

# Trawl surveys of orange roughy on the Chatham Rise, 1984-92

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**NIWA**

*Taihoru Nukurangi*

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## Introduction

This report presents summaries of stratified random trawl surveys of orange roughy (*Hoplostethus atlanticus*) conducted during the spawning period on the Chatham Rise between 1984 and 1992 and an out-of-season survey in September 1988.

For annual surveys between 1984 and 1990 commercial fishing vessels were chartered. As part of the charter agreement some commercial fishing usually was carried out in conjunction with the survey. FV *Otago Buccaneer* (Fletcher Fishing Ltd.) was used from 1984 to 1987 and FV *Cordella* (Pacifica Shipping Ltd.) from 1988 to 1990. No survey was carried out in 1991 and in 1992 the survey was conducted using RV *Tangaroa* (Table 1).

The 1984 to 1988 surveys targeted the spawning population which concentrates in July in an area known, and referred to in this document, as “the spawning box” (or “the box”). This is an area of about 5000 km<sup>2</sup> located about 60 n. miles north of the Chatham Islands between 177° 30' W and 175° W and in the depth range 750–1500 m (Figure 1). Selection of this survey area and timing of the survey was based on knowledge of fishing activity of the fleet over the previous 5 years, and from the *Kaltan* survey in 1982 (Robertson *et al.* 1984). The 1987 survey included some exploratory and pinnacle trawling on the northwest, east, and south Rise, but not as part of the stratified biomass survey. Surveys from 1989 to 1992 also focused on the spawning box, but were extended to cover a wider area of the Chatham Rise following the expansion of the fishery. The 1990 and 1992 surveys were lengthened to 8 weeks to allow complete coverage of the known Chatham Rise orange roughy grounds.

This report does not attempt to analyse in detail the fluctuations in catch rates of orange roughy on the Chatham Rise over the period covered (much of the relative biomass information gained from these surveys has been presented and discussed in N.Z. Fishery Assessment Research Documents, *see* Francis & Robertson (1990, 1991), Francis *et al.* (1992, 1993)), but rather compiles general survey data. The report focuses on orange roughy, and, apart from catch summaries, other species are not covered except for the 1988 out-of-season survey when catches of smooth oreo (*Pseudocyttus maculatus*) made up a significant proportion of the total catch. Each survey is treated separately, in chronological order, and details of objectives, methods, timing of surveys, areas covered, and general results are presented.

Data collected from these surveys are held in the “trawl” database (Mackay 1993) administered by NIWA, Wellington and are checked, managed, and maintained according to standards described by Ng (1992).

## Programme objectives

1. To measure abundance and variation of abundance, and to map the distribution of orange roughy and associated fish species at depths between 750 and 1500 m in Chatham Rise waters.
2. To measure biological parameters of orange roughy such as sex, size, and age structure, in order to monitor population changes over time and provide data for population models to estimate productivity and yields.



## July 1984 (BUC8401)

### Objectives

1. To measure the relative abundance and distribution of orange roughy and other deepwater species in the survey area during the peak of the orange roughy spawning period.
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To collect depth-position data to improve knowledge of the bathymetry of the Chatham Rise.

### Voyage personnel

Skipper, M. Langrick: voyage leader, D. A. Robertson

### Methods

#### Survey area and design

The survey covered the spawning box on the north Chatham Rise between longitudes 177° 30' W and 175° W and depths of 750 to 1250 m (*see* Figure 1).

A single-phase stratified random trawl survey was employed. The box area was divided into 5 subareas and each of these was further divided by depth to produce 25 strata (*see* Figure 1 and Table 2). Stations were assigned within these strata according to random depth and longitude coordinates and the path of the net was to intersect this position at some point during the tow, staying as close as possible to the assigned depth throughout. Sequence and timing of station occupation was planned to minimise the effects of fish moving in and out of the survey area. Length of tow was generally about 3.0 n. miles, but ranged between 1.1 and 5.8 n. miles. Shorter tows were generally due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed using the "Satellite Navigation" (SatNav) system. The start position was taken as the point where the gear was observed to touch the bottom, and the finish position as the point where the gear left the bottom.

#### Vessel and gear specifications

The vessel used was FV *Otago Buccaneer*. Vessel and gear specifications are given in Appendix 1.

## **Treatment of catch**

The catch was sorted by species at all stations. For large catches of orange roughy or oreos the catch weight was back-calculated using a conversion factor (product weight to green weight) calculated during the survey. Lesser catches were weighed directly. All bycatch species were identified and weighed.

At each station 150–200 orange roughy (or the entire catch if fewer than this) were selected at random for recording of length, sex, and gonad stage. A further 20 orange roughy were selected at random for recording of more detailed biological data, including length, sex and gonad stage, fish weight, gonad weight, stomach state, stomach fullness, and details of stomach contents. The otoliths were removed and stored in a solution of 70% isopropyl alcohol and 5% glycerine. A subsample of otoliths kept from the 1984 survey was read in 1994 and used to update orange roughy life history parameters (Doonan 1994).

## **Survey timetable**

*Otago Buccaneer* departed from Dunedin for the Chatham Rise on 7 July 1984. Fishing began on 9 July at the western end of the survey area and progressed generally eastwards for the next 2 weeks. By 22 July the eastern boundary of the survey area had been reached and the vessel turned and fished back westwards picking up stations missed on the first traverse. The survey work was completed by 24 July and the vessel went on to make 16 commercial tows between 24 and 29 July. The vessel completed the survey on 29 July at which time the scientific staff were taken to the Chatham Islands to fly home.

## **Biomass estimation**

Biomass indices were estimated using the area swept method described by Francis (1981, 1989). Vertical and areal availabilities were assumed to be 1.0, and wingspread was assumed to be constant at 19.0 m. The distance between the wingtips was assumed to represent the effective width of the trawl gear and vulnerability was set to 1.0. The recorded start and finish positions were used to calculate the distance towed. Stations were selected for inclusion in the biomass estimation process according to the following criteria.

Only stations in strata 1 to 26 (i.e., the spawning box) were used.

Strata represented by less than two stations were excluded.

Stations where gear performance during the tow was unsatisfactory were excluded.

Commercial stations were excluded.

## Biological analyses

### 1. Length frequency distribution

To represent more accurately the population size structure within the survey area, orange roughy length frequency data were scaled by the percentage of fish sampled per tow, the area swept by the wings, and the biomass calculated from the catch weights.

### 2. Reproductive stages

Gonad stages follow Pankhurst *et al.* 1987.

Stage	Female	Male
1	Immature/resting	Immature/resting
2	Early maturation	Early maturation
3	Maturation	Maturation
4	Ripe	Ripe
5	Running ripe	Spent
6	Spent	-

The spawning period of orange roughy, including peak spawning, was investigated by applying a distance weighted least squares algorithm (SYSTAT, Wilkinson 1987) to data representing the proportion of fish in each of the (mature) reproductive stages at regular intervals during the survey. The peak of spawning can be defined both by the apex of this function fitted to the proportion of ripe or ripe and running ripe fish, and by the point at which this function, when fitted to the proportion of spent fish, passes through a value of 20%.

### 3. Feeding analyses

Orange roughy stomach state data were analysed to indicate to what degree feeding was occurring during spawning. Stomach fullness was ranked and the proportion of each rank in all fish examined was calculated. Prey items were identified, and frequency of occurrence calculated as the number of stomachs in which the item was found as a percentage of all stomachs with identifiable prey items.

## Bathymetry

Depth and position data (from SatNav) were recorded regularly throughout the survey, particularly around features where fish were aggregating. Depths were plotted by hand directly onto charts or recorded with position for later plotting.

## Results

During the survey 132 tows were completed, of which 1 was carried out with the gear not performing to a standard satisfactory for biomass estimation. This station (53) was excluded from all analyses. Blown windows occurred at nine stations (1, 8, 15, 18, 19, 25, 26, 27, and 31) for which recorded catches are minimum estimates.

Seventeen of the stations were specifically commercial, netting a total orange roughy catch of 642 t. The catch composition from these stations was excluded from the survey results, but biological data (where recorded) were included in analyses.

Length and biological data were recorded at all but one of the stations where orange roughy were caught. The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 550 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

Orange roughy were caught in all parts of the box and at all but one station. High catch rates (between 1 and 10 t.km<sup>-1</sup>) were achieved throughout the box, but were highest towards the western end. Catch rates of over 4 t.km<sup>-1</sup> were recorded in strata 1, 2, 7, 8, and 26 and the greatest catch rate was 8.98 t.km<sup>-1</sup> at station 26 in stratum 7. Orange roughy were by far the most abundant species caught, making up 96% of the total research catch. The next most abundant species were basketwork eels (*Diastobranchus capensis*) (total catch 3.3 t) and shovel-nosed spiny dogfish (*Deania calcea*) (2.8 t). Station positions and catch rates of orange roughy are shown in Figure 2, and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box survey biomass index for orange roughy was estimated using the Trawlsurvey Analysis Program (Vignaux 1994). Stratum 25 was excluded from the analysis as it was represented by only one station. The biomass of orange roughy in the survey area was estimated to be 164 073 t, with a c.v. of 17% (Francis *et al.* 1995).

The greatest concentrations of biomass were found at the western end of the box in depths of 750–949 m. Biomass estimates were highest for strata 1, 2, 7, 12, and 26, which together accounted for 72% of the total biomass in the box. By far the greatest concentration of biomass was found in stratum 26 in the 800–849 m depth range. Biomass estimates were lowest for shallower and deeper strata, particularly strata 6, 11, 13, 15, and 24 (Table 3).

## Size structure

Scaled length frequency distributions were calculated for orange roughy within the box (Figure 3). The distribution is strongly unimodal for both sexes with lengths ranging from 11 to 45 cm standard length (SL). Overall, females were larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.2 cm (*s.d.* = 2.1) and 34.3 cm SL (*s.d.* = 3.2), respectively. The sex ratio for orange roughy was even at 51% male (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## **Reproduction**

Gonad development of orange roughy was monitored throughout the survey. When sampling first began, male fish were mostly in the maturing stage and female fish mostly ripe or running ripe (Figure 4). Over the next 2 weeks these fish gradually spawned out and by the end of the survey over 80% of fish of both sexes were spent. With a reference point of 20% spent fish, peak spawning occurred between 20 and 21 July for both sexes. A clear peak of ripe and running ripe female fish was also evident around 15–16 July (Figure 4).

## **Feeding**

During the survey 2503 orange roughy stomachs were examined: 85% were empty and 12% were part full (Table 4). The most frequently occurring prey items in the 360 stomachs with identifiable prey were fish remains (171), crustacean remains (154), and coleoidean cephalopods (75) (Table 5).

## July 1985 (BUC8501)

### Objectives

1. To measure the relative abundance and distribution of orange roughy and other deepwater species in the survey area during the peak of the orange roughy spawning period.
2. To measure the coefficient of variation of abundance indices of orange roughy and to minimise this by conducting a two phase survey.
3. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
4. To determine (using a pelagic trawl) the nature of the midwater echo traces often seen near large catches of spawning orange roughy.
5. To measure (with the aid of net monitor transducers) the distance between trawl doors during the survey.
6. To collect depth-position data to improve knowledge of the bathymetry of the Chatham Rise.

### Voyage personnel

Skipper, T. Smith: voyage leader, D. A. Robertson

### Methods

#### Survey area and design

The survey covered the spawning box on the north Chatham Rise between longitudes 177° 30' W and 175° W and depths of 750 to 1250 m (*see* Figure 1).

A two-phase stratified random trawl survey (*after* Francis 1984) was used for the first time in this area. The two-phase design allows for a greater concentration of survey effort in strata which are shown, by analysis of phase 1 results, to have the greatest influence on the biomass index variance. The stratification was the same as that used in the 1984 survey (*see* Figure 1 and Table 6) and phase 1 of the survey used mostly the same stations occupied in 1984 (Appendix 5). For phase 2, new stations were assigned according to random depth and longitude coordinates. Length of tow was generally about 3 n. miles but ranged from 1.4 to 5.7 n. miles. Shorter tows were usually due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by SatNav.

## **Vessel and gear specifications**

The vessel used was FV *Otago Buccaneer*. Vessel and fishing gear specifications are given in Appendix 1.

## **Treatment of catch**

The catch was treated in the same manner as that from the 1984 survey with the addition that length and sex were also recorded when numbers of other commercial species, such as smooth oreo, spiky oreo (*Neocyttus rhomboidalis*), and hoki (*Macruronus novaezelandiae*), were caught.

## **Survey timetable**

*Otago Buccaneer* departed from Dunedin for the Chatham Rise on 4 July 1985. Fishing began on 6 July at the western end of the survey area and progressed generally eastwards for the next 2 weeks, following the methodology of the previous year's survey. On 12 July and 16 July midwater trawl gear was used to sample plumes of fish around the pinnacle area at 177° W. By 19 July the eastern boundary of the survey area had been reached and *Otago Buccaneer* turned and fished back westwards picking up stations missed on the first traverse. Between 21 and 25 July the vessel made 11 commercial tows in the western half of the box. The vessel left the fishing grounds on 26 July and arrived back in Dunedin on 28 July.

## **Biomass estimation**

Biomass indices were estimated using the methods described for the 1984 survey, except that the recorded distance was used for length of tow.

## **Biological analyses**

Biological analyses followed the methods described for the 1984 survey.

## **Bathymetry**

Depth and position data were recorded using the methods described for the 1984 survey.

## Results

During the survey 127 tows were completed, of which 2 were carried out with the fishing gear not performing to a standard satisfactory for biomass estimation. These stations (49 and 127) were excluded from all analyses. Stations 1 to 103 were phase 1 and 106 onwards phase 2.

Twelve of the tows were specifically commercial and landed 403 t of orange roughy. The catch composition from these stations was excluded from the survey results, but biological data (where recorded) were included in analyses.

Blown windows occurred at four stations (32, 50, 114, and 124) and recorded catches are minimum estimates for these. Orange roughy length frequency data were collected at all stations where orange roughy were caught. Orange roughy biological data were recorded at all but one station. The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 748 t. A full species list is given in Appendix 2.

### Distribution, catch rates, and biomass estimates

Orange roughy were caught in all parts of the box and at every station sampled. The highest catch rates (between 1 and 10 t.km<sup>-1</sup>) were made in the 850–950 m strata 2, 3, 7, 12, and 17, as well as in strata 3 and 26, with the highest catch rate of 11.0 t.km<sup>-1</sup> occurring at station 124 in stratum 7. Orange roughy were by far the most abundant species caught making up 97% of the total research catch. As in the 1984 survey, the next most abundant species were basketwork eels (3.4 t) and shovel-nosed spiny dogfish (2.3 t). Station positions and catch rates of orange roughy are shown in Figure 5, and catches of the more abundant bycatch and commercial species are given in Appendix 3.

Two pelagic tows were made through midwater echo traces to determine the nature of these marks. The first trawl, with the groundrope 30–40 m above the bottom, landed 20 t of orange roughy. Four days later a second tow was made and this, towed over a widely varying depth range, took a large mark with the gear about 200 m off the bottom. This landed 37 t with an estimated 10 t released to get the net on deck.

The spawning box survey biomass index for orange roughy was estimated using Trawlsurvey Analysis Program (Vignaux 1994). Strata 6 and 24 were excluded from the analysis as they were each represented by only one station. The biomass of orange roughy in the survey area was estimated to be 147 093 t, with a c.v. of 15% (Francis *et al.* 1995). This was a decrease in biomass of 10% from the previous year's estimate.

The biomass of orange roughy was concentrated in the 850–949 m strata 2, 7, 12, and 17, as well as stratum 3 (950–1049 m) which together made up over 70% of the estimate for the entire box. Strata which contributed least to the biomass of the survey area were generally toward the eastern boundary and in shallower or deeper water (Table 7).



## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 6). The distribution shows no change from the previous year, being strongly unimodal with fish size ranging from 12 to 45 cm SL. Overall, females were larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.4 cm (*s.d.* = 2.2) and 34.8 cm (*s.d.* = 2.2) SL, respectively. The sex ratio for orange roughy was again even at 50% male (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. Early in July, fish were mostly in the maturing stage with a few ripe fish present (Figure 7). As the month progressed the numbers of ripe fish increased, numbers of maturing fish decreased, and ultimately spent fish (particularly males) became more common in the samples. By the end of the survey male fish were mostly spent and female fish spent or ripe. With 20% spent fish as a reference point, peak spawning took place on about 20 July for males and 25 July for females.

## Feeding

During the survey 2463 orange roughy stomachs were examined, most of which (86.6%) had at most a trace or less of food in them (Table 8). The most frequently occurring prey items in the 339 stomachs with identifiable prey were natant decapods (180), fish remains (108), and coleoidean cephalopods (42) (Table 9).

## Other results

The distance between trawl doors was measured at eight stations using net monitor transducers. The doorspread for these stations ranged from 95 to 112 m with a mean of 101.5 m.

Two midwater trawls were made in areas where large midwater echosounder traces were found. The first, at 50 m above the bottom in 850 m of water, holed the net because of the weight of orange roughy in it, and although most of the catch was lost, 20.3 t of orange roughy and 94 kg of assorted bycatch was landed. The second trawl passed through a mark 120 m off the bottom and 37.5 t of orange roughy were landed with negligible bycatch.

## July 1986 (BUC8601)

### Objectives

1. To measure the relative abundance and distribution of orange roughy and other deepwater species in the survey area during the peak of the orange roughy spawning period.
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth.
3. To collect depth-position data to improve knowledge of the bathymetry of the Chatham Rise.

### Voyage personnel

Skipper, S. Collier: voyage leader, J. M. Fenaughty

### Methods

#### Survey area and design

The survey covered the spawning box on the north Chatham Rise between longitudes 177° 30' W and 175° W and depths of 750 to 1250 m (*see* Figure 1).

A two-phase stratified random trawl survey was used with the same stratification as in the previous survey (*see* Figure 1 and Table 10). Phase 1 of the survey used mostly the same stations occupied during phase 1 of the previous survey (*see* Appendix 5). For phase 2, new stations were assigned according to random depth and longitude coordinates. Length of tow was generally about 3 n. miles, but ranged from 1.4 to 4.1 n. miles. Shorter tows were usually due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by SatNav.

