# Fish and invertebrate bycatch and discards in orange roughy and oreo fisheries from 1990–91 until 2008–09

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# EXECUTIVE SUMMARY

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Commercial catch-effort data and fisheries observer records of catch and discards by species provided by the Ministry of Fisheries (MFish) were used to estimate the rate and level of non-target fish catch (bycatch) and discards (fish returned to the sea whole) in the orange roughy and oreo trawl fisheries for each fishing year from 1990–91 to 2008–09. Estimates were made separately for several categories of catch or discards; the target species, all commercial species combined, other quota species combined, and non-commercial species combined.

Linear mixed-effect models (LMEs) were used to identify key factors influencing variability in observed bycatch and discard rates in order to provide appropriate stratification for scaling up from observed bycatch and discards to the whole fishery. Regression tree methods were used to optimise the number of levels of the key variable, trawl duration, while maintaining the explanatory power of the models. In most cases, this procedure divided trawl duration into two or three strata, depending on the catch category, and these were used to stratify the calculation of annual bycatch and discard totals in each fishery and catch category.

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

For the recent orange roughy fishery (since 2005–06), orange roughy accounted for about 84% of the total estimated catch recorded by observers and about 79% of the total reported catch from the target fishery based on catch-effort forms. The remainder of the (observed) catch comprised mainly the commercial species smooth oreo (8%), black oreo (2%), hoki (0.4%), and cardinalfish (0.3%), plus a range of non-commercial species including various species of deepwater dogfishes (1.8%), rattails (1.0%), morid cods (0.8%), and slickheads (0.3%). Most of the remaining 240 or so species or species groups recorded by observers each accounted for less than 0.01% of the observed catch during the period.

Total annual bycatch in the orange roughy fishery since 1990–91 ranged from about 2300 t to 27 000 t, but declined over time with the decline in catch in this fishery and was less than 4000 t in each of the four most recent fishing years (2005–06 to 2008–09). This bycatch mostly comprised commercial species, with non-commercial species only 5–10% of the total bycatch in the recent period. Total annual discards also decreased over time, from about 3400 t in 1990–91 to about 300 t in 2007–08 and, since about 2000, were almost entirely non-commercial, non-QMS species. Discarding of orange roughy and other commercial species, more prevalent early in the period, was often due to fish lost from torn nets during hauling. The main species discarded since 1990–91 were rattails, shovelnose spiny dogfish, and other deepwater dogfishes, all of which were discarded at a rate of 90% or more.

For the recent oreo fishery (since 2002), oreos (mainly black and smooth oreos) accounted for about 92% of the observed catch and about 96% of the total reported catch from the target fishery. The remainder of the (observed) catch was mainly orange roughy (3.5%), hoki (0.6%), and ling (0.3%), plus non-commercial species of deepwater dogfish (1.2%), rattails (1.0%), morid cods (0.1%), and

slickheads (0.1%). Most of the remaining 240 or so observed species or species groups each accounted for 0.01% or less of the observed catch during the period.

Total annual bycatch in the oreo fishery since 1990–91 ranged from about 270 t to 2200 t with fluctuating levels over time, with levels since 2000–01 (not previously examined) similar to the long term average. Bycatch was split almost evenly between commercial and non-commercial species overall, but after 2002 about 60% of the bycatch comprised commercial species. Discards in the oreo fishery remained relatively stable over time, ranging from about 260 t to 750 t per year, with higher levels in the late 1990s than in the early 1990s or 2000s. Discards mainly comprised non-commercial, non-QMS species, but also included a significant component of the target species in most years. The main species discarded were rattails, Baxters dogfish, and other deepwater dogfishes, all discarded at a rate of 75% or more.

The level of annual discards in the orange roughy fishery, calculated as a fraction of the catch of the target species, has decreased since 2000 to a level of 0.025–0.062 kg of discarded fish for every 1 kg of orange roughy caught, for the four most recent years. The equivalent fractions of discarded fish in the oreo fishery were relatively stable over time, but similar to recent values for the orange roughy fishery, ranging from 0.024 kg to 0.030 kg per 1 kg of oreo caught in the most recent seven years.

# 1. INTRODUCTION

For this study *non-target fish species catch* is equivalent to *bycatch*, all fish caught that were not the stated target species for that trawl, whether or not they were discarded (McCaughran 1992). McCaughran's definition of *discarded catch* (or *discards*) as "all the fish, both target and non-target species, which are returned to the sea whole as a result of economic, legal, or personal considerations", is also adopted. *Discarded catch* in this report is defined to also include fish lost from the net at the surface, but excludes fish returned to the sea alive. The *oreo and orange roughy trawl fisheries* are defined as all fishing using trawling methods where the target species was recorded as orange roughy (ORH) or oreos (smooth oreo, SSO; black oreo, BOE; spiky oreo, SOR; or unspecified oreo, OEO).

Bycatch is common and unavoidable in almost every commercial fishery. Marketable species (either target or non-target) are typically retained for sale, with species for which there is no market, or which cannot economically be brought to market, discarded, i.e., thrown back into the sea.

Bycatch and discarding in commercial fisheries are important issues in fisheries management, and are increasingly being incorporated into the stock assessment process and considered by third party certification schemes as an effect of fishing on the ecosystem. The emphasis was, in the past, on shrimp trawl fisheries (which had a high bycatch component) and drift-net fisheries (with significant bycatch of endangered species such as turtles and dolphins, and "ghost-fishing" from lost nets), but the focus later shifted to include all fisheries which have the potential to catch a variety of unwanted species. There were a number of scientific workshops in the 1990s which focused on bycatch and discard issues, e.g., the Technical Consultation on Reduction of Wastage in Fisheries (Clucas & James 1996). At this time it was estimated that 20–22 million tonnes were discarded annually (Clucas & James 1996). Due mostly to higher retention rates, improved fishing methods, and better fishery management, a more recent study estimates there to be about 7.3 million tonnes of dead or dying fish returned to the sea annually (Kelleher 2004).

In New Zealand, the Ministry of Fisheries has the responsibility for determining impacts of fishing on both target species that are discarded and non-target species taken during normal fishing operations. A specific management objective in their 10-year research plan for deepwater fisheries, which covers both the orange roughy and oreo fisheries, is to "identify and avoid or minimise adverse effects of deepwater and middle-depth fisheries on incidental bycatch species". This objective incorporates the principle that "the abundance of associated or dependent species should be maintained above a level that ensures their long-term viability". To determine this level for each species affected by the orange roughy and oreo fisheries trawl fisheries would be an enormous task; more achievable is the identification of species or species groups that are impacted and an estimation of the level of that impact. In this project, estimates were made of the level of catch and discards of non-target species, and the level of discards of orange roughy and oreos, in the target fisheries for these species. These estimates were based on MFish observer records of catch and discards by species, and catch effort data collected by commercial vessels.

Orange roughy (*Hoplostethus atlanticus*) are found throughout the EEZ (Exclusive Economic Zone) of New Zealand, mostly in depths of 700–1100 m (Anderson et al. 1998). The main fisheries are on the Chatham Rise (in Quota Management Area ORH 3B), along the east coast from East Cape to Banks Peninsula (ORH 2A, ORH 2B, ORH 3A), and the west and northeast coasts of the North Island (ORH 1). Smaller fisheries operate in southern parts of ORH 3B, including around the Pukaki Rise, and several fisheries occur outside the EEZ, including on the west Norfolk Ridge, Lord Howe Rise, northwest Challenger Plateau, and Louisville Ridge (Figures 1 & 2). Fishing takes place year round but there is an emphasis in June and July on orange roughy spawning aggregations, particularly on the Chatham Rise and in the east coast fisheries. About half the catch is landed unprocessed, mainly by ice-boats, and most of the rest is landed in the "dressed" state by factory trawlers.

The oreo fishery catches two main species, smooth oreo (*Pseudocyttus maculatus*) and black oreo (*Allocyttus niger*), as well as spiky oreo (*Neocyttus rhomboidalis*), a species caught in much smaller quantities. The two main oreo species have a similar depth and geographical distribution to orange roughy, except that they are generally not found north of East Cape or on the Challenger Plateau (Anderson et al. 1998). Spawning for both black and smooth oreo occurs from late October to December, mainly on the south Chatham Rise. The oreo fishery operates mostly on the south Chatham Rise (OEO 3A, OEO 4), along the east coast of the South Island (OEO 1), around the northern fringes of the Campbell Plateau and Bounty Plateau, and the northern end of the Macquarie Ridge (OEO 6) (Ministry of Fisheries 2010) (Figures 3 & 4). This fishery therefore strongly overlaps with the orange roughy fishery, with the same fleet of vessels, and trips frequently target and catch a mixture of these species. Like orange roughy, about 40–50% of the catch is landed unprocessed, mainly by ice-boats, and most of the rest is landed in the "dressed" state by factory trawlers.

The orange roughy and oreo fisheries are biologically significant New Zealand fisheries. Total reported trawl catches in 2008–09 were about 11 000 t of orange roughy and 16 000 t of oreos (source: Ministry of Fisheries), and since 2002–03 the total number of bottom trawls targeting these species has ranged from about 7000 to 11 000 per year. Fisheries of this scale have considerable potential to catch large amounts of non-target species, or of the target species that are of unwanted size, or are damaged.

Vessels fish for these species exclusively by bottom trawling, generally using the robust, 'roughy trawl' with ground gear comprising rockhopper rollers or steel bobbins. Previous studies have shown that the main fish bycatch species in these two fisheries are hoki (*Macruronus novaezelandiae*), deepwater dogfishes (Squalidae), cardinalfish (*Epigonus telescopus*), rattails (Macrouridae), and slickheads (Alepocephalidae) (Anderson 2004a, 2009a).

This report updates several earlier studies which reported bycatch and discards in these fisheries; for both fisheries from 1994–95 and 1995–96 (Clark et al. 2000), for orange roughy from 1990–91 to 1998–99 (Anderson et al. 2001), for oreos from 1990–91 to 2001–02 (Anderson 2004a), and for orange roughy from 1999–2000 to 2004–05 (Anderson 2009a). These studies showed that the total estimated annual bycatch was about 6000–8000 t in the orange roughy fishery and about 1000–2500 t in the oreo fishery. The estimated bycatch decreased slowly in the orange roughy fishery since the early 1990s, but peaked in the oreo fishery in the late 1990s, and then decreased.

The annual variation in discard levels tracked that of bycatch in the oreo fishery (i.e., the proportion of the bycatch that was discarded remained relatively constant), but in the orange roughy fishery a greater proportion of bycatch was discarded in more recent years. This was probably because vessels increased trawl lengths to maintain catch rates—leading to higher catches of non-commercial species. In the most recent studies, total discards in the oreo fishery were about 0.05 kg per kilogram of oreos landed, and in the orange roughy fishery about 0.16 kg per kilogram of orange roughy landed (Anderson 2004a, 2009a).

This study complements other recent studies on bycatch and discards in other New Zealand fisheries, including the trawl fisheries for southern blue whiting (*Micromesistius australis*), hoki (*Macruronus novaezelandiae*), arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.), hake (*Merluccius australis*), ling (*Genypterus blacodes*), and scampi (*Metanephrops challengeri*), and the longline fishery for ling (Anderson 2004a, 2004b, 2007, 2008, 2009b, Anderson & Smith 2005, Ballara & Anderson 2009, Ballara et al. 2010).

This report was prepared as an output from the MFish project ENV2009-02 "Bycatch and discards in oreo and orange roughy fisheries" and addresses the following objectives.

1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for oreos for the fishing years 2002/03 to 2008/09 using data from Scientific Observers and commercial fishing returns.

2. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for orange roughy for the fishing years 2004/05 to 2008/09 using data from Scientific Observers and commercial fishing returns.

It was agreed with MFish that, as there is significant overlap between the oreo and orange roughy fisheries, these two objectives would be addressed in combination, using observer data encompassing both fisheries to provide a larger overall data set for the analysis. Orange roughy are the main bycatch species in the oreo fishery, and vice versa, but although oreo bycatch in the target orange roughy fishery is equal to about a third of the total annual orange roughy landings, orange roughy bycatch in the target oreo fishery is only about 1–8% of the annual landings of oreos.

It was also agreed with MFish that the analysis would encompass the entire history of scientific observing in these fisheries, back as far as 1990–91, and provide revised estimates of bycatch and discards for the years preceding 2002–03 (oreos) and 2004–05 (orange roughy). Notably this project documents pattern in bycatch and discards over time but does not generally address the cause of these patterns; this would require additional work which is not funded under this project.

MFish observers have collected bycatch and discard information from these fisheries since 1988–89, but only on a large scale since 1990–91. For the fishing years examined since the last update (from 2001–02 for oreos and from 2004–05 for orange roughy), 17–52% of the target oreo catch, and 33–54% of the target orange roughy catch, were observed annually. Observers recorded the catch weight and (usually) the discard weight by species from each trawl as well as details of the location (start and finish position), bottom depth, trawl duration, and various other fishing parameters. This report provides estimates of bycatch and discards for each target fishery as a whole, calculated by scaling up estimates determined from the observed fraction according to total effort data collected by the fishing industry.

## 2. METHODS

### 2.1 Observer data

The allocation of observers on commercial vessels takes into account a range of data collection requirements and compliance issues for multiple fisheries. It is therefore not always possible to achieve an even or random spread of observer effort in each fishery. However, the observer coverage in these fisheries has steadily increased, with 40–54% coverage annually in the last three years. Although coverage relative to the landed catch was higher in recent times compared with the 1990s, for orange roughy this was mainly due to decreasing annual catch limits rather than the level of observer effort. There is a considerable amount of observer data available for this analysis, with about 450–2200 observed trawls annually in the orange roughy fishery, and 30–100 observed trawls annually in the oreo fishery.

### 2.1.1 Data preparation and grooming

Two datasets were prepared from the MFish observer databases *obs* and *cod*, based on all observed trawls targeting oreos and orange roughy 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 little use in this analysis. Therefore, the dataset produced was limited to those trawls for which the processing data were assessed independently.

A total of 30 905 observed trawls targeting oreos (23%) and orange roughy (77%) was extracted and used in the analysis of bycatch. Because of variability in the recording of fish processing data, there were fewer observed trawls (13 986) available for the analysis of discards – see below. Data grooming was carried out in the same way for each dataset.

For all records, the trawl distance was calculated from the recorded start and finish positions. Records in which a start or finish position was incompletely recorded, or where the calculated distance was more than 50 km, were identified and groomed using median imputation to substitute approximate values. This process substitutes the missing value with the median latitude or longitude for other trawls by the same vessel on the same day. Trawl distances were then recalculated from 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. Where necessary, the few missing fishing speed values (less than 1% of the records) were substituted with the mean value for the remainder of the data set (3.1 knots).

For all records, the bottom depth was calculated from the average of the recorded start and finish bottom depths where possible. For the records where one or both of these values was not recorded, bottom depth was taken from the remaining value or from the seabed depth. Less than 1% of trawls were recorded as not being on the seabed at all times, and less than 0.1% were coded as midwater or a combination of midwater and bottom trawling. Most trawls (62%) were on “pinnacles”, the remainder being mostly recorded as “straight line” (33%) or curved/angled in some way (5%).

When fish were lost from the net before it was brought aboard, observers estimated the amount lost by recording different values for “total greenweight on surface” and “total greenweight on board”. These losses came about through a mixture of burst codends, burst windows/escape panels, and rips in the belly of the net, either below the sea surface or at the surface or on the stern ramp of the vessel. Obvious errors in these values were corrected. For example, where the recorded value for “total greenweight on board” was greater than “total greenweight on surface” the weight of fish lost was set to zero unless it was clear that it was due to an obvious typographical error which could be corrected. Any differences in the recorded values for “total greenweight on surface” and “total greenweight on board” were interpreted as valid fish losses only if they were accompanied by an appropriate code identifying the cause of the loss. Genuine cases of lost fish were rare, occurring in about one trawl in 300, with an average of just under 3 t of lost fish. There is no indication that this has changed over time, although large losses of fish were frequent in the early years of these fisheries as indicated by adjustments to annual catch figures in, e.g., the ORH 3B orange roughy stock assessment (Ministry of Fisheries 2010).

Each record was assigned to an area (see Figure 1), based on a combination of the known stock divisions or management areas for these species and the natural distribution of fishing effort. Only about 3% of records fell outside these defined areas, but were retained in the analysis and designated as area “OTHER”. The number of trawls observed in each area over the 19 years is shown in Tables 1 & 2.

Observer data were available from 86 vessels ranging in length from about 21 to 105 m. No vessel or company is identified in this report, and alpha-numeric codes are used to differentiate between vessels where necessary.

**Table 1: Number of observed trawls targeting orange roughy by area (see Figure 1 for area definitions) and fishing year.**

Orange roughy target fishery

| | Area | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fishing year | 2A2B | BNTY | CHAL | COOK | HOWE | KAIK | LOUI | MACQ | NECR | NWCH | NWCR | ORH1 | OTAG | PUKA | PUYS | SECR | SWCR | OTHER | All areas |
| 1990–91 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 116 | 0 | 88 | 0 | 0 | 0 | 0 | 210 | 2 | 3 | 459 |
| 1991–92 | 0 | 13 | 62 | 0 | 72 | 2 | 0 | 0 | 93 | 53 | 21 | 0 | 3 | 0 | 11 | 327 | 2 | 0 | 659 |
| 1992–93 | 20 | 0 | 57 | 0 | 698 | 0 | 0 | 0 | 14 | 1111 | 14 | 0 | 0 | 0 | 13 | 282 | 0 | 0 | 2 209 |
| 1993–94 | 48 | 0 | 67 | 5 | 584 | 73 | 39 | 63 | 129 | 315 | 55 | 13 | 1 | 0 | 249 | 532 | 56 | 4 | 2 233 |
| 1994–95 | 176 | 2 | 108 | 0 | 0 | 2 | 528 | 25 | 347 | 14 | 68 | 5 | 0 | 0 | 12 | 383 | 3 | 2 | 1 675 |
| 1995–96 | 22 | 10 | 48 | 0 | 0 | 0 | 11 | 2 | 52 | 55 | 30 | 132 | 15 | 0 | 31 | 33 | 10 | 0 | 451 |
| 1996–97 | 55 | 2 | 233 | 0 | 20 | 32 | 0 | 94 | 150 | 28 | 68 | 119 | 3 | 33 | 63 | 200 | 0 | 8 | 1 108 |
| 1997–98 | 43 | 4 | 209 | 10 | 25 | 3 | 24 | 122 | 129 | 36 | 90 | 88 | 12 | 68 | 0 | 232 | 4 | 151 | 1 250 |
| 1998–99 | 61 | 0 | 307 | 0 | 85 | 32 | 0 | 28 | 73 | 109 | 29 | 167 | 0 | 9 | 0 | 36 | 0 | 130 | 1 066 |
| 1999–00 | 104 | 13 | 0 | 37 | 48 | 17 | 0 | 10 | 11 | 240 | 123 | 413 | 6 | 14 | 0 | 66 | 12 | 241 | 1 355 |
| 2000–01 | 21 | 0 | 0 | 1 | 31 | 52 | 77 | 2 | 44 | 102 | 98 | 0 | 1 | 1 | 0 | 248 | 3 | 116 | 797 |
| 2001–02 | 24 | 0 | 0 | 0 | 156 | 0 | 155 | 11 | 245 | 181 | 44 | 210 | 1 | 0 | 0 | 184 | 0 | 16 | 1 227 |
| 2002–03 | 37 | 9 | 0 | 0 | 38 | 0 | 350 | 6 | 121 | 8 | 156 | 205 | 0 | 0 | 0 | 342 | 0 | 0 | 1 272 |
| 2003–04 | 0 | 4 | 0 | 0 | 26 | 0 | 123 | 6 | 146 | 13 | 54 | 149 | 0 | 40 | 0 | 317 | 0 | 12 | 890 |
| 2004–05 | 8 | 8 | 73 | 0 | 0 | 0 | 35 | 2 | 267 | 0 | 137 | 71 | 0 | 154 | 18 | 355 | 0 | 4 | 1 132 |
| 2005–06 | 0 | 14 | 0 | 0 | 42 | 4 | 198 | 0 | 306 | 63 | 111 | 197 | 0 | 41 | 70 | 73 | 0 | 37 | 1 156 |
| 2006–07 | 0 | 6 | 0 | 0 | 23 | 33 | 0 | 0 | 178 | 0 | 127 | 367 | 0 | 162 | 0 | 137 | 19 | 101 | 1 153 |
| 2007–08 | 43 | 1 | 0 | 0 | 184 | 1 | 0 | 5 | 289 | 22 | 197 | 232 | 0 | 109 | 0 | 581 | 2 | 47 | 1 713 |
| 2008–09 | 6 | 0 | 74 | 0 | 436 | 15 | 0 | 0 | 361 | 140 | 81 | 189 | 0 | 16 | 0 | 529 | 0 | 34 | 1 881 |
| All years | 708 | 86 | 1 238 | 53 | 2 468 | 266 | 1 540 | 376 | 3 071 | 2 490 | 1591 | 2 557 | 42 | 647 | 467 | 5 067 | 113 | 906 | 23 686 |

**Table 2: Number of observed trawls targeting oreos by area (see Figure 3 for area definitions) and fishing year.**

Oreo target fishery

| | Area | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2A2B | BNTY | CHAL | COOK | HOWE | KAIK | LOUI | MACQ | NECR | NWCH | NWCR | ORH1 | OTAG | PUKA | PUYS | SECR | SWCR | OTHER | All areas |
| 1990–91 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 9 | 0 | 0 | 48 | 167 | 2 | 237 |
| 1991–92 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 16 | 0 | 30 |
| 1992–93 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 53 |
| 1993–94 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 9 | 0 | 0 | 1 | 37 | 0 | 50 |
| 1994–95 | 0 | 19 | 0 | 0 | 0 | 0 | 38 | 8 | 0 | 0 | 0 | 0 | 9 | 0 | 4 | 18 | 111 | 0 | 207 |
| 1995–96 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 18 | 0 | 3 | 42 | 30 | 1 | 104 |
| 1996–97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 | 0 | 0 | 2 | 0 | 37 | 7 | 5 | 26 | 38 | 3 | 152 |
| 1997–98 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 47 | 0 | 0 | 0 | 0 | 24 | 14 | 0 | 78 | 50 | 10 | 224 |
| 1998–99 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 107 | 0 | 0 | 13 | 0 | 11 | 32 | 0 | 100 | 17 | 17 | 298 |
| 1999–00 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 181 | 0 | 0 | 0 | 0 | 114 | 101 | 51 | 30 | 348 | 26 | 888 |
| 2000–01 | 1 | 22 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 1 | 0 | 16 | 49 | 0 | 38 | 407 | 6 | 551 |
| 2001–02 | 1 | 23 | 0 | 0 | 0 | 0 | 0 | 141 | 0 | 0 | 0 | 0 | 168 | 47 | 1 | 13 | 106 | 0 | 500 |
| 2002–03 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 26 | 52 | 0 | 20 | 57 | 0 | 287 |
| 2003–04 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 41 | 0 | 0 | 3 | 0 | 98 | 110 | 0 | 63 | 22 | 0 | 356 |
| 2004–05 | 0 | 87 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 1 | 0 | 57 | 124 | 0 | 116 | 31 | 1 | 431 |
| 2005–06 | 1 | 98 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 8 | 56 | 0 | 88 | 72 | 7 | 337 |
| 2006–07 | 0 | 112 | 0 | 0 | 0 | 0 | 0 | 18 | 1 | 0 | 0 | 0 | 150 | 566 | 0 | 122 | 37 | 0 | 1006 |
| 2007–08 | 0 | 65 | 0 | 0 | 0 | 0 | 0 | 60 | 0 | 0 | 0 | 0 | 71 | 463 | 0 | 141 | 53 | 1 | 854 |
| 2008–09 | 0 | 61 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 40 | 231 | 0 | 207 | 113 | 0 | 654 |
| All years | 3 | 584 | 1 | 0 | 0 | 0 | 44 | 814 | 14 | 1 | 23 | 0 | 865 | 1 852 | 64 | 1168 | 1712 | 74 | 7 219 |

To create the dataset used to estimate discards, the weights of each species retained and discarded in each “processing group” were obtained from the observer databases. The processing group is the level at which observers record information on the processing of fish on board, including those discarded, and although usually represented by a single trawl, processing data from two or more trawls are frequently combined into one processing group. This grouping of processing data stems from the difficulty of keeping track of the catch from individual trawls in the factory of a vessel. In order to examine how discard levels varied with fishing depth, area, season, etc., either these variables can be summarised over all trawls within each processing group, or processing groups representing more than one trawl can be disregarded. In this case the latter approach was adopted, therefore disregarding about 55% of the available data.

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

- The target species; orange roughy (ORH), and oreos (SSO, BOE, SOR, OEO).
- Other commercial species combined (COM).
- Non-commercial species combined (OTH).
- Quota Management System (QMS) species. Observers recorded 64 QMS species in total, although several of these (e.g., the shallow water sprats (*Sprattus* spp), leatherjackets (*Parika scaber*) and John dory (*Zeus faber*)) are likely to have been the result of misrecording. The QMS category did not include orange roughy or oreo species.

The abbreviations COM, OTH, QMS and the fish codes ORH, SSO, BOE, SOR, and OEO above are used throughout the remainder of this report. Bycatch and discards were estimated separately for each of these species or species categories. Summaries of the observed catch and percentage discarded of individual species are tabulated separately for each target fishery in Appendices 1 & 2.

