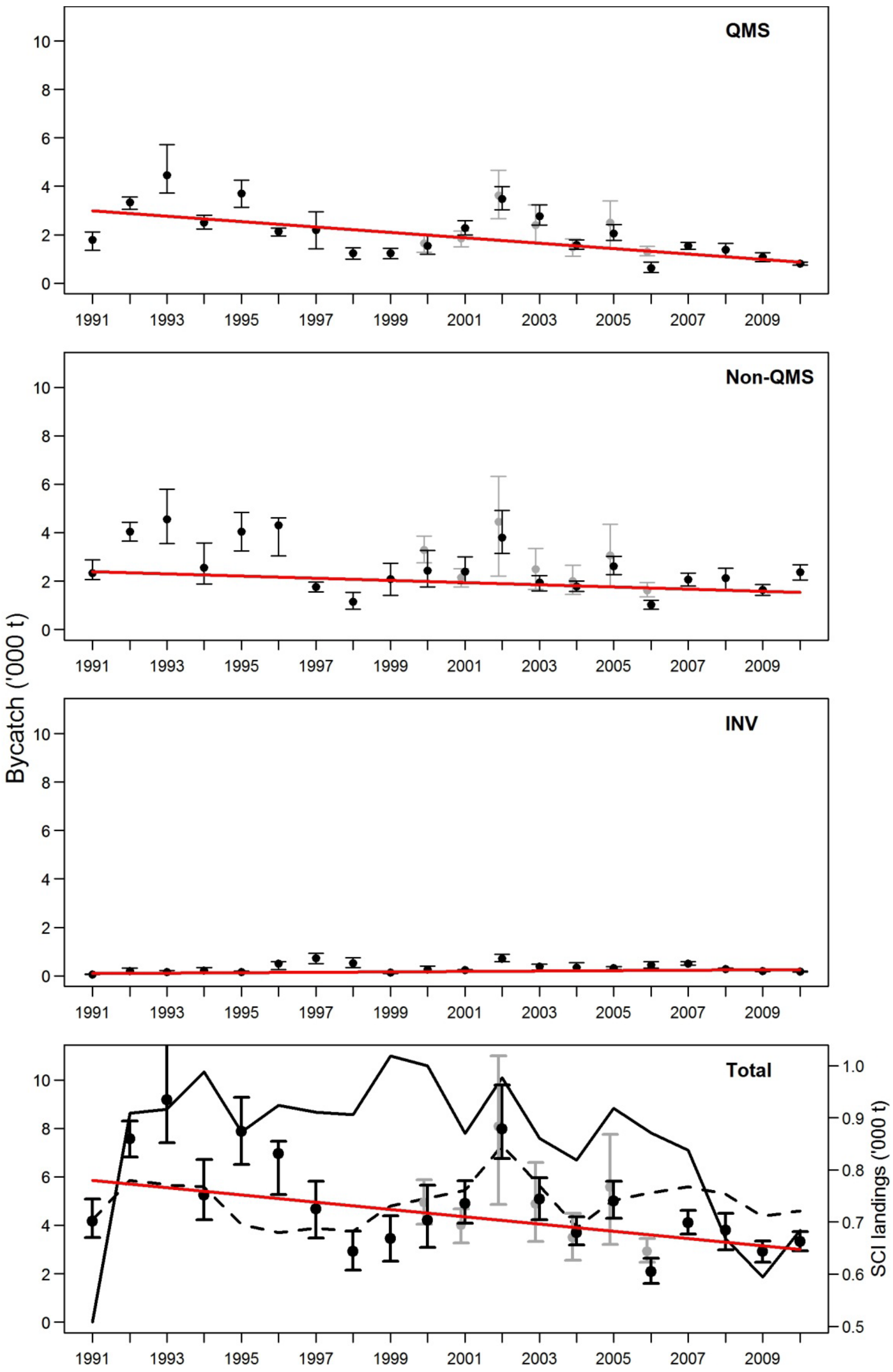

Figure 15: Annual estimates of bycatch in the scampi trawl fishery, for QMS species, non-QMS species, invertebrates (INV), and overall for 1990–91 to 2009–10. Also shown (in grey) are estimates of bycatch in each category (excluding INV) calculated for 1999–2000 to 2005–06 (Ballara & Anderson 2009). Error bars indicate 95% confidence intervals. The straight lines show the fit of the weighted regression to annual bycatch. In the bottom panel the solid black line shows the total annual reported landings of scampi (Ministry of Fisheries 2011) and the dashed line shows annual effort (scaled to have mean equal to that of total bycatch).

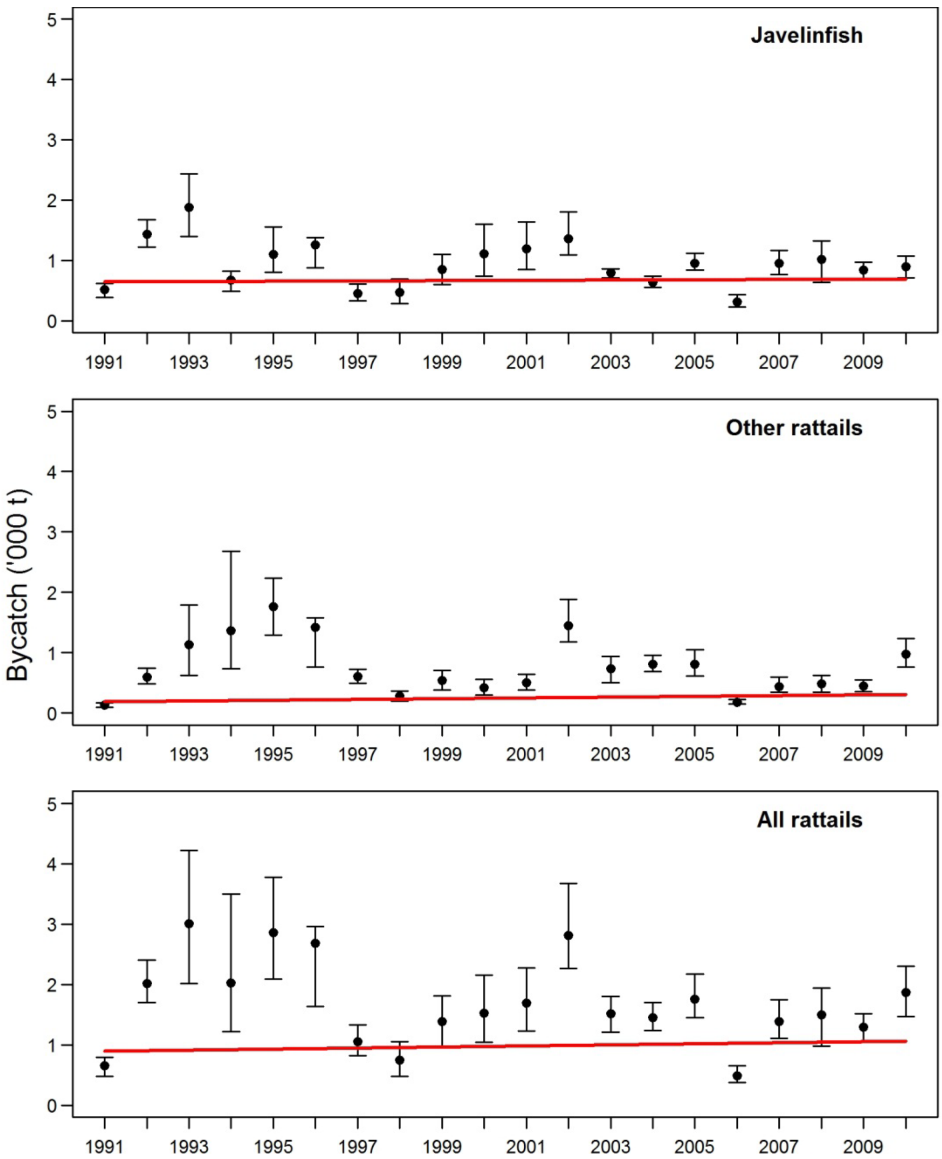

Figure 16: Annual estimates of bycatch in the scampi trawl fishery, for javelinfish, other rattails, and all rattail species combined for 1990–91 to 2009–10. Error bars indicate 95% confidence intervals. The straight lines show the fit of the weighted regression to annual bycatch.

3.5.3 Trends in annual bycatch

Significant trends of decreasing bycatch over time were shown for QMS species and total species bycatch and a significant trend of increasing bycatch was shown for invertebrates (Table 11). Slopes of the fitted regression lines were not significantly different from zero for non-QMS species or for either category of rattail. The weighting in the regressions has a noticeable effect on the fit to the data points, causing it to sit lower through the points than might be expected, as the points with the highest CVs tend to be those with higher estimates of bycatch (Figures 15 and 16). This comes about due to the influence of occasional large values which increase both the median and CV of the bootstrap samples. If the regressions are run without this weighting the overall results and significance levels are similar except that: the negative slope for Non-QMS species increases and becomes slightly significant (p=0.033) and the positive slope for invertebrates becomes less steep and insignificant (p=0.168).

Table 11: Summary of results of regression analyses for trends in annual bycatch, by species category. The *p* values indicate whether the slopes differed significantly from zero. Those results where p values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Slope	*p*
QMS	**-0.065**	**<0.001**
Non-QMS	-0.023	0.130
Invertebrate	**0.056**	**<0.001**
Total	**-0.035**	**0.008**
Javelinfish	0.003	0.842
Other rattails	0.028	0.182
All rattails	0.009	0.637

3.6 Estimation of discards

3.6.1 Discard rates

Discard rates by area and year were calculated for each species category from the observer data (Figure 17, Appendices 6 and 7). No attempt was made to estimate discards of the target species, as such events were very rarely recorded. The variance associated with the discard estimates was calculated using the bootstrap methods described in Section 2.4.

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

Median discard rates of QMS species varied greatly between years in each area, with very low levels (less than 25 kg per tow) estimated for 1990–91 and 2005–06, and the highest levels (200–250 kg per tow) occurring in 1996–97 and 1997–98 and, for CHAT especially, 2003–04.

Not surprisingly, discard rates were consistently much higher for non-QMS species. Discard rates peaked in each area in 1995–96 at over 1600 kg per tow, and in CHAT in 2001–02 (nearly 1300 kg per tow), but in other years were otherwise mostly 300–600 kg per tow in each area.

Discard rates were relatively low for invertebrates but not greatly lower than bycatch rates for this group, as most have no commercial value. Discard rates in this group peaked in 1995–96 and 1996–97 at 150–200 kg per tow, and were otherwise mostly less than 100 kg per tow. Discard rates of javelinfish and other rattails were also only moderately lower than bycatch rates of the same group, these species being of only limited commercial value.

A significant negative trend in discard rates over time, identified by regression modelling, was shown for non-QMS species in WAIR, matching the trend shown for non-QMS bycatch rates in this area (see Section 3.5.1 above). A significant positive trend was shown for rattails in CHAT and for javelinfish in AUCK, CHAT, and NRTH, matching the direction (but not the significance) of the bycatch trend in each case except for javelinfish in NRTH (Table 12).

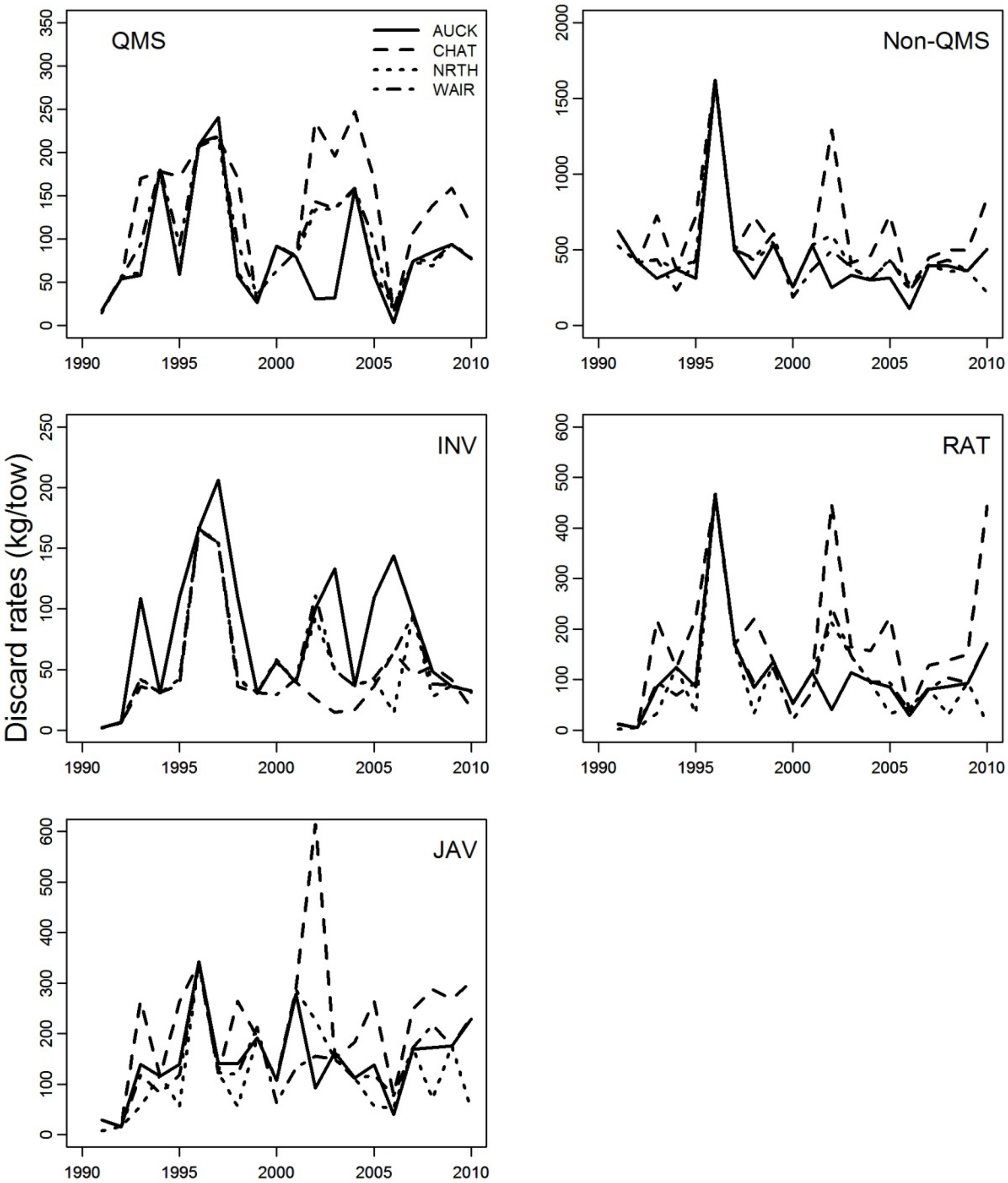

Figure 17: Annual discard rates by species category and areas used for stratification, in the scampi trawl fishery. Discard rates are the median of the bootstrap sample of 1000.