#### Vessel and gear specifications

The vessel used was FV *Otago Buccaneer*. Vessel and fishing gear specifications are given in Appendix 1.

#### Treatment of catch

The catch was treated in the same manner as that from the 1984 survey, with the addition that length and sex were also recorded when numbers of other commercial species, such as smooth oreo and hoki (*Macruronus novaezelandiae*), were caught.

## **Survey timetable**

*Otago Buccaneer* departed from Dunedin for the Chatham Rise on 4 July 1986. Fishing began on 6 July at the western end of the standard survey area. As with the previous 2 years, the survey progressed generally eastwards to the eastern boundary of the survey area over the next 12 days. Returning westwards, deeper stations which were left on the first traverse were sampled to complete phase 1 of the survey. The second half of July was spent completing phase 2 and commercial trawling in the western strata of the box. The last stations were completed on 26 July and staff disembarked at the Chatham Islands to fly home.

## **Biomass estimation**

Biomass indices were estimated using the methods described for the 1984 survey, except that the recorded distance was used for length of tow.

## **Biological analyses**

Biological analyses followed the methods described for the 1984 survey.

## **Bathymetry**

Depth and position data were recorded using the methods described for the 1984 survey.

## **Results**

During the survey 145 tows were completed, all with the fishing gear performing to a standard satisfactory for biomass estimation. Stations 1–132 were a combination of phase 1 and commercial tows, and stations 133–142 (R. I. C. C. Francis, NIWA, Wellington, unpublished results) phase 2.

Twenty-three of the tows were specifically commercial, netting an orange roughy catch of 703 t. The catch composition from these stations was excluded from the survey results, but biological data (where recorded) were included in analyses.

Blown windows occurred at stations 117 and 119 and recorded catches are minimum estimates for these. Orange roughy were caught at all but one station. Orange roughy biological data were collected at all stations where fish were caught and length frequency data collected at all but one of the stations where fish were caught. The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 442 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

Orange roughy were caught in all parts of the box and at all but one station sampled. High catch rates (over  $1 \text{ t.km}^{-1}$ ) were restricted almost entirely to strata west of  $176^\circ \text{ W}$ . Catch rates of over  $2 \text{ t.km}^{-1}$  were recorded in strata 1, 2, 7, 12, and 26 and the greatest catch rate was  $13.05 \text{ t.km}^{-1}$  at station 55 in stratum 12. Orange roughy were by far the most abundant species caught, making up 94% of the total research catch. The next most abundant species were shovel-nosed spiny dogfish (5.0 t total catch) and ribaldo (*Mora moro*) (2.7 t). Station positions and catch rates of orange roughy are shown in Figure 8, and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box survey biomass index for orange roughy was estimated using Trawlsurvey Analysis Program (Vignaux 1994). Strata 24 and 25 were excluded from the analysis as they were represented by one and zero stations respectively. The biomass of orange roughy in the survey area was estimated to be 103 367 t, with a c.v. of 16% (Francis *et al.* 1995). This was a decrease in biomass of 30% from the previous year's estimate.

The biomass of orange roughy was again concentrated in the 850–949 m strata 2, 7, 12, and 17, as well as stratum 1 (750–849 m) and stratum 9 (1050–1149 m). Strata 2, 7, and 12 alone made up almost 50% of the estimate for the entire box, while stratum 26, taking into account its smaller area, was one of the most densely populated areas of the box. Strata out of the optimum depth range (5, 6, 11, 14, 15, 19, and 20 in particular) contained few orange roughy (Table 11).

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 9). The size distribution is similar to that from the previous two surveys except that it shows a higher proportion of smaller fish (less than 30 cm SL). There is a strong mode again at 34–37 cm and a much weaker mode at about 26 cm. Fish size ranged from 7 to 45 cm. Overall, females were larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.6 cm (*s.d.* = 2.0) and 34.8 cm SL (*s.d.* = 2.2) respectively. The sex ratio for orange roughy slightly favoured males at 54% (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. Early in July fish were typically in the maturing stage with a small percentage in the ripe stage (Figure 10). This was reversed by the end of the survey (26 July) and spent fish were more common. The predominance of ripe and running ripe fish at the end of the survey suggests that spawning may have only just begun to peak or perhaps that spent fish were leaving the area. Although the 20% spent reference point was reached for males at around 20 July, for females this point was not reached during the survey

and the real spawning peak may not have been reached until a day or two after sampling ceased.

## **Feeding**

During the survey 2835 orange roughy stomachs were examined, of which 87.4% were empty (Table 12). The most frequently occurring prey items in the 346 stomachs with identifiable prey were fish remains (119), natant decapods (115), and coleoidean cephalopods (47) (Table 13).

## **June–August 1987 (BUC8701)**

### **Objectives**

1. Using a two-phase stratified random trawl survey, measure the distribution, abundance, and the variance of abundance of orange roughy on the north Chatham Rise, south Chatham Rise, and east Chatham Rise during the peak spawning period.
2. To investigate variation in the timing of spawning by conducting pre-survey and post-survey trawling within spawning box strata and during the latter to study the distribution of fish leaving the spawning area.
3. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
4. To sample fish marks located above the bottom in the spawning area with a pelagic trawl to ascertain the species composition and density of these schools.
5. To update the bathymetry of the spawning pinnacle area using the greater accuracy of the GPS (Global Positioning System) system.
6. To collect samples of orange roughy endolymphatic sacs to study changes over time in the cellular composition of the macula region and determine if there are daily microincremental ring structures in the otoliths.
7. To collect a sample of 300 orange roughy otoliths from both inside and outside the spawning area to assess whether there are any differences between rates of increment formation in the two populations.
8. To collect head and gut samples from the north and south Rise for parasite analysis as an indicator of possible stock differences.
9. To trawl with a fine mesh liner in an area where small fish have been determined to be present to collect samples for length frequency analysis.

### **Voyage personnel**

Skipper, S. Collier: voyage leader, J. M. Fenaughty

### **Methods**

#### **Survey area**

1. North Chatham Rise

This area comprised the spawning box between longitudes 177° 30' W and 175° W and between the 750 m and 1250 m isobaths (*see* Figure 1).

## 2. South Chatham Rise

This area comprised 4975 km<sup>2</sup> south and west of the Chatham Islands (closely matching what became subarea 6 in later surveys) where high commercial catch rates have been recorded (see Figure 1).

### Survey design

Three separate sub-surveys were made within the spawning box, with the same stratification as used in previous surveys (see Figure 1 and Table 14). The first began at the eastern boundary of the spawning box and progressed systematically to the western boundary. Station positions were assigned according to random depth and longitude coordinates. This traverse totalled 51 stations (2 per stratum). Then the standard two-phase stratified random trawl survey method was applied to the box. Stratum density was determined by weighting the number of stations per stratum according to previous research and commercial information. Phase 1 used mostly replicate stations occupied during the three previous surveys (see Appendix 5), and the 12 phase 2 stations were randomly generated. Three stations in high concentration areas were also sampled. The third sub-survey involved 47 random stations in a traverse running from west to east in an attempt to study the distribution of fish leaving the survey area. Length of tow was generally about 3 n. miles and ranged from 0.1 to 5.2 n. miles. Shorter tows were usually due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by SatNav or GPS.

The south Rise survey area was conducted in two parts. Pinnacles and other commercially fished areas (see Table 14) were sampled at the beginning of the survey (25 June) — a total of seven stations. These stations were surveyed again a month later (25 July). Thirty random stations were then allocated for the area.

The east Rise was surveyed after the first south Rise survey and before the box survey began. Nine stations were randomly allocated in orange roughy depths (see Table 14) but this area, like the south, was not stratified for biomass estimation.

### Vessel and gear specifications

The vessel used was FV *Otago Buccaneer*. Vessel and fishing gear specifications are given in Appendix 1.

### Treatment of catch

The catch was treated in the same manner as that from the 1984 survey with the addition that recordings of length and sex were also taken when numbers of other commercial species, such as smooth oreo, black oreo (*Allocyttus niger*), and hake (*Merluccius australis*), were caught. When catches of smooth oreo and black oreo were greater than about 1 t, detailed biological data were taken as for orange roughy.

## Survey timetable

*Otago Buccaneer* left Dunedin for the Chatham Rise on 23 June 1987. The known grounds on the south Rise were surveyed on 25 June followed by grounds to the east of the Chatham Islands on 26 June. The first traverse of the north Rise began on 27 June, moving from east to west and finishing on 4 July. The main spawning box area was surveyed over the next 17 days to coincide with the timing of previous surveys in that area. Some pelagic trawling was carried out (on 11 July) and a staff changeover was made at the Chatham Islands (15 July).

Phase 2 stations were sampled between 23 and 25 July, then the vessel steamed back to the south Rise to further survey those grounds. This survey was abandoned because of a combination of rough weather and rough (and uncharted) grounds and after steaming north again a final traverse of the northern Rise was made, this time in a general west to east direction, between 29 July and 3 August. On 3 August five tows were made with a fine-mesh codend liner for juvenile orange roughy. The vessel left the fishing grounds on 9 August with a full hold and arrived in Dunedin on the afternoon of 11 August.

## Biomass estimation

Biomass indices were estimated using the methods described for the 1984 survey, except that only stations occupied during the standard two-phase box survey (stations 68–180) were used, and the recorded distance was used for length of tow.

## Biological analyses

Biological analyses followed the methods described for the 1984 survey.

## Bathymetry

The bathymetry and boundaries of fish distribution around the spawning pinnacle area were accurately determined during a 3 day survey (21–23 July) using the GPS system. At this time GPS satellite coverage was available only for a few hours each day. About 12 hours were spent plotting depths and recording fish marks during this time.

## Results

During the survey 292 tows were completed, of which 2 were carried out with the fishing gear not performing to a standard satisfactory for biomass estimation. These stations (214 and 217) were excluded from all analyses. The first box sub-survey comprised stations 17–67, the standard two-phase box survey stations 68–180 (phase 1) and 192–203 (phase 2), and the final box sub-survey stations 218–245 and 251–



269. With the abandonment of the second part of the south Rise survey only 11 of the 30 stations allocated were occupied making a total of 18 stations for this area. On the east Rise nine stations were completed.

Forty-six of the trawls were specifically commercial and landed 1172 t of orange roughy. The catch composition from these stations was excluded from the survey results, but biological data (where recorded) were included in analyses.

Station 222 resulted in a blown window and the recorded catch is a minimum estimate. Orange roughy length frequency and biological data were recorded from all research stations where fish were caught and from all but six of the commercial tows. The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 799 t. A full species list is given in Appendix 2.

### **Distribution, catch rates, and biomass estimates**

Orange roughy were caught in all parts of the box and at all but three of the stations sampled. High catch rates (over 1 t.km<sup>-1</sup>) were recorded in many parts of the box, but not at all in the easternmost strata. Catch rates of over 2 t.km<sup>-1</sup> were recorded in strata 1, 2, 3, 7, 12, 17, and 26 and the greatest catch rate was 11.17 t.km<sup>-1</sup> at station 221 in stratum 1. Mean catch rates during the third box sub-survey were lower than those for the standard two-phase survey, 754 and 1208 kg.km<sup>-1</sup> respectively, but large variation in catch rates meant that this difference was not significant ( $P > 0.1$ ) and could not demonstrate post-spawning migration away from the spawning area.

Because the second part of the south Rise survey was abandoned, only 18 stations (mostly pinnacle shots between 178.5° W and 179.5° W) were completed in that area. Orange roughy were caught at all of these stations and although catch rates ranged widely overall (0.002–2.2 t.km<sup>-1</sup>), catch rates were over 1.0 t.km<sup>-1</sup> at seven stations. The greatest catch rate of 2.23 t.km<sup>-1</sup> was taken at station 215 near Mt. Kiso pinnacle. Smooth oreo were also caught at all south Rise stations with catch rates ranging from 0.054 to 6.2 t.kg<sup>-1</sup>. Catches greater than 1.0 t.km<sup>-1</sup> were made at six stations with the highest catch rate of 6.17 t.km<sup>-1</sup> occurring at station 209 near the Arrow Tow pinnacle. Although the final 11 stations were surveyed a month after the first 7, catch rates of orange roughy had not altered greatly. Catch composition, however, had shifted from a roughly even mix of orange roughy and smooth oreo in the first survey to being dominated by smooth oreo in the second. A change in the gonad condition of orange roughy (from predominantly ripe to predominantly spent) indicated that spawning had taken place between surveys, and possibly earlier than observed on the north Rise.

On the east Rise, nine tows were made with relatively low catches. Catch rates of orange roughy were generally less than 0.1 t.km<sup>-1</sup>, the highest being 0.17 t.km<sup>-1</sup> at station 15 near the Smiths City pinnacle complex. Station positions and catch rates of orange roughy are shown in Figures 11 and 12.

Orange roughy were by far the most abundant species caught during the survey and made up 82% of the total research catch. There was a large increase in the catch of smooth oreo, however, due to the extension of the survey area onto the south Rise, with 79 t caught. The next most abundant species were shovel-nosed spiny dogfish (11.4 t), Baxter's lantern dogfish (*Etmopterus baxteri*) (92 t), and black oreo (7.8 t).

Catches of the more abundant bycatch and commercial species are given in Appendix 3.

On 11 July two midwater tows were made with the pelagic trawl gear after strong midwater fish marks were located. The first, with the ground rope between 18 and 40 m above the bottom (at 820 m), yielded about 20 t of orange roughy. The second, on stronger marks with the ground rope between 15 and 38 m off the bottom (800 m), caught so much fish that the belly of the trawl burst, losing an unknown amount of fish. Twenty-five tonnes of orange roughy were recovered from the codend. Because of time lost with rough weather, no further pelagic trawling was carried out.

The spawning box survey biomass index for orange roughy was estimated using Trawlsurvey Analysis Program (Vignaux 1994). Strata 20 and 24 were excluded from the analysis as they were each represented by only one station. The biomass of orange roughy in the survey area was estimated to be 79 388 t, with a *c.v.* of 15% (Francis *et al.* 1995). This was a decrease in biomass of 23% from the previous year's estimate.

The biomass of orange roughy was again concentrated in the 850–949 m strata 2, 7, 12, and 17, as well as stratum 3 (750–849 m). These five strata accounted for over 64% of the estimate for the entire box. The smaller stratum 26 also had dense concentrations of fish. Strata out of the optimum depth range, particularly toward the east end of the box, contributed least to the biomass estimate (Table 15). Biomass indices were not calculated for the south Rise as too few stations were occupied.

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 13). The size distribution is strongly unimodal again and does not show the larger number of pre-recruits seen in the 1986 survey. Fish size ranged from 7 to 47 cm SL. Overall, females were again larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.7 cm (*s.d.* = 2.0) and 35.4 cm SL (*s.d.* = 1.9) respectively. The sex ratio for orange roughy was close to even at 52% males (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. Maturity data were analysed for each sex in the box strata (Figure 14). The survey this year covered the entire spawning period from 27 June, when most fish were in the maturing stage, through to early August, by which time most fish were spent. The peak spawning reference point of 20% spent occurred around 20 July for males and 22 July for females. The time at which the proportion of ripe fish peaks can also be used as a reference point and this occurred around 19 July for males and 22 July for females. The tight spread of these reference points suggests very synchronous spawning for this population of orange roughy this year and data from the surveys conducted before and after the standard two-phase box survey helped demonstrate that the timing of the survey was appropriate, as most of the spawning activity took place during the main survey (*see* Figure 14).

## Feeding

During the course of the survey 5728 orange roughy stomachs were examined: 84.5% were empty and 10.6% part full (Table 16). The most frequently occurring prey items in the 863 stomachs with identifiable prey were fish remains (351), natant decapods (228), coleoid cephalopods (154), and crustacean remains (123) (Table 17).

The stomach contents from about 350 fish from the northwest, northeast, and southern survey areas and five size classes (less than 20, 20–25, 26–30, 31–35, and over 36 cm) were collected and preserved in 10% formalin. The results are not reported here.

## Other results

In conjunction with a study of periodic structures in orange roughy otoliths, whole endolymphatic sacs were removed to study time series changes in the cellular composition of the macula over a period of 3 weeks. In a continuous 48 hour study, samples were taken from consecutive tows and fixed in neutral buffered glutaraldehyde. Subsequent microscopic and crystallographic studies provided some evidence that teleost otolith microincremental rings are laid down under central neural control, are related to diurnal processes, and therefore are produced daily (Gauldie & Nelson 1988).

A sample of 300 otoliths each from within and outside the spawning area was collected to assess whether there are any differences between rates of increment formation in the two populations. These otoliths were stored in 70% isopropyl alcohol and 5% glycerine and have yet to be read.

The heads and viscera of 200 orange roughy were collected from the northern survey area for parasite comparisons with a similar sample to be taken from the southern survey area, and for investigations into estimating asymptotic length from considering parasite loads as a function of fish length. The abandonment of the south Rise survey due to bad weather meant that this second sample was not collected, but parasite counts from the northern sample contributed to an independent estimate of  $L_{\infty}$  for orange roughy of 36.7 cm (Gibson & Jones 1993). Isopods from a number of oreos were also collected for taxonomic studies.

Using a fine (60 mm) mesh codend liner, five trawls were made on 3 August in an area where small fish (less than 30 cm) were thought to be most abundant. About 1500 fish were caught and their lengths recorded, but too few small fish were caught to be useful for analysis of size classes.

Net monitor transducers were attached to the trawl doors to measure doorspread at eight stations. The transducers worked well, recording average doorspreads during the tow ranging from 95 to 112 m. At five of the eight stations the average doorspread was recorded as 100 m.