Commercial species (COM) are the same set of species as used in all previous analyses for these fisheries, originally defined as those which represented 0.1% or more of the total observed catch and either were quota species or species for which 75% or more of the catch was retained. This definition was not tested on the expanded data set used here, but the same set of species was retained for consistency with previous analyses which will allow straightforward comparisons between studies to be made. For the oreo fishery, the COM category comprised orange roughy (ORH), hoki (HOK), and pale ghost shark (*Hydrolagus bemisi*, GSP) (Anderson 2004a); and for the orange roughy fishery the COM category comprised oreos (OEO, SSO, BOE, SOR), hoki (HOK), cardinalfish (CDL, EPT), alfonsino (*Beryx* spp., BYX, BYS, BYD), hake (HAK), and ribaldo (*Mora moro*, RIB) (Anderson 2009a). The bycatch and discards of these species were assessed as a group (COM).

## 2.2 Commercial fishing return data

Catch records from commercial fishing returns were obtained from MFish catch-effort databases for all trawls in which orange roughy or oreos were the stated target species for the period 1 October 1990 to 30 September 2009. This included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs) and the high-seas version (HTCEPRs), as well as on Catch, Effort and Landing Returns (CELRs) or HCELRs. Data were groomed for errors using routines developed in the statistical software package ‘R’ (Ihaka & Gentleman 1996) for missing position values, those indicating unusually long trawls and trawl duration as stated in Section 2.1.1. Unusual values of fishing speed were also corrected with median imputation, using values by the same vessel during recent trawls, or by assigning the mean value from all trawls. The top 1% longest duration trawls (over 7.3 h) were replaced by values calculated from trawl distance and fishing speed where the two values differed by more than 50%. Unusually shallow fishing depth and bottom depth values were set to the average value for other trawls within 1 n.mile where possible, and otherwise trimmed to a minimum of 200 m and a maximum of 1600 m.

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

It is possible to use these commercial catch data to directly estimate the total annual non-target catch in these fisheries, as for each trawl the total catch as well as the catch of the target species is recorded. Such estimates are provided here and give an appealing estimate of total bycatch in the fishery because (in contrast to the observer-based estimates) no scaling is required, and they are not confounded by the lack of recorded catch estimates for individual species outside the top five by weight in each trawl. However, a recent 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 it is not possible to estimate the bycatch of individual species or groups of species, because only the top five species by weight are recorded on catch effort forms. Observer-based methods are therefore used throughout the remainder of this document.

## 2.3 Analysis of factors influencing discards and bycatch

Regression analyses were used to identify the most useful strata for the calculations to scale up from the observer records to the whole fishery. Several potentially influential variables are recorded by observers for each observed trawl, but often only a subset of their levels is common to, and therefore useful for stratification of, commercial data. For example, the individual vessel code and trip number could be examined, and previous analyses in other fisheries have shown these factors to be highly influential in the level of bycatch and discards. But, since only a subset of the vessels and trips in the fishery were observed, it is problematic to calculate a ratio for those that were not observed. These influences were addressed by employing linear mixed-effects models, in which the trip variable was treated as a random effect (whereby the trip is assumed to be randomly selected from 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); fishing day (day of the fishing year, 1–365/6); fishing year; area (see Figure 1); vessel tonnage; and nationality.

Each species category (target species, COM, OTH, and QMS) was examined separately, and normal and binomial regression models constructed. Binomial regression models are useful to examine where there is a large proportion of zero values in the data; in this case where there was a large proportion of trawls with no catch (or no discard) of the species group. This combined approach enabled an examination of factors influencing both the *probability* and the *level* of a bycatch or discard. The response variable in the binomial models comprised a binomial vector assigned "0" if no bycatch/discard was recorded and "1" otherwise. The response variable in the normal models was the log of the bycatch/discards of the species/species group.

For each target fishery, regressions were run for bycatch and discards of commercial species (COM), non-commercial species (OTH), and quota species (QMS). Records with discards of target species were too few for useful models to be constructed. From these regressions, summaries were made of 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 target fishery and 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", $\hat{DR}$, 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, one on the total trawl duration, and one on the number of trawls. The estimators had the following form,

$$\hat{DR}_1 = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} l_i} \quad , \quad \hat{DR}_2 = \frac{\sum_{i=1}^{m} d_i}{\sum_{i=1}^{m} t_i} \quad \text{and} \quad \hat{DR}_3 = \frac{\sum_{i=1}^{m} d_i}{m}$$

where $m$ trawls were sampled from a stratum; $d_i$ is the weight of discarded catch from the $i$th trawl sampled; $l_i$ is the weight of the target species caught in the $i$th trawl sampled; and $t_i$ is the duration of the $i$th 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., 30 905 for bycatch, and 13 986 for discards). This resulted in 1000 estimates of $\hat{DR}$ 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, as some vessels received 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 $\hat{DR}$ were derived for each stratum in each fishing year and variances were derived by a more sophisticated bootstrapping procedure that allowed for correlation of discards between trawls within an observed trip. Separate ratios were calculated only for strata with 15 records or more, and overall ratios (using all data) were substituted for strata with fewer than 15 records. The discard ratio calculated for each stratum was then multiplied by either the total estimated catch of the target species, total trawl duration, or number of trawls in the stratum (depending on the version of the estimator chosen), from commercial catch records, to estimate total discards $\hat{D}$:

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

where $L_j$ is the total catch of the target species, $T_j$ the total trawl duration, and $M_j$ the number of trawls, in stratum $j$.

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 stratum 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 stratum. These steps were repeated until the effective number of trawls was approximately equal to the effective number of observed trawls for the stratum. 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 stratum, then the bootstrap sample was accepted. Otherwise a new bootstrap sample was drawn until 1000 samples in all had been accepted.

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

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

## 3. RESULTS

### 3.1 Distribution and representativeness of observer data

The positions of all observed trawls in the target orange roughy and oreo fisheries between 1 October 1991 and 30 September 2009 are shown, along with all trawls recorded with position data on commercial fishing returns from the same period, in Figures 1 to 4.

For the 19-year period as a whole, observer coverage was spread across the entire spatial extent of the orange roughy fishery, with only a few small gaps noticeable, mainly in parts of the Challenger Plateau (ORH 7A), east coast (ORH2A/2B), and Louisville Ridge fisheries. Some of the regions with apparently unobserved groups of trawls are likely to be the result of inaccurate recording of locality data, especially in earlier years (Figure 2) before or during the introduction of GPS navigation.

In the oreo target fishery, fishing and observer coverage was much more restricted to the South Chatham Rise and further south (Figure 3). Within this region, few locations were not covered by observers during the 19 years plotted, but in the smaller fisheries, on the North Chatham Rise, Louisville Ridge, and the east coast from Kaikoura to East Cape, coverage was minimal. Looking at coverage in 5-year blocks (Figure 4) shows that the distribution of the fishery was relatively constant over time and the spread of observer coverage was consistently good, although targeting of oreos along the east coast was more prevalent during the middle period (1996–2005).

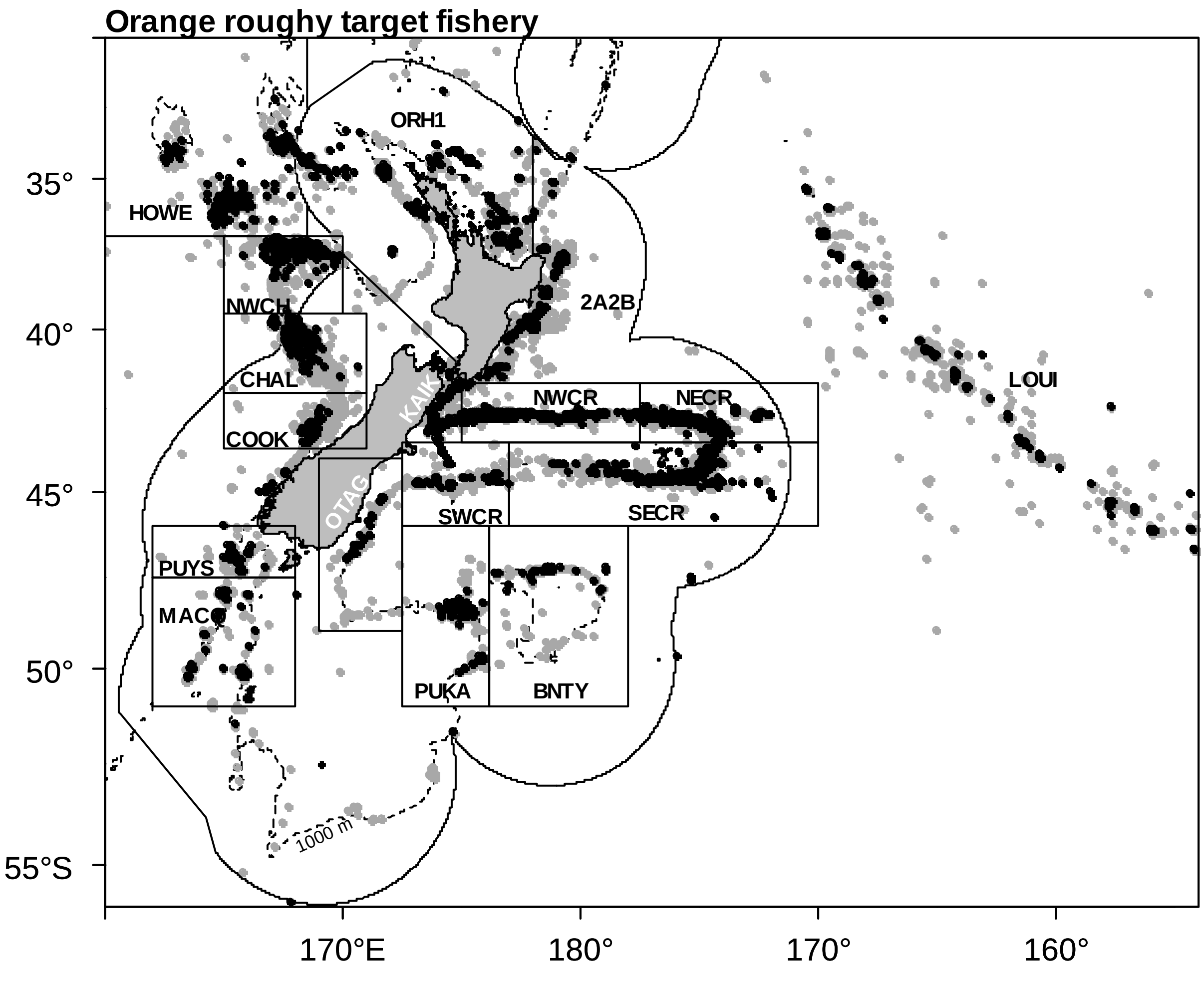



**Figure 1: Distribution of trawl positions recorded by observers on vessels targeting orange roughy (black dots), and all commercial trawls with position data targeting orange roughy (grey dots) for 1990–91 to 2008–09. Area divisions used in the analyses are shown. The dashed line represents the 1000 m contour.**

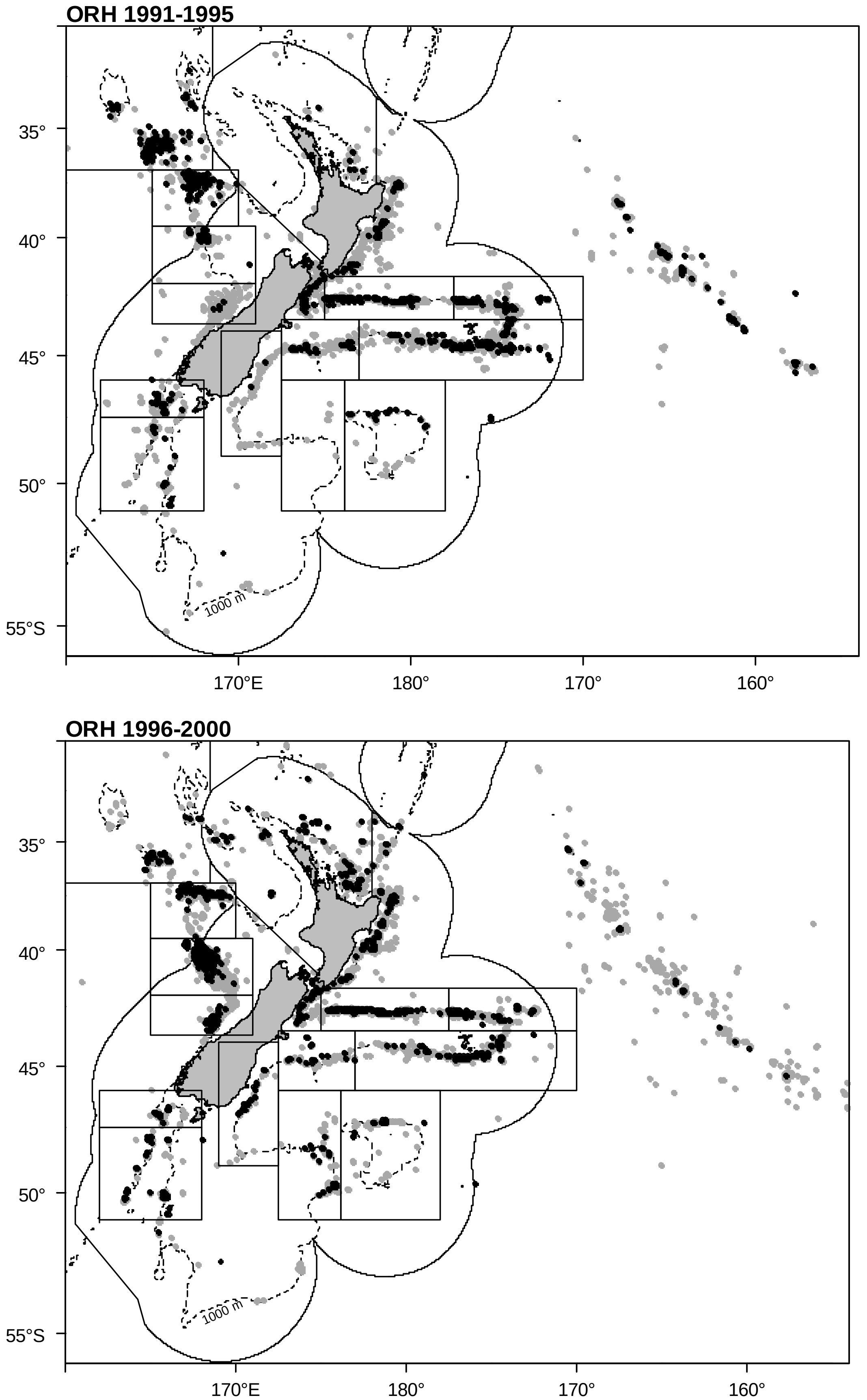
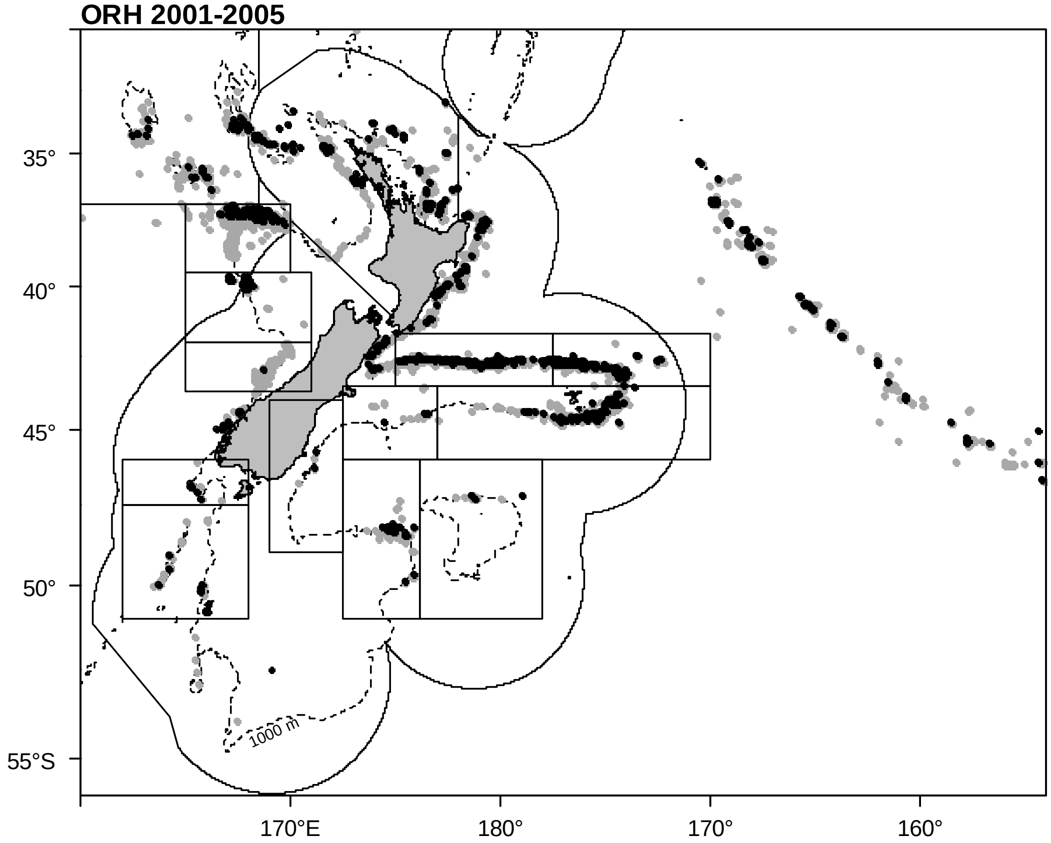



**Figure 2: Distribution of trawl positions recorded by observers on vessels targeting orange roughy (black dots), and all commercial trawls with position data targeting orange roughy (grey dots) by blocks of years. Area divisions used in the analyses are shown. The dashed line represents the 1000 m contour.**

ORH 2001-2005




ORH 2006-2009

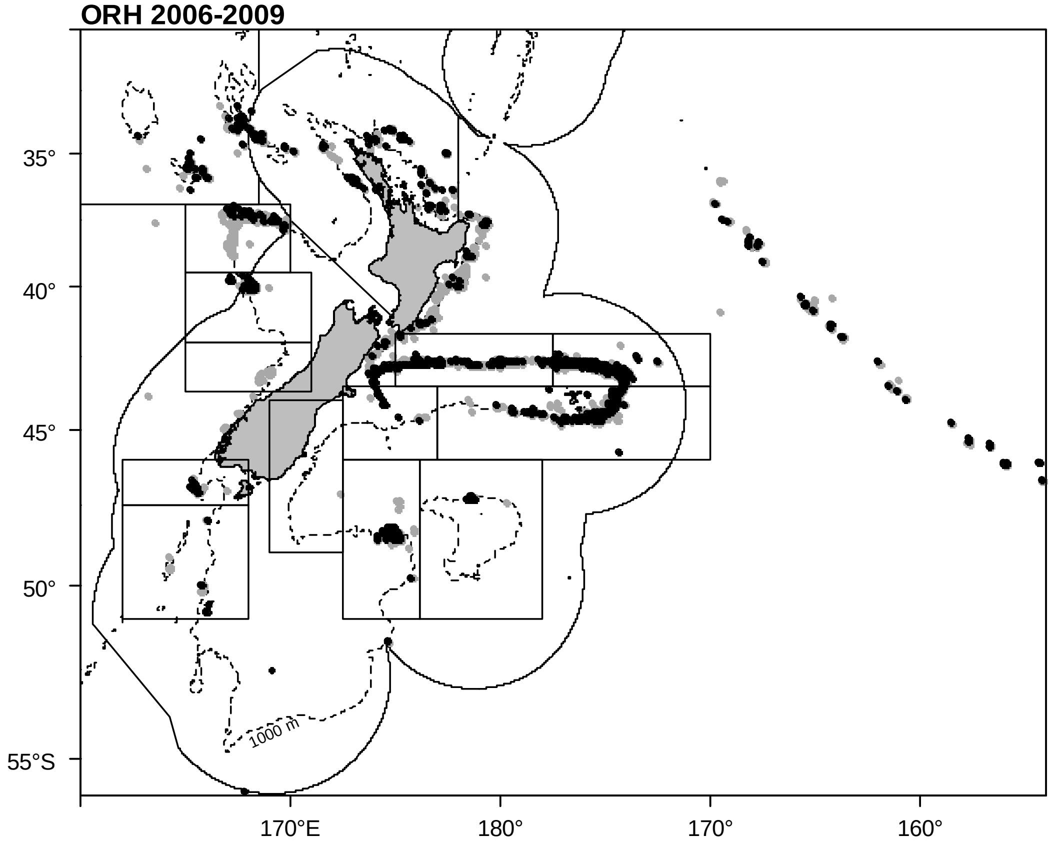



**Figure 2: —*Continued***

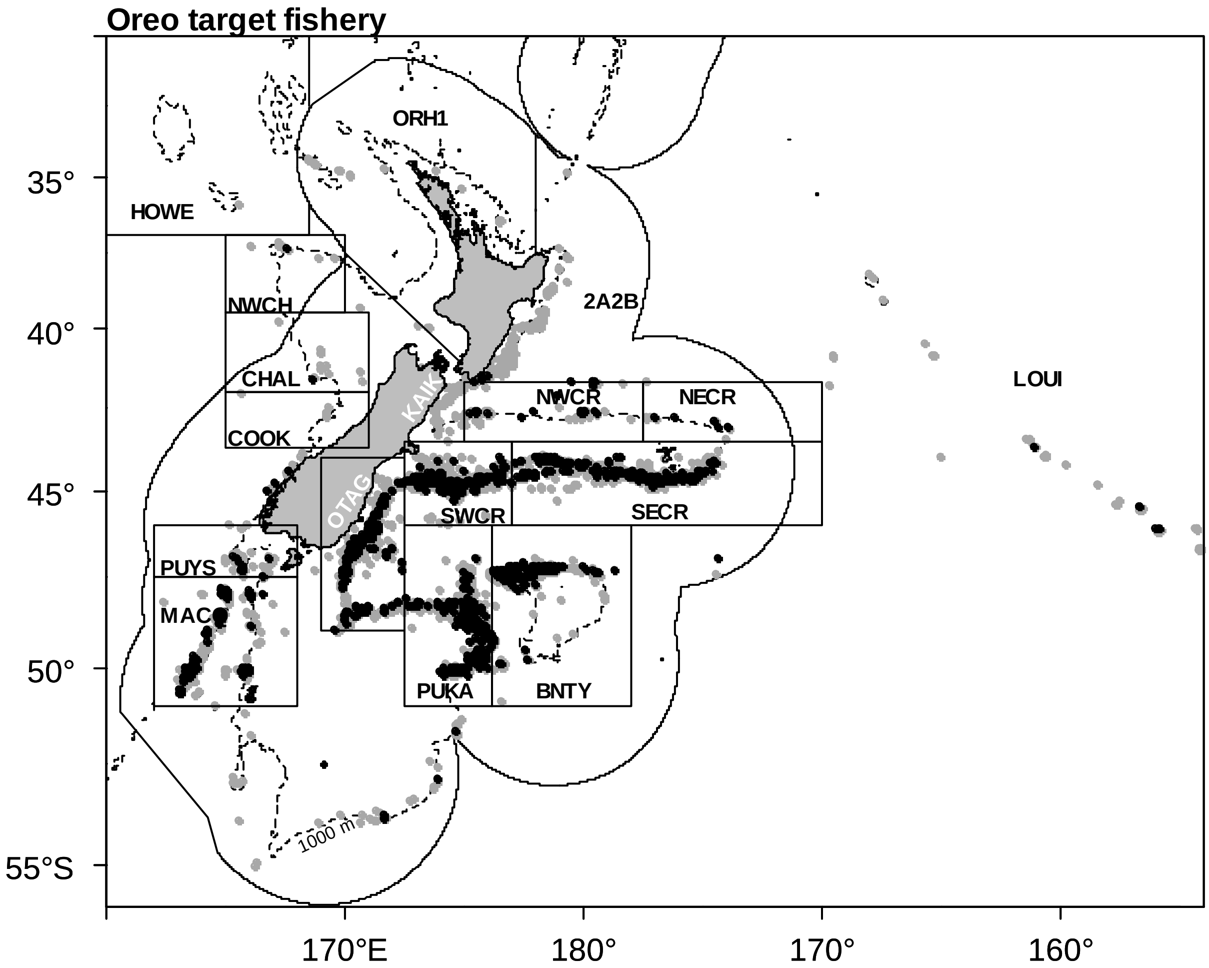
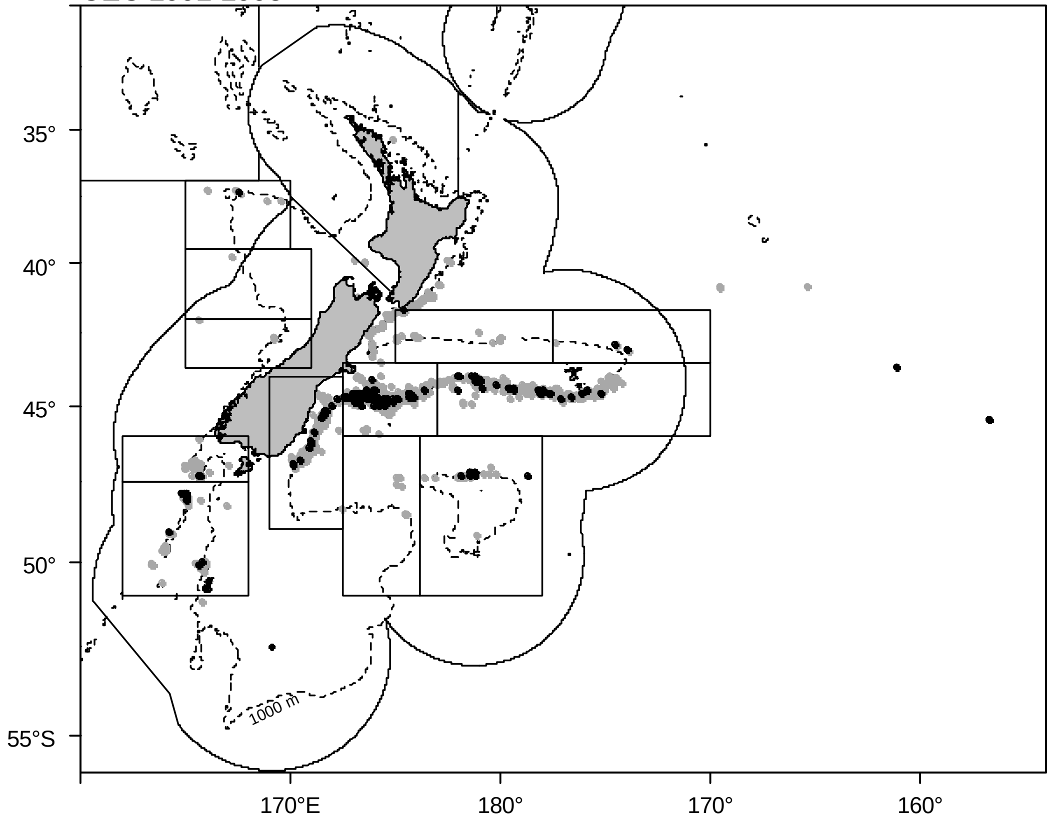