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

Species category	Area	Slope	*p*
QMS	AUCK	0.026	0.677
QMS	CHAT	0.073	0.168
QMS	NRTH	0.029	0.275
QMS	WAIR	-0.049	0.143
Non-QMS	AUCK	0.046	0.244
Non-QMS	CHAT	0.023	0.351
Non-QMS	NRTH	-0.016	0.386
Non-QMS	**WAIR**	**-0.064**	**0.010**
Invertebrates	AUCK	0.072	0.151
Invertebrates	CHAT	0.069	0.128
Invertebrates	NRTH	0.066	0.085
Invertebrates	WAIR	0.037	0.434
Rattails	**AUCK**	**0.114**	**0.062**
Rattails	**CHAT**	**0.121**	**0.030**
Rattails	NRTH	0.066	0.182
Rattails	WAIR	0.014	0.729
Javelinfish	**AUCK**	**0.112**	**0.033**
Javelinfish	**CHAT**	**0.099**	**0.009**
Javelinfish	**NRTH**	**0.071**	**0.026**
Javelinfish	WAIR	0.018	0.541

3.6.2 Annual discard levels

The level of total annual discards in each species category was estimated by multiplying the ratios calculated from observer data for each area and year stratum by the number of trawls in the target scampi fishery for the equivalent stratum, as described in Section 2.4. Precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Tables 13 and 14, Figures 18 and 19). For a breakdown of annual discards by area for each species category refer to Appendices 14–19.

Discarding of QMS species ranged from 60 t in 1990–91 and 2005–06 to 910 t in 1993–94 (Table 13), a wide range influenced strongly by variation in effort as well as catch/discard rates (see Figures 15 and 17). Estimates of QMS species discards for 1999–2000 to 2005–06 by Ballara & Anderson (2009) were moderately similar to the estimates for this period in the current study, with confidence intervals for the pairs of estimates mostly overlapped strongly. The largest difference was for 2004–05 where the new estimate was only about half that of the old estimate (Figure 18).

Discards of non-QMS species in most years were between 1500 t and 2500 t, but were greatest in 1995–96 at 5460 t and were over 3500 t in 2001–02 (Table 13). The estimates for 1999–2000 to 2005–06 also match well those of Ballara & Anderson (2009), especially the middle four of these years (Figure 18).

Annual discards of invertebrates were at their lowest (less than 50 t) in the first two years of the series, 1990–91 and 1991–92, and reached over 600 t in 1996–97 and 2001–02. In other years invertebrate discards were mostly between 150 t and 400 t.

Total annual discards ranged from 6720 in 1995–96 to 1430 in 2005–06. The estimates for 1999–2000 to 2005–06 match well to those of Ballara & Anderson (2009), with considerable overlap of confidence intervals in each year.

Discards of javelinfish and other rattails fluctuated quite strongly between years, and confidence intervals were occasionally quite wide, especially in 1995–96 (Table 14, Figure 19). The level of discards was quite similar for the two groups, generally being about 400–900 t per year and, like invertebrates, was low in the first two years of the series.

The different observer data sets used for discard calculations and bycatch calculations (only records with a one-to-one match of processing data to station data being used for discards), led to differences in some years in the data substitutions for years/areas with insufficient records. Because of this, and because most of the non-QMS species (including javelinfish and other rattails) and invertebrate catch is discarded in this fishery, it is possible for annual estimates of discards in these categories to exceed those of bycatch. Although this occurred in a few cases the differences were relatively small and well within the 95% confidence intervals.

Table 13: Estimates of total annual discards (rounded to the nearest 10 t) in the scampi trawl fishery for the species categories QMS, non–QMS, invertebrates, and overall, based on observed discard rates; 95% confidence intervals in parentheses.

	QMS		Non-QMS		Invertebrates		Total discards	
1990–91	60	(30–120)	2 250	(2 010–2 560)	0	(0–10)	2 310	(2 040–2 690)
1991–92	300	(70–660)	2 220	(1 380–3 270)	40	(0–110)	2 560	(1 450–4 040)
1992–93	590	(390–810)	2 730	(2 070–3 510)	280	(150–440)	3 600	(2 610–4 760)
1993–94	910	(510–1 320)	1 690	(970–2 610)	150	(80–250)	2 750	(1 560–4 180)
1994–95	360	(230–530)	1 760	(1 330–2 230)	240	(130–370)	2 360	(1 690–3 130)
1995–96	700	(110–1 540)	5 460	(3 150–8 430)	560	(0–1330)	6 720	(3 260–11 300)
1996–97	790	(280–1 350)	1 760	(1 420–2 100)	610	(170–940)	3 160	(1 870–4 390)
1997–98	330	(200–460)	1 560	(1 160–1 970)	230	(120–340)	2 120	(1 480–2 770)
1998–99	130	(60–240)	2 450	(2 180–2 750)	130	(60–260)	2 710	(2 300–3 250)
1999–00	390	(150–730)	1 080	(320–1 660)	230	(40–510)	1 700	(510–2 900)
2000–01	410	(210–620)	2 360	(1 750–3 570)	190	(160–250)	2 960	(2 120–4 440)
2001–02	840	(570–1 100)	3 650	(2 610–5 440)	630	(430–940)	5 120	(3 610–7 480)
2002–03	620	(280–1 070)	1 940	(1 370–2 540)	340	(140–510)	2 900	(1 790–4 120)
2003–04	620	(130–1 410)	1 190	(760–1 620)	120	(70–160)	1 930	(960–3 190)
2004–05	480	(320–710)	2 330	(1 780–2 960)	270	(150–420)	3 080	(2 250–4 090)
2005–06	60	(40–100)	1 000	(710–1 280)	370	(170–590)	1 430	(920–1 970)
2006–07	460	(320–600)	2 130	(1 710–2 610)	370	(190–540)	2 960	(2 220–3 750)
2007–08	500	(400–620)	2 100	(1 430–2 760)	220	(170–270)	2 820	(2 000–3 650)
2008–09	470	(250–710)	1 610	(1 220–2 010)	150	(110–230)	2 230	(1 580–2 950)
2009–10	380	(310–480)	2 300	(1 770–2 900)	120	(90–140)	2 800	(2 170–3 520)

Table 14: Estimates of total annual discards (rounded to the nearest 10 t) in the scampi trawl fishery for the species categories RAT and JAV, based on observed discard rates; 95% confidence intervals in parentheses.

	RAT		JAV	
1990–91	20	(0–100)	80	(0–180)
1991–92	30	(0–80)	80	(10–260)
1992–93	690	(490–980)	890	(690–1 130)
1993–94	560	(320–910)	540	(270–820)
1994–95	440	(300–630)	590	(440–760)
1995–96	1 560	(0–3 640)	1140	(10–2 630)
1996–97	590	(430–830)	450	(250–650)
1997–98	370	(250–530)	500	(380–650)
1998–99	580	(400–860)	860	(730–1 020)
1999–00	200	(60–310)	430	(130–710)
2000–01	500	(330–760)	1150	(740–2 050)
2001–02	1 420	(970–2 240)	1390	(910–2 170)
2002–03	720	(370–1 140)	790	(660–940)
2003–04	380	(180–600)	440	(250–620)
2004–05	570	(400–820)	760	(580–970)
2005–06	190	(130–240)	290	(200–470)
2006–07	530	(310–820)	1050	(670–1 480)
2007–08	470	(280–710)	1000	(550–1 470)
2008–09	450	(270–620)	810	(580–1 080)
2009–10	950	(630–1 400)	900	(560–1 170)

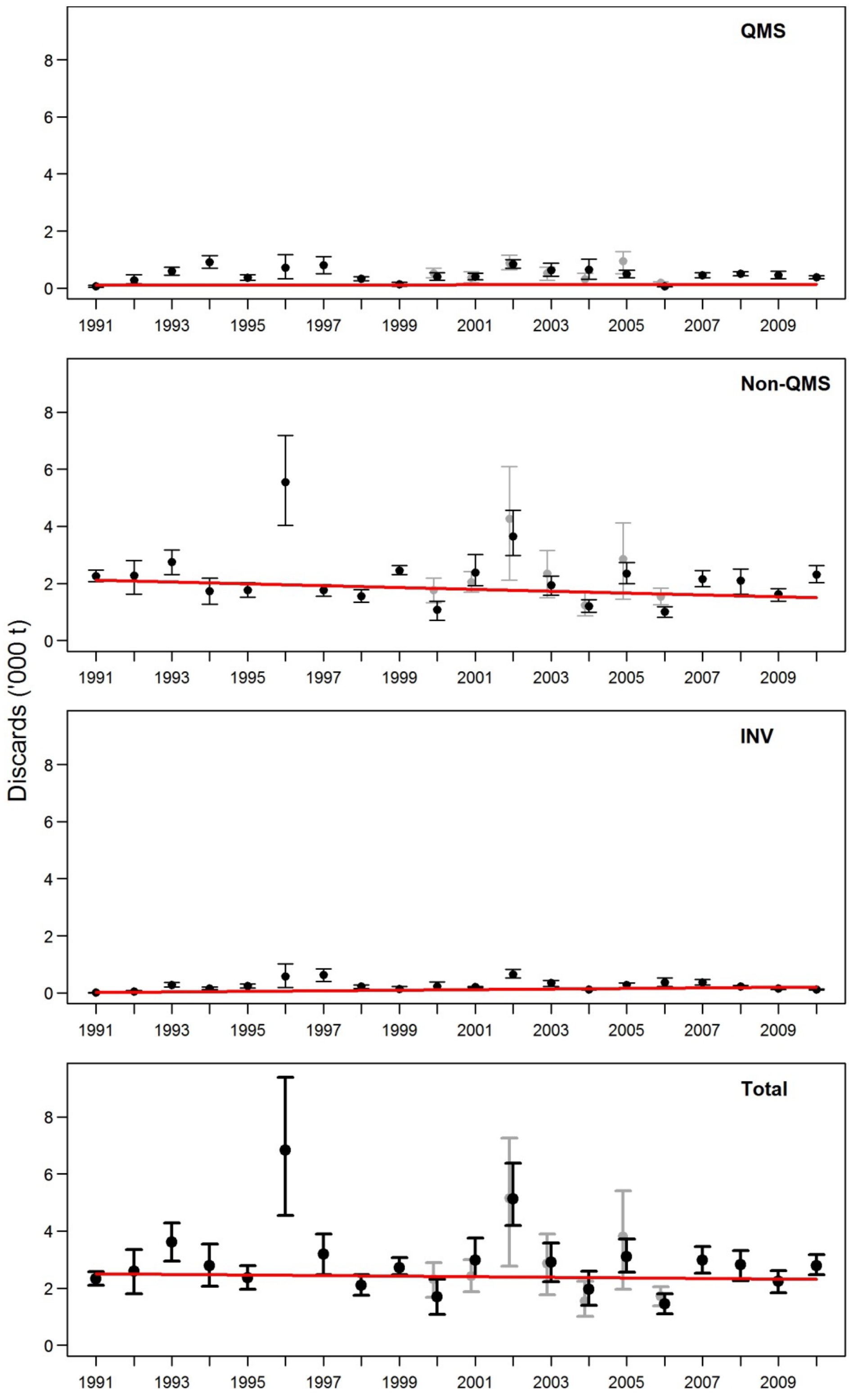

Figure 18: Annual estimates of discards in the scampi trawl fishery, for QMS species, non-QMS species, invertebrates (INV), and overall for 1990–91 to 2009–10. Also shown (in grey) are estimates of discards in each category (excluding INV) calculated for 1999–2000 to 2005–06 (Ballara & Anderson 2009). Error bars indicate 95% confidence intervals. The straight lines show the fit of the weighted regression to annual discards.