## July–August 1988 (COR8801)

### Objectives

1. To measure abundance and variation of abundance, and to map the distribution of fish species (principally orange roughy) at depths between 750 and 1200 m within the spawning box.
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To collect head and viscera tissue samples from orange roughy for analysis of parasites, results to be compared with those from similar collections from other orange roughy fishing grounds as an indicator of stock differences.
4. To collect and chart details of the north Rise bathymetry and to map the distribution of high density spawning schools.
5. To collect orange roughy tissue samples (heart, liver, and muscle) and female gonad samples for genetic studies using electrophoresis.
6. To preserve orange roughy endolymphatic sacs to study changes over time in the cellular composition of the macula region and determine if there are daily microincremental ring structures in the otoliths.

### Voyage personnel

Skipper, G. Courtney: voyage leader, J. M. Fenaughty

### Methods

#### Survey area and design

This survey covered the spawning box on the north Chatham Rise between longitudes  $177^{\circ} 30' W$  and  $175^{\circ} W$  and depths 750 to 1250 m (*see* Figure 1).

A two-phase stratified random trawl survey method was used with the same stratification for the spawning box as in previous surveys (*see* Figure 1 and Table 18). Phase 1 of the survey used mostly the repeat stations occupied on previous surveys (*see* Appendix 5). Stratum 6 was further stratified during the survey as it contained both the main spawning area and a large area of ground on the extreme range of orange roughy depth preference (*see* Table 18 and Fenaughty & Grimes (1989)). Coordinates for the second-phase stations and extra first-phase stations (for the new strata) were randomly generated using the method described for the 1984 survey. After this survey, stratification of the previous surveys in the box was retrospectively altered to include the new stratum (26) within stratum 6, which as a result was reduced in size.

Length of tow was generally about 3 n. miles and ranged from 0.1 to 3.9 n. miles. Shorter trawls were due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by either SatNav or GPS.

## **Vessel and gear specifications**

FV *Cordella* was used for this survey for the first time. The specifications for this vessel and fishing gear are given in Appendix 1.

## **Treatment of catch**

The catch was treated in the same manner as that from the 1984 survey, with the addition that recordings of length and sex were also taken when numbers of smooth oreo were caught, and all orange roughy smaller than 16 cm SL were kept and frozen for ageing studies.

## **Survey timetable**

*Cordella* left Nelson on 11 July 1988 for the Chatham Rise. Fishing began on 13 July at the western end of the standard survey area. Phase 1 stations were occupied in the same order as in previous surveys, proceeding generally from west to east. About 7 days were taken up with commercial fishing and time lost because of bad weather. The survey was completed on 11 August and the vessel arrived back in Nelson on 13 August.

## **Biomass estimation**

Biomass indices were estimated using the methods described for the 1984 survey, except for the following adjustments.

1. The greater headline height of the *Cordella* net when compared to that of *Otago Buccaneer* would be expected to produce a larger catch when fish are schooling up above the bottom. To keep results comparable between vessels this was accounted for in Trawlsurvey Analysis Program by adjusting the vertical availability to a value greater than one for those stations where this behaviour was observed. As a result, the vertical availability at stations 118 and 119 was set to 1.418 (see Fenaughty & Grimes 1989).
2. The recorded distance was used for length of tow.

## Biological analyses

Biological analyses followed the methods described for the 1984 survey.

## Bathymetry

Depth and position data were recorded using the methods described for the 1984 survey, except that GPS was used in addition to SatNav for position fixing.

## Results

During the survey, 154 trawls were completed of which 1 was carried out with the fishing gear not performing to a standard satisfactory for biomass estimation. This station (109) was excluded from all analyses. The trawls included 126 random stations for biomass estimation (1–25, 27–50, 58–89, 92–102 in phase 1; 116–137, 142–153 phase in 2), 2 exploratory pinnacle tows, and 28 commercial tows. The catch composition from the commercial stations was excluded from the survey results, but biological data (where recorded) were included in analyses. The total commercial catch of orange roughy was 649 t.

Blown windows occurred at stations 7, 42, and 118 and recorded catches are minimum estimates with station 42 considered unsuitable for inclusion in the biomass estimation process. At all stations where fish were caught orange roughy length frequency and biological data were collected, and all orange roughy under 16 cm SL were frozen for ageing studies.

The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 549 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

Although orange roughy were caught in all parts of the box and at all but two of the stations sampled, high catch rates (over 1 t.km<sup>-1</sup>) were restricted to just four strata at the western end of the box. Catch rates of over 2 t.km<sup>-1</sup> were recorded in strata 2, 3, 7, and 26 and the greatest catch rate was 88.19 t.km<sup>-1</sup> at station 42 in stratum 26. Orange roughy were by far the most abundant species caught, making up 94% of the total research catch. The next most abundant species were shovel-nosed spiny dogfish (7.5 t total catch), long-nosed velvet dogfish, *Centroscymnus crepidater*, (4.5 t), and smooth oreo (3.4 t). Station positions and catch rates of orange roughy are shown in Figure 15, and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box survey biomass index for orange roughy was estimated using Trawlsurvey Analysis Program (Vignaux 1994). Stratum 20 was excluded from the analysis as it was represented by only one station. The biomass of orange roughy in the survey area was estimated to be 94 583 t, with a c.v. of 25% (Francis *et al.* 1995). This was an increase in biomass of 19% from the previous year's estimate.

The biomass of orange roughy was strongly concentrated in strata 2, 3, and 7, which together accounted for 75% of the biomass estimate for the box, and in stratum 26. Toward the eastern end of the box strata 17, 18, and 25 were the only areas to contribute significantly to the biomass (Table 19).

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 16). The size distribution is typically unimodal with fish ranging in size from 8 to 44 cm SL. Overall, females were again larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.4 cm (*s.d.* = 2.0) and 34.5 cm SL (*s.d.* = 2.0) respectively. The sex ratio for orange roughy (in the box) favoured males at 57% (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. The later start to this survey meant that spawning had begun before the fishing and proportions of maturing and ripe fish in the spawning box were initially almost equal (Figure 17). The survey continued well into August, by which time virtually all fish had spawned. The 20% spent reference point occurred at about 24 July for males and 26–27 July for females. The proportion of ripe fish peaked at about 21 July for males and 23 July for females.

## Feeding

A total of 2895 orange roughy stomachs was examined during the survey, of which 84.1% were empty (Table 20). The most frequently occurring prey items in the 446 stomachs with identifiable prey were fish remains (108), natant decapods (74), and coleoidean cephalopods (19) (Table 21).

## Other results

Depth and position data (using SatNav and GPS) were regularly recorded throughout the survey, particularly around features where fish were aggregating. Depths were plotted by hand directly on charts or recorded with position for later plotting (*see* Fenaughty & Grimes 1989).

Orange roughy tissue samples collected from this survey were frozen in liquid nitrogen and later used in genetic studies which helped to identify separate fish stocks around New Zealand, and also revealed (when compared to samples taken 6 years previously) that there had been a loss of genetic diversity in this species due to fishing pressure (Smith *et al.* 1991, 1996).

The heads and viscera from a number of orange roughy were collected for investigations into estimating asymptotic length from considering parasite loads as a function of fish length. Parasite counts from this sample contributed to an independent estimate of  $L_{\infty}$  for orange roughy of 36.7 cm SL (Gibson & Jones 1993).

One of the lower priority objectives of this survey was to collect orange roughy endolymphatic sacs for growth studies. Although there is no evidence that this was done, it is likely that it was but the samples were not required for the publication resulting from subsequent analysis of the previous year's samples (Gauldie & Nelson 1988).



## September–October 1988 (COR8802)

### Objectives

1. To measure abundance and variation of abundance, and to map the distribution of fish species (principally orange roughy) at depths between 750 and 1200 m over the entire Chatham Rise orange roughy grounds outside the winter spawning aggregation period.
2. To collect basic biological data from orange roughy, and to a lesser extent smooth and black oreo, for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To collect head and viscera tissue samples from orange roughy for analysis of parasites, results to be compared with those from similar collections from other orange roughy fishing grounds as an indicator of stock differences.
4. To collect and chart details of Chatham Rise bathymetry.
5. To collect orange roughy tissue samples (heart, liver, and muscle) and female gonad samples for genetic studies using electrophoresis.
6. To preserve orange roughy endolymphatic sacs to study changes over time in the cellular composition of the macula region.

### Voyage personnel

Skipper, B. Hardcastle: voyage leader, J. M. Fenaughty

### Methods

#### Survey area and design

This survey covered the north Chatham Rise from 174° 30' E to 173° 30' W, the east Chatham Rise, and the south Chatham Rise from 172° 30' E to 173° 30' W between depths of 750 and 1200 m (Figure 1).

The survey area was divided into eight sub-areas which were further divided into depth strata which varied with sub-area (*see* Figure 1 and Table 22 for details). Stations were randomly generated based on depth and longitude and were weighted by sub-area based on previous surveys and in favour of the two deeper strata. The survey was a two-phase design with phase 2 station allocation dependent on the catches in phase 1.

Length of tow was generally about 3 n. miles, but ranged from 0.3 to 5.9 n. miles. Shorter tows were usually due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by either SatNav or GPS.

## **Vessel and gear specifications**

The vessel used was *FV Cordella*. Vessel and fishing gear specifications are given in Appendix 1.

## **Treatment of catch**

The catch was treated in the same manner as that from the 1984 survey, with the addition that recordings of length, sex, and other biological data were also taken when numbers of smooth oreo and black oreo were caught.

## **Survey timetable**

*Cordella* left Wellington for the Chatham Rise on 9 September 1988. Fishing began on 10 September at the western end of the north Rise and progressed in a generally easterly direction along the north Rise, continuing southwards over the east Rise (east of the Chatham Islands) then westwards along the south Rise to the southwestern boundary of the survey area. Seven phase 2 tows were then made in sub-area 1 on the northwestern Rise to complete the survey on 2 October. The vessel arrived back in Wellington on 3 October.

## **Biomass estimation**

Biomass indices for the survey area were estimated using the methods described for the 1984 spawning box survey, except for the following adjustments.

1. The effective fishing width based on Scanmar readings was taken as 26 m.
2. The recorded distance was used for length of tow.
3. Stations were selected for inclusion in the biomass estimation process according to the following criteria.
  - Strata with no calculated area were not used (1E, 7A, 7B, 8A, 8B, 8C, 8S).
  - Strata represented by less than two stations were excluded.
  - Stations where gear performance during the tow was unsatisfactory were excluded.

## **Biological analyses**

Biological analyses followed the methods described for the 1984 survey, but the following should be noted.

1. Orange roughy and smooth oreo length frequency data were assimilated for the entire survey area, not just the spawning box.
2. Smooth oreo length frequencies were scaled in the same manner as those of orange roughy.

3. Gonad stages of smooth oreo followed the protocol used for orange roughy, i.e., Pankhurst *et al.* (1987).
4. As the survey was conducted outside the spawning season of both orange roughy and smooth oreo, change in gonad condition over time was not examined and instead gonad stage frequency overall was summarised for each species.

## Bathymetry

Depth and position data were recorded using the methods described for the 1984 survey, except that GPS was used in addition to SatNav for position fixing.

## Results

A total of 129 trawls was carried out during the survey: 122 phase 1 and 7 phase 2 stations. Orange roughy were caught at 100 of these stations, and smooth oreo at 119 stations. At all stations where orange roughy were caught, length frequency and biological data were collected. These data were also collected regularly from smooth oreo and black oreo, but not at all stations where they were caught. All but two of the random biomass tows were of a standard satisfactory for biomass estimation. These stations (2 and 74) were excluded from all analyses.

The total catch of all fish, molluscan, and crustacean species combined for the survey was 79 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

The total catch of orange roughy (13.9 t) was less than half that of smooth oreo (28.6 t) so some analysis of smooth oreo catch and biology is presented here. This result is in sharp contrast to spawning season surveys where orange roughy have accounted for up to 97% of the total survey catch (BUC8601) and where catches far greater than this total were commonly made in a single trawl. The next most abundant species were basketwork eels (3.5 t total catch) and black oreo (2.7 t). Station positions and catch rates of orange roughy and smooth oreo are shown in Figures 18 and 19, and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The highest catch rates of orange roughy were found along the northwest Rise and on the east Rise. In sub-areas 1 and 2 (*see* Figure 1) catch rates were variable but overall moderate with a mean of just over 80 kg.km<sup>-1</sup>. On the east and southeast Rise (sub-areas 7 and 8) mean catch rates were just under 80 kg.km<sup>-1</sup>. The only other areas to record moderate catches were in sub-area 6, where catch rates averaged 75 kg.km<sup>-1</sup>, and in the spawning box (mean of 65 kg.km<sup>-1</sup>). On the remainder of the south Rise (sub-areas 5, and 9–12) catches were consistently low with a mean of less than 4 kg.km<sup>-1</sup>. In the eight stations occupied in sub-area 11 no orange roughy were caught. The highest catch rate of orange roughy was 647 kg.km<sup>-1</sup> in stratum 3B (Figure 18).

Catches of smooth oreo were highest on the south Rise with catch rates of over  $1 \text{ t.km}^{-1}$  recorded in strata 6B (2), 8C, and 9C, where the highest catch rate ( $10.7 \text{ t.km}^{-1}$ ) was recorded (Figure 19).

The survey area biomass indices for orange roughy and for smooth oreo were estimated using Trawlsurvey Analysis Program (Vignaux 1994). Twenty-nine strata either represented by only one station or without calculated areas were excluded from the analyses. The biomass of orange roughy in the remainder of the survey area (three box strata and various parts of sub-areas 1–7 and 9–12) (Table 23) was estimated to be 16 640 t, with a *c.v.* of 17.6 %. A quarter of this biomass was concentrated in sub-area 6 on the south Rise, with most of the rest spread around the northwest Rise in sub-areas 1 to 4 (45 %) and the east Rise in sub-area 7 (10 %). The biomass of smooth oreo in the same area was estimated to be 85 267 t with a *c.v.* of 60.8 %. This large *c.v.* was partly the result of three large catches on the south Rise in strata 6B and 9C. These two strata combined contributed 89 % of the total biomass.

## Size structure

Scaled length frequency distributions for orange roughy and smooth oreo were calculated for the survey area. All strata represented by more than one station were included, except for 1E, 7A, 7B, 8A, 8B, 8C, and 8S for which no areas were calculated, preventing a proper weighting.

The size distribution of orange roughy suggests bimodality with a possible mode at about 29 cm and another at about 35 cm SL with fish ranging in length from 4 cm to 43 cm (Figure 20). Females were larger than males with means, derived from size distributions scaled to the total population, of 31.85 cm (*s.d.* = 5.26) and 30.51 cm SL (*s.d.* = 4.80) respectively. The sex ratio for orange roughy favoured females slightly at 54%.

Bimodality is also evident in the size structure of smooth oreo with a very sharp mode at 30 cm total length (TL) and another at 37–38 cm TL (*see* Figure 20). Fish ranged in size from 16 cm to 53 cm TL with mean lengths of 32.81 cm (*s.d.* = 5.27) for males and 32.88 TL (*s.d.* = 5.80) for females. Females (60%) were more common than males.

## Reproduction

A total of 1643 orange roughy gonads was examined during the course of the survey. Unlike the fish sampled from the spawning box in July, gonad condition remained stable throughout the survey. Nearly 85% of the male gonads and over 90% of the female gonads examined were in the immature/resting or early maturation stage. Most of the rest were still in a spent state from the recent spawning event (Table 24).

Smooth oreo gonad condition was also monitored and virtually all of the 628 fish examined were in the immature, early maturation, and maturation stages (*see* Table 24).

## Feeding

A total of 1671 orange roughy stomachs was examined during the course of the survey, of which nearly half contained prey and 43% were part full or full (Table 25). This result is in sharp contrast to orange roughy during spawning when typically 80–90% of stomachs have a trace or less of food in them (*see, e.g.,* Tables 4 and 8). Orange roughy appear to be far more active feeders outside spawning. Diet was, however, typical with fish found in over 50% of the 818 stomachs with identifiable prey, natant decapods in 11.1%, cephalopods in 8.2%, and euphausiids in 6.2% (Table 26).

## Other results

Orange roughy tissue samples were frozen in liquid nitrogen and later used in genetic studies which helped to identify separate fish stocks around New Zealand and also revealed (when compared to samples taken 6 years previously) that there had been a loss of genetic diversity in this species due to fishing pressure (Smith *et al.* 1991, 1996).

The heads and viscera from a number of orange roughy were collected for investigations into estimating asymptotic length from considering parasite loads as a function of fish length. Parasite counts from this sample contributed to an independent estimate of  $L_{\infty}$  for orange roughy of 36.7 cm SL (Gibson & Jones 1993).

## **July–August 1989 (COR8901)**

### **Objectives**

1. To measure abundance and variation of abundance, and to map the distribution of fish species (principally orange roughy) at depths between 750 and 1200 m within the standard spawning area and over the remainder of the orange roughy species range of the Chatham Rise.
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To collect and chart details of the Chatham Rise bathymetry and to map the distribution of high density spawning schools.
4. To collect female orange roughy gonads for genetic studies using electrophoresis.
5. To describe fish fauna and the changes in species composition with depth and area.

### **Voyage personnel**

Skipper, B. Hardcastle: voyage leader, J. M. Fenaughty

### **Methods**

#### **Survey area and design**

This survey covered the north Chatham Rise from 174° 30' E to 174° 30' W and the south Chatham Rise from 180° and 177° W between depths of 750 and 1250 m (*see* Figure 1).

The survey used the same stratification as previous surveys in the spawning box (*see* Figure 1 and Table 27). Phase 1 used mostly the repeat stations occupied during previous surveys (*see* Appendix 5), and phase 2 stations were assigned to strata based on phase 1 catches and random depth and longitude coordinates.

The extended survey area was divided into seven sub-areas (four on the north Rise, two on the south Rise, and one on the east Rise) which were further stratified by depth (*see* Figure 1 and Table 27).

Length of tow was generally about 3 n. miles, but ranged from 0.37 to 6.0 n. miles. Shorter tows were usually due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by either SatNav or GPS.

## **Vessel and gear specifications**

The vessel used for this survey was FV *Cordella*. Vessel and fishing gear specifications are given in Appendix 1.

## **Treatment of catch**

The catch was treated in the same manner as that from the 1984 survey with the following additions.