**Figure 3: Distribution of trawl positions recorded by observers on vessels targeting oreos (black dots), and all commercial trawls with position data targeting oreos (grey dots) for 1990–91 to 2008–09. Area divisions used in the analyses are shown. The dashed line represents the 1000 m contour.**

OEO 1991-1995




OEO 1996-2000

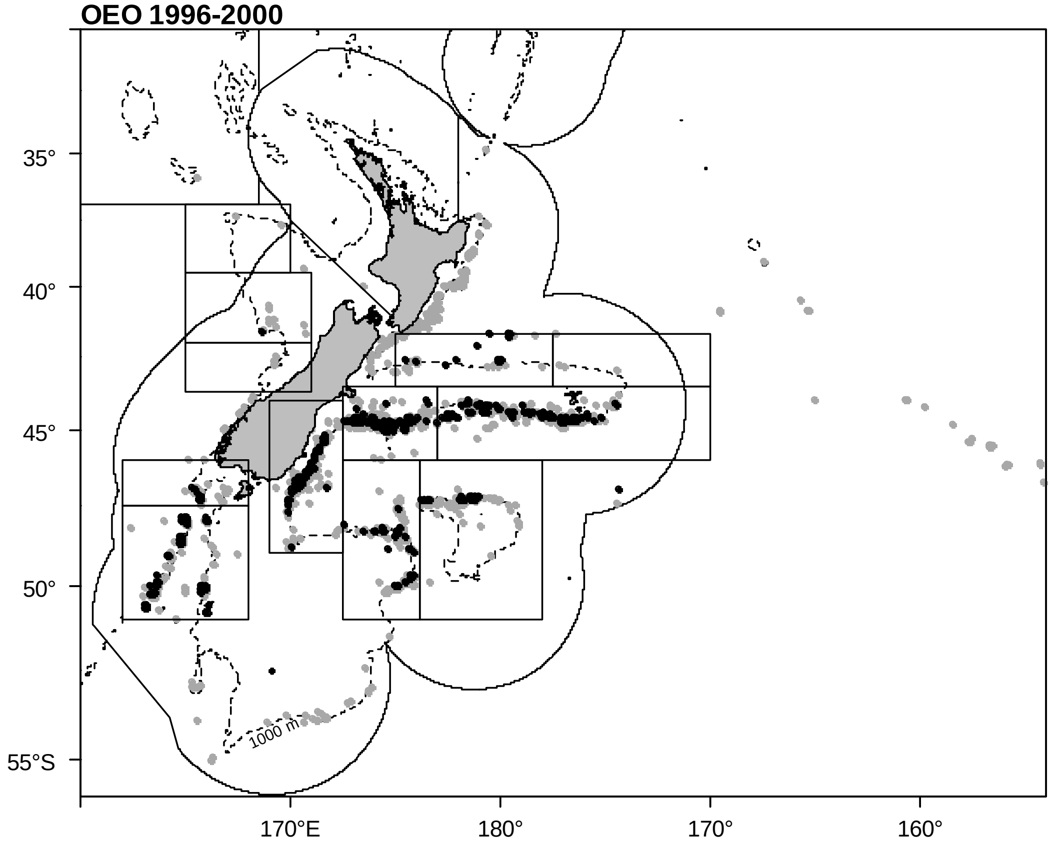
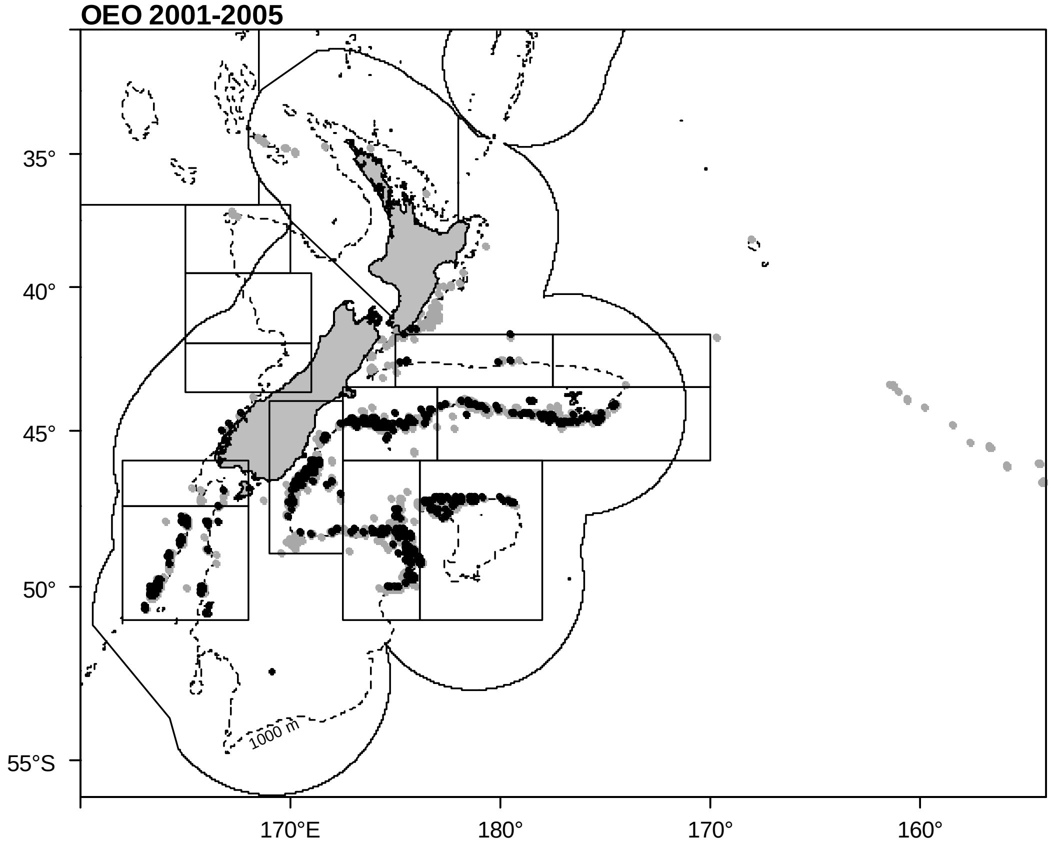


**Figure 4: Distribution of trawl positions recorded by observers on vessels targeting oreos (black dots), and all commercial trawls with position data targeting oreos (grey dots) by blocks of years. Area divisions used in the analyses are shown. The dashed line represents the 1000 m contour.**



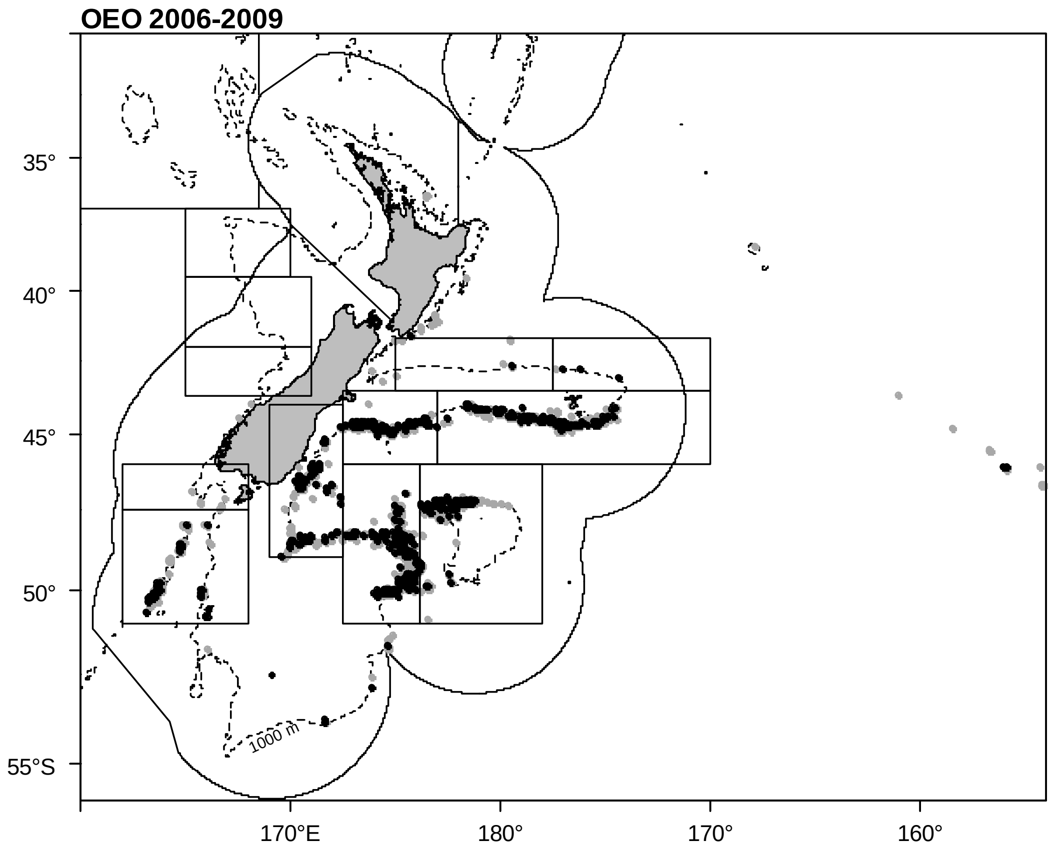



**Figure 4: —*Continued***

A spatial comparison of observed trawls with all commercial trawls recorded with position data was produced using density plots (Figures 5 & 6).

For orange roughy (Figure 5) the spread of observed trawls over the longitudinal and latitudinal extent of the fishery was well matched throughout much of the last two decades. This match was least perfect during the 1991–95 and 1996–2000 periods, for which the extent of the lack of coverage in the east coast fisheries is clearly shown, and oversampling occurred in the Challenger fisheries. Coverage was more even in the following period, 2001–2005, although less well spread sampling on the Challenger Plateau (about 37–39° S) is evident. From 2005–06 onwards, the distribution of commercial effort became more stable, but observer effort remained out of synch in some regions, especially in 2005–06 and 2006–07 when the north Chatham Rise was oversampled and the southeast Rise undersampled. Coverage was almost ideal in the two most recent years, 2007–08 and 2008–09, although oversampling of the (mainly ORH 1) northern fisheries (as in several previous years, and overall) was apparent.

For oreos (Figure 6), the match of observer coverage to commercial effort was in general better than for orange roughy. Oversampling on the south Chatham Rise occurred in some periods, e.g., 2001–2005 and 2008–09, and there was moderate undersampling in the Pukaki/Bounty fisheries in 2005–06 and 2008–09. Elsewhere though, and at other times, coverage was close to ideal and this is clearly shown in the plot for all years combined, in which the two lines are mostly overlapped.

Comparisons made between vessel sizes in the commercial fleets and the observed portion (Figure 7) showed that the full range of vessel sizes was covered by observers in both fisheries. The vessel effort formed roughly into six size groups between about 300 t and 3000 t.

Commercial effort in the orange roughy fishery was mostly by vessels of less than about 1000 t, in two modes at about 300 t and 800 t. While commercial effort was mostly in the 300 t mode, observer coverage was more focused on vessels in the 800 t mode. Observer coverage was well spread over the larger size vessels, all relatively oversampled due to the undersampling of the 300 t mode.

The pattern was similar in the oreo fishery, with undersampling of the vessels less than 1000 t (mainly in the 300 t mode) balanced by oversampling in the main larger vessel modes at about 1400 t and 1900 t. The main difference between the two fisheries, in terms of vessel sizes, was in the greater amount of effort in the oreo fishery by vessels in the 1400 t mode.

Vessel size is linked to fishing area, especially in the orange roughy fishery where the smallest vessels were in the east coast fisheries (area 2A2B in Figure 1). This fishery lacked observer coverage throughout much of the period, partly due to the difficulty of placing observers on vessels with little spare accommodation.

It is useful to note that although about half of all vessels operating in the orange roughy/oreo fisheries between 1990 and 2008 never hosted an observer, these vessels accounted for only about 9% (orange roughy fishery) or 7% (oreo fishery) of the total catch of the target species during that time.

A comparison of the number of trawls, number of vessels and trips, and catch of the target species between the observed portion and the entire fishery is given in Table 3 (orange roughy) and Table 4 (oreos).

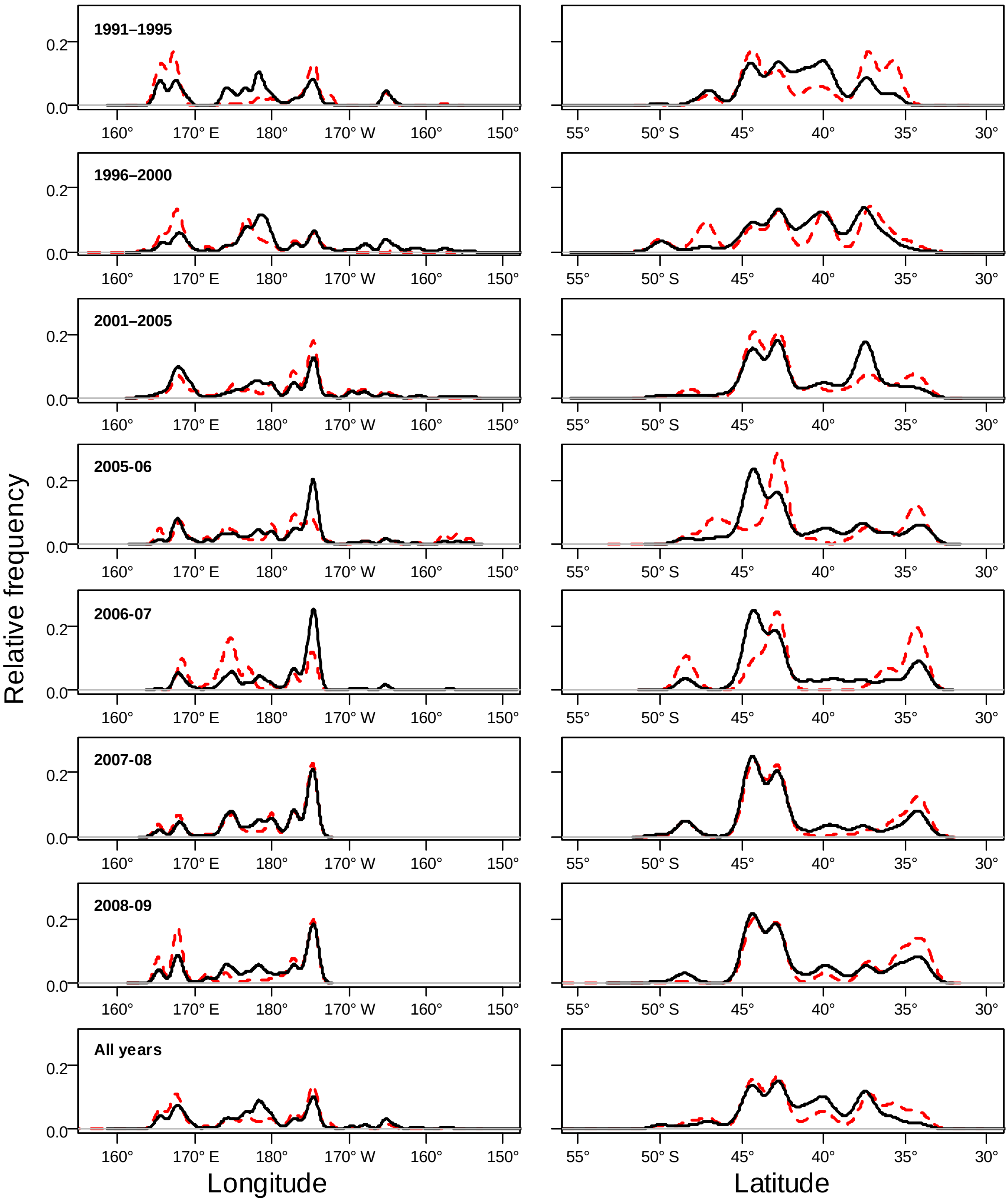



**Figure 5: Orange roughy target fishery. Comparison of start positions (latitude and longitude) of observed trawls (dashed lines) with those of all commercial trawls (solid lines). Fishing years 1990–91 to 2004–2005 are shown in 5-year blocks, fishing years 2005–06 to 2008–09 are shown by year and, in the bottom panel, all 19 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.**

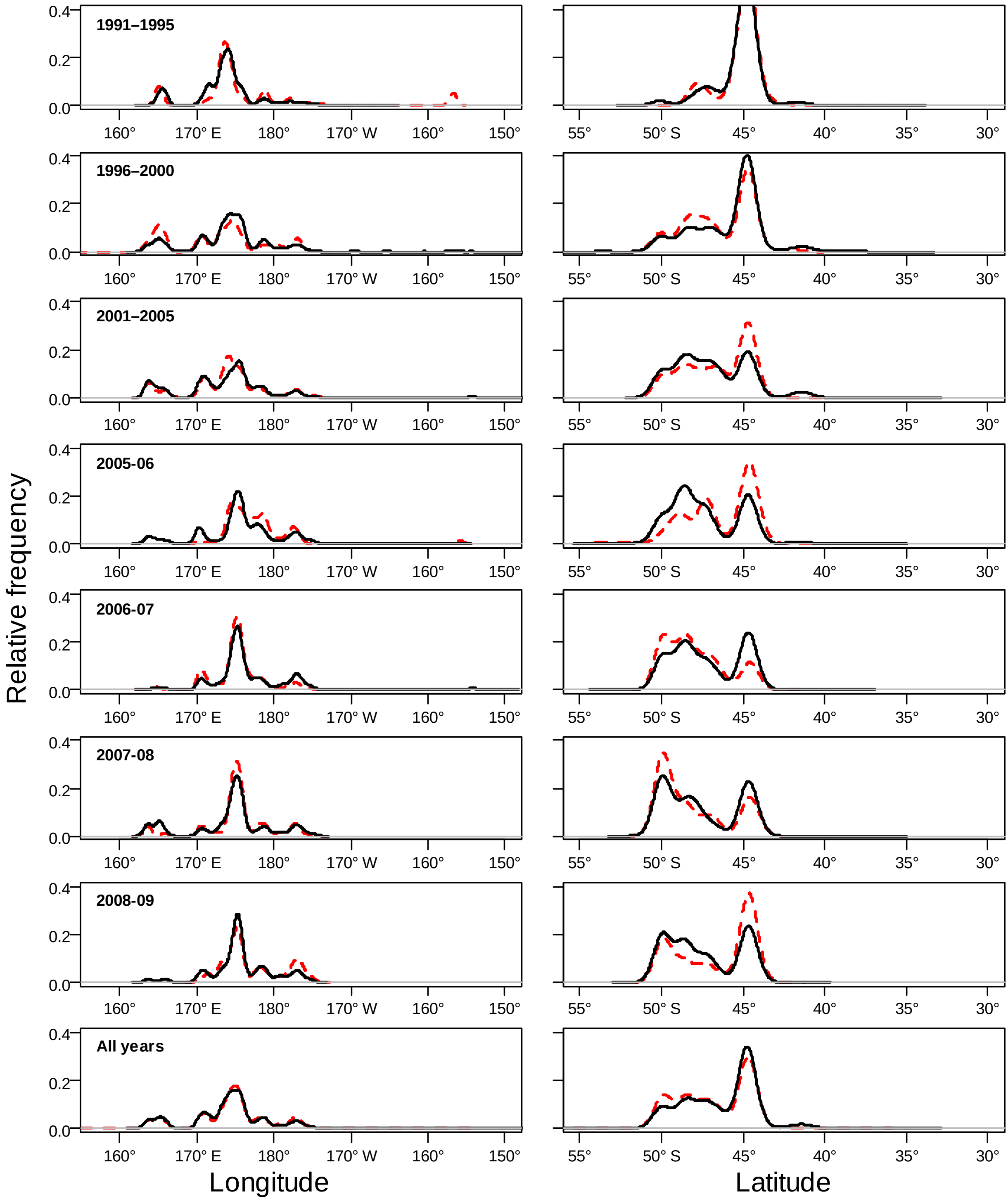



**Figure 6: Oreo roughy target fishery. Comparison of start positions (latitude and longitude) of observed trawls (dashed lines) with those of all commercial trawls (solid lines). Fishing years 1990–91 to 2004–2005 are shown in 5-year blocks, fishing years 2005–06 to 2008–09 are shown by year and, in the bottom panel, all 19 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.**

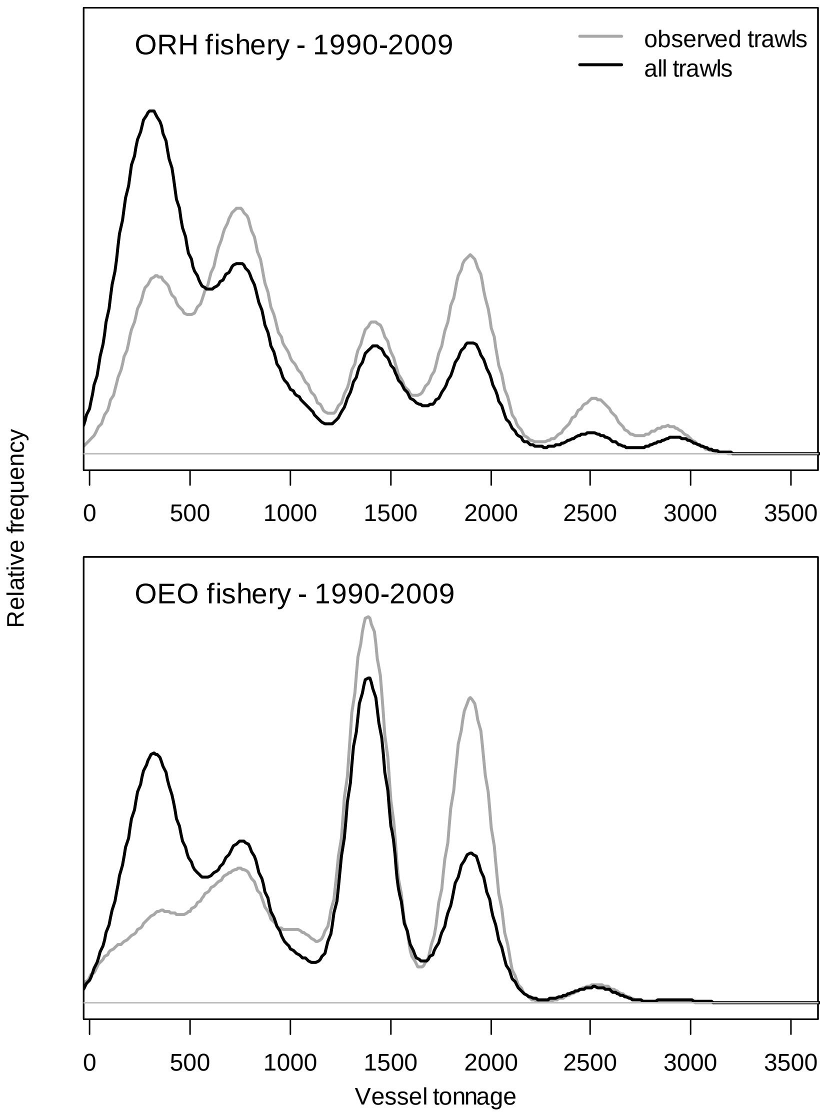



**Figure 7: Comparison of vessel sizes (gross registered tonnage) in observed trawls versus all recorded commercial trawls, by fishery, for the period 1 October 1990 to 30 September 2009. The relative frequency was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.**

The annual number of observed trawls in the orange roughy fishery ranged from 451 to 2233, but was over 1000 trawls in 14 of the 19 years (Table 3). The number of vessels observed in each year ranged from 8 to 23, with more vessels present in the fishery, and observed, in the 1990s than in the 2000s. During the 2005–06 to 2008–09 period (since the last review), between 10 and 12 vessels (30–60% of the fleet) were observed annually, together covering 33–54% of the total annual catch of orange roughy—more than at any time previously. The number of trips observed annually fluctuated over time, from 11 in the first year of the programme to 45 only three years later. Despite the much smaller size of the fishery since 2004–05, and the rapidly decreasing fleet size, the number of observed trips remained high, at 20–30 trips per year.