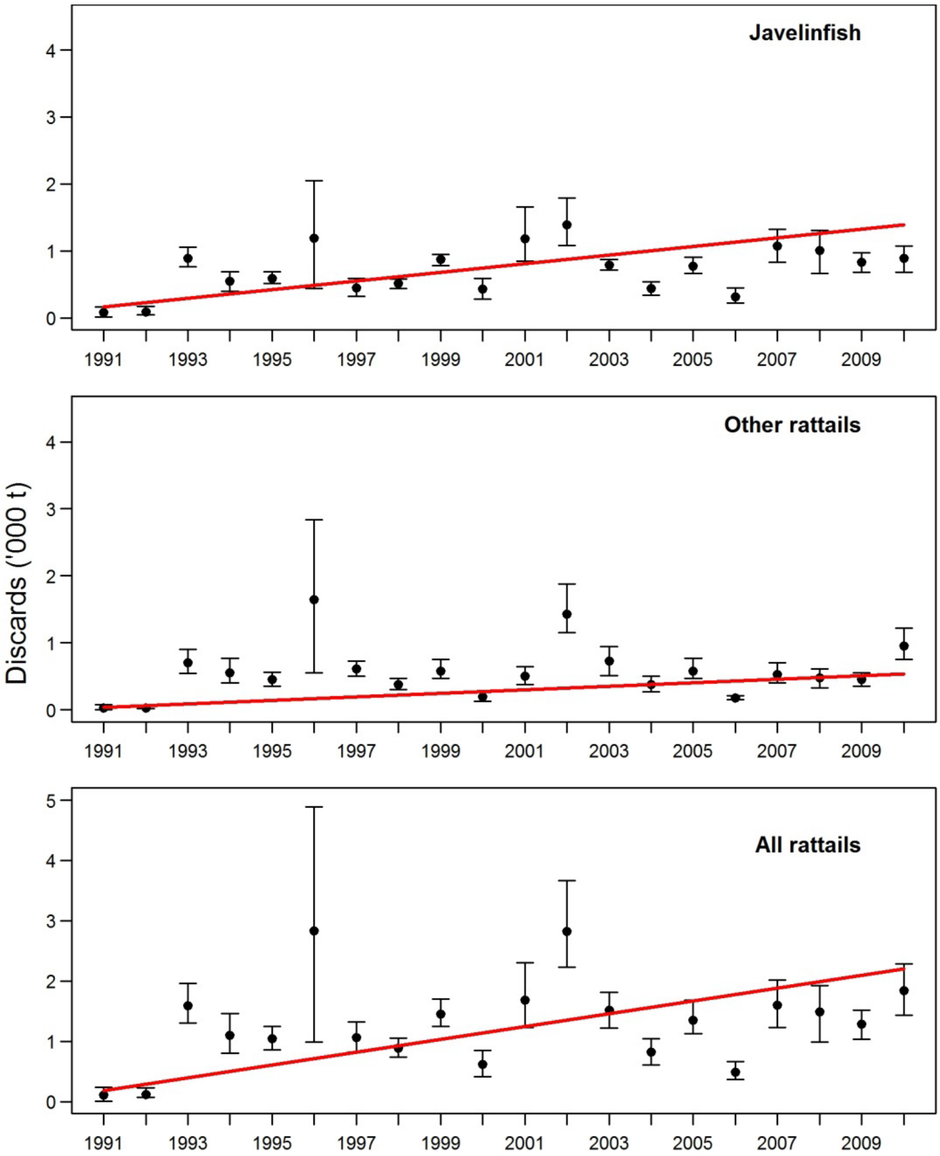

Figure 19: Annual estimates of discards in the scampi trawl fishery, for javelinfish, other rattails, and all rattail species combined for 1990–91 to 2009–10. Error bars indicate 95% confidence intervals. The straight lines show the fit of the weighted regression to annual discards.

3.6.3 Trends in annual discards

No significant trend of decreasing discards over time was shown for any species category but a trend of increasing discards was shown for invertebrates, both rattail categories, and for rattails overall (Table 15). As was shown for bycatch above, the weighting in the regressions causes the fit to sit lower through the points than might be expected, but to a lesser extent (Figures 18 and 19). If the regressions are run without this weighting the overall results and significance levels are similar except that: the positive slope for invertebrates becomes less steep and insignificant (p=0.162) and the significance levels of slopes in each of the rattail categories are reduced (p=0.02–0.09).

Table 15: Summary of results of regression analyses for trends in annual discards, by species category. The *p* values indicate whether the slopes differed significantly from zero. Those results where p values are less than 0.05 (generally considered statistically significant) are shown in bold.

Species category	Slope	*p*
QMS	0.013	0.705
Non-QMS	-0.018	0.152
Invertebrate	**0.155**	**<0.001**
Total	-0.004	0.633
Javelinfish	**0.114**	**0.001**
Other rattails	**0.147**	**<0.001**
All rattails	**0.133**	**<0.001**

3.7 Efficiency of the scampi trawl fishery

Annual discard estimates in the scampi fishery were compared with the estimated annual catch and total annual bycatch, to get a measure of the efficiency of the fisheries (Table 16).

The annual discard fraction (kg of discards/kg of scampi catch) ranged from 1.8 (in 1999–2000 and 2005–06) to 6.6 in 1995–96, with an overall value for the 20-year period of 3.6. The discard fraction showed a high degree of variability throughout this period with no indication of any pattern or, importantly, any increase or decline over time. Between 0.29 and 0.85 of the annual bycatch was discarded, with an increase in this fraction since 2003–04.

Table 16: Estimated annual scampi catch (t), total bycatch (t), and total discards (t) in the target scampi trawl fishery; discard fraction (kg of total discards per kg of scampi caught); and discards as a fraction of bycatch.

Fishing year	Scampi estimated catch	Total bycatch	Total discards*	Discard fraction	Discards/ bycatch
1990–91	432	4160	2320	5.4	0.56
1991–92	799	7540	2580	3.2	0.34
1992–93	856	9240	3490	4.1	0.38
1993–94	908	5210	2780	3.1	0.53
1994–95	825	7860	2270	2.8	0.29
1995–96	846	6970	5550	6.6	0.80
1996–97	875	4670	3170	3.6	0.68
1997–98	903	2910	1680	1.9	0.58
1998–99	947	3460	2370	2.5	0.68
1999–00	912	4190	1670	1.8	0.40
2000–01	912	4880	2990	3.3	0.61
2001–02	887	7940	5140	5.8	0.65
2002–03	783	5080	2890	3.7	0.57
2003–04	674	3700	1930	2.9	0.52
2004–05	829	4990	3110	3.8	0.62
2005–06	794	2080	1430	1.8	0.69
2006–07	768	4120	2900	3.8	0.70
2007–08	607	3780	2820	4.6	0.75
2008–09	550	2900	2200	4.0	0.76
2009–10	629	3310	2800	4.5	0.85

* Total discards were adjusted so that discards did not exceed bycatch in any species category.

3.8 Comparison of bycatch rates with survey relative biomass estimates

There are mixed levels of correlation between bycatch rates in the Chatham Rise scampi fishery and trawl survey relative abundance estimates from the same area (Figure 20). Correlation coefficients (Pearson correlation coefficient) are negative for the QMS and non-QMS species categories, an unlikely scenario in reality, and although the correlation is moderately positive for invertebrate species neither series indicates a clear trend over time and recent values are similar to the long-term average.

Similarly, for the Auckland Islands region, there are mixed levels of correlation between bycatch rates and survey relative abundance estimates, but in this case the correlation is negative for invertebrate species and positive for QMS and Non-QMS species (Figure 21). The indices for both series in each of these species categories are highly variable and have wide confidence intervals, with no obvious long-term trends, but the correlation values of 44% (QMS) and 32% (Non-QMS) do indicate some level of agreement.

The correlations between survey abundance estimates and bycatch rates from this study, for both of these survey series, may have been affected by recent changes in the commercial scampi trawls. Escape gaps in the top of the nets, introduced across the fleet during the mid-2000s, may have led to lower bycatch of fish species. For both QMS species and non-QMS species in Figures 20 and 21 the survey figures lie above the bycatch figures in most years following 2004–05.

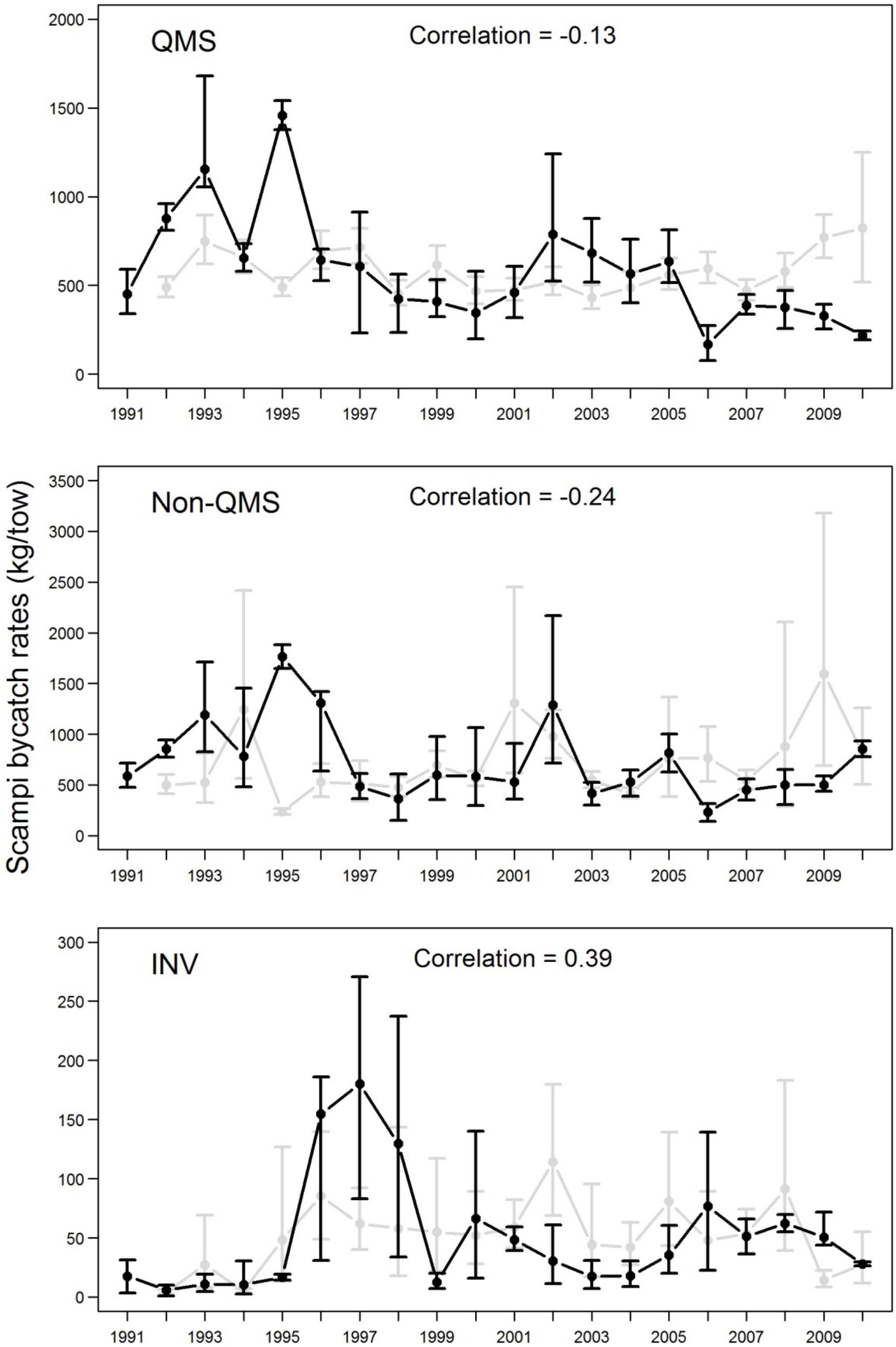

Figure 20: Comparison of estimated annual bycatch rates in the scampi fishery in area CHAT (black) with relative abundance estimates from the time series of Chatham Rise hoki and middle depth species research surveys (grey), scaled so as to have the mean equal to that of the estimated bycatch rates, for three categories of bycatch.