1. Recordings of length and sex were taken when numbers of other commercial species, such as smooth oreo, black oreo, and hoki, were caught.
2. When large catches of smooth oreo or black oreo were made, detailed biological data were taken as for orange roughy.
3. A sample of female orange roughy gonads was collected and frozen in liquid nitrogen to retain freshness for electrophoretic studies.

## **Survey timetable**

*Cordella* left Wellington for the Chatham Rise on 4 July 1989 and began trawling at the western end of the north Rise on 5 July and continued in this area until 9 July. The main spawning area two-phase survey began on 10 July and continued through to 5 August with a staff changeover at the Chatham Islands on 24 July.

The south Rise between 180° and 177° W was surveyed between 5 and 10 August, working from east to west, followed by some stations to the east of the spawning box. The last 4 days of the survey were spent fishing westward along the north Rise from 177° 30' W to 176° 30' E to complete the northwest Rise part of the survey. The vessel left the Rise on 17 August and arrived in Wellington on 18 August.

## **Biomass estimation**

Biomass indices were estimated using the methods described for the 1984 survey, except for the following adjustments.

1. The effective fishing width was taken as 26 m for areas outside the spawning box. For the spawning box survey and future spawning box surveys, the old estimate of 19 m was retained so that estimates would remain directly comparable between years.
2. The recorded distance was used for length of tow, and when this was not possible the start and finish positions were used.
3. Biomass was estimated separately for the area surveyed outside the box and therefore box strata were not included. Station selection otherwise used the same criteria as for the box biomass calculations.

4. At stations 26, 40, 56, and 78 the vertical availability was adjusted to 1.483 because of fish schooling up off the bottom (*see* the corresponding section in COR8801 for a fuller explanation, and note that this value differs from the one used in that survey because of a difference in the mean value of headline height calculated for each survey).

## Biological analyses

Biological analyses followed the methods described for the 1984 survey.

## Bathymetry

Depth and position data were recorded using the methods described for the 1984 survey, except that GPS was used in addition to SatNav for position fixing.

## Results

During the survey 240 trawls were carried out, 4 of which did not perform to a standard satisfactory for biomass estimation. These stations (9, 29, 47, and 192) were excluded from all analyses. Stations 26–30, 37–71, 76, 78–83, and 85–125 made up phase 1 of the spawning box survey, and stations 138–143, 145, 147–150, 156, and 160–172 phase 2. Orange roughy were caught at 225 stations, and at all of these length frequency and biological data were collected.

Forty-two commercial tows were carried out during the survey for a total orange roughy catch of 674 t. The catch composition from these stations was excluded from the survey results, but biological data (where recorded) were included in analyses.

The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 451 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

The distribution of orange roughy in the box was found to be a little less constricted than in the previous year's survey, with catch rates over 1 t.km<sup>-1</sup> in strata 2, 3, 7, 12, and 26, and greater than 2 t.km<sup>-1</sup> in strata 2, 3, 12, and 26. The greatest catch rate in the box was 9.35 t.km<sup>-1</sup> at station 26 in stratum 2.

On the south Rise good catches were made on the pinnacles Mt. Nelson and Trevs Pinnie and in stratum 6B. Orange roughy were caught at most stations, but catch rates were generally less than 100 kg.km<sup>-1</sup> in the other south Rise strata sampled.

On the northwest Rise catches were consistently low (less than 40 kg.km<sup>-1</sup>) in the area 1 substrata, but were higher in the 2, 3, and 4 substrata (up to 1.3 t.km<sup>-1</sup> in 2C).

Overall the highest catch rate was 20.00 t.km<sup>-1</sup> at station 206 on the south Rise pinnacle Mt. Nelson.



Orange roughy was again the most abundant species caught and made up 83% of the total research catch. The next most abundant species were smooth oreo (35.1 t total catch) and shovelnosed spiny dogfish (4.3 t). Station positions and catch rates of orange roughy are shown in Figure 21 (box) and Figure 22 (wide area), and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box and wide area survey biomass indices for orange roughy were estimated using Trawlsurvey Analysis Program (Vignaux 1994). All strata within the spawning box were adequately sampled for inclusion in the analysis, but four strata (4B, 4C, 4D, and 6D) were excluded from the wide area estimate as they were represented by only one station. The biomass of orange roughy in the spawning box was estimated to be 66 955 t, with a *c.v.* of 18% (Francis *et al.* 1995). This was a decrease in biomass of 29% from the previous year's estimate. This biomass was concentrated in strata 2, 3, 7, and 12, which together accounted for 60% of the biomass estimate for the box, and in stratum 26 which had the densest population of fish. The remainder was well spread throughout the box strata between the 850 and 1149 m contours (Table 28).

The biomass of orange roughy in the wide area (sub-areas 1–3, 5–7, and south Rise pinnacles, *see* Table 28) was estimated to be 188 036 t with a *c.v.* of 13.94 %. Strata 7B and 7C in the east Rise sub-area 7 accounted for 61 % of this biomass, while most of the rest was spread around sub-areas 2 (16 %), 3 (9 %), and 6 (7 %). Some strata in some sub-areas were not sampled and others were excluded from the analysis because of undersampling, and this must be taken into account when making comparisons between sub-areas and between years for the same sub-area and for the overall wide area biomass estimate.

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 23). The size distribution is unimodal and symmetrical with fish ranging in size from 12 to 46 cm SL. Overall, females were again larger than males with mean lengths, derived from size distributions scaled to the total population, of 36.2 cm (*s.d.* = 2.1) and 34.7 cm SL (*s.d.* = 2.0) respectively. The sex ratio for orange roughy (in the box) was even at 49% males (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. When first sampled on 10 July, fish in the spawning box were predominantly in the maturing stage and many were already ripe (Figure 24). By the end of the box survey (4 August) most fish had spawned, though about 30% of males were still in the ripe stage. Peak spawning, as described by a reference point of 20% spent fish, occurred around 23–24 July for both males and females. Using the peak of the proportion ripe curve as the reference point, peak spawning occurred around 22 July for both sexes. The closeness of these reference points suggests very synchronous spawning for this population of orange roughy in 1989.

## **Feeding**

A total of 4201 orange roughy stomachs was examined during the course of the survey, of which 78.5% were empty (Table 29). The most frequently occurring prey items in the 894 stomachs with identifiable prey were fish remains (491), natant decapods (272), and coleoidean cephalopods (97). Of the identifiable fish, macrourids were the most common and amongst the crustaceans amphipods, euphausiids, and mysids were well represented (Table 30).

## **June–August 1990 (COR9002)**

### **Objectives**

1. To measure abundance and variation of abundance, and to map the distribution of fish species (principally orange roughy) at depths between 750 and 1500 m within the standard spawning area and over the remainder of the orange roughy species range of the Chatham Rise. (Note the survey depth limit has been increased from 1250 to 1500 m).
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To collect female orange roughy gonads for genetic studies using electrophoresis.
4. To collect flesh samples of orange roughy for comparison of mercury levels in samples collected between 1979 and 1983 and the present.
5. To collect additional biological and length frequency information on oreos and other important fish species.
6. To describe fish fauna and the changes in species composition with depth and area.
7. To collect and chart details of the north Rise bathymetry and to map the distribution of high density spawning schools.
8. To collect female orange roughy gonad samples for fecundity estimation.

### **Voyage personnel**

Skipper, B. Hardcastle: voyage leader, J. M. Fenaughty

### **Methods**

#### **Survey area and design**

This survey covered the north Chatham Rise from 176° E to 173° 30' W (including the area east of the Chatham Islands) and the south Chatham Rise from 178° E to 177° W between depths of 750 and 1500 m (*see* Figure1).

The survey used the same stratification as previous surveys in the spawning box with the addition of five new strata along the northern boundary of the spawning box (*see* Figure 1 and Table 31). Phase 1 of the survey used mostly the repeat stations occupied during previous surveys (*see* Appendix 5), and phase 2 stations and stations in the new strata were assigned using random depth and longitude coordinates.

Length of tow was generally about 3 n. miles, but ranged from 0.15 to 4.79 n. miles. Shorter trawls were generally due to net monitor traces indicating high concentrations of orange roughy. Positions were fixed by either SatNav or GPS.

## Vessel and gear specifications

The vessel used for this survey was FV *Cordella*. Vessel and fishing gear specifications are given in Appendix 1.

## Treatment of catch

The catch was treated in the same manner as that from the 1984 survey, with the following additions.

1. When numbers of other commercial species, such as smooth oreo, black oreo, warty oreo (*Allocyttus verrucosus*), hoki, hake, alfonsino (*Beryx splendens*), and bluenose (*Hyperoglyphe antarctica*), were caught, samples were taken for recordings of length and sex.
2. When large catches of smooth oreo, black oreo, warty oreo, bluenose, alfonsino, and hake were made, detailed biological data were taken as for orange roughy.

## Survey timetable

*Cordella* left Wellington on 14 June for the west Chatham Rise. Fishing started on 15 June and the north Rise between 176° E and 177° 30' W was surveyed in an easterly direction finishing on 27 June. The vessel then steamed to the south Rise and surveyed this area between 28 June and 5 July. After this, trawling began in the spawning box to match the timing of the previous six surveys of this area. Stations in phase 1 were occupied in a similar order to previous surveys, moving in a generally west to east direction. The vessel steamed to Nelson on 10 July for refuelling and crew changeover, returning to recommence fishing on 16 July. The standard area survey was completed by 31 July, at which point the vessel moved east to complete 12 stations on the east and northeast Rise to finish trawling on 5 August. The vessel then left the fishing grounds and arrived back in Wellington on 6 August.

## Biomass estimation

Biomass indices were estimated using the methods described for the 1984 survey, with the following adjustments.

1. The effective fishing width was taken as 26 m for areas outside the spawning box.
2. The recorded distance was used for length of tow, and when this was not possible the start and finish positions were used.
3. Biomass was estimated separately for the area surveyed outside the box and therefore box strata were not included. Station selection otherwise used the same criteria as for box biomass estimates.
4. At stations 127, 160, 248, and 264 the vertical availability was adjusted to 1.380 because of fish schooling up off the bottom (*see* the corresponding section in

COR8801 for a fuller explanation, and note that this value differs from that used in previous *Cordella* surveys because of a difference in the mean value of headline height calculated for each survey).

5. The five new box strata were not used in the calculation of the biomass indices for the box.

## Biological analyses

Biological analyses followed the methods described for the 1984 survey.

## Bathymetry

Depth and position data were recorded using the methods described for the 1984 survey, except that GPS was used in addition to SatNav for position fixing.

## Results

During the survey 281 trawls were carried out, of which 3 did not perform to a standard satisfactory for biomass estimation. These stations (52, 218, and 192) were excluded from all analyses. Stations 127–156 and 158–250 constituted phase 1 of the spawning box survey and stations 251–269 phase 2. One specifically commercial trawl (station 157) was made for orange roughy with a catch of 26.7 t, and while this was excluded from analysis of catch composition, biological data were recorded and used in summaries. Orange roughy were caught at 259 stations, and at all of these length frequency and biological data were collected.

The total catch of all fish, molluscan, and crustacean species combined for the survey (research stations only) was 428 t. A full species list is given in Appendix 2.

## Distribution, catch rates, and biomass estimates

Orange roughy were caught in all parts of the spawning box, but tows with catch rates of over 1 t.km<sup>-1</sup> were few and were restricted to strata 2, 4, 12, and 26 in the west. The greatest catch rate in the box was 11.99 t.km<sup>-1</sup> at station 264 in stratum 12. Catch rates in the eastern box strata were relatively low, as expected. In the new box strata in 1250–1499 m catches were variable from a few fish per tow to almost 1 t.km<sup>-1</sup> at one station in stratum 5X. In the three eastern deep strata (15X, 20X, and 25X) catches were less than 25 kg.km<sup>-1</sup>.

On the south Rise, good catches were again made on the pinnacles sampled during last year's survey, Kiso (maximum catch rate 6.5 t.km<sup>-1</sup>) and Mt. Nelson (maximum catch rate 3.1 t.km<sup>-1</sup>), in particular, and also Trevs Pinnie. Catches in the 5 and 6 substrata were otherwise very low (less than 40 kg.km<sup>-1</sup>) except at one station in 6B which produced a catch rate of 190 kg.km<sup>-1</sup>.

Orange roughy were widely spread throughout the northwest Rise, but of the 78 stations occupied in the 2, 3, and 4 substrata, only 1 (in stratum 4B) produced a catch rate greater than  $100 \text{ kg.km}^{-1}$ . Catches on the east Rise were consistent and ranged from 0.1 to  $1.0 \text{ t.km}^{-1}$ .

Stations sampled in strata 7C, 7D, and 7E on the east Rise also produced catch rates of less than  $100 \text{ kg.km}^{-1}$ , except for one station in 7D where  $386 \text{ kg.km}^{-1}$  were caught.

The highest catch rate outside the box was  $6.5 \text{ t.km}^{-1}$  at station 117 on the south Rise pinnacle Kiso.

Orange roughy were the most abundant species caught, making up 72% of the total research catch. The next most abundant species were shovel-nosed spiny dogfish (7.5 t total catch), long-nosed velvet dogfish (4.5 t), and smooth oreo (3.4 t). Station positions and catch rates of orange roughy are shown in Figure 25 (box) and Figure 26 (wide area), and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box and wide area survey biomass indices for orange roughy were estimated using Trawlsurvey Analysis Program (Vignaux 1994). All strata within the spawning box were adequately sampled for inclusion in the analysis, but stratum 4E on the north Rise was excluded from the wide area survey analysis as only one station was occupied.

The biomass of orange roughy in the spawning box was estimated to be 37 780 t, with a *c.v.* of 19% (Francis *et al.* 1995). This was a decrease in biomass of 44% from the previous year's estimate. The biomass was not as concentrated as in previous years, with strata 2, 12, and 26 containing 53% of the total and strata 3, 4, and 7 contributing 25%. The densest population of fish was in stratum 26 (Table 32).

Biomass in the wide area (sub-areas 2–7 plus south Rise pinnacles, *see* Table 32) was estimated to be 26 187 t, with a *c.v.* of 27.1%. The three sub-area 7 strata accounted for 45% of this, and the remainder of the biomass was distributed evenly over the other sub-areas and pinnacles. Sub-areas 2 and 5 generally had fewer fish, together contributing only 5% of the wide area biomass.

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 27). The size distribution is unimodal and symmetrical with fish ranging in size from 10 to 46 cm SL. Overall, females were again larger than males with mean lengths, derived from size distributions scaled to the total population, of 35.8 cm (*s.d.* = 2.3) and 34.4 cm SL (*s.d.* = 2.1) respectively. The sex ratio for orange roughy (in the box) slightly favoured males at 54% (Francis *et al.* 1995). Length-weight regression coefficients were calculated and are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. Although the box survey began relatively early (6 July), there were already equal numbers of maturing and ripe female orange roughy. Male fish were mostly in the

maturing state at this time (Figure 28). Spawning progressed in typical fashion, except that the timing was slightly different for each sex. Using the 20% spent fish and peak of the proportion ripe curve reference points, female fish reached peak spawning at about 18 July and 16 July and male fish at about 24 July and 20 July, respectively. By the end of July, when the spawning box survey was completed, most fish were spent, except for about 20% of males which were still in the ripe stage.

## Feeding

A total of 4633 orange roughy stomachs was examined during the course of the survey: 80.2% were empty and 12.1% contained a trace of food (Table 33). The most frequently occurring prey items in the 912 stomachs with identifiable prey were fish remains (441), natant decapods (289), coleoidean cephalopods (61), and crustacean remains (60) (Table 34).

## Other results

Flesh samples for measurement of mercury levels were taken from 117 orange roughy between 23 and 42 cm SL, selected at random from 20 stations. Mercury levels ranged from 0.15 to 0.86 mg.kg<sup>-1</sup> (unpublished data held on NIWA, Wellington "heavy metals" database).

Female gonad samples were collected and frozen in liquid nitrogen to retain freshness for electrophoretic studies, though these samples were ultimately not required. A further sample of female gonads was collected and frozen for later estimation of fecundity (*see Clark et al. 1994*).

Weights and ring counts from otoliths collected during this survey were used to update life history parameters for the 1993–94 ORH 3B stock assessment (*see Francis et al. 1993*).

## June–July 1992 (TAN9206)

### Objectives

1. To measure abundance and variation of abundance, and map the distribution of orange roughy and associated fish species at depths between 750 and 1500 m within the standard spawning area as surveyed since 1984 and over the remainder of the orange roughy species range of the Chatham Rise as surveyed in 1989 and 1990.
2. To collect basic biological data from orange roughy for analysis of size structure, reproductive state, diet, and growth, retaining samples of otoliths for ageing.
3. To estimate the percentage of recruited orange roughy not spawning during the 1992 season.
4. To collect additional biological and length frequency information on oreos and other important fish species.
5. To describe fish fauna and the changes in species composition with depth and area.
6. To collect and chart details of the north Rise bathymetry and to map the distribution of high density spawning schools.
7. To collect female orange roughy gonads for genetic studies using electrophoresis.
8. To determine, describe, and illustrate orange roughy embryological stages, measure and describe development rate and its temperature dependence, and measure and describe vertical depth distribution of egg stages in the plankton.
9. TVNZ to film all aspects of the survey and life on board for a “Country Calendar” programme.

### Voyage personnel

Skippers, part 1, R. Goodison; part 2, A. Leachman; voyage leader, J. M. Fenaughty

### Methods

#### Survey area and design

This survey covered the north Chatham Rise from 176° E to 173° 30' W (including the area east of the Chatham Islands) and the south Chatham Rise from 178° E to 173° 30' W between depths of 750 and 1500 m (*see* Figure 1).

A stratified random trawl survey along the northern Chatham Rise, including the standard spawning area, used the same stratification as previous surveys (*see* Figure 1 and Table 35). In an attempt to reduce the variance of catch rates by minimising the time lapse between occupation of phase 1 and phase 2 stations, the box survey was split into two parts. The first part was a single phase survey in strata which previously had low fish densities (strata 5, 10, 15, 16–25, and the new deep strata), and the second was a two-phase survey of the remaining strata. The first survey and phase 1



of the second used mostly the repeat stations occupied during previous surveys (see Appendix 5), and phase 2 stations were assigned using random depth and longitude coordinates.