**Table 3: Summary of effort and estimated catch in the target trawl fishery for orange roughy, for observed trawls and overall, by fishing year. Trips were not exclusively for orange roughy; about a third of trips with some targeting of orange roughy also targeted oreo species on some trawls.**

| Fishing year | Number of trawls | | Number of vessels | | Number of trips | | Total orange roughy catch (t) | | Percentage observed (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | observed | all | observed | all | observed | all | observed | all | catch | trawls |
| 1990–91 | 460 | 6 967 | 9 | 49 | 11 | 487 | 3 973 | 30 991 | 12.8 | 6.6 |
| 1991–92 | 659 | 8 239 | 13 | 52 | 16 | 549 | 3 903 | 35 151 | 11.1 | 8.0 |
| 1992–93 | 2 209 | 11 182 | 23 | 63 | 40 | 579 | 5 957 | 33 256 | 17.9 | 19.8 |
| 1993–94 | 2 233 | 14 896 | 19 | 65 | 45 | 613 | 5 976 | 30 880 | 19.4 | 15.0 |
| 1994–95 | 1 676 | 15 493 | 19 | 64 | 31 | 637 | 4 838 | 33 381 | 14.5 | 10.8 |
| 1995–96 | 451 | 10 506 | 11 | 63 | 19 | 467 | 2 146 | 26 984 | 8.0 | 4.3 |
| 1996–97 | 1 110 | 8 827 | 12 | 57 | 18 | 431 | 2 616 | 17 146 | 15.3 | 12.6 |
| 1997–98 | 1 265 | 10 629 | 16 | 51 | 27 | 485 | 3 526 | 17 489 | 20.2 | 11.9 |
| 1998–99 | 1 067 | 11 558 | 17 | 61 | 26 | 521 | 2 183 | 19 555 | 11.2 | 9.2 |
| 1999–00 | 1 355 | 9 284 | 19 | 50 | 34 | 449 | 1 814 | 16 029 | 11.3 | 14.6 |
| 2000–01 | 797 | 6 718 | 9 | 45 | 16 | 274 | 1 713 | 13 860 | 12.4 | 11.9 |
| 2001–02 | 1 227 | 8 295 | 14 | 42 | 21 | 351 | 3 726 | 16 796 | 22.2 | 14.8 |
| 2002–03 | 1 272 | 7 990 | 16 | 44 | 22 | 342 | 4 027 | 16 134 | 25.0 | 15.9 |
| 2003–04 | 890 | 7 340 | 8 | 42 | 19 | 340 | 1 803 | 14 332 | 12.6 | 12.1 |
| 2004–05 | 1 132 | 7 223 | 10 | 40 | 17 | 339 | 4 747 | 16 169 | 29.4 | 15.7 |
| 2005–06 | 1 156 | 6 328 | 11 | 34 | 20 | 264 | 5 243 | 15 794 | 33.2 | 18.3 |
| 2006–07 | 1 153 | 4 651 | 12 | 28 | 30 | 209 | 6 374 | 13 521 | 47.1 | 24.8 |
| 2007–08 | 1 713 | 3 914 | 10 | 16 | 26 | 154 | 6 805 | 12 613 | 54.0 | 43.8 |
| 2008–09 | 1 881 | 4 192 | 10 | 17 | 24 | 167 | 5 911 | 11 186 | 52.8 | 44.9 |
| All years | 23 706 | 164 232 | 78 | 181 | 452 | 7 600 | 77 280 | 391 268 | 19.8 | 14.4 |

The annual number of observed trawls in the oreo fishery ranged from 30 in 1991–92 to 1006 in 2006–07 and the number of vessels observed ranged from 2 to 12 (Table 4). As for orange roughy, the level of coverage remained at a relatively consistent level over the past 12 years, despite a decrease in the total catch and effort. The observer coverage in this fishery was relatively low in the 1990s (in most years representing less than 10% of the total commercial catch), but since then was consistently over 15%, and in the years since the previous review (after 2001–02) coverage was higher than at any previous time—over 50% in 2008–09. As in the orange roughy fishery the fleet has shrunk in recent years and the remaining vessels are observed more regularly, with 30–60% of the fleet hosting observers annually since 2002–03.

The spread of observer effort throughout each fishing year was compared with the spread of total effort in each fishery by applying a density function to the numbers of trawls per day (Figures 8 & 9).

Commercial fishing in the orange roughy fishery occurred throughout the year over the entire 19-year period (Figure 8). Effort was consistently high during June and July (when orange roughy spawn), and this was usually followed by a tapering off of effort through to the end of the fishing year. There was also in most years a short period of low effort in late December. Although observer effort was also spread throughout the year, there were significant periods during most years when there was little or no observer coverage, e.g., 1991–92 and 2005–06, and in some years the observer coverage was compressed into short periods poorly related to the pattern of commercial effort, e.g., 1991–92 and 2003–04. In other years, however, e.g., 1993–94 and 2007–08, and overall, the spread of observer effort was very well matched to the spread of commercial effort.

**Table 4: Summary of effort and estimated catch in the target trawl fishery for oreos, for observed trawls and overall, by fishing year. Trips were not exclusively for oreos, about 90% of trips with some targeting of oreo species also targeted orange roughy on some trawls.**

| Fishing year | Number of trawls | | Number of vessels | | Number of trips | | Total oreo catch (t) | | Percentage observed (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | observed | all | observed | all | observed | all | observed | all | catch | trawls |
| 1990–91 | 237 | 2 622 | 7 | 32 | 7 | 115 | 943 | 13 732 | 6.9 | 9.0 |
| 1991–92 | 30 | 1 335 | 2 | 27 | 2 | 145 | 385 | 10 734 | 3.6 | 2.2 |
| 1992–93 | 53 | 2 095 | 2 | 28 | 2 | 138 | 455 | 12 298 | 3.7 | 2.5 |
| 1993–94 | 50 | 1 680 | 5 | 28 | 7 | 161 | 161 | 9 740 | 1.7 | 3.0 |
| 1994–95 | 207 | 1 925 | 6 | 32 | 8 | 130 | 1 041 | 9 519 | 10.9 | 10.8 |
| 1995–96 | 104 | 3 090 | 3 | 36 | 4 | 172 | 886 | 14 785 | 6.0 | 3.4 |
| 1996–97 | 152 | 3 484 | 6 | 35 | 7 | 196 | 955 | 14 472 | 6.6 | 4.4 |
| 1997–98 | 226 | 3 289 | 8 | 36 | 10 | 166 | 1 138 | 14 050 | 8.1 | 6.9 |
| 1998–99 | 300 | 3 678 | 7 | 35 | 9 | 178 | 1 670 | 16 563 | 10.1 | 8.2 |
| 1999–00 | 892 | 3 935 | 12 | 26 | 18 | 199 | 4 058 | 15 980 | 25.4 | 22.7 |
| 2000–01 | 551 | 3 510 | 7 | 22 | 13 | 171 | 2 718 | 16 524 | 16.4 | 15.7 |
| 2001–02 | 501 | 2 976 | 10 | 18 | 13 | 134 | 2 624 | 13 604 | 19.3 | 16.8 |
| 2002–03 | 287 | 2 832 | 7 | 18 | 8 | 136 | 2 225 | 11 834 | 18.8 | 10.1 |
| 2003–04 | 356 | 2 564 | 6 | 18 | 13 | 131 | 1 884 | 11 077 | 17.0 | 13.9 |
| 2004–05 | 431 | 2 687 | 8 | 25 | 13 | 135 | 2 845 | 12 517 | 22.7 | 16.0 |
| 2005–06 | 337 | 2 311 | 11 | 18 | 14 | 117 | 3 675 | 11 903 | 30.9 | 14.6 |
| 2006–07 | 1 006 | 2 293 | 8 | 16 | 14 | 97 | 6 374 | 12 302 | 51.8 | 43.9 |
| 2007–08 | 855 | 2 499 | 4 | 12 | 14 | 77 | 6 001 | 12 892 | 46.5 | 34.2 |
| 2008–09 | 654 | 2 167 | 6 | 10 | 12 | 72 | 4 994 | 12 576 | 39.7 | 30.2 |
| All years | 7 229 | 50 972 | 41 | 111 | 178 | 2615 | 45 032 | 247 102 | 18.2 | 14.2 |

Commercial fishing in the oreo fishery also took place throughout the year over the 19 years examined, but with a slightly different, and somewhat complementary, pattern to that of orange roughy (Figure 9). When vessels were focusing on the orange roughy spawning fisheries in June and July, targeting of oreos was very low, and after the orange roughy spawning period when effort in that fishery was tapering off, effort in the oreo fishery increased and was generally at its highest level between September and December. At other times of the year effort was variable, both within and between years. Observer effort was spread less evenly than in the orange roughy fishery, due mostly to the historically smaller size and wide temporal spread of the fishery. In most years, however, the important September–December period was well covered by observers and other times of the year were covered in an almost random fashion. For all years combined, the spread of observer effort closely matched the spread of commercial effort, with only slight undersampling between January and April, and slight oversampling in October and May.

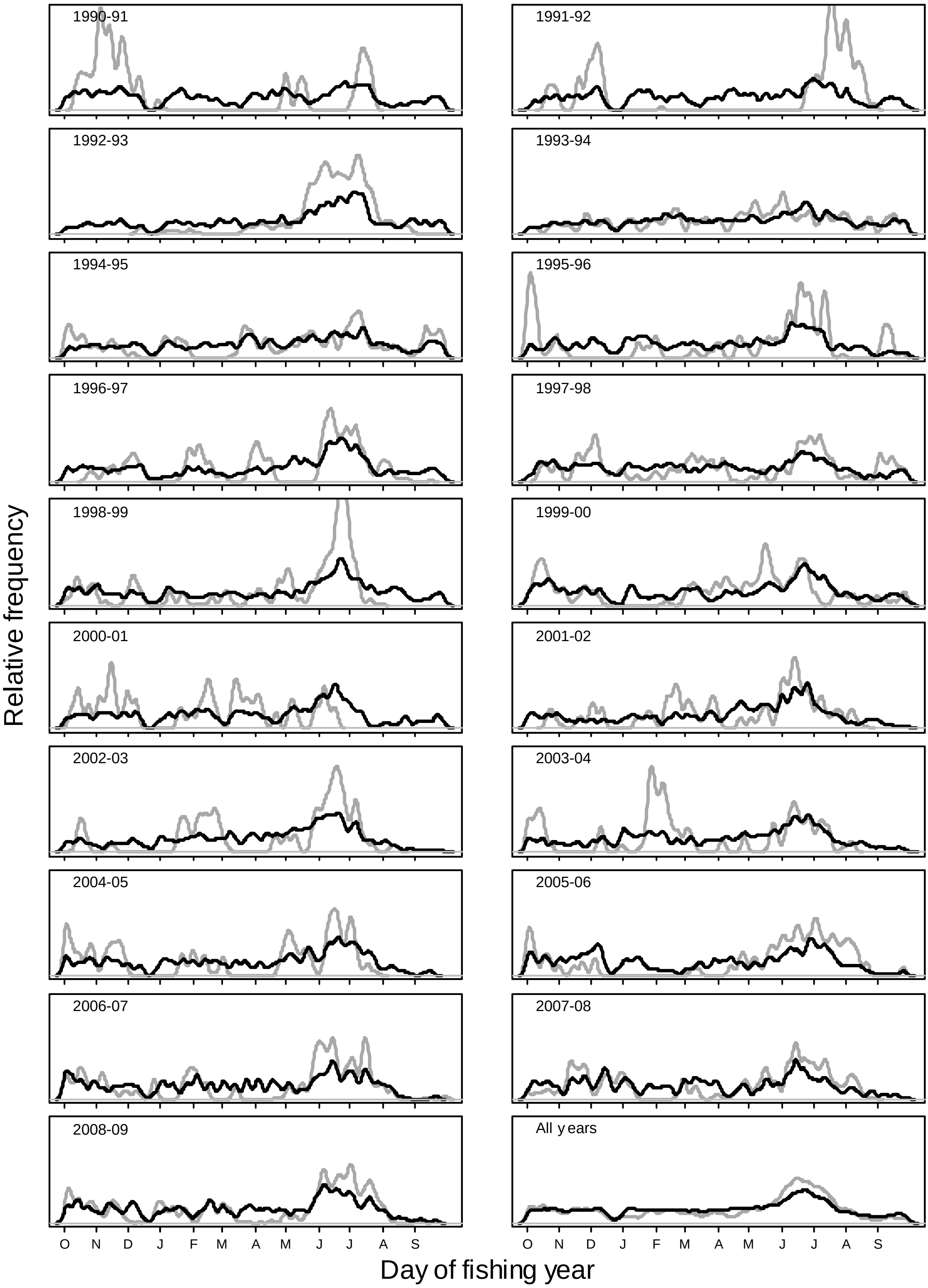



**Figure 8: Orange roughy fishery: Comparison of the temporal spread of observed trawls (grey) with all recorded commercial trawls (black lines) for 1990–91 to 2008–09, and for all fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation to estimate frequencies at a series of equally spaced points.**

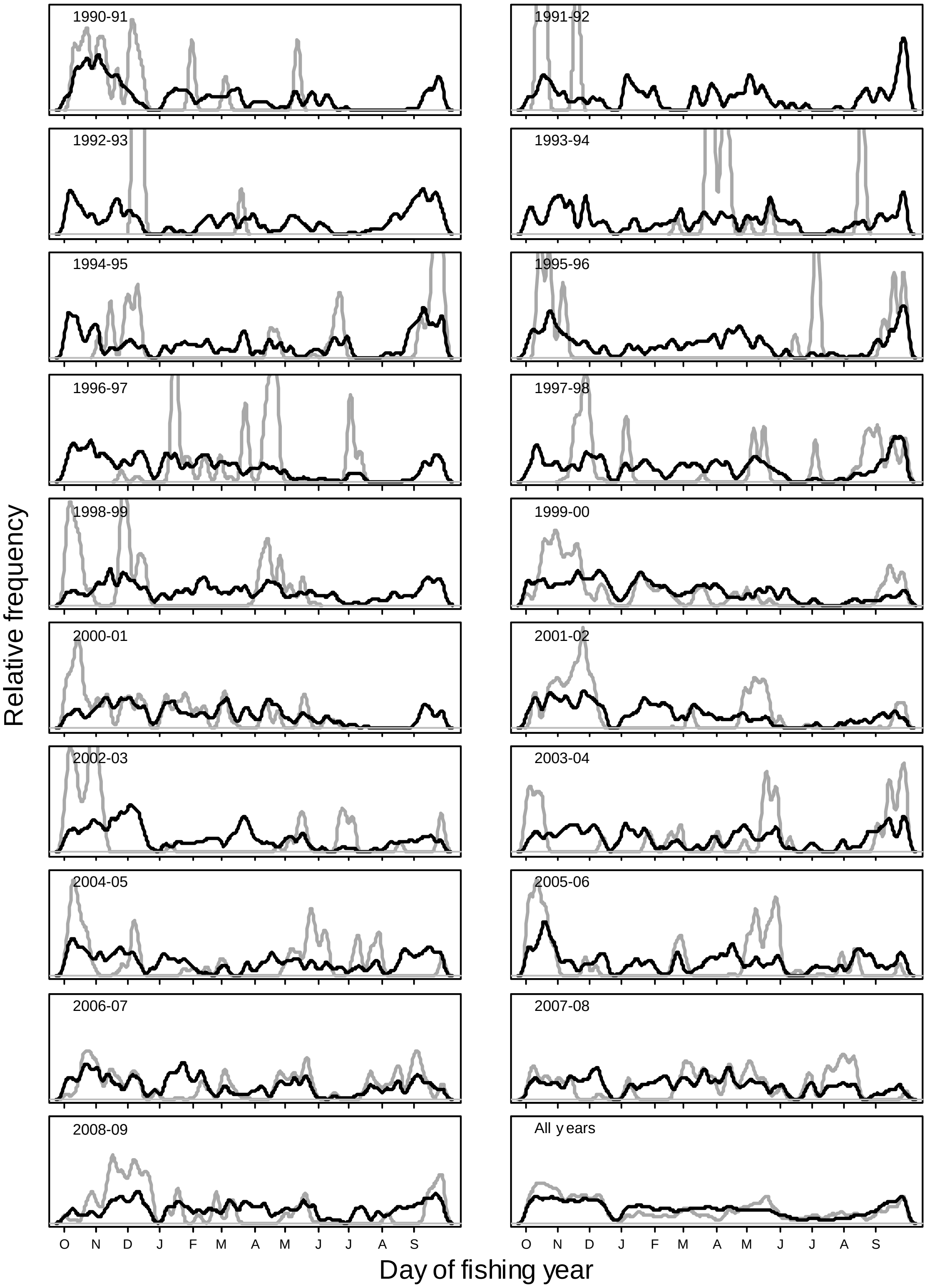



**Figure 9: OEO fishery: Comparison of the temporal spread of observed trawls (grey) with all recorded commercial trawls (black lines) for 1990–91 to 2008–09, and for all fishing years combined. The relative frequency of the numbers of trawls was calculated from a density function which used linear approximation 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 these fisheries (Anderson 2004a, 2009a), a trawl duration-based ratio estimator was used for calculations of bycatch and discards, after comparisons of bootstrap estimated c.v.s from various sets of trial data. In a more recent study, assessing bycatch and discards, in the hoki, hake, and ling trawl fisheries (Ballara et al. 2010), a "per trawl" ratio estimator was used after trials showed it to produce consistently lower c.v.s. This estimator was also trialled here for the orange roughy and oreo fisheries, along with the target species catch and trawl duration forms of the estimator. Although these trials resulted in very small c.v.s for each form of the estimator, the "per trawl" form produced slightly lower c.v.s overall for bycatch and very similar c.v.s overall to the trawl duration-based estimator for discards (Table 5). For this reason, and to enable a better examination of the effect of trawl duration on the level of bycatch, the "per trawl" form of the ratio estimator was selected for all discard and bycatch calculations.

**Table 5: Comparison of ratio estimators.**

| Bycatch/discards | Target fishery | Species category | Estimator | Bycatch ratio | c.v. (%) |
|---|---|---|---|---|---|
| Bycatch | ORH | COM | ORH+OEO catch | 0.470 | 0.82 |
| | ORH | COM | Trawl duration | 1358 | 1.69 |
| | ORH | COM | Catch per trawl | 2156 | 1.46 |
| | ORH | OTH | ORH+OEO catch | 0.039 | 1.78 |
| | ORH | OTH | Trawl duration | 112 | 1.70 |
| | ORH | OTH | Catch per trawl | 177 | 1.67 |
| | OEO | COM | ORH+OEO catch | 0.558 | 1.79 |
| | OEO | COM | Trawl duration | 1613 | 1.72 |
| | OEO | COM | Catch per trawl | 2560 | 1.51 |
| | OEO | OTH | ORH+OEO catch | 0.056 | 3.06 |
| | OEO | OTH | Trawl duration | 161 | 2.89 |
| | OEO | OTH | Catch per trawl | 255 | 2.92 |
| Discards | ORH | COM | ORH+OEO catch | 0.004 | 17.05 |
| | ORH | COM | Trawl duration | 9.2 | 17.37 |
| | ORH | COM | Catch per trawl | 17.1 | 17.32 |
| | ORH | OTH | ORH+OEO catch | 0.041 | 2.57 |
| | ORH | OTH | Trawl duration | 103.2 | 2.50 |
| | ORH | OTH | Catch per trawl | 192.9 | 2.50 |
| | OEO | COM | ORH+OEO catch | 0.002 | 24.03 |
| | OEO | COM | Trawl duration | 5.0 | 23.40 |
| | OEO | COM | Catch per trawl | 9.3 | 23.67 |
| | OEO | OTH | ORH+OEO catch | 0.041 | 2.62 |
| | OEO | OTH | Trawl duration | 104.0 | 2.49 |
| | OEO | OTH | Catch per trawl | 194.4 | 2.49 |

## 3.3 Bycatch data

### 3.3.1 Overview of raw bycatch data

#### Orange roughy fishery

Orange roughy accounted for about 84% of the total estimated catch from all observed trawls targeting orange roughy since 1 October 2005. Much of the remainder of the total catch (about 10%) comprised oreo species: mainly smooth oreo (8%), and black oreo (2.1%). Rattails (various species, 0.8%) and shovelnose spiny dogfish (*Deania calcea*, 0.6%) were the species most adversely affected by this fishery, with over 90% discarded. Other species frequently caught and usually discarded included deepwater dogfishes (family Squalidae), especially *Etmopterus* species, the most common of which is likely to have been Baxter's dogfish (*E. baxteri*), slickheads, and morid cods, especially Johnson's cod (*Halargyreus johnsonii*) and ribaldo.

Over 250 species or species groups were identified as bycatch by observers in the orange roughy target fishery, most being non-commercial species, including invertebrate species, caught in low numbers. Squid (mostly warty squid, *Moroteuthis* spp.) were the largest component of invertebrate catch, followed by various groups of coral, echinoderms (mainly starfish), and crustaceans (mainly king crabs, family Lithodidae). Many invertebrates, in particular corals, echinoderms, and crustaceans, were identified to species, especially in the more recent records, indicating the influence and success of the improved invertebrate identification guides (e.g. Tracey et al. 2007) which have become available to observers (see Appendix 1 for a list of the main observed bycatch species).

Commercial catch reporting (based on the top five species caught in each trawl) indicated that orange roughy accounted for a similar fraction (79%) of the total catch to that calculated from observer records (see Appendix 3). The most commonly caught bycatch species were mostly the same set of species recorded by observers, with smooth oreo comprising 8% of the total catch (compared with 15% from observer data), followed by black oreo (about 2% in both summaries), then deepwater dogfish, rattails, and hoki. Differences between observers and skippers in the level to which rattails, dogfish, and morid cods were identified makes exact comparisons of bycatch percentages for species within these groups difficult, but overall these groups were all well represented near the top of both lists of bycatch species. Although observer catch records are likely to be more accurate (and take into account all species caught from each trawl), commercial records are available for the entire fishery and potentially (depending on the degree of under-reporting of bycatch, see Section 2.2) can better reflect the total catch of at least the commercially valuable quota species that are frequently in the top five species by weight in the trawls.

#### Oreo fishery

Oreo species accounted for about 92% of the total estimated catch from all observed trawls targeting oreos since 1 October 2002. Orange roughy (3.5%) accounted for most of the remainder, with no other species or group of species accounting for more than 0.6% of the total catch. Hoki were the next most common bycatch species, followed by the usually discarded rattails, deepwater dogfish (especially Baxter's dogfish and seal shark (*Dalatias licha*)), slickheads, and basketwork eel (*Diastobranchus capensis*). Ling were also frequently caught, comprising about a quarter of a percent of the total catch.

As in the orange roughy fishery, over 250 species or species groups were identified by observers in the oreo target fishery, including numerous invertebrates. Corals, squids and octopuses, king crabs, and echinoderms were again the main groups caught. Coral, in particular, was a substantial part of the bycatch, accounting for almost 0.4% of the total catch in this fishery (see Appendix 2 for a list of the main observed bycatch species).

Commercial catch records showed that the main catch species, smooth and black oreo, orange roughy, and hoki, each accounted for a very similar fraction of the total catch to that calculated from the observed portion of the fishery records (see Appendix 4). This similarity of bycatch provides some further reassurance that the observer coverage was representative of the fishery as a whole. As in the orange roughy fishery, and the observed oreo fishery, the next most commonly recorded species were rattails and dogfishes, identified to various levels of taxonomic precision. Slickheads were also commonly recorded (about 0.1% of the total catch in both data sets), as were morid cods (including grenadier cod (*Tripterophycis gilchristi*) and Johnson's cod (*Halargyreus johnsonii*)), hake, basketwork eel, ghost sharks/chimaeras, and warty squid (*Moroteuthis* spp.).

### Orange roughy and oreo fishery combined

Exploratory plots were prepared to examine total bycatch per trawl (plotted on a log scale) with respect to the available variables (Figure 10). Because of the similarity of the orange roughy and oreo fisheries in terms of vessels, depth, location, timing, etc, initial plots made for each fishery separately showed similar results and so combined plots are presented, with target species examined as a variable.

Total bycatch was highly variable between trawls, ranging from 0 to 75 t. Total bycatch per trawl increased with increasing trawl duration, from about 55 kg per trawl for trawls less than 1 h to about 450 kg per trawl for trawls of about 8 h duration (less than 4% of trawls were longer than 8 h).

Trawling was mostly at bottom depths of 800–1200 m but some trawls were shallower than 600 m and some deeper than 1400 m. Total bycatch decreased very slightly with increasing bottom depth, from about 105 kg per trawl at 700 m to about 88 kg per trawl at 1300 m. There were large differences in bycatch between the 59 vessels represented by more than 50 records, with medians ranging from about 25 kg per trawl to about 600 kg per trawl. There was no overall trend in bycatch with fishing year, with medians fluctuating between about 60 kg per trawl (in 1995–96) and 120 kg per trawl (in 2000–01). There were some large differences in bycatch levels between the 17 areas examined, although the extreme high values shown for areas KAIK (Kaikoura) and COOK (Cook Canyon) were based on a relatively small number of records. In areas represented by larger numbers of trawls, median bycatch was lowest in LOUI (Louisville Ridge) (30 kg per trawl) and QMA ORH 1 (44 kg per trawl), and highest on the north Chatham Rise in NECR (200 kg per trawl) and NWCR (174 kg per trawl). There were only small variations in bycatch between months, although low median values in July and August were followed by slowly increasing values in successive months until March. The great majority of records come from domestic vessels, and the few records from vessels of other nations showed generally higher levels of bycatch, with the exception of NZKOR (combined New Zealand and Korean crew) with a median bycatch of about 27 kg per trawl. Target species had little influence on bycatch, with very similar medians shown for all four target species codes.