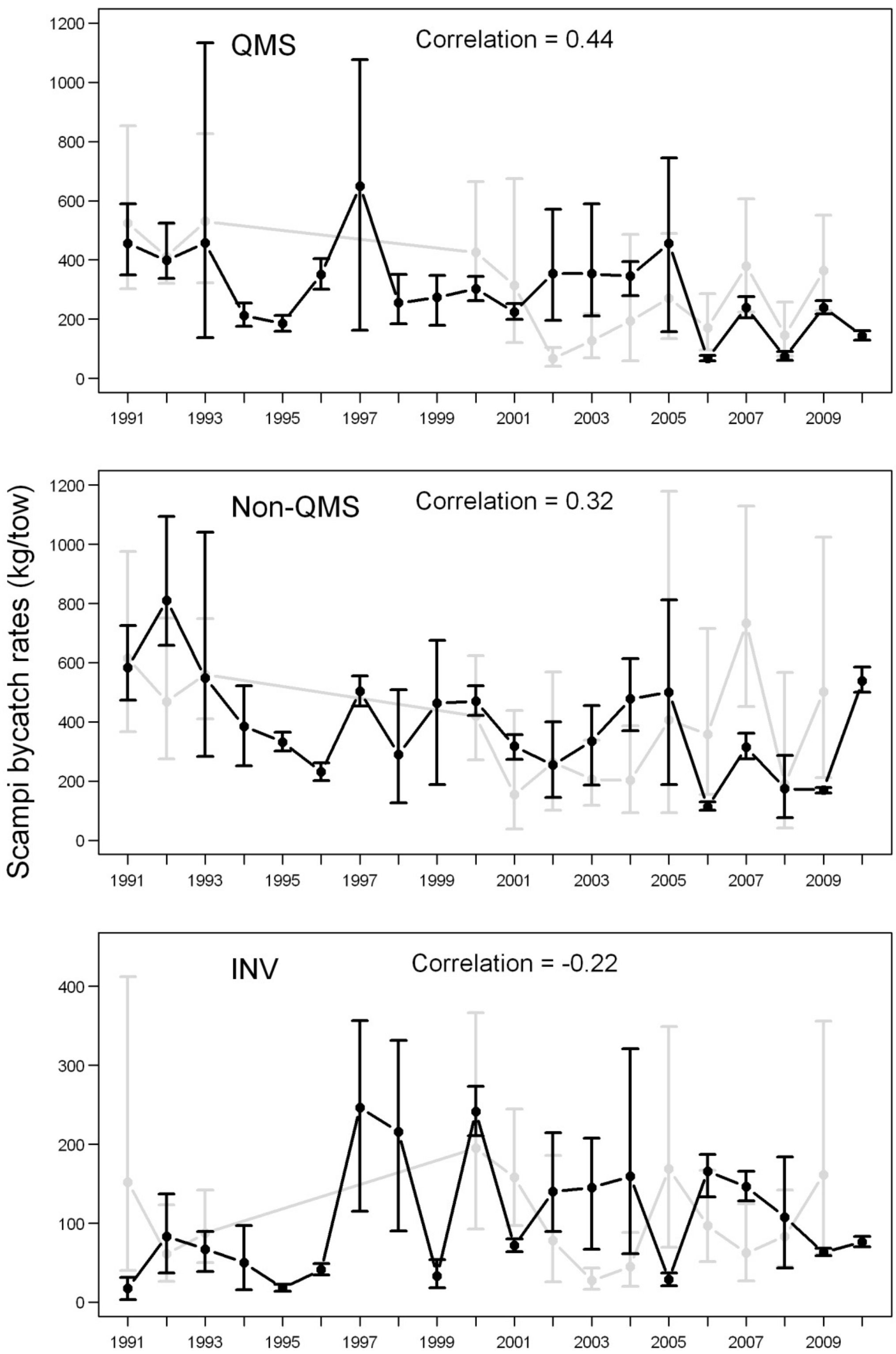

Figure 21: Comparison of estimated annual bycatch rates in the scampi fishery in area AUCK (black) with relative abundance estimates from the time series of Southland and Sub-Antarctic middle depth species research surveys (grey), scaled so as to have the mean equal to that of the estimated bycatch rates, for three categories of bycatch.

4. DISCUSSION

Precision of the annual estimates of bycatch and discards in this fishery, as in all of the Tier-1 species fisheries assessed, is strongly dependent on the level and spread of observer coverage, and also on the quality of this coverage.

Observer coverage in the scampi fishery is relatively low compared with that of other Tier-1 species fisheries assessed, e.g., the orange roughy, oreo, arrow squid, southern blue whiting, and ling longline fisheries (Anderson 2011, Ballara & Anderson 2009, Anderson 2009, Anderson 2008). The long-term level of observer coverage in each of these fisheries is greater than 18% (over 40% for southern blue whiting) by weight of the target fishery catch. Only the jack mackerel fishery (Anderson 2004, 2007) has a similarly low long-term level of coverage to the scampi fishery, both of which are about 11–12% of the target fishery catch. However, coverage in the scampi fishery was greater than 10% (the usual target for these analyses) in 12 of the 20 years, and fell below 5% only in 2000–01, therefore enabling bycatch and discard estimates to be made for most years using data from only those years.

Graphical analysis of the spread of observer effort compared with that of the scampi fishery as a whole, across a range of variables, indicated that the coverage was reasonably well spread. Although some less important regions of the fishery received little or no coverage (e.g. the central Chatham Rise and west coast South Island), the main scampi fisheries are well defined and these were consistently sampled throughout the 20 years examined. Vessels were mainly within a narrow size range, and the small amount of effort by larger vessels was adequately covered, as was the full depth range of the fishery and (despite highly intermittent sampling in several years) the entire fishing year.

The ratio estimator selected for the analysis is the same as used in recent assessments of other Tier-1 fisheries and is preferred to the alternatives because of the reduced possibility of measurement error (being “per tow” rather than “per trawl duration” or per “scampi catch”), because of the better precision achievable, and because this estimator allows trawl duration to be considered as an explanatory variable in regression models. Overall, area was clearly the most critical factor influencing bycatch and discard rates in this fishery and although trawl duration was also important in several instances, there was insufficient observer data to stratify by more than two variables, i.e., area and fishing year. Thus stratification was identical to that applied in the previous assessment (Ballara & Anderson 2009). Other potentially important factors that were not able to be examined in detail, due to a lack of data, included variation in trawl configuration (number of nets) and recent, fleet-wide, alterations to the nets to provide escape gaps for unwanted fish species. Such escape gaps allow for longer tows, as the nets fill up less rapidly, and may have contributed to the lower levels of estimated fish bycatch since 2005–06. Details of these changes, for all vessels in the fleet, are being compiled and should be available for future analyses (Tuck, NIWA, unpublished results).

Estimation of bycatch and discards was limited to five categories of catch; QMS species, non-QMS species, invertebrates, javelinfish, and all other rattails. Only the first two of these categories match those previously assessed, and these only in the most recent assessment (Ballara & Anderson 2009), limiting comparisons between studies to the 1999–2000 to 2005–06 period. The repeated estimates were in most cases very similar to the earlier estimates. The main difference between the earlier assessment and this one was in the form of the ratio estimator, catch per hour in the former compared with catch per tow in this study. This is likely to be the primary cause of the small difference in estimates between studies, especially in the relative sizes of the confidence intervals, which tended to be narrower in the present study. Slight differences in data grooming methods, and the procedure used for dealing with data poor strata, will also have contributed. Although the close similarity of the estimates between the two studies may encourage a certain level of confidence in both, each study is likely to have suffered from the same biases and data limitations, e.g., the effect of observer approved discards on estimates of QMS species discards and the scaling up of bycatch and discard rates from a small fraction of the fishery to make estimates for the entire commercial fishery.

Observer approved discarding complicates the estimation of QMS species discards from observer records. A full accounting of such approvals over this period of the scampi fishery would help to determine the scale of the practice—or more simply all observer recorded QMS species discards could be presumed to have been approved—but more useful would be independent estimates of QMS species discarding when observers were not present. The methods used here make the assumption, valid or not, that discarding of QMS species in the fishery is unaffected by the presence of an observer. This may overestimate (or underestimate) QMS species discards but the alternative assumption, that no QMS species discarding occurs unless an observer is present, leads to a discard rate (and annual discard levels) of zero for the large unobserved fraction of the fishery.

The comparisons of bycatch rate estimates from this study with abundance estimates from time series of trawl surveys on the Chatham Rise and sub-Antarctic plateau were intended to provide a means of providing corroborative evidence for any temporal patterns found. Although correlations between series were generally weak (or in some cases negative), the procedure is worthwhile retaining in these analyses and will undoubtedly be more relevant where trends in the data are stronger.

The species most at risk from the adverse effects of the scampi fishery are likely to be those not under the management of the QMS, examined here in the non-QMS, invertebrate, and rattail categories. The single species most affected has been the javelinfish, whose natural geographical range (and lower half of its depth range) fully overlaps with the scampi fishery (Anderson et al. 1998). According to observer records, almost 16% of the catch when targeting scampi comprises this single species but the real percentage is likely to be somewhat more, as the next most observed bycatch category is unspecified rattails (RAT), which accounts for another 13% of the catch and is likely to include an additional amount of javelinfish. Recent studies have shown that javelinfish may be a relatively short-lived, fast growing species and there is little evidence that the abundance of this species has been reducing. In fact, the biomass of javelinfish on the Chatham Rise has been shown to have increased significantly in recent years, with high levels of biomass also shown to be present in the sub-Antarctic (Livingston et al. 2002, Stevens et al. 2010).

After rattails, the next most reported bycatch species were QMS species (mainly sea perch, ling, and hoki), for which the catch and fishery sustainability are separately monitored and hence were not reported on in detail in this analysis. Sea perch, however, despite being a QMS species, are often an unwanted component of bycatch. Often these fish are too small or of too little value to be retained and are frequently discarded when an observer is present to authorise it. This will result in a bias in the estimates of QMS species discards after 1997–98, when sea perch were introduced into the QMS. But this bias is difficult to quantify and should be considered alongside the unknown bias that might be produced by changes in general discarding behaviour due to the presence of an observer on board—as discussed by Liggins et al. 1997. These biases, along with potential biases due to the difficulties caused by observer recording of discards in groups of tows, estimation of fish lost from damaged nets, and changes in the observer catch-effort logbook forms and observer database structure in the mid-2000s serve to detract from the reliability of discard estimates. In contrast, bycatch estimates are mostly free from these potential sources of bias and are likely to be more reliable.

This study has shown that there has been a statistically significant trend of decreasing QMS bycatch and total bycatch amounts during the period 1990–91 to 2009–10, but (because most discards are non-QMS species) no accompanying trend of decreasing discard amounts. This decrease in QMS bycatch was driven by decreasing rates of QMS bycatch in most areas (most significantly in the east coast North Island fisheries—areas NRTH and WAIR) rather than by any major change in fishing effort. A significant trend of increasing amounts of bycatch of invertebrate species was matched by a similar trend in discard amounts, with positive trends also in bycatch and discard rates in this category. Although bycatch amounts in the rattail categories showed no trend over time (with bycatch rates showing a mixture of positive and negative trends, generally not significant), discard amounts increased significantly for javelinfish, other rattails, and all rattail species combined—along with consistently positive trends in discard rates. Although there is considerable interannual variation in both the estimates and precision of these discard amounts, and some of the trends detected are dependent on the weighting used in the regressions, these trends are a cause for concern, as all are in the least preferred direction.

The overall rate of discarding has also shown no sign of reducing, with the average value since the previous assessment of 4.2 kg of discards per kilogram of scampi caught slightly greater than the 3.5 kg average value for the 16 previous years. This fishery has the highest such ratio of the major New Zealand fisheries which have been examined, with the equivalent recent efficiency figures as follows: southern blue whiting, 0.005 kg; oreos, 0.03; orange roughy, 0.04; jack mackerel and hoki, 0.06; arrow squid, 0.2; ling longline, 0.35. (Anderson 2007, 2008, 2009, 2011, Ballara & Anderson 2009). However, scampi fisheries elsewhere also suffer from high rates of discarding, with an estimated 9 kg of discards per kilogram of target catch in Scotland's Clyde Sea *Nephrops norvegicus* fishery (Bergmann et al. 2002).

The difference between the catch-effort data-based and observer data-based estimates of total bycatch was high, especially in the earlier years, so that although reporting of (non-QMS) bycatch by vessels has clearly improved in recent years, a considerable portion of it is unaccounted for. It is worth noting that in the orange roughy fishery and (to a lesser extent) the oreo fishery the differences between the two estimates showed a similar decreasing trend over time (Anderson 2011) but were considerably smaller for recent years than in the scampi fishery, often less than 10%.

These analyses would benefit from better identification of bycatch species, especially rattails. Although the readily distinguishable javelinfish appears to have been well identified over time, other rattail species have been almost universally identified only to family level. The code MIX (mixed fish) has also been used extensively in this fishery, representing the sixth greatest observed bycatch category by weight. Although improvements in this area have been made in recent years there is still room for more, and new field guides such as those of McMillan et al. (2011a, 2011b, 2011c) and Tracey et al. (2011a) should help.

5. ACKNOWLEDGEMENTS

I would like to thank the observers of the Ministry for Primary Industries for their dedication and continued efforts over a long period to collect the high quality data that made this analysis possible. Thanks also to the following NIWA staff: Ian Doonan for his help with some of the analyses, Dan Fu for help with SurvCalc, Sira Ballara for her assistance with data extracts and grooming code, and Suze Baird for her thorough review of the initial draft of the report. Members of the Aquatic Environment Working Group also provided valuable feedback on a draft of the report, which resulted in several improvements. This work was funded by the Ministry for Primary Industries (Project DAE2010/02).

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Appendix 1: Observed fish bycatch. Species codes, common and scientific names, estimated catch, percentage of total catch, and overall percentage discarded of the top 100 fish species or species groups by weight from observer records for the scampi target fishery from 1 Oct 1990 to 30 Sep 2010. Records are ordered by decreasing percentage of catch, codes in bold are QMS species. Estimated catches are based on all observed target scampi tows; discards are based on all trips where scampi was the sole target species. NB: discard percentages are conservative, as where 'destination' was missing the catch was presumed to have been retained.