In addition, known commercial fishing areas based on drop-offs and pinnacles were sampled along the southern Chatham Rise using randomly assigned stations.

Trawling was carried out as close as possible to the generated depth for the length of the tow. Length of tow was generally 3 n. miles, but ranged from 0.4 to 5.19 n. miles (excluding one exploratory pinnacle tow of 8.95 n. miles). Shorter trawls were generally due to net monitor traces indicating high concentrations of orange roughy. On the last 2 days of the survey tow lengths were reduced to 2 n. miles because of heavy catches. Positions were fixed by GPS.

When trawling operations ceased because of fish processing requirements, and at other convenient times, plankton tows were made in a random fashion in high density fish areas.

## Vessel and gear specifications

RV *Tangaroa* was used for this survey for the first time. The specifications for this vessel and its fishing gear are given in Appendix 1.

## Treatment of catch

The catch was treated in the same manner as that from the 1984 survey, with the following additions.

1. When numbers of other commercial species, such as smooth oreo, black oreo, and deepsea cardinalfish (*Epigonus telescopus*), were caught, samples were taken for recordings of sex and length.
2. Detailed biological data as for orange roughy were also taken from larger catches of smooth oreo and black oreo.
3. Otoliths were stored dry.

## Survey timetable

*Tangaroa* left Wellington for the Chatham Rise on 1 June 1992. Fishing began on the south Rise on the afternoon of 2 June. The survey proceeded eastwards from here following the contour of the Rise as far north as 44° S. Between 16 and 24 June the northwest Rise was surveyed in a westward direction starting at 177° 30' W, with the vessel steaming to the Chathams early in this period to get medical attention for an injured crew member. Part one of the survey completed, the vessel steamed to Wellington for maintenance, repairs, reprovisioning, and crew changeover.

On 27 June the vessel left Wellington and began the northeast Rise (north of 44° S) survey on 30 June, moving westwards. This was followed by the survey of the standard spawning area between 7 and 25 July. On 7 July the egg/larval and "Country Calendar" teams were uplifted from Owenga at the Chatham Islands and their projects

run at the same time. By 25 July the survey was completed and the vessel steamed for Wellington arriving on the afternoon of 27 July.

## **Biomass estimation**

Biomass indices were estimated using the same methods described for the 1984 survey, with the following adjustments.

1. The effective fishing width was taken as 26 m for areas outside the spawning box.
2. The recorded distance was used for length of tow, and when this was not possible the start and finish positions were used.
3. Biomass was estimated separately for the area surveyed outside the box and therefore box strata were not included. Station selection otherwise used the same criteria as for the box biomass estimates.
4. The five deep box strata were not used in the calculation of the biomass indices for the box.

## **Biological analyses**

Biological analyses followed the methods described for the 1984 survey.

## **Embryology**

Eggs obtained from plankton sampling and from strip fertilising running ripe orange roughy caught during trawling were cultured under controlled water temperature conditions. Water temperatures were varied to emulate temperatures experienced by the eggs at different positions in the water column. At regular intervals eggs were removed from the experiment, photographed, and preserved in formaldehyde for later description and drawing.

## **Plankton sampling**

The vertical distribution of orange roughy eggs was studied using a multiple opening-closing net (MOCNESS). MOCNESS tows to the depth of spawning orange roughy were made over the spawning area. Nine nets were deployed sequentially on each tow, stratified evenly over the water column. For the duration of operation of each net, depth, temperature, conductivity, and position data were automatically logged by the MOCNESS system. Samples were preserved in 4% formaldehyde.

## Bathymetry

Depth position data were routinely collected by the “SeaPlot” system at each 3 m depth change. Pinnacles and drop-offs sampled were more intensively surveyed and contoured. In particular, less well known bathymetry to the east of the Chatham Islands was intensively studied.

## Results

During the survey 281 tows were completed, of which 5 were considered not satisfactory for inclusion in the biomass estimation process. These stations (15, 41, 50, 116, and 134) were excluded from all analyses. Stations 1–154 were outside the box on the south, east, and northwest Rise. Within the box, the deep (greater than 1150 m) and west strata were covered by stations 155–212, and the remaining strata by stations 213–263 (phase 1) and 264–281 (phase 2). Orange roughy were caught at 269 stations, and at all of these length frequency and biological data were collected. The total catch of all fish, molluscan, and crustacean species combined for the survey was 402 t. A full species list is given in Appendix 2.

### Distribution, catch rates, and biomass estimates

Orange roughy were found in all parts of the spawning box, but only four tows with catch rates of over 1 t.km<sup>-1</sup> were made, in strata 2 and 7, between the 850 and 950 m depth contours. The highest catch rate in the box was 16.2 t.km<sup>-1</sup> at station 264 in stratum 2. The deeper strata instituted in last year's survey were all sampled, but no tows produced more than 30 kg.km<sup>-1</sup>. Catch rates in the rest of the box strata were uniformly low, mostly less than 100 kg.km<sup>-1</sup>.

Pinnacle tows were carried out at 38 stations on the south and east Rise (*see* Table 26 for details), a number of which produced good catches. On the east Rise, in particular, several catches of over 3 t.km<sup>-1</sup> were made, the highest being 41.4 t.km<sup>-1</sup> in the Sir Michael complex.

Orange roughy were widely spread throughout the northwest Rise in similar concentrations to the previous year with only 2 of the 60 stations in sub-areas 2, 3, and 4 (in strata 3B and 4B) producing catch rates greater than 100 kg.km<sup>-1</sup>.

The east Rise was well sampled with multiple stations in all strata of sub-area 7. Catches were low to moderate, with most stations producing catch rates of less than 100 kg.km<sup>-1</sup> with the highest catch rate of 330 kg.km<sup>-1</sup> achieved in stratum 7C.

Orange roughy were the most abundant species caught making up 54% of the total research catch. Smooth oreo accounted for 28% and black oreo 5% of the total catch. Station positions and catch rates of orange roughy are shown in Figure 29 (box) and Figure 30 (wide area), and catches of the more abundant bycatch and commercial species are given in Appendix 3.

The spawning box and wide area survey biomass indices for orange roughy were estimated using TrawlSurvey Analysis Program (Vignaux 1994). All strata within the spawning box were adequately sampled for inclusion in the analysis. The biomass of

orange roughy in the survey area was estimated to be 29 011 t, with a *c.v.* of 34% (Francis *et al.* 1995). This was a decrease in biomass of 23% from the previous year's estimate.

The biomass of orange roughy in the spawning box was concentrated mainly in strata 2 and 7, which held about 66% of the biomass of the box, with stratum 3 and, unusually, strata 22 and 23 being the next most important. Stratum 26 also had a dense population of fish (Table 36). In the wide area survey no strata were excluded from analysis because of undersampling, and biomass was estimated for sub-areas 2, 3, 4, and 7 for a total estimate of 22 655 t (*c.v.* 15.4 %). Sub-area 7 contributed 43% of this total, with the remainder spread over the northwest Rise strata (Table 36).

## Size structure

Scaled length frequency distributions for orange roughy were calculated for the box overall (Figure 31). The size distribution is unimodal, but pre-recruit fish (less than 30 cm SL) are better represented than in previous surveys in the box. Fish ranged in size from 2 cm to 47 cm SL. Overall, females were again larger than males with mean lengths, derived from size distributions scaled to the total population, of 37.0 cm (*s.d.* = 2.1) and 34.5 cm SL (*s.d.* = 2.4) respectively. The sex ratio for orange roughy (in the box) favoured females strongly with only 28% males (Francis *et al.* 1995). This was an unexpected result in light of consistently even sex ratios (range 49% to 57% males) in all previous surveys in the area. Length-weight regression coefficients are given in Appendix 4.

## Reproduction

Gonad development of orange roughy was monitored throughout the survey. As in the previous year, ripe female fish were present in similar numbers to maturing females in the spawning box early in July (Figure 32). The proportion of ripe fish of both sexes was quite erratic throughout the month and showed no clear peak. Using the 20% spent fish reference point, peak spawning occurred around 18 July for males and 14 July for females.

## Embryology and plankton sampling

The MOCNESS net was deployed seven times. This was enough to provide good information on the depth distribution of eggs of different ages, to enable egg stages to be identified and described, and to provide enough viable eggs for culture experiments. This enabled a detailed account of the development and vertical distribution of orange roughy eggs in the water column (Zeldis *et al.* 1994), and later the determination and complete description of the 29 developmental stages of the eggs, as well as early larval stages, of orange roughy (Grimes *et al.* in press). The ability to age orange roughy eggs has been central to the development of egg production methods of biomass estimation currently in use in New Zealand's orange roughy fisheries.

## Feeding

During the survey 5238 orange roughy stomachs were examined: 71.6% were empty and 15.3% were part full (Table 37). The most frequently occurring prey items in the 1473 stomachs with identifiable prey were crustacean remains (853), fish remains (563), and coleoidean cephalopods (91) (Table 38).

## Other results

Orange roughy tissue samples collected from this survey were frozen in liquid nitrogen and later used in genetic studies which helped to identify separate fish stocks around New Zealand (Smith *et al.* 1996).

Because of a perception that the spawning fraction of recruited orange roughy had been dropping over recent years, the percentage of orange roughy of recruited length (32 cm SL or over) in spawning condition was calculated from staged length frequency records. Within the spawning box, 88% of males and 89% of females of recruited length were in a gonad state indicating that spawning would take place that season. This was identical to the values calculated for 1990, but less than those for 1989 when 95% of males and 97% of females were in spawning condition.

The TVNZ staff on board successfully filmed many aspects of the survey and produced a programme "Orange roughy" which screened on television some months after the voyage.

## Discussion

This time series of trawl surveys is unique in that over a period of 8 years it closely monitored a large and valuable fishery from an almost virgin population through the fishdown phase and beyond. The time series survey data have contributed to every stock assessment for Chatham Rise orange roughy and have therefore played a key role in the management decisions for this fishery. Assessments have shown that a virgin biomass estimated to be over 400 000 t was reduced by an estimated 79–86% over this time (Francis *et al.* 1993). In terms of the primary objective, measuring changes in abundance of orange roughy on the Chatham Rise, the surveys were successful.

Although three vessels were involved in the time series, the spawning box was surveyed in a repeatable manner, producing relatively precise indices of biomass. As the fishery progressed, however, and the stock size was reduced, the pattern of distribution of fish changed within the spawning box so that the stock was less evenly spread. This resulted in more variable catch rates and therefore less precise biomass estimates, so imprecise that ultimately the time series of full spawning box trawl surveys was discontinued.

This reduction in stock size of orange roughy on the Chatham Rise contributed to a substantial change of tactics in the commercial fishery. Since 1989 there has been increasingly less fishing effort in the spawning box and more around hill complexes, particularly on the east Rise and northwest Rise (Francis *et al.* 1993) where large aggregations of fish were found. The survey tactics changed to match, evolving from a survey of just the spawning box from 1984 to 1986, to a survey which included part of the south and east Rise in 1987, to the additional survey covering all flat areas of the Chatham Rise in 1988, and finally to surveys covering virtually all the north Rise flat area, the main south Rise grounds, and the spawning box in each of the last three years 1989, 1990, and 1992. The last two surveys included grounds on the east Rise, particularly in 1992, when a number of pinnacles were surveyed.

Another change in the survey method was the inclusion of six deeper strata (1250–1500 m) across the spawning box in 1990 and 1992 to ensure that fish residing in these depths yet to migrate upwards to spawn were included. Moderate catches (up to 5 t per tow) were recorded from a few stations in these strata in the 1990 survey, but very few orange roughy were caught in the same strata in 1992.

Evidence of migration of fish during the survey, both to and from the spawning box and between strata within the spawning box, was also the reason for redesigning the box survey for the 1992 voyage (R. I. C. C. Francis, NIWA, Wellington, unpublished results).

In order that the surveys would accurately reflect changes in population parameters over time, it was important that the surveys were timed to match as closely as possible the spawning period of orange roughy in the spawning box. If the survey was too early (or too late) then fish still migrating towards or away from the area (*see* Coburn & Doonan 1994) would not be available to the survey method, resulting in an underestimate of stock size. Analysis of gonad stage data showed that peak spawning did occur at some point during each spawning box survey, except in 1986 when the survey may have finished just on or before peak spawning. Despite this the timing of

spawning was remarkably consistent over the 8 years of the series with peak spawning consistently occurring between 14 and 27 July.

The biomass surveys gathered a variety of additional information, as detailed in the survey objectives. Generally these secondary objectives were well met, resulting in improved knowledge of population parameters of orange roughy and other commercial species, of stock boundaries, diet, fecundity, development, ageing, as well as a vast amount of data relating to the distribution and abundance of many bycatch species, both commercial and non-commercial, including one or two species new to science.

Knowledge of the bathymetry of the Chatham Rise was also greatly improved, through the development of precise navigation systems and continuous recording of depth throughout each survey.

## Acknowledgments

We thank the officers and crew of FV *Otago Buccaneer*, FV *Cordella*, and RV *Tangaroa*, all the scientific staff who provided support at sea, and Don Robertson, survey leader on the first two voyages. Malcolm Clark, Dianne Tracey, and Chris Francis helped with advice and data and Paul Grimes, Dave Banks, Peter McMillan, Paul Breen, and Rosie Hurst made helpful comments on the manuscript.

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**Table 1: Summary of survey details 1984 to 1995**

Year	Vessel	Voyage code	Start date	Finish date	No. of stations	No. of research stations in "box"
1984	<i>Otago Buccaneer</i>	BUC8401	9 Jul	29 Jul	132	131
1985	<i>Otago Buccaneer</i>	BUC8501	6 Jul	26 Jul	127	115
1986	<i>Otago Buccaneer</i>	BUC8601	6 Jul	26 Jul	145	143
1987	<i>Otago Buccaneer</i>	BUC8701	25 Jun	9 Aug	292	214
1988	<i>Cordella</i>	COR8801	13 Jul	11 Aug	154	126
1988	<i>Cordella</i>	COR8802	10 Sep	3 Oct	129	13
1989	<i>Cordella</i>	COR8901	5 Jul	17 Aug	240	153
1990	<i>Cordella</i>	COR9002	15 Jun	5 Aug	281	143
1992	<i>Tangaroa</i>	TAN9206	1 Jun	25 Jul	281	128
Total					1 781	1 153

**Table 2: Strata descriptions and areas (BUC8401)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description (spawning box, ° W)	Depth (m)
0001	320.9	3	177.5–177.0	750–849
0002	173.7	4	177.5–177.0	850–949
0003	139.7	3	177.5–177.0	950–1 049
0004	137.6	3	177.5–177.0	1 050–1 149
0005	126.7	3	177.5–177.0	1 150–1 249
0006	200.2	2	177.0–176.5 <sup>1</sup>	750–849
0007	207.9	9	177.0–176.5	850–949
0008	181.4	7	177.0–176.5	950–1049
0009	159.3	2	177.0–176.5	1 050–1 149
0010	153.9	3	177.0–176.5	1 150–1 249
0011	357.0	4	176.5–176.0	750–849
0012	209.9	4	176.5–176.0	850–949
0013	167.5	6	176.5–176.0	950–1 049
0014	158.7	3	176.5–176.0	1 050–1 149
0015	120.6	3	176.5–176.0	1 150–1 249
0016	527.4	4	176.0–175.5	750–849
0017	274.9	10	176.0–175.5	850–949
0018	213.2	5	176.0–175.5	950–1049
0019	179.9	3	176.0–175.5	1 050–1 149
0020	160.5	3	176.0–175.5	1 150–1 249
0021	555.8	4	175.5–175.0	750–849
0022	406.1	10	175.5–175.0	850–949
0023	323.5	10	175.5–175.0	950–1 049
0024	229.9	3	175.5–175.0	1 050–1 149
0025	156.7	1	175.5–175.0	1 150–1 249
0026 <sup>2</sup>	33.0	2	177.0–176.75	800–849

## Non-biomass/commercial stations

Spawning box (commercial)	17
Northeast Rise (exploratory)	1

<sup>1</sup> Excluding the area defined by stratum 26.<sup>2</sup> Stratum defined retrospectively (see text).

**Table 3: Biomass of orange roughy by stratum**

Stratum	Biomass (t)	c. v. (%)
1	21 482	99
2	30 332	35
3	5 622	45
4	5 115	11
5	1 978	40
6	117	100
7	32 306	37
8	6 340	76
9	2 025	60
10	587	28
11	223	51
12	21 470	31
13	506	26
14	673	47
15	486	26
16	845	55
17	9 442	48
18	1 243	46
19	1 372	33
20	727	18
21	1 460	39
22	5 896	41
23	887	11
24	539	33
25	0	-
26	12 398	3
Total	164 073	17

**Table 4: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	85.2	2 132
Trace	0.0	0
Part-full	11.9	297
Full	2.8	69
Everted	0.2	5
<i>n</i>		2 503

**Table 5: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Amphipoda	1	0.3
Mysidacea	3	0.8
Crustacean remains	154	42.8
Mollusca		
Cephalopoda Coleoidea	75	20.8
Pisces		
Fish remains	171	47.5
Thaliacea		
Salpidae	2	0.6
Unidentified	3	0.8

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 360.