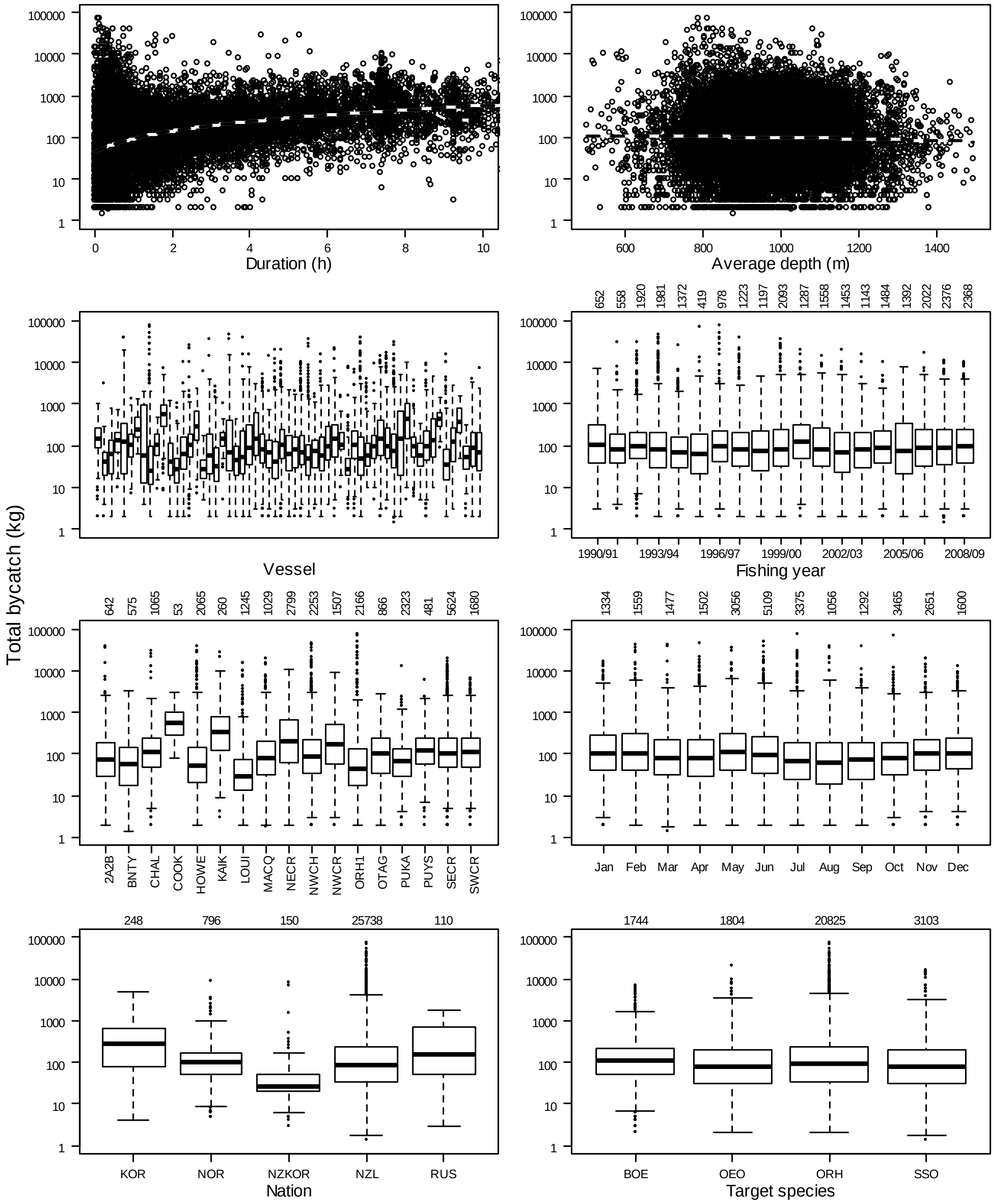



**Figure 10: Total bycatch (all species excluding oreos and orange roughy) per trawl plotted against selected variables in the combined orange roughy and oreo target fisheries. Total bycatch is plotted on a log scale. The dashed lines in the top panel represent mean fits (using a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. The numbers above each plot indicate the number of records associated with that level of the variable: vessels represented by fewer than 50 records, and nations represented by fewer than 100 records, were not plotted. In the vessel plot, vessels are ordered by size, from shortest to longest. Average depth is the average of the start and finish gear depth. KOR, Korea; NOR, Norway; NZKOR, combined New Zealand and Korean; NZL, New Zealand; RUS, Russia. See Figure 1 for area codes.**

### 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. Because there was a significant fraction of trawls with no bycatch in each species group, both linear and binomial models were constructed to enable the identification of factors affecting both the level and likelihood of bycatch of the species.

In the orange roughy target fishery, the variables *duration* and *subarea* were the most influential overall in both the normal and binomial models of COM, OTH, and QMS species bycatch, although *depth* was also influential in the QMS models (Table 6). The variable *fday* was the only other factor with a consistent, if minor, influence in the models.

In the oreo target fishery, *duration* was selected first in five of the six models for COM, OTH, and QMS species, with *subarea* selected first in the normal model for COM species (Table 7). The variable *depth* was also influential in all but the OTH binomial model, and *fday* had a minor influence again, but not in the OTH species models.

The consistent selection of *duration* in the normal models shows that bycatch tends to increase with increasing trawl duration. This is to be expected in trawls when fishing on longer, planned or random trawl-lines within a fishery area which would be likely to accumulate non-target species along with the species of interest, but not necessarily when fishing operations target aggregations on seamounts, hills, or other features. Even less surprising is the result that the *probability* of catching some bycatch species increases strongly with trawl duration, as shown by the primary position of *duration* in all binomial models except that for orange roughy COM species.

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

**Table 6: Summary of LME modelling of bycatch in the orange roughy trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year.**

| Species cat. | Model type | Variable | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *duration* | *subarea* | *depth* | *fyr* | *fday* | *nation* | *tonnage* |
| COM | Normal | 3 | 1 | 4 | 2 | 6 | – | 5 |
| COM | Binomial | 2 | 1 | 3 | – | 4 | – | – |
| OTH | Normal | 1 | 2 | 5 | – | 3 | 6 | 4 |
| OTH | Binomial | 1 | – | 2 | 3 | 4 | – | – |
| QMS | Normal | 2 | 3 | 1 | – | 6 | 5 | 4 |
| QMS | Binomial | 1 | 3 | 2 | 4 | – | – | – |

**Table 7: Summary of LME modelling of bycatch in the oreo trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year.**

| Species cat. | Model type | Variable | | | | | |
|---|---|---|---|---|---|---|---|
| | | *duration* | *subarea* | *depth* | *fday* | *nation* | *tonnage* |
| COM | Normal | 3 | 1 | 2 | 4 | 6 | 5 |
| COM | Binomial | 1 | 3 | 2 | 4 | – | – |
| OTH | Normal | 1 | 2 | 3 | – | – | – |
| OTH | Binomial | 1 | 2 | – | – | – | – |
| QMS | Normal | 1 | 3 | 2 | 5 | 6 | 4 |
| QMS | Binomial | 1 | 2 | 3 | 4 | – | – |

## 3.4 Estimation of bycatch

### 3.4.1 Bycatch rates

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

As well as providing the basis from which total bycatch can be determined from target fishery effort totals, these ratios also indicate how the catch rates of each species group vary by trawl duration (Tables 8 & 9).

In the orange roughy fishery, median bycatch rates of COM species were higher in the shorter duration category in each year (Table 8). This is likely to be due to the influence of numbers of short trawls targeting a mark on the ships echo sounder which turned out to be a commercial species other than that recorded as being targeted. A similar result was reported in the southern blue whiting fishery (Anderson 2009b). For OTH species and, to a lesser extent QMS species, longer trawls produced more bycatch in most years than medium or short duration trawls. This is the expected result for species categories made up of a variety of species caught in generally smaller amounts.

In the oreo fishery, median bycatch rates of COM species were variable between years but overall were similar for long and short trawls, and lower for medium duration trawls (Table 9). For OTH species, long trawls generally had higher rates of bycatch than medium duration trawls, and short trawls had the lowest rates. There were few records in some years in the long and short trawl duration classes for COM and OTH species (and in all years for QMS species) and in these cases rates based on data from all years were applied and therefore no comment can be made about temporal variation. The overall rates calculated for QMS species show greater median bycatch rates for longer trawls than for medium or short duration trawls.

**Table 8: Bycatch rates (kg/trawl) of commercial (COM), non-commercial (OTH), and QMS fish species in the orange roughy trawl fishery, by trawl duration category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.**

| | COM | | OTH | | | QMS | | |
|---|---|---|---|---|---|---|---|---|
| Fishing year | long (>0.9 h) | short (<0.9 h) | long (>6.4 h) | medium (0.3–6.4 h) | short (<0.3 h) | long (>2.7 h) | medium (0.4–2.7 h) | short (<0.4 h) |
| 1990–91 | 1 868 | 3 388 | 310 | 117 | 446 | 162 | 146 | 1 |
| 1991–92 | 1 486 | 3 224 | 110 | 122 | 76 | 313 | 182 | 28 |
| 1992–93 | 221 | 1 256 | 153 | 66 | 97 | 154 | 128 | 259 |
| 1993–94 | 899 | 1 832 | 261 | 92 | 73 | 324 | 322 | 264 |
| 1994–95 | 899 | 1 178 | 283 | 103 | 61 | 114 | 27 | 17 |
| 1995–96 | 1 018 | 1 320 | 102 | 71 | 33 | 227 | 60 | 635 |
| 1996–97 | 715 | 2 487 | 352 | 120 | 154 | 69 | 183 | 457 |
| 1997–98 | 474 | 1 669 | 316 | 98 | 199 | 166 | 153 | 105 |
| 1998–99 | 129 | 664 | 424 | 129 | 72 | 68 | 68 | 26 |
| 1999–00 | 281 | 627 | 704 | 138 | 57 | 79 | 160 | 241 |
| 2000–01 | 505 | 1 236 | 885 | 197 | 408 | 209 | 112 | 40 |
| 2001–02 | 225 | 377 | 997 | 115 | 66 | 94 | 19 | 26 |
| 2002–03 | 189 | 521 | 646 | 121 | 89 | 93 | 34 | 36 |
| 2003–04 | 255 | 869 | 603 | 175 | 133 | 99 | 39 | 13 |
| 2004–05 | 205 | 915 | 778 | 178 | 156 | 58 | 33 | 22 |
| 2005–06 | 346 | 408 | 1 034 | 143 | 32 | 141 | 19 | 26 |
| 2006–07 | 229 | 319 | 745 | 169 | 77 | 154 | 41 | 23 |
| 2007–08 | 483 | 687 | 1 576 | 150 | 114 | 108 | 72 | 18 |
| 2008–09 | 564 | 735 | 1 314 | 171 | 58 | 195 | 82 | 33 |

**Table 9: Bycatch rates (kg/trawl) of commercial (COM), non-commercial (OTH), and QMS fish species in the oreo trawl fishery, by trawl duration category and fishing year, based on observed catch data. Bycatch rates are the median of the bootstrap sample of 1000, rounded to the nearest whole number.**

| | COM | | | OTH | | | *QMS | | |
|---|---|---|---|---|---|---|---|---|---|
| Fishing year | long (>3.0 h) | medium (0.4–3.0 h) | short (<0.4 h) | long (>2.6 h) | medium (0.3–2.6 h) | short (<0.3 h) | long (<1.9 h) | medium (1.9–6.4 h) | short (<1.9 h) |
| 1990–91 | 217 | 84 | 817 | 590 | 101 | 76 | 330 | 96 | 10 |
| 1991–92 | *240 | *130 | 238 | *350 | *152 | *130 | 330 | 96 | 10 |
| 1992–93 | *240 | *130 | 238 | *350 | *152 | *130 | 330 | 96 | 10 |
| 1993–94 | *240 | *130 | 238 | *350 | *152 | *130 | 330 | 96 | 10 |
| 1994–95 | 216 | 71 | 35 | 119 | 86 | 38 | 330 | 96 | 10 |
| 1995–96 | *240 | *130 | 238 | *350 | *152 | *130 | 330 | 96 | 10 |
| 1996–97 | 29 | 153 | 125 | 179 | 88 | 30 | 330 | 96 | 10 |
| 1997–98 | 123 | 377 | 47 | 238 | 394 | 307 | 330 | 96 | 10 |
| 1998–99 | 150 | 273 | 752 | 361 | 123 | 83 | 330 | 96 | 10 |
| 1999–00 | 236 | 134 | 29 | 304 | 161 | 298 | 330 | 96 | 10 |
| 2000–01 | 674 | 39 | 24 | 265 | 111 | 40 | 330 | 96 | 10 |
| 2001–02 | 293 | 47 | 138 | 250 | 251 | 109 | 330 | 96 | 10 |
| 2002–03 | 540 | 488 | 165 | 497 | 221 | 396 | 330 | 96 | 10 |
| 2003–04 | 104 | 129 | 184 | 335 | 85 | 55 | 330 | 96 | 10 |
| 2004–05 | 50 | 212 | 282 | 368 | 123 | 72 | 330 | 96 | 10 |
| 2005–06 | 272 | 253 | 72 | 582 | 196 | 54 | 330 | 96 | 10 |
| 2006–07 | 48 | 70 | 238 | 237 | 115 | 64 | 330 | 96 | 10 |
| 2007–08 | 31 | 47 | 61 | 486 | 133 | 48 | 330 | 96 | 10 |
| 2008–09 | 245 | 115 | 645 | 636 | 178 | 80 | 330 | 96 | 10 |

* Due to insufficient records, bycatch rates in these cases were based on bycatch data from all years

### 3.4.2 Annual bycatch levels

Annual bycatch was estimated from observer data by multiplying the ratios calculated for each duration and year stratum by the number of trawls in the target fishery for the equivalent stratum, as described in Section 2.4, and precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Tables 10 & 11, Figures 11 & 12).

In the orange roughy fishery, the annual bycatch of commercial species (COM) peaked at 21 000 t in 1993–94 and has decreased considerably since then, alongside decreasing total landings of orange roughy. Bycatch of COM species in the four years since the last review was at a lower level than in any previous period, but has shown an increase in the two years since the low in 2006–07 (Table 10). In contrast, the bycatch of non-commercial species (OTH) remained relatively constant between 1990–91 and 2004–05 at 1000–1500 t in most years. Only in the last four years has there been consistently lower bycatch of OTH species, but this decrease has been considerable, dropping to an estimated 490 t in 2008–09. The bycatch of QMS species fluctuated considerably between years, most likely due to occasional large catches of oreos or other deepwater quota species, but decreased after 1999–2000 and has remained relatively steady at about 160–420 t over the last eight years. Total bycatch is composed mostly of COM species and so follows a similar pattern of high levels (16 000–27 000 t per year) before 1998–99, and decreasing levels since then, in line with decreasing orange roughy landings (Figure 11). Total bycatch has been stable at 2300–3700 t per year in the four years since the last review. Estimates of total bycatch from the two previous reviews were lower than the current estimates for the first six years of the period with updated estimates, and higher for the subsequent nine years. In a few years these differences are large (e.g., 1990–91) but in all other years the confidence intervals strongly overlap, and generally the scale and trend of the estimates is similar. The difference in estimates between studies is not surprising given the different ratio estimator and stratification used, and the revised methods for estimating variance are evident in the generally wider confidence intervals for the latest estimates compared to previous estimates when they were not used (pre-1999–2000). The current estimates of bycatch are more similar to the earlier estimates in the COM category, especially for the 1998–99 to 2004–05 period, when the earlier estimates in the OTH were less similar to recent estimates. Estimates of OTH bycatch otherwise varied little between studies.

In the oreo fishery, bycatch of COM and OTH species have generally been at a similar level, and have remained relatively stable over time (Table 11). In most years since 1990–91 COM bycatch has been between 130 t and 840 t per year, with a maximum (in 1998–99) of 1760 t, although in the two most recent years examined, it increased from 140 t to 1000 t. Similarly, bycatch of OTH species was between 140 t and 890 t in most years, with only one year (1997–98) outside this range. Bycatch of OTH species has been stable at 240–400 t per year in the last four years. Bycatch of QMS species was considerably lower than that of COM species and OTH species in every year, ranging from a low of 40 t per year in 1991–92 and in the two most recent years, to 120 t per year in 1999–2000. Total bycatch in the oreo fishery has fluctuated over time with higher levels occurring in the middle of the period (at the end of the 1990s) but no clear trend outside of this period. The decrease in landings of oreos since the peak in 1996–97 is only weakly matched by decreasing total bycatch (Figure 12). Estimates of total bycatch from the previous review were similar to current estimates for most years, with the confidence intervals generally overlapping strongly, although not at all for 1994–95 or 2000–01. The same pattern can be seen for COM and OTH species separately.

**Table 10: Estimates of total annual bycatch (rounded to the nearest 10 t) in the orange roughy trawl fishery for the species categories COM, OTH, QMS, and overall, based on observed catch rates, 95% confidence intervals in parentheses.**

| | COM | | OTH | | QMS | | Total bycatch | |
|---|---|---|---|---|---|---|---|---|
| 1990–91 | 18 270 | (14 010–24 090) | 1 400 | (930–1 900) | 780 | (420–1 280) | 20 450 | (15 360–27 270) |
| 1991–92 | 20 010 | (13 740–27 310) | 920 | (680–1 160) | 1 320 | (210–2 640) | 22 250 | (14 630–31 110) |
| 1992–93 | 8 730 | (3 390–17 950) | 860 | (570–1 190) | 2 060 | (890–3 650) | 11 650 | (4 850–22 790) |
| 1993–94 | 21 090 | (15 040–27 800) | 1 320 | (940–1 840) | 4 810 | (2 140–7 730) | 27 220 | (18 120–37 370) |
| 1994–95 | 16 900 | (10 360–23 660) | 1 420 | (1 160–1 750) | 620 | (230–1 440) | 18 940 | (11 750–26 850) |
| 1995–96 | 13 350 | (5 910–23 330) | 630 | (310–1 000) | 3 960 | (430–10 510) | 17 940 | (6 650–34 840) |
| 1996–97 | 17 460 | (10 050–25 160) | 1 240 | (760–1 830) | 3 180 | (570–6 960) | 21 880 | (11 380–33 950) |
| 1997–98 | 13 330 | (8 820–19 020) | 1 520 | (880–2 430) | 1 650 | (620–3 160) | 16 500 | (10 320–24 610) |
| 1998–99 | 5 140 | (2 370–9 550) | 1 440 | (900–2 040) | 630 | (410–900) | 7 210 | (3 680–12 490) |
| 1999–00 | 4 880 | (2 530–7 700) | 1 170 | (830–1 590) | 1 770 | (500–3 630) | 7 820 | (3 860–12 920) |
| 2000–01 | 6 430 | (3 630–9 930) | 2 080 | (1 150–3 640) | 710 | (330–1 080) | 9 220 | (5 110–14 650) |
| 2001–02 | 2 650 | (1 400–3 960) | 1 210 | (860–1 620) | 390 | (270–530) | 4 250 | (2 530–6 110) |
| 2002–03 | 3 300 | (1 650–5 250) | 1 130 | (810–1 500) | 420 | (270–630) | 4 850 | (2 730–7 380) |
| 2003–04 | 4 820 | (2 690–7 080) | 1 290 | (890–2 010) | 290 | (150–410) | 6 400 | (3 730–9 500) |
| 2004–05 | 4 530 | (3 510–5 930) | 1 380 | (1 160–1 740) | 250 | (180–350) | 6 160 | (4 850–8 020) |
| 2005–06 | 2 500 | (1 280–3 930) | 790 | (510–1 070) | 330 | (200–560) | 3 620 | (1 990–5 560) |
| 2006–07 | 1 400 | (500–2 700) | 660 | (410–1 000) | 240 | (150–350) | 2 300 | (1 060–4 050) |
| 2007–08 | 2 630 | (1 510–4 330) | 530 | (400–690) | 160 | (130–190) | 3 320 | (2 040–5 210) |
| 2008–09 | 2 940 | (1 420–4 820) | 490 | (390–600) | 300 | (210–440) | 3 730 | (2 020–5 860) |

**Table 11: Estimates of total annual bycatch (rounded to the nearest 10 t) in the oreo trawl fishery for the species categories COM, OTH, QMS, and overall, based on observed catch rates, 95% confidence intervals in parentheses.**

| | COM | | OTH | | QMS | | Total bycatch | |
|---|---|---|---|---|---|---|---|---|
| 1990–91 | 1 200 | (790–1 580) | 400 | (250–580) | 70 | (50–100) | 1 600 | (1 040–2 160) |
| 1991–92 | 250 | (170–360) | 230 | (200–270) | 40 | (30–60) | 480 | (370–630) |
| 1992–93 | 390 | (250–610) | 340 | (280–410) | 60 | (40–90) | 730 | (530–1 020) |
| 1993–94 | 310 | (220–440) | 320 | (280–370) | 60 | (40–90) | 630 | (500–810) |
| 1994–95 | 130 | (50–260) | 140 | (100–220) | 50 | (40–80) | 270 | (150–480) |
| 1995–96 | 580 | (380–900) | 510 | (430–610) | 80 | (50–110) | 1 090 | (810–1 510) |
| 1996–97 | 470 | (190–850) | 280 | (220–410) | 100 | (70–150) | 750 | (410–1 260) |
| 1997–98 | 620 | (290–1 080) | 1 360 | (460–2 760) | 70 | (50–110) | 1 980 | (750–3 840) |
| 1998–99 | 1 760 | (410–4 140) | 500 | (330–680) | 110 | (80–150) | 2 260 | (740–4 820) |
| 1999–00 | 390 | (240–630) | 890 | (540–1 340) | 120 | (90–170) | 1 280 | (780–1 970) |
| 2000–01 | 250 | (150–380) | 320 | (290–360) | 70 | (50–110) | 570 | (440–740) |
| 2001–02 | 350 | (140–700) | 570 | (390–810) | 70 | (50–110) | 920 | (530–1 510) |
| 2002–03 | 840 | (430–1 410) | 890 | (450–1 690) | 50 | (30–80) | 1 730 | (880–3 100) |
| 2003–04 | 440 | (120–940) | 230 | (170–300) | 60 | (40–90) | 670 | (290–1 240) |
| 2004–05 | 670 | (120–1 450) | 350 | (220–480) | 70 | (50–100) | 1 020 | (340–1 930) |
| 2005–06 | 400 | (180–720) | 400 | (310–520) | 60 | (40–80) | 800 | (490–1 240) |
| 2006–07 | 480 | (100–1 110) | 240 | (200–270) | 50 | (30–80) | 720 | (300–1 380) |
| 2007–08 | 140 | (70–260) | 260 | (240–300) | 40 | (20–70) | 400 | (310–560) |
| 2008–09 | 1 000 | (160–2 010) | 350 | (300–390) | 40 | (20–60) | 1 350 | (460–2 400) |

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 lower than the observer data-based estimate in all but two years in the orange roughy fishery (Table 12). Before 1998–99 this direct estimate was generally less than half of the observer data-based estimate, but since then the two estimates have become closer, and in five of the most recent eight years they were within about 10% of each other. In the oreo fishery, however, the direct estimate has been much more variable, and in many years was either considerably less than or considerably greater than the observer data-based estimate. Again this estimate generally improved over time, with similar values in some of the more recent years (but not 2008–09), but in general it seems to be a less reliable alternative estimate than in the orange roughy fishery. This may be due to discrepancies between vessel and observer recording of target species, especially if the discrepancy is due to a large catch of, e.g., orange roughy when nominally targeting oreos.