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
JAV	Javelinfish	*Lepidorhynchus denticulatus*	1651	15.94	92
RAT	Rattails	Macrouridae	1365	13.17	91
SPE	Sea perch	*Helicolenus* spp.	872	8.42	67
LIN	Ling	*Genypterus blacodes*	772	7.46	2
HOK	Hoki	*Macruronus novaezelandiae*	632	6.10	5
MIX	Mixed fish		235	2.27	27
STA	Giant stargazer	*Kathetostoma giganteum*	219	2.12	1
GSH	Dark ghost shark	*Hydrolagus novaezealandiae*	207	2.00	28
FHD	Deepsea flathead	*Hoplichthys haswelli*	206	1.99	97
RCO	Red cod	*Pseudophycis bachus*	194	1.88	10
SWA	Silver warehou	*Seriolella punctata*	141	1.36	1
SPD	Spiny dogfish	*Squalus acanthias*	130	1.25	95
SSK	Smooth skate	*Dipturus innominatus*	127	1.23	35
SKA	Skate	Rajidae, Arhynchobatidae	116	1.12	87
HAK	Hake	*Merluccius australis*	77	0.75	1
SRH	Silver roughy	*Hoplostethus mediterraneus*	76	0.74	100
CDO	Capro dory	*Capromimus abbreviatus*	70	0.68	99
BBE	Banded bellowsfish	*Centriscops humerosus*	67	0.64	99
SKI	Gemfish	*Rexea solandri*	57	0.55	1
RHY	Common roughy	*Paratrachichthys trailli*	56	0.54	99
TOA	Toadfish	*Neophrynichthys* sp.	56	0.54	89
SSI	Silverside	*Argentina elongata*	54	0.52	78
LDO	Lookdown dory	*Cyttus traversi*	51	0.49	42
WWA	White warehou	*Seriolella caerulea*	46	0.44	3
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	46	0.44	1
RSK	Rough skate	*Zearaja nasuta*	35	0.33	44
BEL	Bellowsfish	*Centriscops* spp.	32	0.31	98
BNS	Bluenose	*Hyperoglyphe antarctica*	26	0.25	0
RIB	Ribaldo	*Mora moro*	25	0.24	62
DSK	Deepwater spiny skate	*Amblyraja hyperborea*	22	0.21	100
MDO	Mirror dory	*Zenopsis nebulosus*	21	0.21	88
HAG	Hagfish	*Eptatretus cirrhatus*	20	0.19	95
BER	Numbfish	*Typhlonarke* spp.	20	0.19	99
ERA	Electric ray	*Torpedo fairchildi*	18	0.18	99
CSH	Catshark		18	0.17	82
CON	Conger eel	*Conger* spp.	16	0.15	94
SDO	Silver dory	*Cyttus novaezealandiae*	15	0.15	94
SBW	Southern blue whiting	*Micromesistius australis*	15	0.14	71
CAR	Carpet shark	*Cephaloscyllium isabellum*	14	0.14	100
SCH	School shark	*Galeorhinus galeus*	14	0.14	4
DCS	Dawsons catshark	*Halaelurus dawsoni*	12	0.12	98
BYX	Alfonsino & long-finned beryx	*Beryx splendens* & *B. decadactylus*	10	0.10	2
FLA	Flats		9	0.09	99
CDX	Dark banded rattail	*Coelorinchus maurofasciatus*	9	0.09	100
EEL	Eels marine		9	0.09	100
HAP	Hapuku	*Polyprion oxygeneios*	8	0.08	0
YBO	Yellow boarfish	*Pentaceros decacanthus*	7	0.07	100
PSK	Longnosed deepsea skate	*Bathyraja shuntovi*	7	0.06	98
HPB	Hapuku & bass	*Polyprion oxygeneios* & *P americanus*	6	0.06	0

Appendix 1 — *Continued*

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
ETL	Lucifer dogfish	*Etmopterus lucifer*	6	0.06	99
SND	Shovelnose spiny dogfish	*Deania calcea*	6	0.06	100
BRZ	Brown stargazer	*Xenocephalus armatus*	6	0.05	47
BSH	Seal shark	*Dalatias licha*	6	0.05	96
OSD	Other sharks and dogs	Selachii	5	0.05	100
TOP	Pale toadfish	*Ambophthalmos angustus*	5	0.04	100
NSD	Northern spiny dogfish	*Squalus griffini*	4	0.04	99
SCO	Swollenhead conger	*Bassanago bulbiceps*	4	0.04	94
PDG	Prickly dogfish	*Oxynotus bruniensis*	4	0.04	97
BWH	Bronze whaler shark	*Carcharhinus brachyurus*	4	0.04	72
YSG	Yellow spotted gurnard	*Pterygotrigla pauli*	4	0.04	91
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	4	0.04	87
GSP	Pale ghost shark	*Hydrolagus bemisi*	4	0.04	32
TAR	Tarakihi	*Nemadactylus macropterus*	4	0.04	0
BAS	Bass groper	*Polyprion americanus*	4	0.04	0
PIG	Pigfish	*Congiopodus leucopaecilus*	3	0.03	100
BTH	Bluntnose skates	*Notoraja* spp.	3	0.03	67
STR	Stingray		3	0.03	99
WIT	Witch	*Arnoglossus scapha*	3	0.03	99
BYS	Alfonsino	*Beryx splendens*	3	0.03	49
SBR	Southern bastard cod	*Pseudophycis barbata*	3	0.02	96
OFH	Oilfish	*Ruvettus pretiosus*	3	0.02	92
SHA	Shark		3	0.02	100
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae*	2	0.02	3
TAY	Blind electric ray	*Typhlonarke aysoni*	2	0.02	100
DWD	Deepwater dogfish		2	0.02	70
HCO	Hairy conger	*Bassanago hirsutus*	2	0.02	78
SNI	Snipefish	*Macroramphosus scolopax*	2	0.02	100
CUC	Cucumber fish	*Chlorophthalmus nigripinnis*	2	0.02	64
NOS	Sloan's arrow squid	*Nototodarus sloanii*	2	0.02	1
LSK	Softnose skate	*Arhynchobatis asperrimus*	2	0.02	99
SSH	Slender smooth-hound	*Gollum attenuatus*	2	0.02	98
HEX	Sixgill shark	*Hexanchus griseus*	2	0.02	83
FRO	Frostfish	*Lepidopus caudatus*	2	0.02	42
BRC	Northern bastard cod	*Pseudophycis breviuscula*	2	0.02	93
DWE	Deepwater eel		2	0.02	100
NOG	Gould's arrow squid	*Nototodarus gouldi*	2	0.01	0
RAY	Rays	Torpedinidae, Dasyatidae, Myliobatidae, Mobulidae	1	0.01	74
SPK	Spikefish	*Macrorhamphosodes uradoi*	1	0.01	100
OPE	Orange perch	*Lepidoperca aurantia*	1	0.01	96
API	Alert pigfish	*Alertichthys blacki*	1	0.01	88
SPO	Rig	*Mustelus lenticulatus*	1	0.01	3
HYM	*Hymenocephalus* spp	*Hymenocephalus* spp.	1	0.01	100
SEE	Silver conger	*Gnathophis habenatus*	1	0.01	99
LAN	Lantern fish	Myctophidae	1	0.01	100
JGU	Spotted gurnard	*Pterygotrigla picta*	1	0.01	62
COL	Olivers rattail	*Coelorinchus oliverianus*	1	0.01	100
OSK	Skate other	Rajidae	1	0.01	100
LCH	Long-nosed chimaera	*Harriotta raleighana*	1	0.01	91
RBY	Ruby fish	*Plagiogeneion rubiginosum*	1	0.01	11
RPE	Red perch		1	0.01	100

Appendix 2: Observed invertebrate catch. Species codes, common and scientific names, estimated catch, percentage of total catch, and overall percentage discarded of the top 100 invertebrate species or species groups by weight from observer records for the scampi target fishery from 1 Oct 1990 to 30 Sep 2010. Records are ordered by decreasing percentage of catch, codes in bold are QMS species. Estimated catches are based on all observed target scampi tows; discards are based on all trips where scampi was the sole target species. NB: discard percentages are conservative, as where 'destination' was missing the catch was presumed to have been retained.

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
SCI	Scampi	*Metanephrops challengeri*	1776	17.14	1
CRB	Crab		118	1.14	89
SFI	Starfish	Asteroidea & Ophiuroidea	81	0.78	90
ANT	Anemones	Anthozoa	39	0.37	88
PRK	Prawn killer	*Ibacus alticrenatus*	28	0.27	81
SCC	Sea cucumber	*Stichopus mollis*	26	0.26	84
SMK	Spiny masking crab	*Teratomaia richardsoni*	15	0.15	100
ASR	Asteroid	Asteroidea	15	0.15	100
COU	Coral (unspecified)		14	0.13	100
SPI	Spider crab		13	0.13	93
HSI	Jackknife prawn	*Haliporoides sibogae*	12	0.12	63
WSQ	Warty squid	*Onykia* spp.	12	0.11	96
CRU	Crustaceans	Crustacea	11	0.11	90
OCT	Octopus	*Pinnoctopus cordiformis*	11	0.10	79
GSC	Giant spider crab	*Jacquinotia edwardsii*	10	0.09	85
ECN	Sea urchin	Echinoidea	8	0.08	100
HTH	Sea cucumber	Holothuroidea	7	0.06	100
GAS	Gastropods	Gastropoda	6	0.06	100
ECH	Echinoderms	Echinodermata	6	0.05	95
MOL	Molluscs	Mollusca	5	0.05	75
VOL	Volute	Volutidae (Family)	5	0.05	92
URO	Sea urchin	Echinoidea	4	0.04	100
PRA	Prawn		4	0.04	97
TFA	Frilled crab	*Trichopeltarion fantasticum*	4	0.04	100
MIQ	Warty squid	*Onykia ingens*	4	0.03	93
OPI	Umbrella octopus	*Opisthoteuthis* spp.	3	0.03	100
SUR	Kina	*Evechinus chloroticus*	3	0.03	100
SPT	Heart urchin	*Spatangus multispinus*	3	0.03	100
PSI	Geometric star	*Psilaster acuminatus*	3	0.03	100
SHL	Shovelnosed lobster	*Scyllarus* sp.	3	0.03	53
JFI	Jellyfish	Scyphozoa	2	0.02	49
ACS	Deepsea anemone	Actinostolidae	2	0.02	100
GMC	Garrick's masking crab	*Leptomithrax garricki*	2	0.02	100
SLG	Sea slug	*Scutus breviculus*	2	0.02	100
FMA	Magellanic rock-whelk	*Fusitriton magellanicus*	2	0.02	100
HMT	Deepsea anemone	Hormathiidae	1	0.01	100
SSC	Giant masking crab	*Leptomithrax australis*	1	0.01	100
MSL	Starfish	*Mediaster sladeni*	1	0.01	99
LHO	Omega prawn	*Lipkius holthuisi*	1	0.01	100
WHE	Whelks	Buccinidae	1	0.01	100
ONG	Sponges	Porifera	1	0.01	94
DMG	Magnificent sea-star	*Dipsacaster magnificus*	1	0.01	100
NUD	Nudibranch	Nudibranchia	1	0.01	100
SQX	Squid	Teuthoidea	1	0.01	45
ZOR	Rat-tail star	*Zoroaster* spp.	1	0.01	100
GVO	Golden volute	*Provocator mirabilis*	1	0.01	98
DAP	Antlered crab	*Dagnaudus petterdi*	1	0.01	100
OCP	Octopod	Octopoda	1	0.01	100

Appendix 2 — *Continued*

Species code	Common name	Scientific name	Observed catch (t)	% of catch	% discarded
DIR	Pagurid	*Diacanthurus rubricatus*	1	0.01	100
PMU	Heart urchin	*Paramaretia peloria*	1	0.01	100
HYA	Floppy tubular sponge	*Hyalascus* sp.	1	0.01	100
CBB	Coral rubble		1	<0.01	100
COR	Hydrocorals	Stylasteridae	<1	<0.01	100
AFO	Royal red prawn	*Aristaeomorpha foliacea*	<1	<0.01	95
CPA	Pentagon star	*Ceramaster patagonicus*	<1	<0.01	100
PRU	*Pseudechinaster rubens*	*Pseudechinaster rubens*	<1	<0.01	79
GDU	Bushy hard coral	*Goniocorella dumosa*	<1	<0.01	99
CTU	Cooks turban shell	*Cookia sulcata*	<1	<0.01	100
LAG	*Laetmogone* spp.	*Laetmogone* spp.	<1	<0.01	100
MNI	Munida unidentified	*Munida* spp.	<1	<0.01	100
CAM	Sabre prawn	*Camplyonotus rathbunae*	<1	<0.01	96
HTR	Trojan starfish	*Hippasteria phrygiana*	<1	<0.01	100
PNE	*Proserpinaster neozelanicus*	*Proserpinaster neozelanicus*	<1	<0.01	100
SMT	*Spatangus mathesoni*	*Spatangus mathesoni*	<1	<0.01	100
PED	Scarlet prawn	*Aristaeopsis edwardsiana*	<1	<0.01	46
CVI	Two-spined crab	*Carcinoplax victoriensis*	<1	<0.01	100
PSE	Sea urchin	*Pseudechinus* spp.	<1	<0.01	100
DWO	Deepwater octopus	*Graneledone* spp.	<1	<0.01	100
KIC	King crab	*Lithodes aotearoa* & *Neolithodes*	<1	<0.01	100
BOC	Deepsea anemone	*Bolocera* spp.	<1	<0.01	100
TAM	Tam O' Shanter urchin	Echinothuriidae & Phormosomatidae	<1	<0.01	100
EZE	Yellow octopus	*Enteroctopus zealandicus*	<1	<0.01	98
ALL	*Alcithoe larochei*	*Alcithoe larochei*	<1	<0.01	94
SDM	Pagurid	*Sympagurus dimorphus*	<1	<0.01	99
KSP	Kina spat	*Evechinus chloroticus*	<1	<0.01	100
PCH	*Penion chathamensis*	*Penion chathamensis*	<1	<0.01	90
PNN	Purple sea pen	*Pennatula* spp.	<1	<0.01	100
CJA	Sun star	*Crossaster multispinus*	<1	<0.01	100
DHO	Sea urchin	*Dermechinus horridus*	<1	<0.01	100
CDY	*Cosmasterias dyscrita*	*Cosmasterias dyscrita*	<1	<0.01	100
PDO	*Paphies donacina*	*Paphies donacina*	<1	<0.01	100
CAL	Giant purple pedinid	*Caenopedina porphyrogigas*	<1	<0.01	100
PAM	*Pannychia moseleyi*	*Pannychia moseleyi*	<1	<0.01	100
CRA	Rock lobster	*Jasus edwardsii*	<1	<0.01	100
APE	*Acanthephyra pelagica*	*Acanthephyra pelagica*	<1	<0.01	100
KWH	Knobbed whelk	*Austrofucus glans*	<1	<0.01	98
GAT	*Gastroptychus* spp.	*Gastroptychus* spp.	<1	<0.01	100
PLT	Abyssal stars	*Plutonaster* spp.	<1	<0.01	100
EGA	*Euciroa galatheae*	*Euciroa galatheae*	<1	<0.01	100
HIS	*Histocidaris* spp.	*Histocidaris* spp.	<1	<0.01	90
AER	*Aeneator recens*	*Aeneator recens*	<1	<0.01	90
SCA	Scallop	*Pecten novaezelandiae*	<1	<0.01	0
SMO	Cross-fish	*Sclerasterias mollis*	<1	<0.01	100
DSU	Silky dosinia	*Dosinia subrosea*	<1	<0.01	100
CRO	*Centrostephanus rodgersii*	*Centrostephanus rodgersii*	<1	<0.01	100
DDI	Crested cup coral	*Desmophyllum dianthus*	<1	<0.01	100
NMA	*Notopandalus magnoculus*	*Notopandalus magnoculus*	<1	<0.01	100
LNV	Rock star	*Lithosoma novaezelandiae*	<1	<0.01	100
TLO	Long polyp soft coral	*Telesto* spp.	<1	<0.01	100
LMI	Masking crabs	*Leptomithrax* spp.	<1	<0.01	100