**Table 6: Strata descriptions and areas (BUC8501)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description (spawning box, ° W)	Depth (m)
0001	320.9	3	177.5–177.0	750–849
0002	173.7	6	177.5–177.0	850–949
0003	139.7	7	177.5–177.0	950–1 049
0004	137.6	3	177.5–177.0	1 050–1 149
0005	126.7	3	177.5–177.0	1 150–1 249
0006	200.2	1	177.0–176.5 <sup>1</sup>	750–849
0007	207.9	14	177.0–176.5	850–949
0008	181.4	5	177.0–176.5	950–1 049
0009	159.3	3	177.0–176.5	1 050–1 149
0010	153.9	2	177.0–176.5	1 150–1 249
0011	357.0	3	176.5–176.0	750–849
0012	209.9	11	176.5–176.0	850–949
0013	167.5	4	176.5–176.0	950–1 049
0014	158.7	3	176.5–176.0	1 050–1 149
0015	120.6	3	176.5–176.0	1 150–1 249
0016	527.4	4	176.0–175.5	750–849
0017	274.9	8	176.0–175.5	850–949
0018	213.2	3	176.0–175.5	950–1 049
0019	179.9	3	176.0–175.5	1 050–1 149
0020	160.5	2	176.0–175.5	1 150–1 249
0021	555.8	4	175.5–175.0	750–849
0022	406.1	7	175.5–175.0	850–949
0023	323.5	4	175.5–175.0	950–1 049
0024	229.9	1	175.5–175.0	1 050–1 149
0025	156.7	2	175.5–175.0	1 150–1 249
0026 <sup>2</sup>	33.0	4	177.0–176.75	800–849

## Non-biomass/commercial stations

Spawning box (commercial)	12
Spawning box (midwater trawling)	2

<sup>1</sup> Excluding the area defined by stratum 26.<sup>2</sup> Stratum defined retrospectively (see text).

**Table 7: Biomass of orange roughy by stratum**

Stratum	Biomass (t)	c. v. (%)
1	43	73
2	21 927	43
3	20 251	46
4	7 776	55
5	6 694	95
6	0	–
7	22 945	41
8	4 944	22
9	4 067	34
10	4 778	78
11	249	48
12	17 569	45
13	818	62
14	783	28
15	686	38
16	1 716	82
17	20 996	47
18	676	53
19	369	50
20	482	8
21	816	53
22	1 454	33
23	2 433	43
24	0	–
25	295	7
26	4 325	40
Total	147 093	15

**Table 8: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	0.8	20
Trace	85.8	2 113
Part-full	8.1	199
Full	5.1	125
Everted	0.2	6
<i>n</i>		2 463

**Table 9: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	180	53.1
Mysidacea	1	0.3
Crustacean remains	5	1.5
Mollusca		
Cephalopoda Coleoidea	42	12.4
Pisces		
Macrouridae	4	1.2
Mesopelagic group <sup>1</sup>	9	2.7
Other groups <sup>2</sup>	5	1.5
Fish remains	108	31.9
Thaliacea		
Salpidae	2	0.6
Unidentified	2	0.6

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 339.

<sup>1</sup> Includes families Paralepididae, Myctophidae.

<sup>2</sup> Includes families Bathylagidae, Apogonidae, Alepocephalidae.



**Table 10: Strata descriptions and areas (BUC8601)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description (spawning box, ° W)	Depth (m)
0001	320.9	6	177.5–177.0	750–849
0002	173.7	8	177.5–177.0	850–949
0003	139.7	6	177.5–177.0	950–1 049
0004	137.6	5	177.5–177.0	1 050–1 149
0005	126.7	3	177.5–177.0	1 150–1 249
0006	200.2	2	177.0–176.5 <sup>1</sup>	750–849
0007	207.9	11	177.0–176.5	850–949
0008	181.4	6	177.0–176.5	950–1 049
0009	159.3	3	177.0–176.5	1 050–1 149
0010	153.9	2	177.0–176.5	1 150–1 249
0011	357.0	3	176.5–176.0	750–849
0012	209.9	16	176.5–176.0	850–949
0013	167.5	3	176.5–176.0	950–1 049
0014	158.7	3	176.5–176.0	1 050–1 149
0015	120.6	2	176.5–176.0	1 150–1 249
0016	527.4	5	176.0–175.5	750–849
0017	274.9	9	176.0–175.5	850–949
0018	213.2	3	176.0–175.5	950–1 049
0019	179.9	6	176.0–175.5	1 050–1 149
0020	160.5	2	176.0–175.5	1 150–1 249
0021	555.8	4	175.5–175.0	750–849
0022	406.1	4	175.5–175.0	850–949
0023	323.5	5	175.5–175.0	950–1 049
0024	229.9	1	175.5–175.0	1 050–1 149
0026 <sup>2</sup>	33.0	3	177.0–176.75	800–849

## Non-biomass/commercial stations

Northeast Rise (exploratory)	1
Spawning box (commercial)	23

<sup>1</sup> Excluding the area defined by stratum 26.<sup>2</sup> Stratum defined retrospectively (see text).

**Table 11: Biomass of orange roughy by stratum**

Stratum	Biomass (t)	c. v. (%)
1	5 806	97
2	15 243	64
3	3 352	37
4	1 169	35
5	595	66
6	175	27
7	17 966	32
8	2 129	52
9	7 576	35
10	3 546	82
11	601	52
12	15 412	57
13	2 465	67
14	785	11
15	520	32
16	6 013	71
17	6 197	24
18	3 261	57
19	497	24
20	174	28
21	1 017	55
22	2 485	39
23	4 349	42
24	0	–
25	0	–
26	2 034	61
Total	103 367	16

**Table 12: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	87.4	2 477
Trace	1.9	53
Part-full	8.6	243
Full	2.0	58
Everted	0.1	4
<i>n</i>		2 835

**Table 13: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	115	33.2
Euphausiacea	10	2.9
Mysidacea	5	1.4
Mollusca		
Cephalopoda Coleoidea	47	13.6
Pisces		
Macrouridae	1	0.3
Mesopelagic group <sup>1</sup>	6	1.7
Other groups <sup>2</sup>	3	0.9
Fish remains	119	34.4
Thaliacea		
Salpidae	2	0.6
Annelida		
Polychaeta	1	0.3
Unidentified	1	0.3

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 346.

<sup>1</sup> Includes families Myctophidae, Malacosteidae, Chauliodontidae.

<sup>2</sup> Includes families Apogonidae, Alepocephalidae.

**Table 14: Strata descriptions and areas (BUC8701)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description (spawning box, ° W)	Depth (m)
0001	320.9	9	177.5–177.0	750–849
0002	173.7	8	177.5–177.0	850–949
0003	139.7	9	177.5–177.0	950–1 049
0004	137.6	7	177.5–177.0	1 050–1 149
0005	126.7	6	177.5–177.0	1 150–1 249
0006	200.2	6	177.0–176.5 <sup>1</sup>	750–849
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0008	181.4	10	177.0–176.5	950–1 049
0009	159.3	7	177.0–176.5	1 050–1 149
0010	153.9	6	177.0–176.5	1 150–1 249
0011	357.0	7	176.5–176.0	750–849
0012	209.9	17	176.5–176.0	850–949
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0023	323.5	5	175.5–175.0	950–1 049
0024	229.9	5	175.5–175.0	1 050–1 149
0025	156.7	4	175.5–175.0	1 150–1 249
0026 <sup>2</sup>	33.0	5	177.0–176.75	800–849

## Non-biomass/commercial stations

Spawning box (commercial)	45
Spawning box (midwater trawls)	2
Spawning box (exploratory)	6
Northwest Rise (exploratory)	6
Arrow Tow pinnacle (south Rise)	5
Trevis Pinnacle (south Rise)	1
Buccaneer Steps pinnacle (south Rise)	5
Other south Rise pinnacles	5
South Rise flat trawls	2
East Rise flat trawls	9

<sup>1</sup> Excluding the area defined by stratum 26.<sup>2</sup> Stratum defined retrospectively (see text).

**Table 15: Biomass of orange roughy by stratum**

Stratum	Biomass (t)	c. v. (%)
1	752	56
2	12 477	52
3	8 310	54
4	1 485	33
5	620	21
6	156	100
7	9 741	49
8	2 421	16
9	5 105	48
10	1 790	2
11	2 286	82
12	13 076	31
13	1 664	31
14	419	25
15	380	9
16	1 533	30
17	7 374	47
18	2 540	74
19	419	19
20	0	–
21	108	82
22	2 896	66
23	1 574	46
24	0	–
25	91	26
26	2 172	75
Total	79 388	15

**Table 16: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	84.5	4 843
Trace	2.7	156
Part-full	10.6	609
Full	1.8	103
Everted	0.3	17
<i>n</i>		5 728

**Table 17: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	228	26.4
Euphausiacea	37	4.3
Mysidacea	2	0.2
Isopoda	10	1.2
Crustacean remains	123	14.3
Mollusca		
Cephalopoda Coleoidea	154	17.8
Pisces		
Macrouridae	3	0.3
Mesopelagic group <sup>1</sup>	4	0.5
Fish remains	351	40.7
Thaliacea		
Salpidae	1	0.1
Unidentified	20	2.3

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 863.

<sup>1</sup> Includes families Myctophidae, Photichthyidae, Malacosteidae.

**Table 18: Strata descriptions and areas (COR8801)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description (spawning box, ° W)	Depth (m)
0001	320.9	4	177.5–177.0	750–849
0002	173.7	12	177.5–177.0	850–949
0003	139.7	4	177.5–177.0	950–1049
0004	137.6	3	177.5–177.0	1 050–1149
0005	126.7	3	177.5–177.0	1 150–1 249
0006	200.2	9	177.0–176.5 <sup>1</sup>	750–849
0007	207.9	12	177.0–176.5	850–949
0008	181.4	4	177.0–176.5	950–1 049
0009	159.3	4	177.0–176.5	1 050–1 149
0010	153.9	3	177.0–176.5	1 150–1 249
0011	357.0	2	176.5–176.0	750–849
0012	209.9	7	176.5–176.0	850–949
0013	167.5	4	176.5–176.0	950–1 049
0014	158.7	4	176.5–176.0	1 050–1 149
0015	120.6	2	176.5–176.0	1 150–1 249
0016	527.4	4	176.0–175.5	750–849
0017	274.9	8	176.0–175.5	850–949
0018	213.2	3	176.0–175.5	950–1 049
0019	179.9	3	176.0–175.5	1 050–1 149
0020	160.5	1	176.0–175.5	1 150–1 249
0021	555.8	4	175.5–175.0	750–849
0022	406.1	4	175.5–175.0	850–949
0023	323.5	3	175.5–175.0	950–1 049
0024	229.9	2	175.5–175.0	1 050–1 149
0025	156.7	2	175.5–175.0	1 150–1 249
0026 <sup>2</sup>	33.0	15	177.0–176.75	800–849

## Commercial stations

Camerons pinnacle (east Rise)	2
Spawning box	26

<sup>1</sup> Excluding the area defined by stratum 26.<sup>2</sup> See text, stratum created during survey.

**Table 19: Biomass of orange roughy by stratum**

Stratum	Biomass (t)	c. v. (%)
1	22	95
2	32 529	63
3	16 273	47
4	1 108	60
5	527	33
6	36	53
7	22 000	36
8	862	49
9	1 162	51
10	265	36
11	126	57
12	1 263	40
13	863	80
14	910	27
15	520	72
16	173	35
17	4 727	33
18	3 587	77
19	1 098	39
20	0	–
21	46	24
22	1 230	33
23	287	34
24	749	69
25	1 732	94
26	2 489	42
Total	94 583	25



**Table 20: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	84.1	2 435
Trace	5.1	147
Part-full	8.4	242
Full	2.3	68
Everted	0.1	3
<i>n</i>		2 895

**Table 21: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	74	16.6
Euphausiacea	1	0.2
Mysidacea	6	1.3
Mollusca		
Cephalopoda Coleoidea	19	4.3
Pisces		
Macrouridae	5	1.1
Paralepididae	1	0.2
Synphobranchidae	1	0.2
Fish remains	108	24.2
Cnidaria		
Scyphozoa	1	0.2
Unidentified	1	0.2

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 446.

Table 22: Strata descriptions and areas (COR8802)

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
2	173.7	3	spawning box, 177.5° W–177.0°W	850–949
4	137.6	1	spawning box, 177.5° W–177.0°W	1 050–1 149
7	207.9	1	spawning box, 177.0°W–176.5°W	850–949
10	153.9	1	spawning box, 177.0°W–176.5°W	1 150–1 249
13	167.5	5	spawning box, 176.5°W–176.0°W	950–1 049
17	274.9	2	spawning box, 176.0°W–175.5°W	850–949
17S	345.0	1	spawning box, 176.0°W–175.5°W	600–800
21	555.8	1	spawning box, 175.5°W–175.0°W	750–849
23	323.5	1	spawning box, 175.5°W–175.0°W	950–1 049
1A	404.2	2	north-west Rise, 175.0°E–176.0°E	750–849
1B	405.9	4	north-west Rise, 175.0°E–176.0°E	850–949
1C	561.2	9	north-west Rise, 175.0°E–176.0°E	950–1 049
1D	1000.0	3	north-west Rise, 175.0°E–176.0°E	1 050–1 249
1E	*	1	north-west Rise, 175.0°E–176.0°E	1 250–1 500
2B	609.1	4	north-west Rise, 176.0°E–178.0°E	850–949
2D	707.6	5	north-west Rise, 176.0°E–178.0°E	1 050–1 249
2S	123.0	3	north-west Rise, 176.0°E–178.0°E	600–800
3A	667.8	1	north-west Rise, 178.0°E–180.0°	759–849
3B	667.2	3	north-west Rise, 178.0°E–180.0°	850–949
3D	1084.9	1	north-west Rise, 178.0°E–180.0°	1 050–1 249
3S	345.0	1	north-west Rise, 178.0°E–180.0°	600–800
4A	885.7	1	north-west Rise, 180.0°–177.5°W	750–849
4B	764.2	1	north-west Rise, 180.0°–177.5°W	850–949
4C	692.8	2	north-west Rise, 180.0°–177.5°W	950–1 049
4D	1545.7	2	north-west Rise, 180.0°–177.5°W	1 050–1 249
4S	567.0	2	north-west Rise, 180.0°–177.5°W	600–800
5A	653.9	1	south Rise, 180.0°–179.0°W	750–899
5B	484.9	1	south Rise, 180.0°–179.0°W	900–1 049
5C	1275.2	2	south Rise, 180.0°–179.0°W	1 050–1 249
6A	1870.0	4	south Rise, 179.0°W–177.0°W	750–899
6B	1659.2	4	south Rise, 179.0°W–177.0°W	900–1 049
6C	1951.9	2	south Rise, 179.0°W–177.0°W	1 050–1 249
6S	789.0	2	south Rise, 179.0°W–177.0°W	600–800
7A	*	4	north-east Rise, 175.0°W–173.5°W	750–849
7B	*	3	north-east Rise, 175.0°W–173.5°W	850–949
7C	1554.4	1	north-east Rise, 175.0°W–173.5°W	950–1 049
7D	2436.2	2	north-east Rise, 175.0°W–173.5°W	1 050–1 249
7S	123.0	1	north-east Rise, 175.0°W–173.5°W	600–800
8A	*	3	east Rise, 176.5°W–174.5°W <sup>1</sup>	800–900
8B	*	3	east Rise, 176.5°W–174.5°W <sup>1</sup>	900–1 000
8C	*	3	east Rise, 176.5°W–174.5°W <sup>1</sup>	1 000–1 200
8S	*	1	east Rise, 176.5°W–174.5°W <sup>1</sup>	600–800
9B	902.3	1	south Rise, 178.75°E–180.0°	800–900
9C	1613.1	4	south Rise, 178.75°E–180.0°	1 000–1 100
9D	844.1	1	south Rise, 178.75°E–180.0°	1 100–1 200
10A	3781.3	2	south Rise, 176.0°E–178.75°E	600–800
10B	1570.7	1	south Rise, 176.0°E–178.75°E	800–900
10C	1677.0	5	south Rise, 176.0°E–178.75°E	900–1 000
10D	2123.1	4	south Rise, 176.0°E–178.75°E	1 000–1 100
10E	3041.6	2	south Rise, 176.0°E–178.75°E	1 100–1 200
11B	2161.9	1	south Rise, 173.5°E–176.0°E	800–900
11C	1086.7	1	south Rise, 173.5°E–176.0°E	1 000–1 100

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
11D	1788.9	5	south Rise, 173.5°E–176.0°E	800–1 100
11E	1684.9	1	south Rise, 173.5°E–176.0°E	1 100–1 200
12C	1434.6	1	south Rise, 172.5°E–173.5°E	900–1 000
12D	1272.3	2	south Rise, 172.5°E–173.5°E	1 000–1 100

<sup>1</sup> South of 44° S.

\* Area not calculated.

**Table 23: Biomass of orange roughy (ORH) and smooth oreo (SSO) by stratum**

Stratum	Biomass		Biomass	
	ORH (t)	c. v. (%)	SSO (t)	c. v. (%)
2	231	7	1	31
13	62	26	1	19
17	33	45	1	14
1A	5	100	562	53
1B	135	43	26	18
1C	638	41	71	37
1D	1 547	45	226	99
2B	344	55	22	24
2D	1 256	28	477	81
2S	5	65	2	18
3B	2 921	34	109	66
4C	682	82	7	55
4D	1 706	11	102	58
4S	8	100	4	100
5C	129	12	126	6
6A	366	68	2 268	66
6B	3 551	71	27 456	68
6C	823	8	1 755	7
6S	0	–	481	97
7D	1 791	12	822	88
9C	179	51	48 378	100
10A	51	100	42	100
10C	79	79	385	54
10D	100	88	628	82
10E	0	–	199	52
11D	0	–	880	85
12D	0	–	236	23
Total	16 640	17.6	85 267	60.8

**Table 24: Gonad stage percentage frequency of orange roughy and smooth oreo from the entire survey area**

## orange roughy

Stage	% male	% female
1	34.5	22.7
2	49.6	70.5
3	0.4	0.8
4	0.0	0.0
5	14.9	0.6
6	–	5.0
<i>n</i>	811	840

## smooth oreo

Stage	% male	% female
1	55.4	25.5
2	28.0	19.6
3	13.4	53.0
4	0.0	0.0
5	0.0	0.0
6	0.3	0.0
<i>n</i>	307	321

**Table 25: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	50.5	844
Trace	6.3	105
Part-full	31.6	528
Full	11.4	191
Everted	0.2	3
<i>n</i>		1 671

**Table 26: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	91	11.1
Amphipoda	20	2.4
Euphausiacea	51	6.2
Mysidacea	24	2.9
Isopoda	2	0.2
Crustacean remains	57	7.0
Mollusca		
Cephalopoda Coleoidea	67	8.2
Pisces		
Macrouridae	17	2.1
Mesopelagic group <sup>1</sup>	17	2.1
Others <sup>2</sup>	25	3.1
Fish remains	414	50.6
Unidentified	4	0.5

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 818.