**Table 12: Total annual bycatch estimates for the orange roughy and oreo fisheries, based on catch effort records. Estimates are derived by summing the difference between TCEPR records of total catch and target species catch for each trawl (TCE) or group of trawls (CEL).**

| Fishing | Orange roughy | | Oreos | |
|---|---|---|---|---|
| year | Bycatch (t) | % of observer-based estimate | Bycatch (t) | % of observer-based estimate |
| 1990–91 | 6 674 | 33 | 1 927 | 120 |
| 1991–92 | 10 139 | 46 | 1 320 | 275 |
| 1992–93 | 10 065 | 86 | 1 481 | 203 |
| 1993–94 | 15 337 | 56 | 249 | 40 |
| 1994–95 | 9 079 | 48 | 941 | 349 |
| 1995–96 | 8 191 | 46 | 1 045 | 96 |
| 1996–97 | 8 893 | 41 | 709 | 95 |
| 1997–98 | 7 975 | 48 | 956 | 48 |
| 1998–99 | 5 443 | 75 | 1 448 | 64 |
| 1999–00 | 4 588 | 59 | 1 019 | 80 |
| 2000–01 | 4 866 | 53 | 807 | 142 |
| 2001–02 | 4 074 | 96 | 686 | 75 |
| 2002–03 | 4 441 | 92 | 565 | 33 |
| 2003–04 | 4 572 | 71 | 544 | 81 |
| 2004–05 | 4 043 | 66 | 1 013 | 99 |
| 2005–06 | 3 985 | 110 | 744 | 93 |
| 2006–07 | 3 246 | 141 | 874 | 121 |
| 2007–08 | 3 137 | 94 | 508 | 127 |
| 2008–09 | 3 407 | 91 | 527 | 39 |

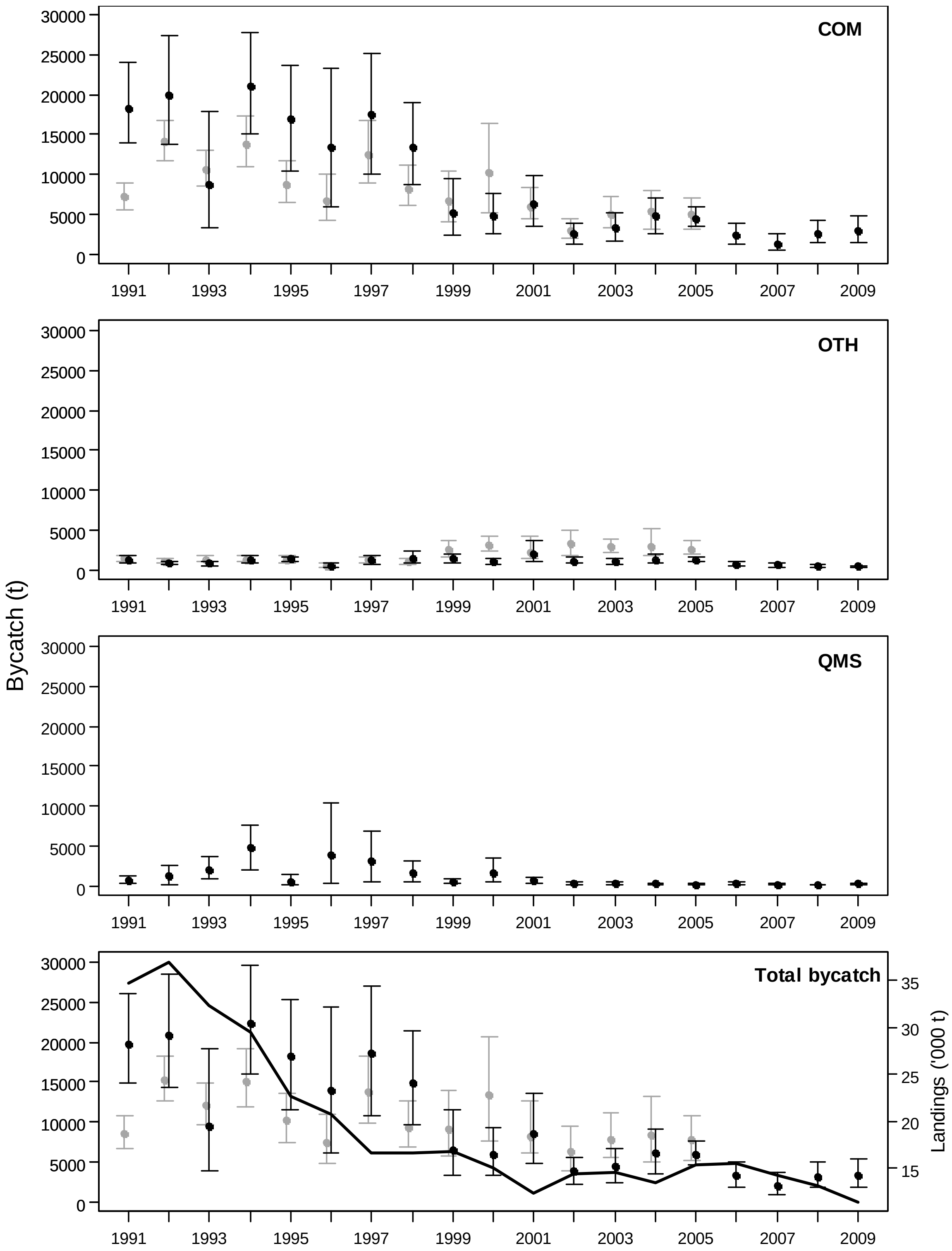



**Figure 11: Annual estimates of fish bycatch in the orange roughy trawl fishery, calculated for commercial species (COM), non-commercial species (OTH), QMS species, and overall for 1990–91 to 2008–09 (black points). Also shown (grey points) are estimates of bycatch in each category (excluding QMS) calculated for 1990–91 to 2004–05 (Anderson et al. 2001, Anderson 2009a). Error bars show the 95% confidence intervals. The black line in the bottom panel shows the total annual estimated landings of orange roughy (O. Anderson & M. Dunn (NIWA), unpublished data).**

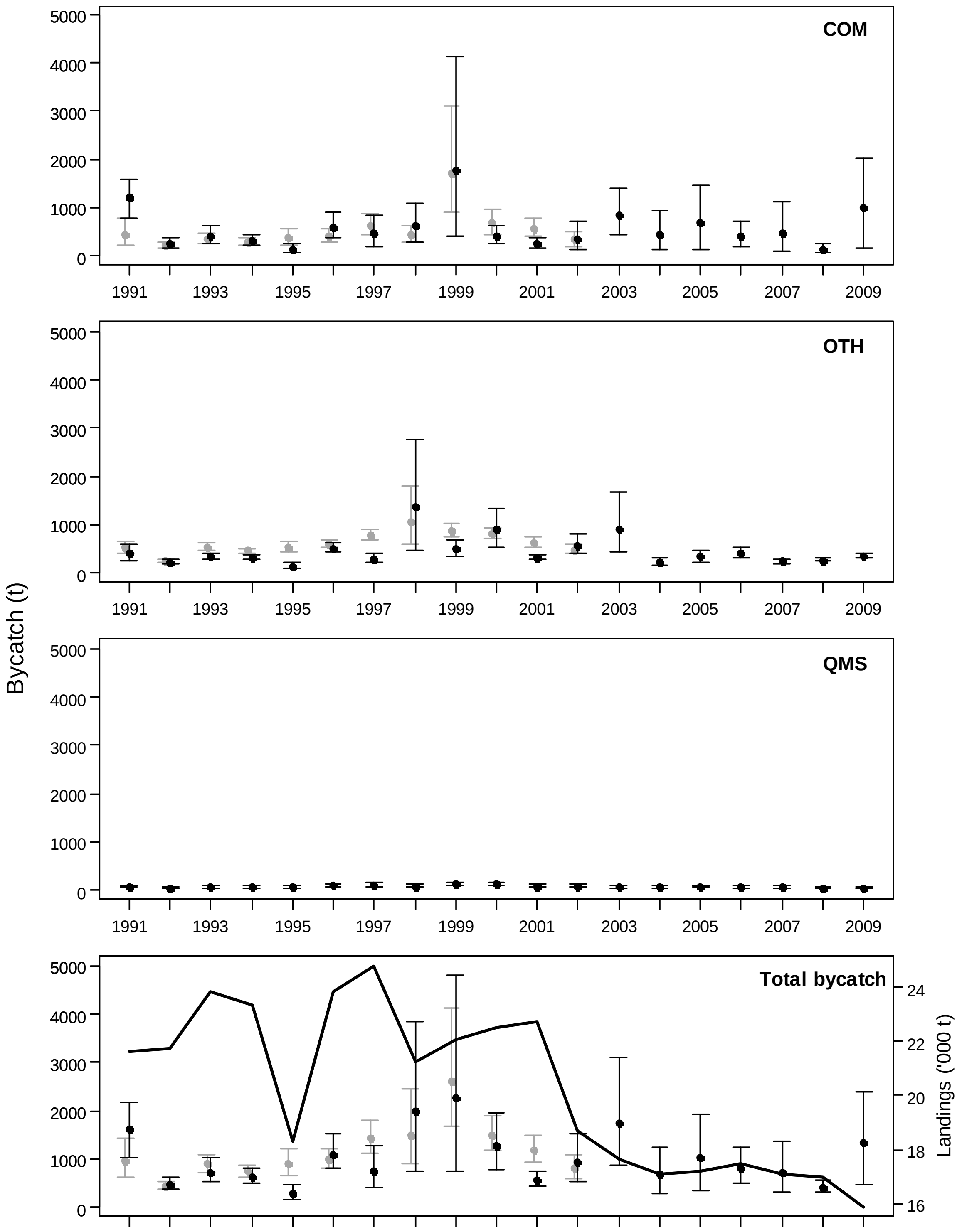



**Figure 12: Annual estimates of fish bycatch in the oreo trawl fishery, calculated for commercial species (COM), non-commercial species (OTH), QMS species, and overall for 1990–91 to 2008–09 (black points). Also shown (grey points) are estimates of bycatch in each category (excluding QMS) calculated for 1990–91 to 2001–02 (Anderson 2004a). Error bars show the 95% confidence intervals. The black line in the bottom panel shows the total annual estimated landings of oreos (Ministry of Fisheries 2010).**

## 3.5 Discard data

### 3.5.1 Overview of raw discard data

The bycatch species most affected by discarding in the orange roughy fishery was the shovelnose dogfish, the most commonly caught species after orange roughy and oreos, and over 90% of which was recorded as discarded. As a group, rattails made up a larger fraction of the bycatch, but this will have comprised a number of species which were frequently not fully identified by observers. Based on catch records from research surveys for orange roughy (e.g., Tracey et al. 1997), these are likely to have been mainly species of *Coryphaenoides*, especially the serrulate rattail (*C. serrulatus*), the four-rayed rattail (*C. subserrulatus*), and the notable rattail (*Coelorinchus innotabilis*), but also have included at least a dozen species in these and other genera. Morid cods, especially Johnson's cod, were also a significant part of the discarded catch, as were basketwork eel and javelinfish (*Lepidorhynchus denticulatus*, another species of rattail). Of the invertebrate species caught, only king crabs (Lithodidae), managed under the QMS since 2004, were not predominantly discarded (see Appendix 1).

In the oreo fishery, shovelnose dogfish were considerably less vulnerable than in the orange roughy fishery, appearing much further down the list of bycatch species, but still generally discarded (see Appendix 2). This may be because of the somewhat less complete spatial overlap of the distribution of this species with that of oreo species compared to orange roughy (see Anderson et al. 1998). Dogfishes in general, however, especially *Etmopterus* species, comprised a large part of the discards. Rattails were again, as a group, caught in the greatest amounts in this fishery, and generally discarded. The ridge scale rattail (*Macrourus carinatus*) is an anomaly, being the most significant non-QMS bycatch species by total weight, but not discarded. This result may be due to an error in coding or recording of the processing data, or the species code, but this species was also rarely discarded in the orange roughy fishery (see Appendix 1). Slickheads and basketwork eel also contributed substantially to the discarded catch in this fishery.

Exploratory plots were prepared to examine the variability in the total level of discards per trawl with respect to some of the available factors (Figure 13). As for bycatch, plots are presented for the orange roughy and oreo fisheries combined, with target species examined as a variable.

As was shown for bycatch in these fisheries, the quantity of discards tended to increase with increasing trawl duration, from about 40 kg for a 5 minute trawl to about 300 kg for an 8 hour trawl (based on lowess fits, a locally weighted regression smoother, see Becker et al. 1988). Discard levels varied little with depth, however, with the lowess fit showing totals discards of between 55 kg and 85 kg per trawl across the entire depth range of the fisheries. Discards were highly variable between vessels, with medians ranging from 12 kg to 400 kg per trawl across the 39 vessels with more than 50 records of discards. Discard levels showed a general decrease over time, from a high of about 300 kg per trawl in 1990–91 down to a low of 30 kg per trawl in 2008–09. Discard levels also varied among fishery areas, with the lowest values recorded in LOUI and ORH 1, and the highest values (ignoring again KAIK and COOK with low numbers of records) in NECR and NWCR, the same areas for which bycatch was shown (above) to be lowest and highest. Discards were similar throughout much of the year, although during July and August median levels were only a half to a third of levels in other months. Vessels coded as KOR had slightly greater discard levels, and vessels coded as NZKOR slightly lower discard levels compared with domestic vessels, but there were comparatively few records for the non-domestic vessels. As for bycatch, median discard levels were very similar across each of the four target species categories. There was also little discernible difference in bycatch rates between freezer vessels and ice boats and between vessels with and without a meal plant.

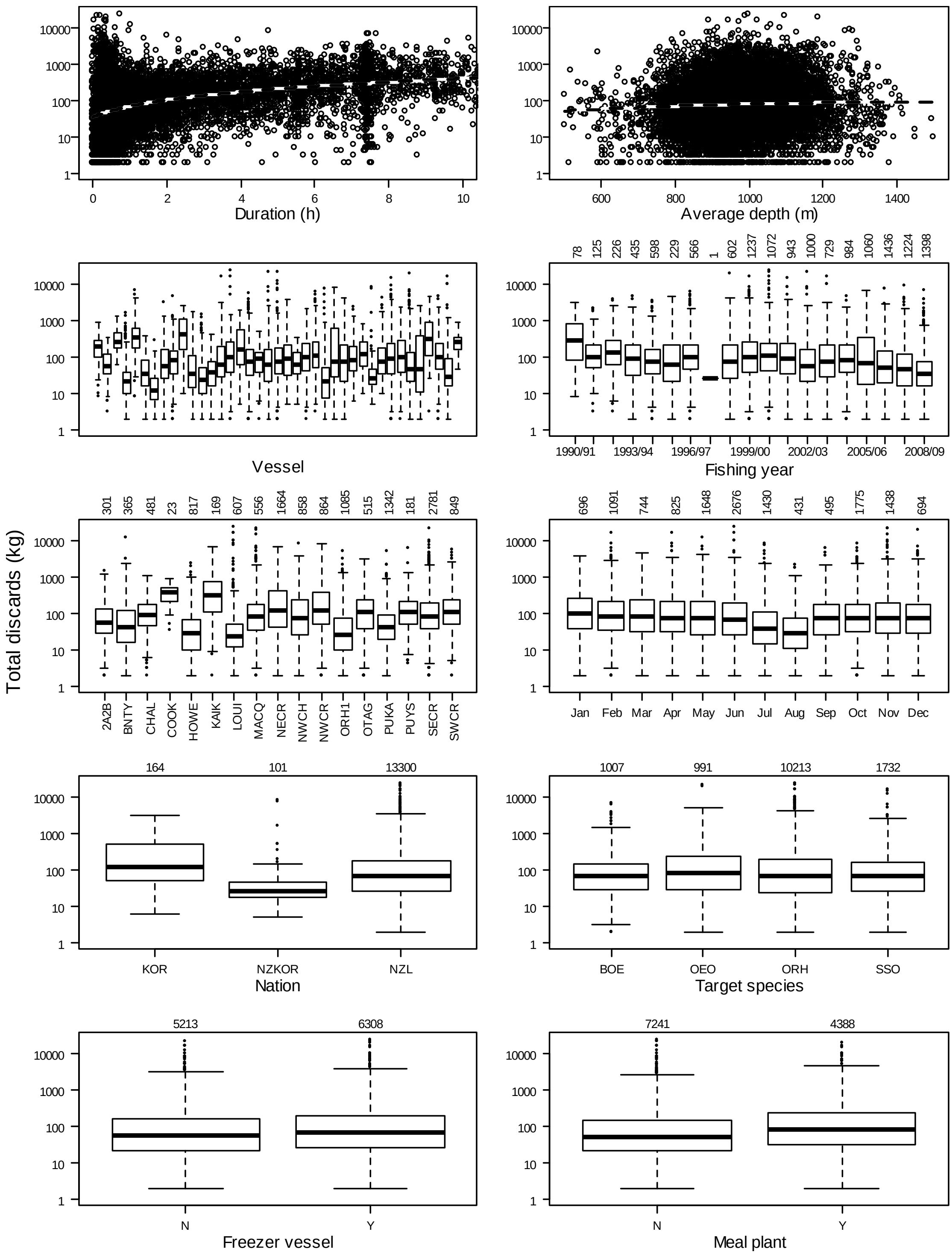



**Figure 13: Total discards per trawl (all species) plotted against selected variables in the combined orange roughy and oreo target fisheries. Total discards are plotted on a log scale. The dashed lines in the top panel show "lowess" fits (a locally weighted regression smoother) to the data. The box and whisker plots show medians and lower and upper quartiles in the box, whiskers extending up to 1.5x the interquartile range, and outliers individually plotted beyond the whiskers. The numbers above each plot indicate the number of records associated with that level of the variable: vessels represented by fewer than 50 records, and nations represented by fewer than 100 records, were not plotted. In the vessel plot, vessels are ordered by size, from shortest to longest. Average depth is the average of the start and finish gear depth. See Figure 1 for area codes.**

### 3.5.2 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. With a significant fraction of trawls with no discards in some species groups, both linear and binomial models were constructed, where data were sufficient, to enable the identification of factors affecting both the level and likelihood of discarding.

For the orange roughy target fishery, the variables *duration* and *subarea* were of similar importance overall, although *subarea* was of primary importance in discards of COM species (Table 13). With few records showing zero discards of OTH species, a binomial model was not required, and the normal model included *duration* as the main predictor. The variable *depth* also had an influence in most models, but never as the first variable selected. *Fishing year* also had a minor influence in three of the models.

In the oreo target fishery, *duration* was selected as the main explanatory variable in each of the models, with *subarea* and *depth* also having some additional explanatory power in three of the five models (Table 14). Although *subarea* could have been selected to stratify the calculation of COM discards, to be consistent across all categories and with the bycatch analyses, *duration* was used to stratify all discard calculations.

Recorded values of trawl duration were assigned to one of two or three strata in each species category with the use of regression tree partitioning. As in the bycatch calculations above, separate ratios were calculated only for strata in which at least two vessels were represented, to acknowledge the influence of *vessel* on rates of bycatch.

**Table 13: Summary of LME modelling of discards in the orange roughy trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year.**

| Species cat. | Model type | Variable | | | | |
|---|---|---|---|---|---|---|
| | | *duration* | *subarea* | *depth* | *fyr* | *fday* |
| COM | Normal | 3 | 1 | 2 | 4 | – |
| COM | Binomial | 2 | 1 | 3 | – | – |
| OTH | Normal | 1 | 2 | 4 | – | 3 |
| QMS | Normal | 1 | – | 2 | 3 | – |
| QMS | Binomial | 2 | 1 | – | 3 | – |

**Table 14: Summary of LME modelling of discards in the oreo trawl fishery. The numbers denote the order in which the variable entered the model. Variables: *fday*, fishing day; *fyr*, fishing year.**

| Species cat. | Model type | Variable | | | | | |
|---|---|---|---|---|---|---|---|
| | | *duration* | *subarea* | *depth* | *fyr* | *fday* | *nation* |
| COM | Normal | 1 | – | – | – | – | – |
| COM | Binomial | 1 | – | – | – | – | 2 |
| OTH | Normal | 1 | 2 | 3 | – | 4 | – |
| QMS | Normal | 1 | 2 | 3 | – | 4 | – |
| QMS | Binomial | 1 | 3 | – | 2 | – | – |

## 3.6 Estimation of discards

### 3.6.1 Discard rates

Discard ratios for each species category were separately calculated from observer data for each of the trawl duration categories determined from regression tree partitioning and for each year where possible, for each fishery. The variance in these discard ratios was calculated using the bootstrap methods described above.

#### Orange roughy

With few observer records of orange roughy discards in the orange roughy fishery, a single ratio was calculated based on data from all years. This provided a median orange roughy discard rate of 10.9 kg per trawl (Table 15)

Because regression modelling showed that trawl duration was not strongly influential in rates of COM discards, and regression tree partitioning did not reveal any significant splits in duration, discard ratios for the COM species category in the orange roughy fishery were calculated from the observer data without any stratification other than fishing year. Additionally, because of few observer records of discards for 1997–98, calculations for this year were based on an overall ratio from all years (Table 15). Annual discard rates of COM species decreased considerably over time, from as much as 126 kg per trawl in 1991–92 to less than 3 kg per trawl in each year since 2000–01.

For the OTH species category in the orange roughy fishery, discard ratios were calculated for each of the trawl duration categories determined from regression tree partitioning for all but four years in which discard records were too few. In these cases overall ratios were substituted (Table 15). Discard rates of OTH were higher for long trawls than for medium and short duration trawls in all years, and there was no evidence of any trend in the rates over time.

For QMS species in the orange roughy fishery, ratios for each duration category were calculated based on data from all years, due to low numbers of records in the long duration strata in most years. This showed that the discard rate of QMS species was relatively low overall, and greater for longer trawls than medium or short trawls.

**Table 15: Discard rates (kg/trawl) of orange roughy (ORH), commercial species (COM), non-commercial species (OTH), and QMS species in the orange roughy trawl fishery, by fishing year, based on observed catch data. Discard rates are the median of the bootstrap sample of 1000. See text for further explanation.**

| | *ORH | COM | | | OTH | | | *QMS |
|---|---|---|---|---|---|---|---|---|
| Fishing year | | | long (>5.8 h) | medium (0.3–5.8 h) | short (<0.3 h) | long (>10.5 h) | medium (3.2–10.5 h) | short (<3.2 h) |
| 1990–91 | 10.9 | 31.5 | *443 | *443 | *443 | 18.6 | 6.5 | 2.3 |
| 1991–92 | 10.9 | 126.4 | *136 | *136 | *136 | 18.6 | 6.5 | 2.3 |
| 1992–93 | 10.9 | 29.9 | 212 | 209 | 62 | 18.6 | 6.5 | 2.3 |
| 1993–94 | 10.9 | 38.8 | 154 | 124 | 109 | 18.6 | 6.5 | 2.3 |
| 1994–95 | 10.9 | 9.1 | 180 | 146 | 97 | 18.6 | 6.5 | 2.3 |
| 1995–96 | 10.9 | 57.4 | *122 | *122 | *122 | 18.6 | 6.5 | 2.3 |
| 1996–97 | 10.9 | 17.8 | 304 | 184 | 272 | 18.6 | 6.5 | 2.3 |
| 1997–98 | 10.9 | *8.1 | 592 | 147 | 138 | 18.6 | 6.5 | 2.3 |
| 1998–99 | 10.9 | 5.5 | *467 | *160 | *178 | 18.6 | 6.5 | 2.3 |
| 1999–00 | 10.9 | 10.9 | 485 | 149 | 63 | 18.6 | 6.5 | 2.3 |
| 2000–01 | 10.9 | 0.9 | 701 | 209 | 522 | 18.6 | 6.5 | 2.3 |
| 2001–02 | 10.9 | 2.6 | 825 | 137 | 124 | 18.6 | 6.5 | 2.3 |
| 2002–03 | 10.9 | 1.9 | 566 | 117 | 136 | 18.6 | 6.5 | 2.3 |
| 2003–04 | 10.9 | 0.6 | 557 | 213 | 182 | 18.6 | 6.5 | 2.3 |
| 2004–05 | 10.9 | 0.0 | 744 | 172 | 128 | 18.6 | 6.5 | 2.3 |
| 2005–06 | 10.9 | 2.6 | 978 | 146 | 40 | 18.6 | 6.5 | 2.3 |
| 2006–07 | 10.9 | 0.1 | 548 | 137 | 26 | 18.6 | 6.5 | 2.3 |
| 2007–08 | 10.9 | 0.3 | 443 | 109 | 186 | 18.6 | 6.5 | 2.3 |
| 2008–09 | 10.9 | 2.4 | 342 | 74 | 24 | 18.6 | 6.5 | 2.3 |

* Discard rates in these cases were based on discard data from all years, all duration categories, or both.

## Oreos

Discard ratios in each species category in the oreo fishery were not calculated separately for each year, and only a single overall ratio was calculated for the target species and commercial species categories, due to the lack of discard records in a large number of strata (Table 16). Discarding of oreo species in this fishery was estimated to be about four times the rate of discarding of orange roughy in the orange roughy fishery. The discard rate of COM species in the oreo fishery was less than 1 kg per trawl overall (similar to the rate of COM discards in the orange roughy fishery in recent years), but the rate of QMS species discarding was higher for medium and long trawls. Discard rates for OTH species were roughly similar to the overall rates for this category in the orange roughy fishery (see Table 15, 1998–99), with a higher rate for long trawls and similar rates for medium and short trawls.

**Table 16: Discard rates (kg/trawl) of oreo (OEO), commercial species (COM), non-commercial species (OTH), and QMS species in the oreo trawl fishery, based on observed catch data. Discard rates are the median of the bootstrap sample of 1000.**

| | OEO | COM | | | OTH | | | QMS |
|---|---|---|---|---|---|---|---|---|
| Fishing year | | | Long (>2.9 h) | Medium (1.0–2.9 h) | Short (<1.0 h) | Long (>5.2 h) | Medium (1.8–5.2 h) | Short (<1.8 h) |
| All years | 38.4 | 0.9 | 304 | 135 | 131 | 24.3 | 3.0 | 0.6 |

### 3.6.2 Annual discard levels

Annual discard levels were estimated from observer data by multiplying the ratios calculated for each duration and year stratum by the number of trawls in the target fishery for the equivalent stratum, as described in Section 2.4, and precision of the estimates was determined from the variability in the bootstrap samples of 1000 ratios (Tables 17 & 18, Figures 14 & 15).