Appendix 3: Observed bycatch by species group. Estimated catch, percentage of total catch, and overall percentage discarded by species group from observer records for the scampi target fishery from 1 Oct 1990 to 30 Sep 2010 and, in parentheses, for just the last five years (1 Oct 2005 to 30 Sep 2010). Records are ordered by decreasing percentage of catch. Estimated catches are based on all observed target scampi tows; discards are based on all trips where scampi was the sole target species. NB: discard percentages are conservative, as where 'destination' was missing the catch was presumed to have been retained.

Group	Observed catch (t)	% of catch	% discarded
Invertebrates			
Crustacea	226	2.2 (4.1)	88 (86)
Echinoderms	163	1.6 (2.0)	93 (100)
Cnidaria	60	0.6 (0.6)	89 (100)
Other molluscs	24	0.2 (0.6)	95 (98)
Squid	16	0.2 (0.1)	90 (100)
Octopuses	15	0.1 (0.1)	86 (70)
Sponges	2	<0.1 (0.1)	97 (99)
Polychaetes	0	<0.1 (<0.1)	100 (100)
Fish and arrow squid			
Fish (other)	4 142	40.0 (30.7)	33 (72)
Rattails	3 029	29.2 (31.7)	92 (100)
Rays & skates	359	3.5 (3.6)	67 (35)
Sharks & dogfish	238	2.3 (4.2)	87 (93)
Chimaeras	212	2.0 (3.0)	28 (11)
Arrow squid	49	0.5 (0.7)	1 (1)
Eels	28	0.3 (0.2)	93 (100)
Flatfish	13	0.1 (0.1)	98 (98)

Appendix 4: Bycatch rates (kg/trawl) of QMS and non-QMS fish species, and invertebrates in the scampi trawl fishery, by area and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	QMS				Non-QMS				Invertebrates			
	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR
1990–91	*458	*451	403	512	*583	*585	528	659	*18	*18	31	4
1991–92	398	878	*493	*487	801	854	*642	*643	84	6	*50	*50
1992–93	446	1 153	*733	726	547	1 190	*718	710	72	11	*33	*33
1993–94	210	653	*480	570	405	782	*538	235	64	10	*43	58
1994–95	*893	1 458	*908	634	*1 022	1 763	*1 005	417	*42	17	*42	71
1995–96	*641	*642	*641	*640	*1 304	*1 305	*1 305	*1 302	*156	*155	*155	*155
1996–97	648	*607	*605	*608	503	*484	*486	*484	246	*180	*180	*180
1997–98	254	*423	*419	*416	294	*361	*362	*358	217	*130	*128	*129
1998–99	*272	409	*271	229	*468	598	*472	427	*35	13	*34	39
1999–00	*346	*346	*347	283	*580	*580	*580	*368	*65	*66	*65	35
2000–01	*454	*460	*461	461	*540	*528	*541	375	*48	*48	*48	42
2001–02	354	786	*530	533	252	1 289	*603	527	139	30	*105	110
2002–03	358	682	*581	*586	334	416	*388	*386	145	17	*55	*56
2003–04	344	564	*464	*466	477	526	*502	*504	162	18	*80	*79
2004–05	†311	†634	†293	†442	†410	†815	†438	†434	†129	†35	†58	†46
2005–06	68	*167	100	*167	113	*230	287	*231	166	*77	*24	75
2006–07	239	387	172	*283	316	450	417	*410	149	51	*161	105
2007–08	*247	376	152	271	*401	498	373	442	*62	62	55	43
2008–09	*242	328	*242	*242	*367	500	*363	*365	*51	51	*51	*51
2009–10	*183	217	169	*185	*504	852	227	*512	*48	28	46	*48

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

† Insufficient records in this year, bycatch rates based on bycatch data from all years for this area.

Appendix 5: Bycatch rates (kg/trawl) of RAT and JAV species categories in the scampi trawl fishery, by area and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	RAT				JAV			
	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR
1990–91	*37	*38	18	46	*131	*132	110	153
1991–92	117	137	*91	*92	402	215	*270	*267
1992–93	147	316	*171	167	218	479	*297	301
1993–94	194	470	*307	70	94	193	*129	84
1994–95	*402	934	*400	49	*265	492	*261	132
1995–96	*436	*432	*436	*437	*383	*386	*381	*385
1996–97	172	*166	*165	*164	140	*122	*123	*121
1997–98	81	*83	*82	*80	107	*152	*149	155
1998–99	*122	190	*126	93	*179	318	*181	150
1999–00	*110	*110	*111	45	*275	*278	*277	158
2000–01	*115	*115	*115	78	*290	*295	*295	134
2001–02	41	446	*217	251	94	615	*226	155
2002–03	115	165	*147	*144	162	151	*150	*151
2003–04	274	173	*214	*213	131	236	*194	*194
2004–05	†121	†323	†47	†92	†174	†322	†78	†153
2005–06	29	*39	44	*38	40	*78	52	*78
2006–07	54	129	23	*84	162	250	52	*173
2007–08	*85	138	30	104	*174	285	72	216
2008–09	*96	153	*95	96	*175	270	*176	177
2009–10	*175	447	15	*175	*232	310	50	*227

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

† Insufficient records in this year, bycatch rates based on bycatch data from all years for this area.

Appendix 6: Discard rates (kg/trawl) of QMS and non-QMS fish species, and invertebrates in the scampi trawl fishery, by area and fishing year, based on observed discard data. Discard rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.

	QMS				Non-QMS				Invertebrates			
	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR
1990–91	*18	*18	15	*17	*623	*621	526	*623	*2	*2	2	*2
1991–92	*54	*55	*55	*55	*420	*417	*418	*421	*6	*6	*7	*6
1992–93	†57	†171	†63	†95	†313	†715	†429	†443	†110	†36	†42	†43
1993–94	*177	*176	*178	182	*371	*373	*370	235	*31	*31	*31	*31
1994–95	†57	†170	†62	†94	†313	†714	†430	†438	†110	†36	†43	†43
1995–96	*209	*207	*208	*205	*1 628	*1 623	*1 624	*1 630	*167	*166	*168	*164
1996–97	242	*217	*215	*220	501	*496	*499	*500	206	*155	*155	*154
1997–98	†58	†171	†64	†94	†312	†722	†434	†440	†110	†36	†42	†44
1998–99	*26	*26	*27	36	*539	*538	*537	607	*32	*31	*32	34
1999–00	*93	*93	*92	62	*253	*254	*255	185	*56	*57	*57	30
2000–01	*79	*83	*80	85	*536	*537	*532	373	*39	*39	*40	42
2001–02	31	234	*135	144	253	1286	*589	494	102	26	*92	110
2002–03	32	192	*134	*134	334	418	*387	*389	133	15	*50	*50
2003–04	*155	254	*156	*153	304	450	*303	*304	*36	17	*36	*36
2004–05	†57	†167	†62	†95	†310	†725	†435	†444	†108	†37	†42	†43
2005–06	3	*15	22	*15	112	*229	278	*230	143	*63	14	*64
2006–07	*75	108	*75	*75	*402	447	*403	*403	*95	45	*94	*96
2007–08	*86	138	70	76	*396	497	356	435	*48	53	28	38
2008–09	*92	159	*92	*92	*361	493	*362	*360	*36	41	*37	*37
2009–10	*77	118	78	*77	*504	840	219	*502	*32	18	31	*32

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

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

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

	RAT				JAV			
	AUCK	CHAT	NRTH	WAIR	AUCK	CHAT	NRTH	WAIR
1990–91	*11	*12	2	*11	*29	*29	7	*28
1991–92	*5	*5	*5	*5	*16	*15	*15	*16
1992–93	†86	†222	†33	†94	†139	†264	†56	†119
1993–94	*124	*122	*123	69	*117	*115	*117	81
1994–95	†85	†220	†33	†95	†138	†265	†56	†119
1995–96	*464	*468	*467	*467	*338	*338	*339	*338
1996–97	172	*170	*172	*170	141	*122	*123	*122
1997–98	†85	†223	†33	†94	†140	†264	†56	†118
1998–99	*135	*137	*135	125	*191	*192	*193	214
1999–00	*52	*52	*53	21	*109	*110	*107	63
2000–01	*115	*116	*117	78	*292	*292	*291	134
2001–02	41	447	*221	243	94	612	*226	157
2002–03	113	164	*146	*149	163	153	*150	*150
2003–04	*95	152	*96	*96	*113	182	*110	*111
2004–05	†86	†222	†33	†94	†140	†264	†55	†118
2005–06	29	*38	45	*38	40	*78	52	*76
2006–07	*82	129	*85	*83	*171	248	*172	*173
2007–08	*88	138	30	103	*172	285	71	217
2008–09	*92	152	*96	*93	*174	269	*176	*174
2009–10	*173	444	14	*172	*232	304	49	*230

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

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

Appendix 8: QMS bycatch. Estimated annual bycatch (rounded to the nearest 10 t) of QMS species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	10	(0–10)	110	(80–140)	610	(490–650)	1 060	(670–1 390)	0	(0–0)
1991–92	320	(270–420)	1 790	(1 640–1 970)	490	(390–590)	710	(570–850)	10	(10–10)
1992–93	400	(120–850)	2 390	(2 190–3 490)	550	(350–810)	950	(600–1 400)	80	(70–100)
1993–94	290	(240–350)	1 140	(1 010–1 290)	280	(210–350)	790	(570–1 010)	0	(0–0)
1994–95	1 180	(650–1 700)	1 570	(1 480–1 660)	390	(230–570)	530	(490–580)	30	(30–40)
1995–96	850	(700–920)	550	(450–600)	220	(180–240)	540	(440–600)	10	(0–10)
1996–97	810	(200–1 330)	440	(160–680)	230	(90–350)	690	(260–1 040)	20	(10–20)
1997–98	290	(210–400)	290	(160–390)	170	(90–230)	450	(250–600)	40	(30–40)
1998–99	360	(220–460)	300	(230–390)	100	(70–130)	350	(200–480)	130	(110–150)
1999–00	450	(280–750)	320	(190–540)	240	(140–380)	440	(270–690)	60	(50–80)
2000–01	640	(440–850)	360	(250–470)	390	(280–520)	790	(730–880)	90	(80–110)
2001–02	560	(310–910)	620	(410–960)	580	(420–740)	1 670	(1 530–1 820)	40	(30–40)
2002–03	500	(290–810)	720	(550–960)	450	(360–540)	980	(790–1 170)	120	(100–140)
2003–04	430	(350–500)	420	(300–560)	360	(280–450)	340	(270–430)	30	(30–40)
2004–05	400	(240–560)	1 100	(900–1 420)	260	(200–320)	300	(240–350)	10	(10–10)
2005–06	90	(80–100)	340	(160–550)	80	(70–90)	120	(50–190)	0	(0–0)
2006–07	320	(270–370)	890	(780–1 040)	130	(120–150)	200	(140–250)	0	(0–0)
2007–08	320	(190–460)	760	(510–950)	130	(110–150)	170	(150–190)	0	(0–0)
2008–09	350	(210–490)	430	(330–510)	190	(120–260)	100	(60–140)	0	(0–0)
2009–10	170	(140–220)	310	(280–350)	160	(150–180)	150	(120–190)	0	(0–0)