<sup>1</sup> Includes families Anoplogastridae, Myctophidae, Chauliodontidae, Melamphaidae, Photichthyidae, Paralepididae, Sternoptychidae.

<sup>2</sup> Includes families Bathylagidae, Apogonidae, Alepocephalidae.

**Table 27: Strata descriptions and areas (COR8901)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
0001	320.9	2	spawning box, 177.5°W–177.0°W	750–849
0002	173.7	14	spawning box, 177.5°W–177.0°W	850–949
0003	139.7	6	spawning box, 177.5°W–177.0°W	950–1 049
0004	137.6	4	spawning box, 177.5°W–177.0°W	1 050–1 149
0005	126.7	3	spawning box, 177.5°W–177.0°W	1 150–1 249
0006	200.2	5	spawning box, 177.0°W–176.5°W <sup>1</sup>	750–849
0007	207.9	7	spawning box, 177.0°W–176.5°W	850–949
0008	181.4	6	spawning box, 177.0°W–176.5°W	950–1 049
0009	159.3	3	spawning box, 177.0°W–176.5°W	1 050–1 149
0010	153.9	2	spawning box, 177.0°W–176.5°W	1 150–1 249
0011	357.0	2	spawning box, 176.5°W–176.0°W	750–849
0012	209.9	6	spawning box, 176.5°W–176.0°W	850–949
0013	167.5	5	spawning box, 176.5°W–176.0°W	950–1 049
0014	158.7	4	spawning box, 176.5°W–176.0°W	1 050–1 149
0015	120.6	2	spawning box, 176.5°W–176.0°W	1 150–1 249
0016	527.4	4	spawning box, 176.0°W–175.5°W	750–849
0017	274.9	9	spawning box, 176.0°W–175.5°W	850–949
0018	213.2	3	spawning box, 176.0°W–175.5°W	950–1 049
0019	179.9	3	spawning box, 176.0°W–175.5°W	1 050–1 149
0020	160.5	2	spawning box, 176.0°W–175.5°W	1 150–1 249
0021	555.8	3	spawning box, 175.5°W–175.0°W	750–849
0022	406.1	5	spawning box, 175.5°W–175.0°W	850–949
0023	323.5	4	spawning box, 175.5°W–175.0°W	950–1 049
0024	229.9	2	spawning box, 175.5°W–175.0°W	1 050–1 149
0025	156.7	2	spawning box, 175.5°W–175.0°W	1 150–1 249
0026	33.0	6	spawning box, 177.0°W–176.75°W	800–849
001A	404.2	2	north-west Rise, 175.0°E–176.0°E	750–849
001B	405.9	8	north-west Rise, 175.0°E–176.0°E	850–949
001C	561.2	9	north-west Rise, 175.0°E–176.0°E	950–1 049
001D	1000.0	6	north-west Rise, 175.0°E–176.0°E	1 050–1 249
002B	609.1	2	north-west Rise, 176.0°E–178.0°E	850–949
002C	1177.2	3	north-west Rise, 176.0°E–178.0°E	950–1 049
002D	707.6	2	north-west Rise, 176.0°E–178.0°E	1 050–1 249
003B	667.2	2	north-west Rise, 178.0°E–180.0°	850–949
003C	656.8	3	north-west Rise, 178.0°E–180.0°	950–1 049
003D	1084.9	3	north-west Rise, 178.0°E–180.0°	1 050–1 249
004B	764.2	1	north-west Rise, 180.0°–177.5°W	850–949
004C	692.8	1	north-west Rise, 180.0°–177.5°W	950–1 049
004D	1545.7	1	north-west Rise, 180.0°–177.5°W	1 050–1 249
005A	653.9	5	south Rise, 180.0°–179.0°W	750–899
005B	484.9	6	south Rise, 180.0°–179.0°W	900–1 049
005C	1275.2	5	south Rise, 180.0°–179.0°W	1 050–1 249
006A	1870.0	6	south Rise, 179.0°W–177.0°W	750–899
006B	1659.2	9	south Rise, 179.0°W–177.0°W	900–1 049
006C	1951.9	3	south Rise, 179.0°W–177.0°W	1 050–1 249
006D	1500.0	1	south Rise, 179.0°W–177.0°W	1 250–1 500

<sup>1</sup> Excluding the area defined by stratum 26.

Non-biomass/commercial stations	No. of stations
Northeast Rise (commercial)	7
Spawning box (commercial)	35
Kiso pinnacle (south Rise, exploratory)	2
Mt Nelson pinnacle (south Rise, exploratory)	2
Trevis Pinnacle (south Rise, exploratory)	2

**Table 28: Biomass of orange roughy by stratum**

Spawning box			Wide area		
Stratum	Biomass (t)	c. v. (%)	Stratum	Biomass (t)	c. v. (%)
1	243	47	1A	0	–
2	12 050	49	1B	75	60
3	8 556	62	1C	195	36
4	1 666	60	1D	893	22
5	707	6	2B	1 678	82
6	415	53	2C	26 006	63
7	6 010	32	2D	3 238	74
8	1 212	18	3B	2 628	10
9	669	49	3C	4 429	27
10	776	35	3D	9 708	46
11	174	20	5B	2 685	99
12	13 479	49	5C	97	41
13	1 851	75	6A	27	45
14	890	38	6B	13 332	66
15	1 206	76	6C	389	49
16	335	47	7B	94 708	17
17	1 443	31	7C	20 536	32
18	1 622	44	KISO	23	52
19	1 397	33	NEL	6 284	32
20	541	16	TPIN	1 104	44
21	211	55			
22	3 385	69	Total	188 036	13.9
23	383	32			
24	4 231	98			
25	111	8			
26	3 390	30			
Total	66 955	18			

**Table 29: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	78.5	3 297
Trace	8.2	346
Part-full	7.2	304
Full	5.9	248
Everted	0.1	6
<i>n</i>		4 201

**Table 30: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	272	30.4
Amphipoda	18	2
Euphausiacea	22	2.5
Mysidacea	19	2.1
Isopoda	1	0.1
	5	0.6
Copepoda		
Mollusca		
Cephalopoda Coleoidea	97	10.9
Pisces		
Macrouridae	26	2.9
Mesopelagic group <sup>1</sup>	10	1.1
Alepocephalidae	8	0.9
Fish remains	491	54.9
Thaliacea		
Salpidae	4	0.4
Unidentified	1	0.1

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 894.

<sup>1</sup> Includes families Idiacanthidae, Myctophidae, Chauliodontidae.



Table 31: Strata descriptions and areas (COR9002)

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
0001	320.9	2	spawning box, 177.5°W–177.0°W	750–849
0002	173.7	8	spawning box, 177.5°W–177.0°W	850–949
0003	139.7	4	spawning box, 177.5°W–177.0°W	950–1 049
0004	137.6	3	spawning box, 177.5°W–177.0°W	1 050–1 149
0005	126.7	4	spawning box, 177.5°W–177.0°W	1 150–1 249
0006	200.2	2	spawning box, 177.0°W–176.5°W <sup>1</sup>	750–849
0007	207.9	8	spawning box, 177.0°W–176.5°W	850–949
0008	181.4	5	spawning box, 177.0°W–176.5°W	950–1 049
0009	159.3	3	spawning box, 177.0°W–176.5°W	1 050–1 149
0010	153.9	3	spawning box, 177.0°W–176.5°W	1 150–1 249
0011	357.0	2	spawning box, 176.5°W–176.0°W	750–849
0012	209.9	18	spawning box, 176.5°W–176.0°W	850–949
0013	167.5	4	spawning box, 176.5°W–176.0°W	950–1 049
0014	158.7	3	spawning box, 176.5°W–176.0°W	1 050–1 149
0015	120.6	2	spawning box, 176.5°W–176.0°W	1 150–1 249
0016	527.4	3	spawning box, 176.0°W–175.5°W	750–849
0017	274.9	7	spawning box, 176.0°W–175.5°W	850–949
0018	213.2	4	spawning box, 176.0°W–175.5°W	950–1 049
0019	179.9	4	spawning box, 176.0°W–175.5°W	1 050–1 149
0020	160.5	3	spawning box, 176.0°W–175.5°W	1 150–1 249
0021	555.8	3	spawning box, 175.5°W–175.0°W	750–849
0022	406.1	4	spawning box, 175.5°W–175.0°W	850–949
0023	323.5	3	spawning box, 175.5°W–175.0°W	950–1 049
0024	229.9	3	spawning box, 175.5°W–175.0°W	1 050–1 149
0025	156.7	3	spawning box, 175.5°W–175.0°W	1 150–1 249
0026	33.0	6	spawning box, 177.0°W–176.75°W	800–849
005X	368.7	6	spawning box, 177.5°W–177.0°W	1 250–1 500
010X	371.1	12	spawning box, 177.0°W–176.5°W	1 250–1 500
015X	316.0	3	spawning box, 176.5°W–176.0°W	1 250–1 500
020X	356.0	3	spawning box, 176.0°W–175.5°W	1 250–1 500
025X	367.2	3	spawning box, 175.5°W–175.0°W	1 250–1 500
002A	778.3	3	north-west Rise, 176.0°E–178.0°E	750–849
002B	609.1	4	north-west Rise, 176.0°E–178.0°E	850–949
002C	1177.2	10	north-west Rise, 176.0°E–178.0°E	950–1 049
002D	707.6	2	north-west Rise, 176.0°E–178.0°E	1 050–1 249
002E	707.6	8	north-west Rise, 176.0°E–178.0°E	1 250–1 500
003A	667.8	2	north-west Rise, 178.0°E–180.0°	759–849
003B	667.2	5	north-west Rise, 178.0°E–180.0°	850–949
003C	656.8	7	north-west Rise, 178.0°E–180.0°	950–1 049
003D	1084.9	5	north-west Rise, 178.0°E–180.0°	1 050–1 249
003E	1084.9	5	north-west Rise, 178.0°E–180.0°	1 250–1 500
004A	885.7	4	north-west Rise, 180.0°–177.5°W	750–849
004B	764.2	6	north-west Rise, 180.0°–177.5°W	850–949
004C	692.8	9	north-west Rise, 180.0°–177.5°W	950–1 049
004D	1545.7	7	north-west Rise, 180.0°–177.5°W	1 050–1 249
004E	1545.7	1	north-west Rise, 180.0°–177.5°W	1 250–1 500
005A	653.9	3	south Rise, 180.0°–179.0°W	750–899
005B	484.9	4	south Rise, 180.0°–179.0°W	900–1 049
005C	1275.2	4	south Rise, 180.0°–179.0°W	1 050–1 249

<sup>1</sup> Excluding the area defined by stratum 26.

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
005D	1300.0	4	south Rise, 180.0°W–179.0°W	1 250–1 500
006A	1870.0	4	south Rise, 179.0°W–177.0°W	750–899
006B	1659.2	6	south Rise, 179.0°W–177.0°W	900–1 049
006C	1951.9	6	south Rise, 179.0°W–177.0°W	1 050–1 249
006D	1500.0	2	south Rise, 179.0°W–177.0°W	1 250–1 500
007C	1554.4	3	north-east Rise, 175.0°W–173.5°W	950–1 049
007D	2436.2	5	north-east Rise, 175.0°W–173.5°W	1 050–1 249
007E	3285.3	4	north-east Rise, 175.0°W–173.5°W	1 250–1 500

## Non-biomass/commercial stations

Spawning box (commercial)	1
Kiso pinnacle (south Rise, exploratory)	2
Mt Nelson pinnacle (south Rise, exploratory)	3
Trevs Pinnie pinnacle (south Rise, exploratory)	3
Spawning box (exploratory)	1

**Table 32: Biomass of orange roughy by stratum**

Stratum	Spawning box		Stratum	Wide area	
	Biomass (t)	c.v. (%)		Biomass (t)	c.v. (%)
1	0	–	2A	24	74
2	5 372	63	2B	329	69
3	2 847	33	2C	540	26
4	3 123	83	2D	335	75
5	318	57	2E	15	36
6	10	51	3A	539	2
7	3 117	25	3B	1 141	27
8	1 688	36	3C	650	20
9	1 229	29	3D	1 107	38
10	903	22	3E	48	63
11	88	23	4A	225	57
12	10 883	49	4B	2 418	52
13	351	27	4C	761	24
14	460	21	4D	996	24
15	238	6	5A	47	85
16	189	64	5B	53	43
17	985	40	5C	9	58
18	218	21	5D	0	–
19	214	17	6A	126	77
20	293	22	6B	2 277	87
21	172	45	6C	499	96
22	623	18	6D	0	–
23	109	36	7C	555	42
24	358	24	7D	10 621	61
25	189	34	7E	610	62
26	3 803	46	KISO	1 351	100
			NEL	664	46
Total	37 780	19	TPIN	246	15
			Total	26 186	27

**Table 33: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	80.2	3 714
Trace	12.1	561
Part-full	5.2	243
Full	2.5	114
Everted	0.0	1
<i>n</i>		4 633

**Table 34: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	289	31.7
Euphausiacea	19	2.1
Mysidacea	11	1.2
Isopoda	2	0.2
	10	1.1
Copepoda		
Crustacean remains	60	6.6
Mollusca		
Cephalopoda Coleoidea	61	6.7
Pisces		
Macrouridae	19	2.1
Mesopelagic group <sup>1</sup>	24	2.6
Other groups <sup>2</sup>	20	2.2
Fish remains	441	48.4
Thaliacea		
Salpidae	2	0.2
Cnidaria		
Scyphozoa	1	0.1
Unidentified	2	0.2

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 912.

<sup>1</sup> Includes families Anoplogaster, Idiacanthidae, Gonostomatidae, Myctophidae, Melamphaidae, Photichthyidae, Chauliodontidae, Evermannellidae, Scopelarchidae, Notosudidae.

<sup>2</sup> Includes families Bathylagidae, Apogonidae, Alepocephalidae.

**Table 35: Strata descriptions and areas (TAN9206)**

Stratum	Area (km <sup>2</sup> )	No. of stations	Description	Depth (m)
0001	320.9	3	spawning box, 177.5°W–177.0°W	750–849
0002	173.7	17	spawning box, 177.5°W–177.0°W	850–949
0003	139.7	6	spawning box, 177.5°W–177.0°W	950–1 049
0004	137.6	4	spawning box, 177.5°W–177.0°W	1 050–1 149
0005	126.7	3	spawning box, 177.5°W–177.0°W	1 150–1 249
0006	200.2	2	spawning box, 177.0°W–176.5°W <sup>1</sup>	750–849
0007	207.9	14	spawning box, 177.0°W–176.5°W	850–949
0008	181.4	2	spawning box, 177.0°W–176.5°W	950–1 049
0009	159.3	3	spawning box, 177.0°W–176.5°W	1 050–1 149
0010	153.9	2	spawning box, 177.0°W–176.5°W	1 150–1 249
0011	357.0	2	spawning box, 176.5°W–176.0°W	750–849
0012	209.9	7	spawning box, 176.5°W–176.0°W	850–949
0013	167.5	5	spawning box, 176.5°W–176.0°W	950–1 049
0014	158.7	4	spawning box, 176.5°W–176.0°W	1 050–1 149
0015	120.6	2	spawning box, 176.5°W–176.0°W	1 150–1 249
0016	527.4	3	spawning box, 176.0°W–175.5°W	750–849
0017	274.9	2	spawning box, 176.0°W–175.5°W	850–949
0018	213.2	4	spawning box, 176.0°W–175.5°W	950–1 049
0019	179.9	2	spawning box, 176.0°W–175.5°W	1 050–1 149
0020	160.5	3	spawning box, 176.0°W–175.5°W	1 150–1 249
0021	555.8	4	spawning box, 175.5°W–175.0°W	750–849
0022	406.1	5	spawning box, 175.5°W–175.0°W	850–949
0023	323.5	3	spawning box, 175.5°W–175.0°W	950–1 049
0024	229.9	4	spawning box, 175.5°W–175.0°W	1 050–1 149
0025	156.7	5	spawning box, 175.5°W–175.0°W	1 150–1 249
0026	33.0	2	spawning box, 177.0°W–176.75°W	800–849
005X	368.7	4	spawning box, 177.5°W–177.0°W	1 250–1 500
010X	371.1	3	spawning box, 177.0°W–176.5°W	1 250–1 500
015X	316.0	3	spawning box, 176.5°W–176.0°W	1 250–1 500
020X	356.0	2	spawning box, 176.0°W–175.5°W	1 250–1 500
025X	367.2	2	spawning box, 175.5°W–175.0°W	1 250–1 500
002A	778.3	2	north-west Rise, 176.0°E–178.0°E	750–849
002B	609.1	3	north-west Rise, 176.0°E–178.0°E	850–949
002C	1177.2	5	north-west Rise, 176.0°E–178.0°E	950–1 049
002D	707.6	4	north-west Rise, 176.0°E–178.0°E	1 050–1 249
002E	707.6	2	north-west Rise, 176.0°E–178.0°E	1 250–1 500
003A	667.8	3	north-west Rise, 178.0°E–180.0°	759–849
003B	667.2	5	north-west Rise, 178.0°E–180.0°	850–949
003C	656.8	5	north-west Rise, 178.0°E–180.0°	950–1 049
003D	1084.9	4	north-west Rise, 178.0°E–180.0°	1 050–1 249
003E	1084.9	3	north-west Rise, 178.0°E–180.0°	1 250–1 500
004A	885.7	3	north-west Rise, 180.0°–177.5°W	750–849
004B	764.2	8	north-west Rise, 180.0°–177.5°W	850–949
004C	692.8	6	north-west Rise, 180.0°–177.5°W	950–1 049
004D	1545.7	4	north-west Rise, 180.0°–177.5°W	1 050–1 249
004E	1545.7	3	north-west Rise, 180.0°–177.5°W	1 250–1 500
007A	1191.5	4	north-east Rise, 175.0°W–173.5°W	750–849
007B	3259.0	7	north-east Rise, 175.0°W–173.5°W	850–949
007C	1554.4	9	north-east Rise, 175.0°W–173.5°W	950–1 049
007D	2436.2	10	north-east Rise, 175.0°W–173.5°W	1 050–1 249
007E	3285.3	4	north-east Rise, 175.0°W–173.5°W	1 250–1 500

Non-biomass stations	No. of stations	Description
<b>Pinnacles</b>		
Bobbin Tow	2	south Rise
Mt. Nelson	1	south Rise
Treys Pinnie	2	south Rise
Buccaneer Steps	4	south Rise
The Steps	1	south Rise
West of Rectangle	1	south Rise
Hegerville	2	south Rise
Big Chief complex <sup>2</sup>	6	southeast Rise
Not Till Sunday	5	east Rise
Sir Michael complex <sup>3</sup>	4	east Rise
Morgue/Mummy	1	northwest Rise
Smith's City	1	northeast Rise
Other east Rise pinnacles	1	
Other south Rise pinnacles	9	
<b>Exploratory</b>		
South Rise	15	
East Rise	2	
North Rise	1	
Northwest Rise	2	

<sup>1</sup> Excluding the area defined by stratum 26.