#### Orange roughy

In the orange roughy fishery, annual discards of orange roughy were estimated to be 100–200 t per year for much of the 1990s. This level decreased to about 50–80 t per year in the last four years (Table 17). Discards of COM species showed a much more significant decrease, from a highly variable 70–1040 t per year in the 1990s, to less than 25 t per year in each year since. Discards of QMS species were much less than COM in most years (COM includes oreo species whereas QMS does not) and were less variable than the COM and OTH categories due to the single ratio applied to all years. Most discarding was, not surprisingly, in the non-commercial species (OTH) category, in which annual discards were 1100–3090 t up until 2004–05. In the most recent four years OTH discards have dropped to about 200–900 t per year. There was a steady decline in total annual discards in the orange roughy fishery, from a high in 1990–91 of about 3400 t to a low in 2008–09 of about 280 t, which roughly tracked the decrease in landings (and therefore effort) in this fishery (Figure 14). Estimates of discards from previous reviews were similar to the current estimates, particularly in the ORH and COM categories. In the OTH category the previous estimates tended to be lower up until 1997–98, and higher subsequently, than the current estimates, but wide confidence intervals around both sets of estimates show that these differences were mostly not significant. Estimates of total discards were much more similar between studies, with a strong overlap in confidence intervals for most years.

**Table 17: Estimates of discards (to the nearest 10 t) in the target orange roughy trawl fishery by fishing year, for the species categories ORH, COM, OTH, QMS, and overall, based on observed catch rates and total effort. The 95% confidence intervals are shown in parentheses.**

| | ORH | | COM | | OTH | | QMS | | Total discards | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990–91 | 80 | (40–150) | 250 | (20–650) | 3 090 | (1 610–4 670) | 20 | (10–30) | 3 420 | (1 660–5 470) |
| 1991–92 | 100 | (40–180) | 1 040 | (570–1 740) | 1 100 | (790–1 560) | 20 | (10–40) | 2 240 | (1 410–3 470) |
| 1992–93 | 130 | (60–240) | 360 | (100–700) | 1 960 | (1 040–3 260) | 30 | (20–50) | 2 450 | (1 200–4 200) |
| 1993–94 | 180 | (80–320) | 580 | (170–1 080) | 1 800 | (1 380–2 240) | 40 | (20–70) | 2 550 | (1 630–3 650) |
| 1994–95 | 180 | (80–330) | 150 | (70–280) | 2 050 | (1 640–2 620) | 40 | (20–70) | 2 380 | (1 790–3 230) |
| 1995–96 | 120 | (60–230) | 680 | (10–2 390) | 1 340 | (420–2 340) | 30 | (20–50) | 2 140 | (480–4 960) |
| 1996–97 | 100 | (50–190) | 180 | (20–430) | 2 000 | (1 380–2 750) | 30 | (20–40) | 2 280 | (1 450–3 370) |
| 1997–98 | 130 | (60–230) | 90 | (40–150) | 1 660 | (1 410–1 940) | 30 | (20–50) | 1 880 | (1 510–2 320) |
| 1998–99 | 140 | (60–250) | 70 | (10–190) | 2 190 | (1 230–3 360) | 40 | (30–60) | 2 400 | (1 300–3 800) |
| 1999–00 | 110 | (50–200) | 140 | (10–410) | 1 340 | (950–1 900) | 30 | (20–40) | 1 590 | (1 010–2 510) |
| 2000–01 | 80 | (40–150) | 10 | (0–20) | 2 470 | (1 370–4 270) | 20 | (10–30) | 2 560 | (1 410–4 430) |
| 2001–02 | 100 | (40–180) | 20 | (0–50) | 1 820 | (1 160–2 530) | 30 | (20–40) | 1 940 | (1 210–2 760) |
| 2002–03 | 90 | (40–170) | 20 | (0–40) | 1 450 | (950–2 290) | 30 | (20–40) | 1 560 | (990–2 500) |
| 2003–04 | 90 | (40–160) | 10 | (0–20) | 1 660 | (1 110–2 710) | 20 | (20–40) | 1 750 | (1 150–2 880) |
| 2004–05 | 90 | (40–160) | 10 | (0–30) | 1 440 | (1 250–1 720) | 20 | (20–30) | 1 530 | (1 290–1 910) |
| 2005–06 | 80 | (30–140) | 20 | (0–60) | 870 | (560–1 220) | 20 | (10–30) | 960 | (590–1 420) |
| 2006–07 | 60 | (30–100) | 0 | (0–0) | 450 | (260–700) | 10 | (10–20) | 510 | (290–800) |
| 2007–08 | 50 | (20–80) | 0 | (0–10) | 610 | (330–1 140) | 10 | (10–20) | 660 | (350–1 230) |
| 2008–09 | 50 | (20–90) | 10 | (0–30) | 220 | (140–310) | 10 | (10–20) | 280 | (160–430) |

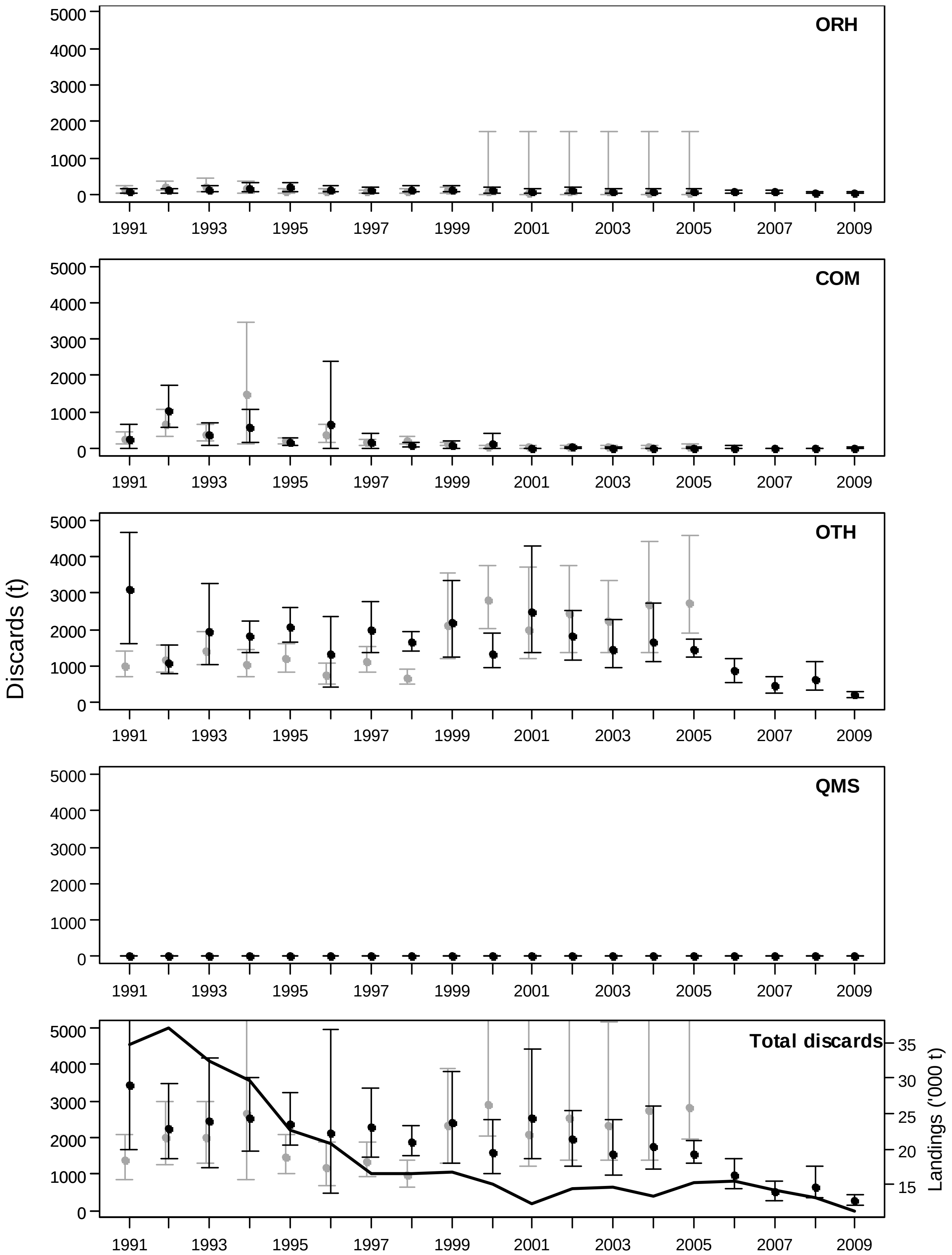



**Figure 14: Annual estimates of fish discards in the orange roughy trawl fishery, calculated for the target species (ORH), commercial species (COM), non-commercial species (OTH), QMS species, and overall for 1990–91 to 2008–09 (black points). Also shown (grey points) are estimates of discards in each category (excluding QMS) calculated for 1990–91 to 2004–05 (Anderson et al. 2001, Anderson 2009a). Error bars show the 95% confidence intervals. The black line in the bottom panel shows the total annual estimated landings of orange roughy (O. Anderson & M. Dunn (NIWA), unpublished data).**

### Oreos

In the oreo fishery, total discards were again mostly composed of non-commercial (OTH) species, discarded at a rate of about 200–600 t per year (Table 18). Oreo species comprised most of the remainder, at about 50–160 t per year. Discards of COM and QMS species were low, 10 t or less in each year. Total discards showed a steady increase to a peak in about 1999–2000 and a slow decrease since then, with the 390 t estimated for 2008–09 the lowest for 14 years. Estimates from the previous review were very similar to the current estimates in all years for the COM and OTH categories, but were different in some years for the OEO category (Figure 15). The higher estimates of OEO discards from the previous review for some years (especially 1996–97 which was strongly influenced by the stratification and ratio estimator used in that study) are also evident in the plot of total discards. The relationship between annual discards and landings is relatively weak, as total discards only decreased slightly in the last ten years while total landings decreased by about 7000 t.

**Table 18: Estimates of discards in the target oreo trawl fishery to the nearest 10 t (or 1 t for COM and QMS) by fishing year, for the species categories OEO, COM, OTH, QMS, and overall, based on observed catch rates and total effort. The 95% confidence intervals are shown in parentheses.**

| | OEO | | COM | | OTH | | QMS | | Total discards | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990–91 | 100 | (20–190) | 3 | (0–6) | 400 | (320–520) | 6 | (2–10) | 510 | (340–710) |
| 1991–92 | 50 | (10–100) | 1 | (0–3) | 210 | (170–270) | 3 | (1–5) | 260 | (180–370) |
| 1992–93 | 80 | (10–150) | 2 | (0–5) | 300 | (240–390) | 5 | (2–7) | 390 | (250–550) |
| 1993–94 | 70 | (10–120) | 2 | (0–4) | 280 | (230–340) | 5 | (2–7) | 350 | (240–460) |
| 1994–95 | 80 | (10–140) | 2 | (0–5) | 290 | (230–380) | 4 | (1–6) | 370 | (240–520) |
| 1995–96 | 120 | (20–220) | 3 | (0–8) | 460 | (360–600) | 6 | (2–10) | 590 | (380–830) |
| 1996–97 | 140 | (20–250) | 4 | (0–9) | 520 | (420–670) | 8 | (3–12) | 660 | (440–930) |
| 1997–98 | 130 | (20–240) | 4 | (0–8) | 470 | (360–630) | 7 | (2–10) | 610 | (380–870) |
| 1998–99 | 150 | (30–260) | 4 | (0–9) | 550 | (450–710) | 9 | (3–14) | 700 | (480–980) |
| 1999–00 | 160 | (30–280) | 4 | (0–10) | 590 | (470–750) | 10 | (3–15) | 750 | (500–1 040) |
| 2000–01 | 140 | (20–250) | 4 | (0–9) | 510 | (400–680) | 6 | (2–10) | 650 | (420–940) |
| 2001–02 | 120 | (20–210) | 3 | (0–7) | 430 | (340–570) | 6 | (2–9) | 550 | (360–790) |
| 2002–03 | 110 | (20–200) | 3 | (0–7) | 400 | (300–540) | 5 | (1–8) | 520 | (320–750) |
| 2003–04 | 100 | (20–180) | 3 | (0–6) | 370 | (290–490) | 5 | (2–8) | 480 | (310–680) |
| 2004–05 | 110 | (20–190) | 3 | (0–7) | 400 | (320–520) | 6 | (2–9) | 510 | (340–720) |
| 2005–06 | 90 | (20–170) | 2 | (0–6) | 340 | (270–440) | 5 | (2–7) | 430 | (290–610) |
| 2006–07 | 90 | (20–160) | 2 | (0–6) | 330 | (250–430) | 4 | (1–7) | 420 | (270–600) |
| 2007–08 | 100 | (20–180) | 3 | (0–6) | 350 | (260–480) | 4 | (1–7) | 450 | (280–660) |
| 2008–09 | 90 | (20–160) | 2 | (0–5) | 300 | (230–420) | 4 | (1–6) | 390 | (250–580) |

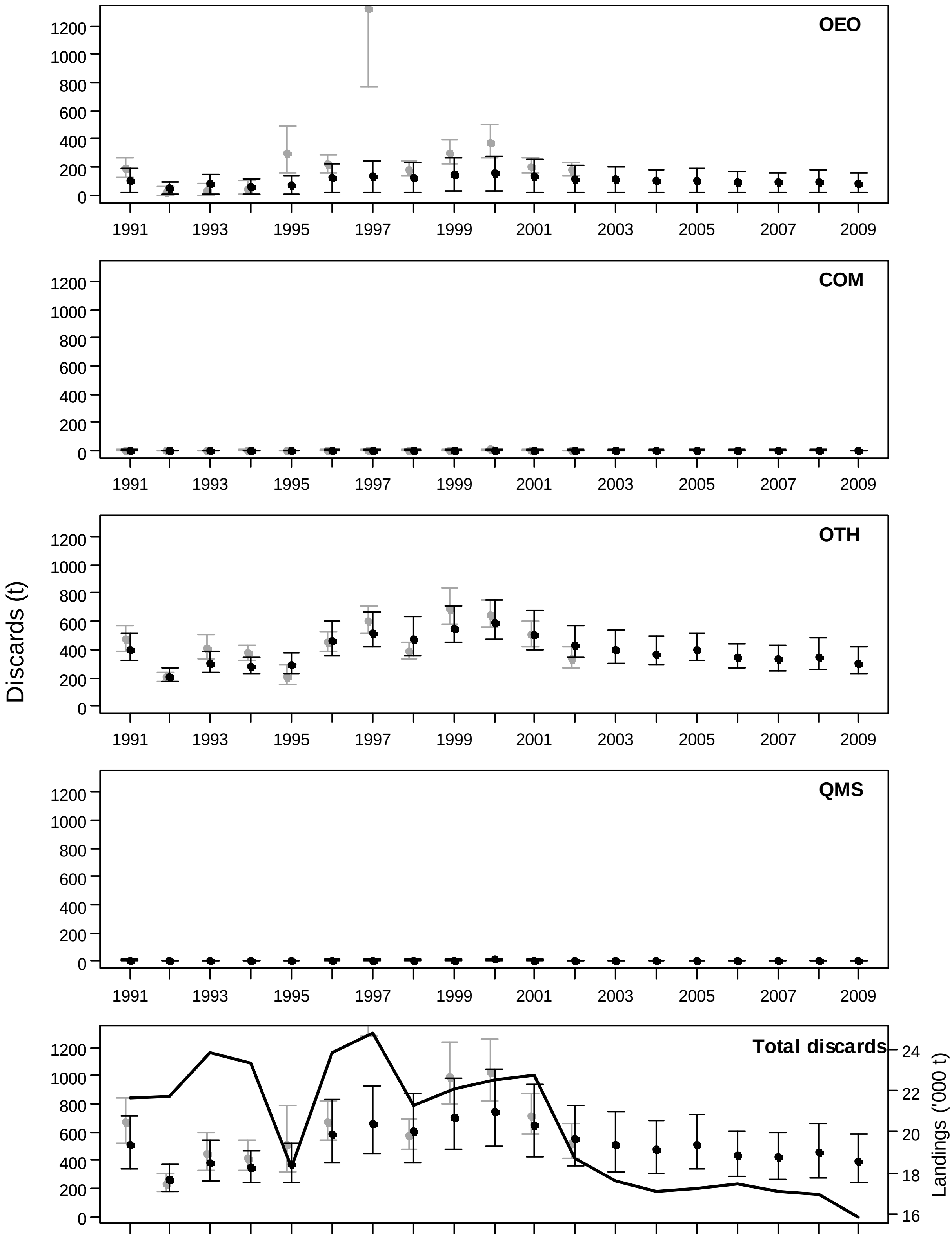



**Figure 15: Annual estimates of fish discards in the oreo trawl fishery, calculated for the target species (OEO), commercial species (COM), non-commercial species (OTH), QMS species, and overall for 1990–91 to 2008–09 (black points). Also shown (grey points) are estimates of discards in each category (excluding QMS) calculated for 1990–91 to 2001–02 (Anderson 2004a). Error bars show the 95% confidence intervals. The black line in the bottom panel shows the total annual estimated landings of oreos (Ministry of Fisheries 2010).**

### 3.7 Efficiency of the orange roughy and oreo trawl fisheries

Annual discards in the orange roughy and oreo trawl fisheries estimated in this study were compared to the reported annual landings of the target species and the total annual bycatch to get a measure of the efficiency of the fisheries (Tables 19 & 20).

The discard fraction (kg of discards/kg of orange roughy catch) was about 0.06–0.10 between 1990–91 and 1995–96, and for the following nine years was at a slightly higher level (0.10–0.21). Following this the discard fraction steadily decreased, reaching a low of 0.025 in 2008–09 (Table 19). Total discards were always considerably less than total bycatch but discards as a fraction of bycatch increased over time, to between 0.24 and 0.48 between 1998–99 and 2005–06. This fraction generally decreased since then, sharply in 2008–09 to an historic low of 0.07.

**Table 19: Total estimated landings of orange roughy (t) in the target trawl fishery, total estimated bycatch and discards (t), the discard fraction (kg of total discards per kg of orange roughy landed), and discards (excluding orange roughy discards) as a fraction of bycatch, by fishing year.**

| Fishing year | ORH landings | Total bycatch | Total discards | Discard fraction | Discards/bycatch |
|---|---|---|---|---|---|
| 1990–91 | 34 749 | 20 450 | 3 424 | 0.099 | 0.170 |
| 1991–92 | 36 995 | 22 250 | 2 236 | 0.060 | 0.102 |
| 1992–93 | 32 345 | 11 650 | 2 452 | 0.076 | 0.242 |
| 1993–94 | 29 582 | 27 220 | 2 551 | 0.086 | 0.106 |
| 1994–95 | 22 703 | 18 940 | 2 382 | 0.105 | 0.120 |
| 1995–96 | 20 706 | 17 940 | 2 144 | 0.104 | 0.144 |
| 1996–97 | 16 645 | 21 880 | 2 280 | 0.137 | 0.116 |
| 1997–98 | 16 632 | 16 500 | 1 877 | 0.113 | 0.118 |
| 1998–99 | 16 743 | 7 210 | 2 398 | 0.143 | 0.344 |
| 1999–00 | 15 025 | 7 820 | 1 587 | 0.106 | 0.244 |
| 2000–01 | 12 347 | 9 220 | 2 555 | 0.207 | 0.291 |
| 2001–02 | 14 380 | 4 250 | 1 940 | 0.135 | 0.477 |
| 2002–03 | 14 609 | 4 850 | 1 561 | 0.107 | 0.331 |
| 2003–04 | 13 415 | 6 400 | 1 752 | 0.131 | 0.273 |
| 2004–05 | 15 368 | 6 160 | 1 532 | 0.100 | 0.245 |
| 2005–06 | 15 499 | 3 620 | 964 | 0.062 | 0.270 |
| 2006–07 | 14 167 | 2 300 | 505 | 0.036 | 0.218 |
| 2007–08 | 13 110 | 3 320 | 657 | 0.050 | 0.193 |
| 2008–09 | 11 365 | 3 730 | 280 | 0.025 | 0.067 |

For the oreo fishery, the discard fraction (kg of discards/kg of oreo catch) was much lower than in the orange roughy fishery, and relatively steady at about 0.01–0.03 for the whole period (Table 20). The comparison is probably unfair, however, as a greater fraction of the oreo landings came from bycatch in the orange roughy fishery than vice versa. The trend, or lack of it, over time is more relevant, showing little improvement in the utilisation of bycatch since 1990. Total discards as a fraction of bycatch was higher than in the orange roughy fishery, fluctuating between 0.2 and 1.1 but usually about 0.4–0.5 and, despite the lowest value in the series occurring in the most recent year, there is no sign of a general decrease in this fraction.

**Table 20: Total estimated landings of oreo (t) in the target trawl fishery, total estimated bycatch and discards (t), the discard fraction (kg of total discards per kg of oreo landed), and discards (excluding oreo discards) as a fraction of bycatch, by fishing year.**

| Fishing year | OEO landings | Total bycatch | Total discards | Discard fraction | Discards/bycatch |
|---|---|---|---|---|---|
| 1990–91 | 21 614 | 1 600 | 507 | 0.023 | 0.252 |
| 1991–92 | 21 718 | 480 | 264 | 0.012 | 0.440 |
| 1992–93 | 23 820 | 730 | 385 | 0.016 | 0.414 |
| 1993–94 | 23 318 | 630 | 349 | 0.015 | 0.448 |
| 1994–95 | 18 291 | 270 | 369 | 0.020 | 1.081 |
| 1995–96 | 23 810 | 1 090 | 586 | 0.025 | 0.425 |
| 1996–97 | 24 779 | 750 | 662 | 0.027 | 0.699 |
| 1997–98 | 21 249 | 1 980 | 605 | 0.028 | 0.239 |
| 1998–99 | 22 083 | 2 260 | 700 | 0.032 | 0.245 |
| 1999–00 | 22 518 | 1 280 | 750 | 0.033 | 0.464 |
| 2000–01 | 22 719 | 570 | 653 | 0.029 | 0.902 |
| 2001–02 | 18 721 | 920 | 551 | 0.029 | 0.471 |
| 2002–03 | 17 621 | 1 730 | 515 | 0.029 | 0.233 |
| 2003–04 | 17 105 | 670 | 475 | 0.028 | 0.557 |
| 2004–05 | 17 220 | 1 020 | 510 | 0.030 | 0.395 |
| 2005–06 | 17 475 | 800 | 434 | 0.025 | 0.428 |
| 2006–07 | 17 113 | 720 | 423 | 0.025 | 0.461 |
| 2007–08 | 16 979 | 400 | 452 | 0.027 | 0.882 |
| 2008–09 | 15 877 | 1 350 | 388 | 0.024 | 0.224 |

## 4. DISCUSSION

With the methods used in this study, precision of the annual estimates of bycatch and discards in the orange roughy and oreo fisheries is strongly linked to the degree and spread of coverage achieved by observers.

The degree of observer coverage in these fisheries was relatively high and uninterrupted for the 19 years examined. Coverage in the orange roughy fishery was more than 10% (in terms of the total fishery catch) in all but one fishing year, and over 50% in some years. Although coverage was slightly less overall in the oreo fishery, for both fisheries the coverage achieved for the period since the last review was higher than for any previous period in these fisheries, higher also than in the recent hoki fishery (Ballara et al. 2010), and similar to recent coverage levels in the southern blue whiting trawl fishery (Anderson 2009b).

Graphical analysis of the spread of the observer data compared with that of each fishery as a whole, across a range of variables, showed that coverage was not always evenly spread. Most notable was the lack of observer coverage on smaller vessels, in areas such as the east coast fisheries in QMAs ORH 2A, ORH 2B, and ORH 3A, and the less even and less extensive coverage in some of the earlier years of the observer programme. The orange roughy fishery is the most widespread of any New Zealand fishery, therefore achieving even coverage across its entire extent is a difficult task. Only about 15% of the observed trips examined in this study predominantly targeted oreos, and nearly 30% of the sampled trawls in the oreo fishery were from trips which predominantly targeted orange roughy, therefore achieving an even spread of observer coverage in this fishery is also problematic.

The use of a ratio estimator based on numbers of trawls was preferable to the alternatives, not only because it proved likely to provide more precise estimates, but also because it allowed the effect of trawl duration (used predominantly in recent studies as the measure of effort in the ratio estimator) to be examined independently in the regression models. Overall, trawl duration had the most consistent effect on bycatch and discards in the models, leading to stratification by trawl duration in most of the calculations. The finding that longer duration trawls tended to produce more bycatch of non-commercial species was expected, but the opposite effect with commercial species bycatch was less obvious. This effect is likely to be due to target misidentification, where short trawls targeting a mark on the ships echo-sounder catch a large quantity of, e.g., oreo species when the target species was recorded as orange roughy, or vice versa.

Calculation of bycatch and discards in these fisheries was limited to commercial, non-commercial, and QMS species categories (and target species discards), with no estimates made for individual bycatch species. Although it may have been possible in some cases to do so, the main bycatch species in the orange roughy fishery were oreos, and vice versa, and other QMS species, for which such estimations would serve little purpose. The species most at risk from the adverse effects of these fisheries are likely to be those not under the management of the QMS, and bycatch and discards of these species were estimated as a group in the non-commercial species category (equivalent to non-QMS species).

Confidence intervals around the estimates made in this study were variable in width, and often wide when a few large bycatch or discard values were present in the re-sampled figures. Often the intervals were wide in comparison to those from the earlier oreo and earliest orange roughy studies, due to changes in the methodology used to calculate them. This bootstrap method produced more conservative confidence intervals due the allowance for correlation between trawls within the same trip. Such a correlation may be logically expected due to the proximity in space and time between one trawl and the next, as well as differences between vessels in power, personnel, and the set-up and use of the fishing gear, and also to alternating crews from trip to trip on the same vessel. In general, precision tended to be better for the non-commercial species than for commercial species, because the former generally comprises a large number of species caught in generally small amounts.