Appendix 9: Non-QMS bycatch. Estimated annual bycatch (rounded to the nearest 10 t) of non-QMS species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	10	(10–10)	140	(110–170)	790	(730–900)	1 380	(1 140–1 950)	0	(0–0)
1991–92	650	(530–870)	1 750	(1 580–1 920)	650	(480–850)	940	(710–1 210)	10	(10–10)
1992–93	490	(250–900)	2 470	(1 740–3 580)	540	(350–750)	950	(610–1 280)	80	(70–100)
1993–94	550	(360–740)	1 410	(820–2 230)	310	(190–490)	330	(200–470)	0	(0–0)
1994–95	1 310	(570–2 000)	1 900	(1 780–2 010)	450	(200–690)	350	(320–380)	40	(30–40)
1995–96	1 720	(850–1 870)	1 110	(540–1 210)	450	(220–490)	1 100	(550–1 200)	10	(10–10)
1996–97	630	(560–700)	360	(270–460)	190	(140–240)	550	(430–700)	10	(10–20)
1997–98	330	(150–590)	250	(110–410)	140	(60–240)	390	(160–650)	30	(20–40)
1998–99	620	(260–910)	440	(260–680)	180	(80–260)	630	(170–1 000)	210	(150–270)
1999–00	760	(390–1 410)	550	(280–1 020)	400	(210–730)	580	(350–890)	100	(70–140)
2000–01	740	(510–1 260)	420	(280–680)	460	(310–750)	640	(590–700)	100	(80–130)
2001–02	400	(230–640)	1 030	(570–2 040)	660	(420–970)	1 640	(1 500–2 130)	40	(30–70)
2002–03	460	(260–640)	440	(320–560)	300	(230–400)	650	(470–860)	80	(70–90)
2003–04	600	(460–770)	390	(290–470)	390	(310–460)	360	(290–440)	30	(30–40)
2004–05	520	(400–640)	1 410	(1 100–1 760)	390	(290–490)	290	(230–350)	10	(10–10)
2005–06	150	(130–170)	470	(270–640)	240	(220–250)	160	(100–220)	0	(0–0)
2006–07	420	(360–480)	1 030	(810–1 280)	320	(260–370)	290	(230–340)	0	(0–0)
2007–08	530	(350–810)	1 000	(600–1 310)	320	(280–360)	270	(240–310)	0	(0–0)
2008–09	530	(350–680)	660	(580–770)	290	(200–380)	150	(100–190)	0	(0–0)
2009–10	480	(290–730)	1 230	(1 120–1 360)	220	(200–240)	410	(250–620)	0	(0–0)

Appendix 10: INV bycatch. Estimated annual bycatch (rounded to the nearest 10 t) of INV species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	0	(0–10)	50	(40–70)	10	(0–20)	0	(0–0)
1991–92	70	(30–110)	10	(0–20)	50	(20–100)	70	(30–150)	0	(0–0)
1992–93	60	(30–90)	20	(10–40)	30	(10–40)	40	(10–70)	0	(0–10)
1993–94	90	(20–210)	20	(0–50)	20	(10–40)	80	(40–120)	0	(0–0)
1994–95	50	(30–80)	20	(20–20)	20	(10–30)	60	(50–70)	0	(0–0)
1995–96	210	(40–250)	130	(30–160)	50	(10–60)	130	(30–160)	0	(0–0)
1996–97	310	(140–440)	130	(60–200)	70	(30–100)	200	(100–300)	10	(0–10)
1997–98	250	(70–380)	90	(30–160)	50	(10–90)	140	(30–250)	10	(10–20)
1998–99	40	(20–80)	10	(0–10)	10	(10–20)	60	(30–100)	10	(10–20)
1999–00	80	(20–190)	60	(20–130)	50	(10–90)	50	(20–110)	10	(10–20)
2000–01	70	(60–80)	40	(30–50)	40	(30–50)	70	(60–90)	10	(10–10)
2001–02	220	(140–340)	20	(10–50)	110	(50–160)	340	(290–460)	10	(0–10)
2002–03	200	(90–290)	20	(10–30)	40	(10–70)	90	(30–150)	10	(10–20)
2003–04	200	(80–400)	10	(10–20)	60	(30–90)	60	(30–80)	10	(0–10)
2004–05	160	(110–210)	60	(30–100)	50	(40–70)	30	(20–40)	0	(0–0)
2005–06	220	(180–250)	150	(50–290)	20	(20–20)	50	(20–100)	0	(0–0)
2006–07	200	(170–230)	120	(80–150)	120	(80–170)	70	(30–110)	0	(0–0)
2007–08	80	(70–110)	130	(110–140)	50	(40–50)	30	(20–30)	0	(0–0)
2008–09	70	(60–100)	70	(60–90)	40	(30–50)	20	(20–30)	0	(0–0)
2009–10	40	(30–60)	40	(40–40)	40	(40–50)	40	(30–50)	0	(0–0)

Appendix 11: RAT bycatch. Estimated annual bycatch (rounded to the nearest 10 t) in the RAT species category in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	10	(0–10)	30	(20–30)	100	(60–140)	0	(0–0)
1991–92	90	(80–120)	280	(180–420)	90	(60–120)	130	(80–180)	0	(0–0)
1992–93	130	(100–160)	660	(210–1 240)	130	(30–220)	220	(50–370)	20	(10–30)
1993–94	270	(130–480)	850	(280–1 810)	180	(70–380)	100	(70–120)	0	(0–0)
1994–95	530	(80–950)	1 000	(910–1 100)	180	(30–330)	40	(40–50)	20	(10–20)
1995–96	570	(120–660)	370	(80–420)	150	(30–170)	370	(80–430)	0	(0–0)
1996–97	210	(170–300)	120	(80–170)	60	(40–90)	190	(120–260)	0	(0–10)
1997–98	90	(30–160)	60	(30–100)	30	(20–50)	90	(50–140)	10	(10–10)
1998–99	160	(70–250)	140	(80–220)	50	(20–70)	140	(30–220)	60	(40–80)
1999–00	140	(70–250)	100	(50–190)	80	(40–140)	70	(40–120)	20	(10–20)
2000–01	160	(90–260)	90	(50–140)	100	(50–160)	130	(110–150)	20	(20–30)
2001–02	60	(50–80)	350	(150–640)	240	(100–360)	790	(690–1 120)	20	(10–20)
2002–03	160	(30–280)	170	(100–250)	120	(60–180)	240	(140–390)	30	(20–40)
2003–04	350	(240–470)	120	(90–170)	160	(130–200)	150	(120–180)	10	(10–20)
2004–05	150	(110–200)	560	(370–780)	40	(20–60)	60	(40–90)	0	(0–0)
2005–06	40	(30–50)	80	(50–110)	40	(30–40)	30	(20–40)	0	(0–0)
2006–07	70	(60–80)	300	(200–430)	20	(10–20)	60	(30–90)	0	(0–0)
2007–08	110	(50–210)	280	(160–370)	30	(20–30)	60	(50–80)	0	(0–0)
2008–09	140	(60–220)	200	(160–240)	80	(30–120)	40	(20–60)	0	(0–0)
2009–10	160	(50–370)	650	(570–740)	10	(10–20)	140	(40–310)	0	(0–0)

Appendix 12: JAV bycatch. Estimated annual bycatch (rounded to the nearest 10 t) in the JAV species category in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	30	(20–40)	170	(150–220)	320	(190–420)	0	(0–0)
1991–92	330	(230–460)	440	(360–520)	270	(170–380)	390	(240–560)	0	(0–0)
1992–93	200	(100–370)	1010	(630–1 600)	230	(150–340)	390	(250–590)	30	(30–40)
1993–94	130	(70–200)	340	(200–450)	70	(50–100)	120	(40–200)	0	(0–0)
1994–95	330	(80–740)	530	(480–570)	110	(30–250)	110	(100–130)	10	(10–10)
1995–96	510	(240–570)	330	(150–370)	130	(60–150)	320	(150–370)	0	(0–0)
1996–97	180	(90–300)	90	(50–150)	50	(30–80)	140	(80–220)	0	(0–0)
1997–98	120	(30–260)	110	(30–200)	60	(10–110)	170	(40–310)	10	(10–20)
1998–99	240	(100–360)	230	(140–340)	70	(20–100)	220	(50–350)	90	(60–110)
1999–00	360	(140–720)	260	(100–520)	190	(70–370)	250	(120–420)	50	(30–70)
2000–01	390	(230–810)	220	(130–440)	250	(140–480)	230	(210–250)	50	(40–70)
2001–02	150	(40–290)	490	(300–810)	250	(140–400)	480	(430–620)	20	(10–30)
2002–03	230	(190–260)	160	(120–200)	120	(100–140)	250	(210–300)	30	(30–40)
2003–04	160	(130–210)	180	(120–240)	150	(100–190)	140	(90–180)	10	(10–10)
2004–05	220	(180–260)	550	(450–690)	70	(60–90)	100	(80–130)	0	(0–0)
2005–06	50	(50–60)	150	(90–270)	40	(40–50)	50	(30–90)	0	(0–0)
2006–07	210	(180–260)	570	(400–750)	40	(30–50)	120	(70–180)	0	(0–0)
2007–08	230	(100–450)	580	(300–790)	60	(50–70)	130	(110–150)	0	(0–0)
2008–09	260	(140–370)	350	(320–420)	140	(80–200)	70	(40–100)	0	(0–0)
2009–10	220	(90–330)	450	(380–530)	50	(40–60)	190	(80–280)	0	(0–0)

Appendix 13: TOTAL bycatch. Estimated TOTAL annual bycatch (rounded to the nearest 10 t) in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	20	(10–20)	250	(190–320)	1 450	(1 260–1 620)	2 450	(1 810–3 360)	0	(0–0)
1991–92	1 040	(830–1 400)	3 550	(3 220–3 910)	1 190	(890–1 540)	1 720	(1 310–2 210)	20	(20–20)
1992–93	950	(400–1 840)	4 880	(3 940–7 110)	1 120	(710–1 600)	1 940	(1 220–2 750)	160	(140–210)
1993–94	930	(620–1 300)	2 570	(1 830–3 570)	610	(410–880)	1 200	(810–1 600)	0	(0–0)
1994–95	2 540	(1 250–3 780)	3 490	(3 280–3 690)	860	(440–1 290)	940	(860–1 030)	70	(60–80)
1995–96	2 780	(1 590–3 040)	1 790	(1 020–1 970)	720	(410–790)	1 770	(1 020–1 960)	20	(10–20)
1996–97	1 750	(900–2 470)	930	(490–1 340)	490	(260–690)	1 440	(790–2 040)	40	(20–50)
1997–98	870	(430–1 370)	630	(300–960)	360	(160–560)	980	(440–1 500)	80	(60–100)
1998–99	1 020	(500–1 450)	750	(490–1 080)	290	(160–410)	1 040	(400–1 580)	350	(270–440)
1999–00	1 290	(690–2 350)	930	(490–1 690)	690	(360–1 200)	1 070	(640–1 690)	170	(130–240)
2000–01	1 450	(1 010–2 190)	820	(560–1 200)	890	(620–1 320)	1 500	(1 380–1 670)	200	(170–250)
2001–02	1 180	(680–1 890)	1 670	(990–3 050)	1350	(890–1 870)	3 650	(3 320–4 410)	90	(60–120)
2002–03	1 160	(640–1 740)	1 180	(880–1 550)	790	(600–1 010)	1 720	(1 290–2 180)	210	(180–250)
2003–04	1 230	(890–1 670)	820	(600–1 050)	810	(620–1 000)	760	(590–950)	70	(60–90)
2004–05	1 080	(750–1 410)	2 570	(2 030–3 280)	700	(530–880)	620	(490–740)	20	(20–20)
2005–06	460	(390–520)	960	(480–1 480)	340	(310–360)	330	(170–510)	0	(0–0)
2006–07	940	(800–1 080)	2 040	(1 670–2 470)	570	(460–690)	560	(400–700)	0	(0–0)
2007–08	930	(610–1 380)	1 890	(1 220–2 400)	500	(430–560)	470	(410–530)	0	(0–0)
2008–09	950	(620–1 270)	1 160	(970–1 370)	520	(350–690)	270	(180–360)	0	(0–0)
2009–10	690	(460–1 010)	1 580	(1 440–1 750)	420	(390–470)	600	(400–860)	0	(0–0)

Appendix 14: QMS discards. Estimated annual discards (rounded to the nearest 10 t) of QMS species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	0	(0–10)	20	(20–30)	40	(10–80)	0	(0–0)
1991–92	50	(10–100)	110	(30–260)	60	(10–120)	80	(20–180)	0	(0–0)
1992–93	50	(20–90)	360	(240–480)	50	(30–70)	120	(90–160)	10	(10–10)
1993–94	250	(150–340)	310	(180–430)	100	(60–140)	250	(120–410)	0	(0–0)
1994–95	70	(20–130)	180	(130–260)	30	(20–40)	80	(60–100)	0	(0–0)
1995–96	270	(40–600)	180	(30–390)	70	(10–160)	180	(30–390)	0	(0–0)
1996–97	290	(60–540)	160	(70–260)	80	(40–140)	250	(110–400)	10	(0–10)
1997–98	70	(20–120)	120	(80–160)	30	(20–40)	100	(70–130)	10	(10–10)
1998–99	40	(30–60)	20	(10–30)	10	(10–20)	50	(0–110)	10	(10–20)
1999–00	120	(50–250)	90	(30–170)	60	(20–130)	100	(40–160)	20	(10–20)
2000–01	110	(40–190)	60	(20–110)	70	(20–120)	150	(120–180)	20	(10–20)
2001–02	50	(20–70)	180	(130–260)	150	(80–240)	450	(330–520)	10	(10–10)
2002–03	40	(30–60)	210	(100–320)	110	(40–210)	230	(90–440)	30	(20–40)
2003–04	190	(40–450)	190	(40–410)	120	(20–270)	110	(20–260)	10	(10–20)
2004–05	70	(30–130)	290	(200–410)	60	(40–90)	60	(50–80)	0	(0–0)
2005–06	0	(0–10)	30	(20–50)	20	(10–20)	10	(10–20)	0	(0–0)
2006–07	100	(70–140)	250	(170–310)	60	(40–80)	50	(40–70)	0	(0–0)
2007–08	110	(80–160)	280	(230–330)	60	(50–70)	50	(40–60)	0	(0–0)
2008–09	140	(60–240)	210	(140–270)	80	(30–130)	40	(20–70)	0	(0–0)
2009–10	70	(50–100)	170	(150–200)	80	(70–90)	60	(40–90)	0	(0–0)

Appendix 15: Non-QMS discards. Estimated annual discards (rounded to the nearest 10 t) of non-QMS species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	10	(10–10)	150	(130–160)	790	(720–900)	1 300	(1 150–1 490)	0	(0–0)
1991–92	340	(250–500)	850	(640–1 250)	420	(290–620)	610	(200–890)	0	(0–10)
1992–93	280	(220–340)	1 490	(1 130–1 940)	330	(250–420)	580	(430–750)	50	(40–60)
1993–94	520	(290–790)	640	(380–1 000)	210	(110–330)	320	(190–490)	0	(0–0)
1994–95	400	(310–490)	780	(590–1 020)	190	(140–230)	370	(280–470)	20	(10–20)
1995–96	2 140	(1 230–3 290)	1 380	(800–2 130)	560	(320–860)	1 370	(790–2130)	10	(10–20)
1996–97	620	(550–690)	370	(280–460)	190	(150–230)	570	(430–700)	10	(10–20)
1997–98	360	(270–440)	500	(370–660)	170	(130–220)	480	(350–600)	50	(40–50)
1998–99	710	(620–810)	390	(340–450)	200	(180–230)	910	(820–1 010)	240	(220–250)
1999–00	330	(70–510)	240	(50–370)	180	(40–270)	290	(130–450)	40	(30–60)
2000–01	740	(500–1 260)	420	(280–720)	460	(310–760)	640	(580–700)	100	(80–130)
2001–02	400	(230–640)	1 020	(570–1 770)	650	(390–940)	1 540	(1 390–2 030)	40	(30–60)
2002–03	470	(260–640)	440	(330–560)	300	(230–400)	650	(480–850)	80	(70–90)
2003–04	380	(220–520)	340	(250–450)	230	(140–320)	220	(130–300)	20	(20–30)
2004–05	400	(310–490)	1 230	(940–1 600)	390	(300–490)	300	(220–370)	10	(10–10)
2005–06	150	(130–170)	460	(270–640)	230	(220–250)	160	(90–220)	0	(0–0)
2006–07	530	(440–630)	1 020	(790–1 280)	300	(250–370)	280	(230–330)	0	(0–0)
2007–08	520	(340–800)	1 010	(590–1 310)	300	(260–340)	270	(240–310)	0	(0–0)
2008–09	520	(350–680)	650	(570–760)	290	(200–380)	150	(100–190)	0	(0–0)
2009–10	470	(260–710)	1 220	(1 100–1 340)	210	(190–240)	400	(220–610)	0	(0–0)

Appendix 16: INV discards. Estimated annual discards (rounded to the nearest 10 t) of INV species in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	0	(0–0)	0	(0–0)	0	(0–10)	0	(0–0)
1991–92	10	(0–20)	10	(0–40)	10	(0–20)	10	(0–30)	0	(0–0)
1992–93	100	(60–140)	80	(40–150)	30	(20–50)	60	(30–90)	10	(0–10)
1993–94	40	(20–60)	50	(30–80)	20	(10–30)	40	(20–80)	0	(0–0)
1994–95	140	(80–200)	40	(20–80)	20	(10–30)	40	(20–60)	0	(0–0)
1995–96	220	(0–520)	140	(0–340)	60	(0–140)	140	(0–330)	0	(0–0)
1996–97	260	(90–390)	110	(30–180)	60	(10–90)	180	(40–270)	0	(0–10)
1997–98	120	(70–180)	30	(10–50)	20	(10–30)	50	(30–70)	10	(0–10)
1998–99	40	(20–70)	20	(10–40)	10	(0–20)	50	(20–110)	10	(10–20)
1999–00	80	(10–170)	50	(10–120)	40	(10–90)	50	(10–110)	10	(0–20)
2000–01	50	(40–70)	30	(20–40)	30	(30–40)	70	(60–90)	10	(10–10)
2001–02	160	(90–260)	20	(0–40)	100	(50–150)	340	(290–480)	10	(0–10)
2002–03	190	(90–260)	20	(10–30)	40	(10–60)	80	(20–140)	10	(10–20)
2003–04	50	(30–60)	10	(0–30)	30	(20–40)	30	(20–30)	0	(0–0)
2004–05	140	(80–200)	60	(30–120)	40	(20–60)	30	(20–40)	0	(0–0)
2005–06	190	(120–240)	130	(30–250)	10	(10–10)	40	(10–90)	0	(0–0)
2006–07	130	(60–190)	100	(70–140)	70	(30–110)	70	(30–100)	0	(0–0)
2007–08	70	(40–90)	110	(90–120)	20	(20–30)	20	(20–30)	0	(0–0)
2008–09	50	(30–80)	50	(50–80)	30	(20–50)	20	(10–20)	0	(0–0)
2009–10	30	(20–40)	30	(20–30)	30	(30–30)	30	(20–40)	0	(0–0)

Appendix 17: RAT discards. Estimated annual discards (rounded to the nearest 10 t) in the RAT species category in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	0	(0–10)	0	(0–10)	20	(0–80)	0	(0–0)
1991–92	0	(0–10)	10	(0–30)	10	(0–20)	10	(0–20)	0	(0–0)
1992–93	70	(50–100)	460	(330–650)	30	(20–30)	120	(80–190)	10	(10–10)
1993–94	170	(90–290)	220	(120–380)	70	(40–120)	100	(70–120)	0	(0–0)
1994–95	110	(70–150)	240	(170–340)	10	(10–20)	80	(50–120)	0	(0–0)
1995–96	610	(0–1 430)	400	(0–920)	160	(0–370)	390	(0–910)	0	(0–10)
1996–97	210	(170–300)	130	(90–170)	60	(40–90)	190	(130–260)	0	(0–10)
1997–98	100	(60–130)	150	(110–210)	10	(10–20)	100	(60–160)	10	(10–10)
1998–99	180	(120–280)	100	(60–160)	50	(30–80)	190	(140–270)	60	(50–70)
1999–00	70	(20–110)	50	(10–80)	40	(10–60)	30	(10–50)	10	(10–10)
2000–01	160	(90–270)	90	(50–150)	100	(50–160)	130	(120–150)	20	(20–30)
2001–02	60	(50–80)	360	(150–670)	230	(100–360)	750	(660–1 110)	20	(10–20)
2002–03	160	(30–280)	170	(100–260)	110	(70–180)	250	(150–380)	30	(20–40)
2003–04	120	(50–190)	110	(60–170)	70	(30–120)	70	(30–110)	10	(10–10)
2004–05	110	(70–150)	370	(270–530)	30	(20–40)	60	(40–100)	0	(0–0)
2005–06	40	(30–50)	80	(50–110)	40	(30–40)	30	(20–40)	0	(0–0)
2006–07	110	(50–180)	300	(200–430)	60	(30–110)	60	(30–100)	0	(0–0)
2007–08	110	(50–220)	280	(160–380)	20	(20–30)	60	(50–80)	0	(0–0)
2008–09	140	(60–210)	200	(160–230)	70	(30–120)	40	(20–60)	0	(0–0)
2009–10	160	(30–350)	640	(560–730)	10	(10–20)	140	(30–300)	0	(0–0)

Appendix 18: JAV discards. Estimated annual discards (rounded to the nearest 10 t) in the JAV species category in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

	AUCK		CHAT		NRTH		WAIR		OTHER	
1990–91	0	(0–0)	10	(0–20)	10	(0–20)	60	(0–140)	0	(0–0)
1991–92	10	(0–40)	30	(10–100)	20	(0–50)	20	(0–70)	0	(0–0)
1992–93	120	(80–160)	550	(450–700)	40	(30–60)	160	(120–190)	20	(10–20)
1993–94	160	(90–240)	200	(110–300)	70	(40–100)	110	(30–180)	0	(0–0)
1994–95	180	(120–240)	280	(220–360)	20	(20–30)	100	(80–120)	10	(0–10)
1995–96	450	(10–1030)	290	(0–670)	120	(0–270)	280	(0–660)	0	(0–0)
1996–97	170	(90–310)	90	(50–110)	50	(30–60)	140	(80–170)	0	(0–0)
1997–98	160	(110–210)	180	(150–240)	20	(10–30)	130	(100–150)	10	(10–20)
1998–99	250	(210–300)	140	(120–170)	70	(60–90)	320	(260–370)	80	(80–90)
1999–00	140	(30–240)	100	(20–180)	70	(20–130)	100	(50–140)	20	(10–20)
2000–01	410	(230–820)	220	(120–440)	240	(140–470)	230	(210–250)	50	(40–70)
2001–02	150	(40–290)	480	(300–800)	250	(130–410)	490	(430–640)	20	(10–30)
2002–03	230	(190–260)	160	(130–200)	120	(100–140)	250	(210–300)	30	(30–40)
2003–04	140	(70–200)	130	(90–180)	80	(40–120)	80	(40–110)	10	(10–10)
2004–05	180	(120–230)	450	(370–570)	50	(30–70)	80	(60–100)	0	(0–0)
2005–06	50	(50–60)	150	(80–270)	40	(40–50)	50	(30–90)	0	(0–0)
2006–07	230	(140–350)	570	(390–750)	130	(70–200)	120	(70–180)	0	(0–0)
2007–08	230	(100–460)	580	(290–790)	60	(50–70)	130	(110–150)	0	(0–0)
2008–09	250	(140–350)	350	(320–430)	140	(80–200)	70	(40–100)	0	(0–0)
2009–10	220	(90–320)	440	(370–520)	50	(40–50)	190	(60–280)	0	(0–0)

Appendix 19: TOTAL discards. Estimated TOTAL annual discards (rounded to the nearest 10 t) in the scampi trawl fishery, by area, based on observed bycatch data; 95% confidence intervals in parentheses. See Figure 1 for area boundaries.

		AUCK		CHAT		NRTH		WAIR		OTHER
1990–91	10	(10–10)	150	(130–170)	810	(740–930)	1 340	(1 160–1 580)	0	(0–0)
1991–92	400	(260–620)	970	(670–1 550)	490	(300–760)	700	(220–1 100)	0	(0–10)
1992–93	430	(300–570)	1 930	(1 410–2 570)	410	(300–540)	760	(550–1 000)	70	(50–80)
1993–94	810	(460–1 190)	1 000	(590–1 510)	330	(180–500)	610	(330–980)	0	(0–0)
1994–95	610	(410–820)	1 000	(740–1 360)	240	(170–300)	490	(360–630)	20	(10–20)
1995–96	2 630	(1 270–4 410)	1 700	(830–2 860)	690	(330–1 160)	1 690	(820–2 850)	10	(10–20)
1996–97	1 170	(700–1 620)	640	(380–900)	330	(200–460)	1 000	(580–1 370)	20	(10–40)
1997–98	550	(360–740)	650	(460–870)	220	(160–290)	630	(450–800)	70	(50–70)
1998–99	790	(670–940)	430	(360–520)	220	(190–270)	1 010	(840–1 230)	260	(240–290)
1999–00	530	(130–930)	380	(90–660)	280	(70–490)	440	(180–720)	70	(40–100)
2000–01	900	(580–1 520)	510	(320–870)	560	(360–920)	860	(760–970)	130	(100–160)
2001–02	610	(340–970)	1 220	(700–2 070)	900	(520–1 330)	2 330	(2 010–3 030)	60	(40–80)
2002–03	700	(380–960)	670	(440–910)	450	(280–670)	960	(590–1 430)	120	(100–150)
2003–04	620	(290–1 030)	540	(290–890)	380	(180–630)	360	(170–590)	30	(30–50)
2004–05	610	(420–820)	1 580	(1 170–2 130)	490	(360–640)	390	(290–490)	10	(10–10)
2005–06	340	(250–420)	620	(320–940)	260	(240–280)	210	(110–330)	0	(0–0)
2006–07	760	(570–960)	1 370	(1 030–1 730)	430	(320–560)	400	(300–500)	0	(0–0)
2007–08	700	(460–1 050)	1 400	(910–1 760)	380	(330–440)	340	(300–400)	0	(0–0)
2008–09	710	(440–1 000)	910	(760–1 110)	400	(250–560)	210	(130–280)	0	(0–0)
2009–10	570	(330–850)	1 420	(1 270–1 570)	320	(290–360)	490	(280–740)	0	(0–0)