This study has shown that the discard rate in the New Zealand orange roughy trawl fishery has decreased in recent years. The average value across the last four years of 0.04 kg of discards per kilogram of orange roughy caught, is considerably lower than the 0.16 kg recorded for this fishery for the 1999–2000 to 2004–05 period (Anderson 2009a). The equivalent figures in the oreo fishery are slightly lower, with the average value across the last seven years of 0.03 kg of discards per kilogram of oreo caught. Although this figure is less than the 0.05 kg recorded for the period preceding this (Anderson 2004a), it is similar to the revised estimates in this study for the same period. These fisheries can be considered relatively un-wasteful, with the equivalent efficiency figures in other New Zealand fisheries being: southern blue whiting, 0.005; jack mackerel and hoki, 0.06 kg; arrow squid, 0.2 kg; ling longline, 0.35 kg; scampi, 2.5 kg (Anderson 2007, 2008, 2009b, Anderson & Smith 2005, Ballara & Anderson 2009).

Despite the low discard rates, there is still potential for better use of bycatch in these fisheries. The species groups discarded most (by weight) were rattails and deepwater sharks, and there is potential for processing these species, e.g., by mealing or filleting, if markets can be developed. The high catch and discard rates of shovelnose dogfish, especially in the orange roughy fishery, is of particular concern as it currently has little if any market value and is relatively long-lived and slow growing (Clarke et al. 2002). The same species is a significant part of the bycatch in deepwater trawl and longline fisheries in the North Atlantic, where although livers which are rich in the hydrocarbon squalene are sometimes retained, there is also no market (Clarke et al. 2002).

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**Appendix 1: Orange roughy fishery. Species codes, common and scientific names, estimated catch, percentage of the total catch, and percentage discarded of the top 50 fish species or species groups by weight, and all invertebrates, from observer records for the target orange roughy fishery since 1 October 2005. Records in each section are ordered by decreasing percentage of catch. Quota species are shown in bold.**

| Fish Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| **ORH** | Orange roughy | *Hoplostethus atlanticus* | 10 928 | 83.94 | 0 |
| **SSO** | Smooth oreo | *Pseudocyttus maculatus* | 1 040 | 7.99 | 0 |
| **BOE** | Black oreo | *Allocyttus niger* | 279 | 2.14 | 0 |
| RAT | Rattails (unidentified) | Macrouridae | 105 | 0.81 | 92 |
| SND | Shovelnose spiny dogfish | *Deania calcea* | 80 | 0.61 | 91 |
| **HOK** | Hoki | *Macruronus novaezelandiae* | 50 | 0.38 | 0 |
| ETM | | *Etmopterus* sp. | 48 | 0.37 | 87 |
| DWD | Deepwater dogfish (unidentified) | Squalidae | 42 | 0.32 | 98 |
| SLK | Slickheads (unidentified) | Alepocephalidae | 40 | 0.31 | 99 |
| MOD | Morid cods (unidentified) | Moridae | 37 | 0.29 | 96 |
| **CDL** | Cardinalfish (unidentified) | Epigonidae | 35 | 0.27 | 0 |
| HJO | Johnson's cod | *Halargyreus johnsonii* | 34 | 0.26 | 100 |
| CYP | Longnose velvet dogfish | *Centroscymnus crepidater* | 30 | 0.23 | 99 |
| **RIB** | Ribaldo | *Mora moro* | 29 | 0.22 | 8 |
| BEE | Basketwork eel | *Diastobranchus capensis* | 18 | 0.14 | 99 |
| JAV | Javelinfish | *Lepidorhynchus denticulatus* | 18 | 0.14 | 96 |
| LCH | Long-nosed spookfish | *Harriotta raleighana* | 15 | 0.12 | 87 |
| BSH | Seal shark | *Dalatias licha* | 14 | 0.11 | 74 |
| SHA | Shark (unidentified) | | 14 | 0.11 | 30 |
| **SOR** | Spiky oreo | *Neocyttus rhomboidalis* | 7 | <0.10 | 1 |
| WHX | White rattail | *Trachyrincus aphyodes* | 7 | <0.10 | 76 |
| **BYX** | Alfonsino & long-finned beryx | *Beryx splendens* & *B. decadactylus* | 7 | <0.10 | 0 |
| MCA | Ridge-scaled rattail | *Macrourus carinatus* | 4 | <0.10 | 5 |
| **GSP** | Pale ghost shark | *Hydrolagus bemisi* | 4 | <0.10 | 9 |
| **HAK** | Hake | *Merluccius australis* | 3 | <0.10 | 7 |
| CYO | Smooth skin dogfish | *Centroscymnus owstoni* | 3 | <0.10 | 78 |
| CSQ | Leafscale gulper shark | *Centrophorus squamosus* | 3 | <0.10 | 63 |
| RCH | Widenosed spookfish | *Rhinochimaera pacifica* | 2 | <0.10 | 88 |
| APR | Catshark | *Apristurus* spp. | 2 | <0.10 | 99 |
| SOP | Pacific sleeper shark | *Somniosus pacificus* | 2 | <0.10 | 100 |
| SCM | Largespine velvet dogfish | *Centroscymnus macracanthus* | 1 | <0.10 | 100 |
| **BNS** | Bluenose | *Hyperoglyphe antarctica* | 1 | <0.10 | 0 |
| BTH | Bluntnose skates | *Notoraja* spp. | 1 | <0.10 | 98 |
| TOA | Toadfish | *Neophrynichthys* sp. | 1 | <0.10 | 99 |
| PLS | Plunket's shark | *Centroscymnus plunketi* | 1 | <0.10 | 127 |
| OSK | Skates (unidentified) | Rajidae | 1 | <0.10 | 4 |
| CHI | Chimaeras | *Chimaera* spp. | 1 | <0.10 | 91 |
| SBO | Southern boarfish | *Pseudopentaceros richardsoni* | 1 | <0.10 | 0 |
| WOE | Warty oreo | *Allocyttus verrucosus* | 1 | <0.10 | 24 |
| CHG | Giant chimaera | *Chimaera lignaria* | 1 | <0.10 | 90 |
| **GSH** | Ghost shark | *Hydrolagus novaezealandiae* | 1 | <0.01 | 0 |
| MST | Scaleless black dragonfish | Melanostomiidae | 1 | <0.01 | 99 |
| BSL | Black slickhead | *Xenodermichthys* spp. | 1 | <0.01 | 20 |
| LAN | Lanternfish (unidentified) | Myctophidae | 1 | <0.01 | 100 |
| **LIN** | Ling | *Genypterus blacodes* | <1 | <0.01 | 0 |
| **SPE** | Sea perch | *Helicolenus* spp. | <1 | <0.01 | 2 |
| **SSK** | Smooth skate | *Dipturus innominatus* | <1 | <0.01 | 84 |
| DSK | Deepwater spiny skate | *Amblyraja hyperborea* | <1 | <0.01 | 100 |
| VCO | Violet cod | *Antimora rostrata* | <1 | <0.01 | 100 |
| HYD | | *Hydrolagus* sp. | <1 | <0.01 | 100 |

**Appendix 1—*continued***

Invertebrates

Echinoderms

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| ASR | Starfish | Asteroidea | 2 | 0.02 | 99 |
| HTH | Sea cucumber | Holothuroidea | 1 | 0.01 | 99 |
| ECN | Sea urchin | Echinoidea | 1 | 0.01 | 101 |
| ECH | Echinoderms (unidentified) | Echinodermata | 0 | <0.01 | 70 |

Crustaceans

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| **KIC** | King crab | Lithodidae | 2 | <0.01 | 1 |
| PRA | Prawn | | 0 | <0.01 | 83 |
| PAG | Hermit crab | Paguroidea | 0 | <0.01 | 100 |
| CRB | Crab (unidentified) | Decapoda | 0 | <0.01 | 80 |
| CRU | Crustacean (unidentified) | Crustacea | 0 | <0.01 | 63 |

Cnidaria

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| COU | Coral (unidentified) | Cnidaria | 12 | 0.10 | 99 |
| COR | Hydrocoral | Stylasteridae | 2 | 0.02 | 99 |
| ANT | Anemone | Anthozoa | 2 | 0.01 | 99 |
| PAB | Bubblegum coral | *Paragorgia arborea* | 1 | 0.01 | 99 |
| JFI | Jellyfish | Actiniaria | 0 | <0.01 | 86 |
| GDU | Bushy hard coral | *Goniocorella dumosa* | 0 | <0.01 | 99 |
| COB | Black coral | Antipatharia | 0 | <0.01 | 83 |

Other invertebrates

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| WSQ | Warty squid | *Moroteuthis* spp. | 43 | 0.33 | 100 |
| SQX | Squid (unidentified) | | 2 | 0.01 | 91 |
| ONG | Sponges | Porifera | 0 | <0.01 | 94 |
| MOL | Molluscs (unidentified) | | 0 | <0.01 | 93 |

**Appendix 2: Oreo fishery. Species codes, common and scientific names, estimated catch, percentage of the total catch, and percentage discarded of the top 50 fish species or species groups by weight, and all invertebrates, from observer records for the target oreo fishery since 1 October 2002. Records in each section are ordered by decreasing percentage of catch. Quota species are shown in bold.**

| Fish Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| **SSO** | Smooth oreo | *Pseudocyttus maculatus* | 5 679 | 56.89 | 0 |
| **BOE** | Black oreo | *Allocyttus niger* | 3 554 | 35.60 | 0 |
| **ORH** | Orange roughy | *Hoplostethus atlanticus* | 350 | 3.51 | 0 |
| **HOK** | Hoki | *Macruronus novaezelandiae* | 60 | 0.60 | 0 |
| RAT | Rattails (unidentified) | Macrouridae | 57 | 0.57 | 83 |
| MCA | Ridge scaled rattail | *Macrourus carinatus* | 31 | 0.31 | 0 |
| ETM | | *Etmopterus* sp. | 29 | 0.29 | 98 |
| ETB | Baxter’s lantern dogfish | *Etmopterus baxteri* | 27 | 0.27 | 76 |
| **LIN** | Ling | *Genypterus blacodes* | 25 | 0.25 | 0 |
| DWD | Deepwater dogfish (unidentified) | Squalidae | 29 | 0.29 | 82 |
| BSH | Seal shark | *Dalatias licha* | 14 | 0.14 | 81 |
| SLK | Slickhead (unidentified) | Alepocephalidae | 12 | 0.12 | 94 |
| BEE | Basketwork eel | *Diastobranchus capensis* | 10 | 0.10 | 98 |
| JAV | Javelinfish | *Lepidorhynchus denticulatus* | 6 | <0.10 | 33 |
| **GSP** | Pale ghost shark | *Hydrolagus bemisi* | 5 | <0.10 | 0 |
| MOD | Morid cods (unidentified) | Moridae | 5 | <0.10 | 90 |
| **SPD** | Spiny dogfish | *Squalus acanthias* | 2 | <0.10 | 0 |
| **CDL** | Cardinalfish (unidentified) | Epigonidae | 2 | <0.10 | 0 |
| **HAK** | Hake | *Merluccius australis* | 2 | <0.10 | 0 |
| LCH | Long-nosed spookfish | *Harriotta raleighana* | 2 | <0.10 | 84 |
| **WWA** | White warehou | *Seriolella caerulea* | 2 | <0.10 | 0 |
| HJO | Johnson's cod | *Halargyreus johnsonii* | 1 | <0.10 | 100 |
| WOE | Warty oreo | *Allocyttus verrucosus* | 1 | <0.10 | 100 |
| CMU | Abyssal rattail | *Coryphaenoides murrayi* | 1 | <0.10 | 100 |
| ETL | Lucifer dogfish | *Etmopterus lucifer* | 1 | <0.10 | 100 |
| CHI | | *Chimaera* spp. | 1 | <0.10 | 97 |
| SND | Shovelnose spiny dogfish | *Deania calcea* | 1 | <0.10 | 95 |
| **SWA** | Silver warehou | *Seriolella punctata* | 1 | <0.10 | 10 |
| GRC | Grenadier cod | *Tripterophycis gilchristi* | 1 | <0.10 | 0 |
| **RCO** | Red cod | *Pseudophycis bachus* | 1 | <0.10 | 0 |
| RUD | Rudderfish | *Centrolophus niger* | 1 | <0.10 | 100 |
| **SOR** | Spiky oreo | *Neocyttus rhomboidalis* | 1 | <0.10 | 0 |
| **RIB** | Ribaldo | *Mora moro* | <1 | <0.01 | 0 |
| CYP | Longnose velvet dogfish | *Centroscymnus crepidater* | <1 | <0.01 | 100 |
| **GSH** | Ghost shark | *Hydrolagus novaezealandiae* | <1 | <0.01 | 8 |
| LAN | Lanternfish (unidentified) | Myctophidae | <1 | <0.01 | 100 |
| **LDO** | Lookdown dory | *Cyttus traversi* | <1 | <0.01 | 0 |
| VCO | Violet cod | *Antimora rostrata* | <1 | <0.01 | 100 |
| CHP | | *Chimaera* sp. | <1 | <0.01 | 87 |
| CSQ | Leafscale gulper shark | *Centrophorus squamosus* | <1 | <0.01 | 100 |
| HYD | | *Hydrolagus* sp. | <1 | <0.01 | 100 |
| CHG | Giant chimaera | *Chimaera lignaria* | <1 | <0.01 | 100 |
| TOA | Toadfish | *Neophrynichthys* sp. | <1 | <0.01 | 77 |
| RAG | Ragfish | *Icichthys australis* | <1 | <0.01 | 36 |
| DWE | Deepwater eel (unspecified) | | <1 | <0.01 | 1 |
| **BNS** | Bluenose | *Hyperoglyphe antarctica* | <1 | <0.01 | 0 |
| **SBW** | Southern blue whiting | *Micromesistius australis* | <1 | <0.01 | 0 |
| **STA** | Giant stargazer | *Kathetostoma giganteum* | <1 | <0.01 | 0 |
| **SCH** | School shark | *Galeorhinus galeus* | <1 | <0.01 | 0 |
| **SSK** | Smooth skate | *Dipturus innominatus* | <1 | <0.01 | 28 |

**Appendix 2—*continued***

Invertebrates

Echinoderms

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| ECN | Sea urchins | Echinoidea | 1 | 0.01 | 98 |
| ASR | Starfish | Asteroidea | <1 | <0.01 | 92 |
| HTH | Sea cucumbers | Holothuroidea | <1 | <0.01 | 95 |
| OPH | Brittle stars | Ophiuroidea | <1 | <0.01 | 73 |
| CRN | Sea lilies, feather stars | Crinoidea | <1 | <0.01 | 25 |

Crustaceans

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| **KIC** | King crabs | Lithodidae | <1 | <0.01 | 12 |
| PRA | Prawns | | <1 | <0.01 | 86 |
| CRB | Crabs | | <1 | <0.01 | 85 |
| CRU | Crustacea (other) | | <1 | <0.01 | 18 |

Cnidaria

| | | | | | |
|---|---|---|---|---|---|
| COU | Coral (unspecified) | | 34 | 0.34 | 100 |
| | Stony corals | Scleractinia | 2 | 0.02 | 99 |
| | Gorgonian corals | Gorgonacea | 1 | 0.01 | 95 |
| ANT | Anemones | Anthozoa | <1 | <0.01 | 91 |
| HDR | Hydroids | Hydrozoa | <1 | <0.01 | 94 |
| COB | Black corals | Antipatharia | <1 | <0.01 | 53 |
| JFI | Jellyfish | Scyphozoa | <1 | <0.01 | 100 |

Molluscs

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| SQX | Squid (various) | | 7 | 0.07 | 87 |
| OCP | Octopuses | Octopoda | <1 | <0.01 | 97 |
| GAS | Gastropods | Gastropoda | <1 | <0.01 | 70 |
| BIV | Bivalves | Bivalvia | <1 | <0.01 | 40 |

Other

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch | % discarded |
|---|---|---|---|---|---|
| ONG | Sponges | Porifera | <1 | <0.01 | 96 |

**Appendix 3: Species codes, common and scientific names, estimated catch weight, and percentage of the total catch of the top 50 species or species groups from all commercial fishing returns for the target orange roughy trawl fishery since 1 October 2005. Records are ordered by decreasing percentage of catch. NB: only the top 5 species, by weight, are recorded on these forms. Quota species are shown in bold**

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch |
|---|---|---|---|---|
| **ORH** | Orange roughy | *Hoplostethus atlanticus* | 52 333 | 79.49 |
| **SSO** | Smooth oreo | *Pseudocyttus maculatus* | 8 596 | 13.06 |
| **BOE** | Black oreo | *Allocyttus niger* | 1 772 | 2.69 |
| DWD | Deepwater dogfish (unidentified) | Squalidae | 615 | 0.93 |
| RAT | Rattails (unidentified) | Macrouridae | 414 | 0.63 |
| **HOK** | Hoki | *Macruronus novaezelandiae* | 370 | 0.56 |
| **CDL** | Cardinalfish | *Epigonus telescopus* | 318 | 0.48 |
| BSH | Seal shark | *Dalatias licha* | 277 | 0.42 |
| MOD | Morid cods (unidentified) | Moridae | 247 | 0.38 |
| SLK | Slickheads (unidentified) | Alepocephalidae | 206 | 0.31 |
| **SND** | Shovelnose spiny dogfish | *Deania calcea* | 187 | 0.28 |
| **RIB** | Ribaldo | *Mora moro* | 107 | 0.16 |
| **SOR** | Spiky oreo | *Neocyttus rhomboidalis* | 66 | 0.10 |
| **BYX** | Alfonsino & long-finned beryx | *Beryx splendens* & *B. decadactylus* | 65 | 0.10 |
| **OEO** | Oreos (unidentified) | Oreosomatidae | 48 | <0.10 |
| JAV | Javelinfish | *Lepidorhynchus denticulatus* | 38 | <0.10 |
| LCH | Long-nosed spookfish | *Harriotta raleighana* | 29 | <0.10 |
| WSQ | Warty squid | *Moroteuthis* spp. | 26 | <0.10 |
| BEE | Basketwork eel | *Diastobranchus capensis* | 21 | <0.10 |
| HJO | Johnson's cod | *Halargyreus johnsonii* | 19 | <0.10 |
| **HAK** | Hake | *Merluccius australis* | 15 | <0.10 |
| **BNS** | Bluenose | *Hyperoglyphe antarctica* | 8 | <0.10 |
| **SPE** | Sea perch | *Helicolenus* spp. | 8 | <0.10 |
| VCO | Violet cod | *Antimora rostrata* | 6 | <0.10 |
| **SCH** | School shark | *Galeorhinus galeus* | 5 | <0.10 |
| BSL | Black slickhead | *Xenodermichthys* spp. | 3 | <0.01 |
| WHX | White rattail | *Trachyrincus aphyodes* | 2 | <0.01 |
| BSK | Basking shark | *Cetorhinus maximus* | 2 | <0.01 |
| SOP | Pacific sleeper shark | *Somniosus pacificus* | 2 | <0.01 |
| **GSP** | Pale ghost shark | *Hydrolagus bemisi* | 2 | <0.01 |
| **GSH** | Ghost shark | *Hydrolagus novaezealandiae* | 2 | <0.01 |
| SSI | Silverside | *Argentina elongata* | 2 | <0.01 |
| UNI | Unidentified | | 2 | <0.01 |
| CHI | Chimaeras | *Chimaera* spp. | 1 | <0.01 |
| OFH | Oilfish | *Ruvettus pretiosus* | 1 | <0.01 |
| WOE | Warty oreo | *Allocyttus verrucosus* | 1 | <0.01 |
| SDO | Silver dory | *Cyttus novaezealandiae* | 1 | <0.01 |
| **LIN** | Ling | *Genypterus blacodes* | 1 | <0.01 |
| DWE | Deepwater eel (unspecified) | | 1 | <0.01 |
| CHG | Giant chimaera | *Chimaera lignaria* | 1 | <0.01 |
| WHR | Unicorn rattail | *Trachyrincus longirostris* | 1 | <0.01 |
| **SQU** | Arrow squid | *Nototodarus sloanii* & *N. gouldi* | 1 | <0.01 |
| LAN | Lanternfish (unidentified) | Myctophidae | 1 | <0.01 |
| MPH | Big-scale fish (unidentified) | Melamphaidae | 1 | <0.01 |
| GRC | Grenadier cod | *Tripterophycis gilchristi* | 1 | <0.01 |
| **SBW** | Southern blue whiting | *Micromesistius australis* | 1 | <0.01 |
| **RCO** | Red cod | *Pseudophycis bachus* | 1 | <0.01 |
| SMC | Small-headed cod | *Lepidion microcephalus* | <1 | <0.01 |
| **WWA** | White warehou | *Seriolella caerulea* | <1 | <0.01 |
| MDO | Mirror dory | *Zenopsis nebulosus* | <1 | <0.01 |

**Appendix 4: Species codes, common and scientific names, estimated catch weight, and percentage of the total catch of the top 50 species or species groups from all commercial fishing returns for the target oreo trawl fishery since 1 October 2002. Records are ordered by decreasing percentage of catch. NB: only the top 5 species, by weight, are recorded on these forms. Quota species are shown in bold**

| Species code | Common name | Scientific name | Estimated catch (t) | % of catch |
|---|---|---|---|---|
| **SSO** | Smooth oreo | *Pseudocyttus maculatus* | 30 886 | 59.61 |
| **BOE** | Black oreo | *Allocyttus niger* | 18 494 | 35.70 |
| **ORH** | Orange roughy | *Hoplostethus atlanticus* | 1 206 | 2.33 |
| **OEO** | Oreos (unidentified) | Oreosomatidae | 279 | 0.54 |
| **HOK** | Hoki | *Macruronus novaezelandiae* | 223 | 0.43 |
| DWD | Deepwater dogfish (unidentified) | Squalidae | 259 | 0.50 |
| RAT | Rattails (unidentified) | Macrouridae | 173 | 0.33 |
| BSH | Seal shark | *Dalatias licha* | 60 | 0.12 |
| SLK | Slickheads (unidentified) | Alepocephalidae | 52 | 0.10 |
| JAV | Javelinfish | *Lepidorhynchus denticulatus* | 30 | <0.10 |
| UNI | Unidentified | | 29 | <0.10 |
| **HAK** | Hake | *Merluccius australis* | 20 | <0.10 |
| BEE | Basketwork eel | *Diastobranchus capensis* | 15 | <0.10 |
| MOD | Morid cods (unidentified) | Moridae | 14 | <0.10 |
| BSL | Black slickhead | *Xenodermichthys* spp. | 12 | <0.10 |
| WSQ | Warty squid | *Moroteuthis* spp. | 11 | <0.10 |
| GRC | Grenadier cod | *Tripterophycis gilchristi* | 8 | <0.10 |
| HJO | Johnson's cod | *Halargyreus johnsonii* | 7 | <0.10 |
| SSI | Silverside | *Argentina elongata* | 5 | <0.10 |
| ETB | Baxter’s lantern dogfish | *Etmopterus baxteri* | 3 | <0.10 |
| SND | Shovelnose spiny dogfish | *Deania calcea* | 2 | <0.01 |
| **GSP** | Pale ghost shark | *Hydrolagus bemisi* | 2 | <0.01 |
| LCH | Long-nosed spookfish | *Harriotta raleighana* | 2 | <0.01 |
| **SWA** | Silver warehou | *Seriolella punctata* | 2 | <0.01 |
| DWE | Deepwater eel (unspecified) | | 2 | <0.01 |
| **SPD** | Spiny dogfish | *Squalus acanthias* | 2 | <0.01 |
| CHI | Chimaeras | *Chimaera* spp. | 2 | <0.01 |
| **SOR** | Spiky oreo | *Neocyttus rhomboidalis* | 1 | <0.01 |
| **LIN** | Ling | *Genypterus blacodes* | 1 | <0.01 |
| **SQU** | Arrow squid | *Nototodarus sloanii* & *N. gouldi* | 1 | <0.01 |
| VCO | Violet cod | *Antimora rostrata* | 1 | <0.01 |
| LAN | Lanternfish (unidentified) | Myctophidae | 1 | <0.01 |
| CHG | Giant chimaera | *Chimaera lignaria* | <1 | <0.01 |
| **SBW** | Southern blue whiting | *Micromesistius australis* | <1 | <0.01 |
| **RIB** | Ribaldo | *Mora moro* | <1 | <0.01 |
| DWO | Deepwater octopus | *Granelodone* spp. | <1 | <0.01 |
| **GSH** | Ghost shark | *Hydrolagus novaezealandiae* | <1 | <0.01 |
| GUL | Gulper eel | *Eurypharynx pelecanoides* | <1 | <0.01 |
| **WWA** | White warehou | *Seriolella caerulea* | <1 | <0.01 |
| **SPE** | Sea perch | *Helicolenus* spp. | <1 | <0.01 |
| SSC | Giant masking crab | *Leptomithrax australis* | <1 | <0.01 |
| **KIC** | King crabs (unidentified) | Lithodidae | <1 | <0.01 |
| **CDL** | Cardinalfish | *Epigonus telescopus* | <1 | <0.01 |
| **RSK** | Rough skate | *Dipturus nasutus* | <1 | <0.01 |
| LEG | Giant lepidion | *Lepidion schmidti* & *L. inosimae* | <1 | <0.01 |
| MIQ | Warty squid | *Moroteuthis ingens* | <1 | <0.01 |
| PTO | Patagonian toothfish | *Dissostichus eleginoides* | <1 | <0.01 |
| DSK | Deepwater spiny skate | *Amblyraja hyperborea* | <1 | <0.01 |
| **GSC** | Giant spider crab | *Jacquinotia edwardsii* | <1 | <0.01 |
| **SKI** | Gemfish | *Rexea solandri* | <1 | <0.01 |