<sup>2</sup> Big Chief, Lucky, Teepee, Charlie Horsecock, Flintstone.

<sup>3</sup> Sir Michael, Possum, Cotopaxi, Rachael, Jimmy, Dickies.

**Table 36: Biomass of orange roughy by stratum**

Spawning box			Wide area		
Stratum	Biomass (t)	c. v. (%)	Stratum	Biomass (t)	c. v. (%)
1	128	88	2A	400	87
2	14 557	65	2B	106	64
3	1 571	44	2C	634	41
4	903	71	2D	88	28
5	189	31	2E	13	24
6	1	100	3A	656	79
7	4 743	41	3B	1 678	25
8	346	29	3C	1 250	23
9	208	27	3D	1 265	22
10	72	19	3E	460	84
11	36	96	4A	95	82
12	140	39	4B	2 538	74
13	90	11	4C	788	30
14	218	39	4D	2 283	46
15	81	33	4E	549	50
16	702	55	7A	1 535	61
17	195	19	7B	1 205	25
18	236	13	7C	3 878	55
19	151	29	7D	2 588	32
20	70	16	7E	645	87
21	170	72			
22	1 987	41	Total	22 655	15.4
23	1 330	71			
24	217	19			
25	45	29			
26	624	87			
Total	29 011	34			

**Table 37: Stomach states of orange roughy examined during the survey**

State	%	<i>n</i>
Empty	71.6	3 752
Trace	8.8	463
Part-full	15.3	800
Full	4.3	223
Everted	0.0	0
<i>n</i>		5 238

**Table 38: Major prey groups of orange roughy from the survey area\***

Prey group	Frequency	
	<i>n</i>	%
Crustacea		
Decapoda Natantia	6	0.4
Crustacean remains	853	57.9
Mollusca		
Cephalopoda Coleoidea	91	6.2
Pisces		
Bathylagidae	1	0.1
Fish remains	563	38.2
Thaliacea		
Salpidae	9	0.6
Unidentified	69	4.7

\* *n*, number of fish with prey group; number of stomachs with identifiable prey items, 1473.

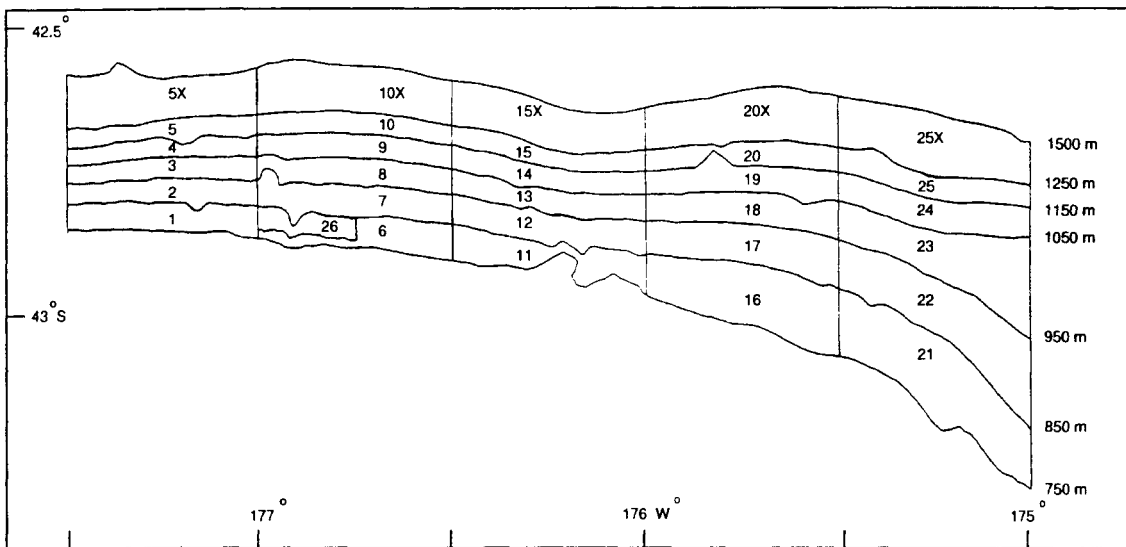
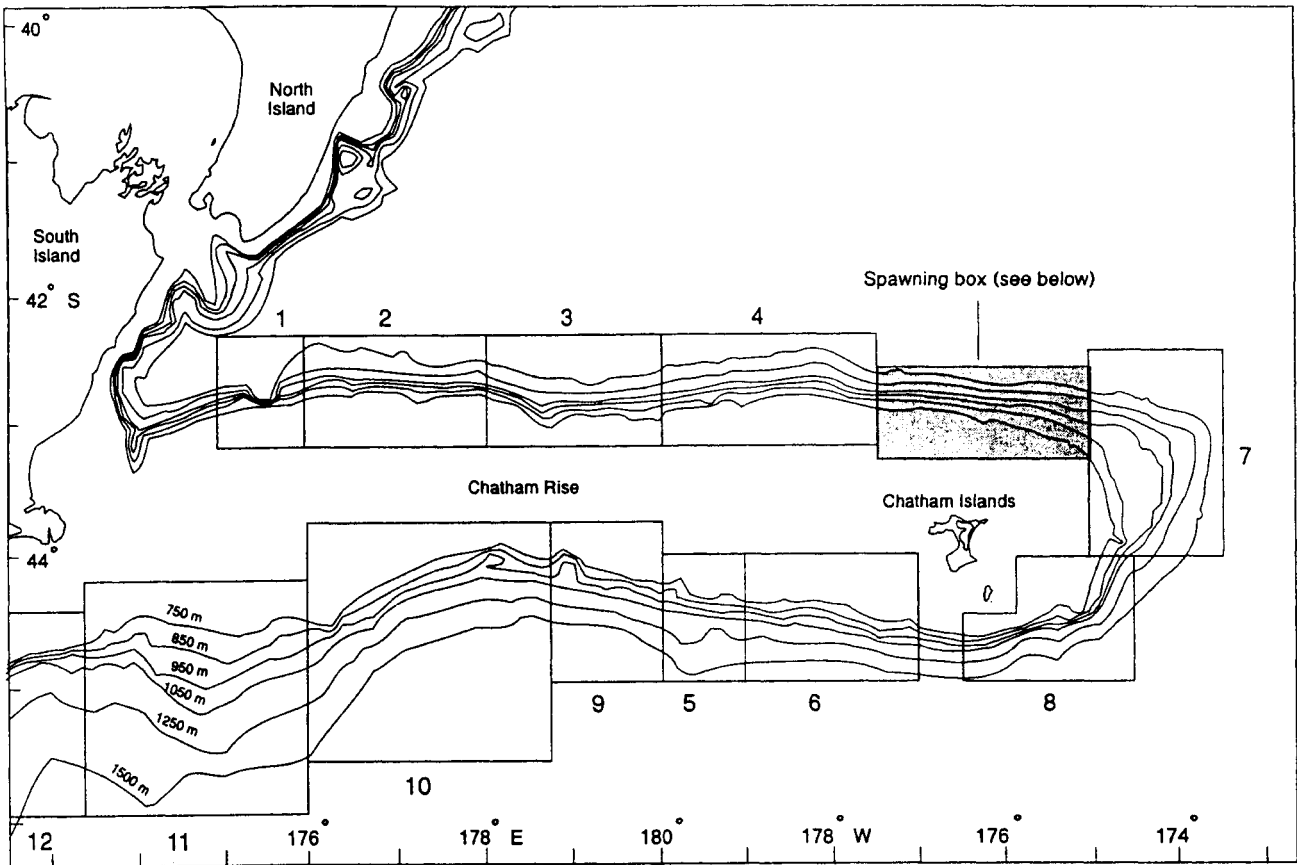


Figure 1: Survey areas and details of spawning box. Sub-areas 1–12 (top) are further stratified by depth (see strata description tables for details).



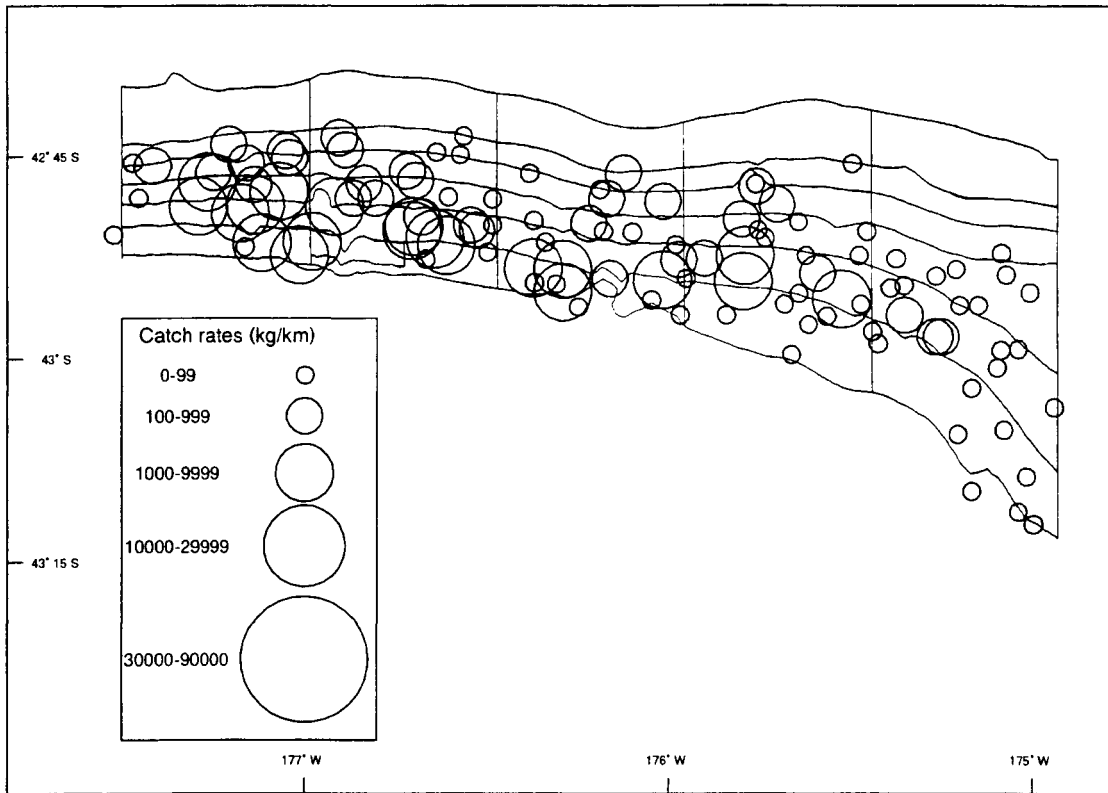


Figure 2: Catch rates (kg/km) of orange roughy in the spawning box. (BUC8401)

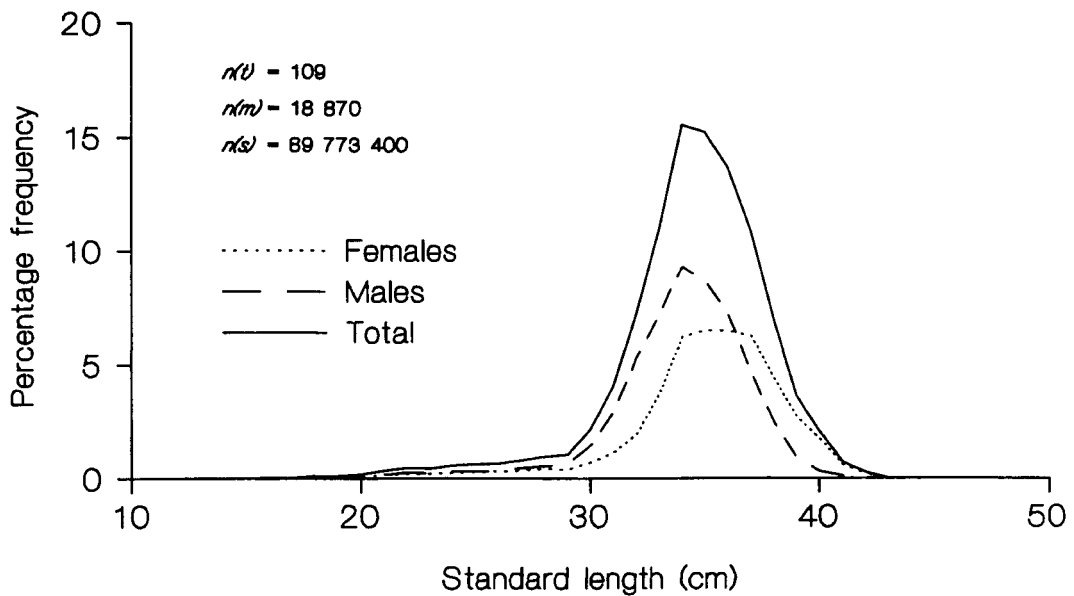


Figure 3: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (BUC8401)

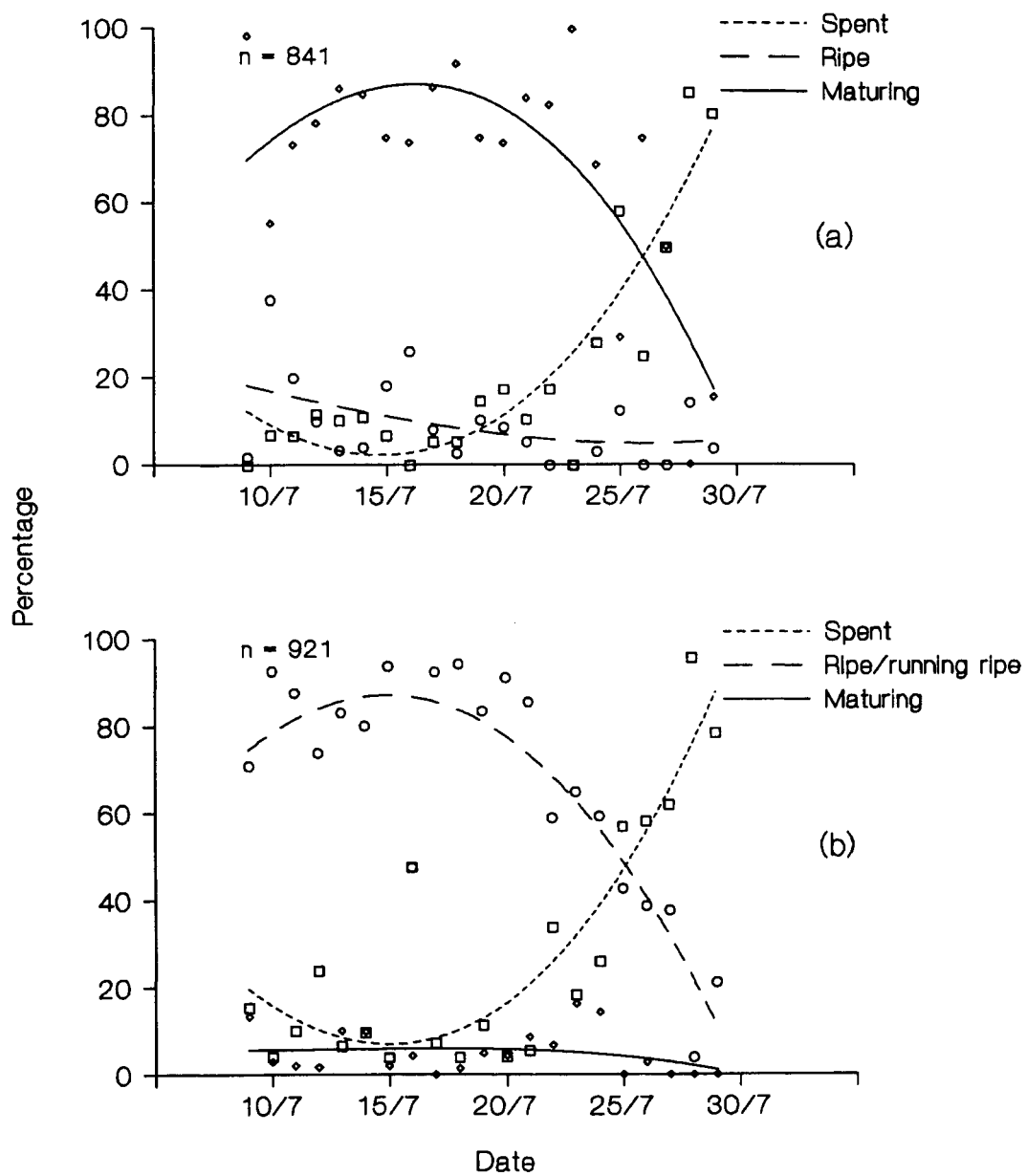


Figure 4: Gonad state of (a) male and (b) female orange roughy during the survey. Percentage refers to percent of mature fish only. (BUC8401)

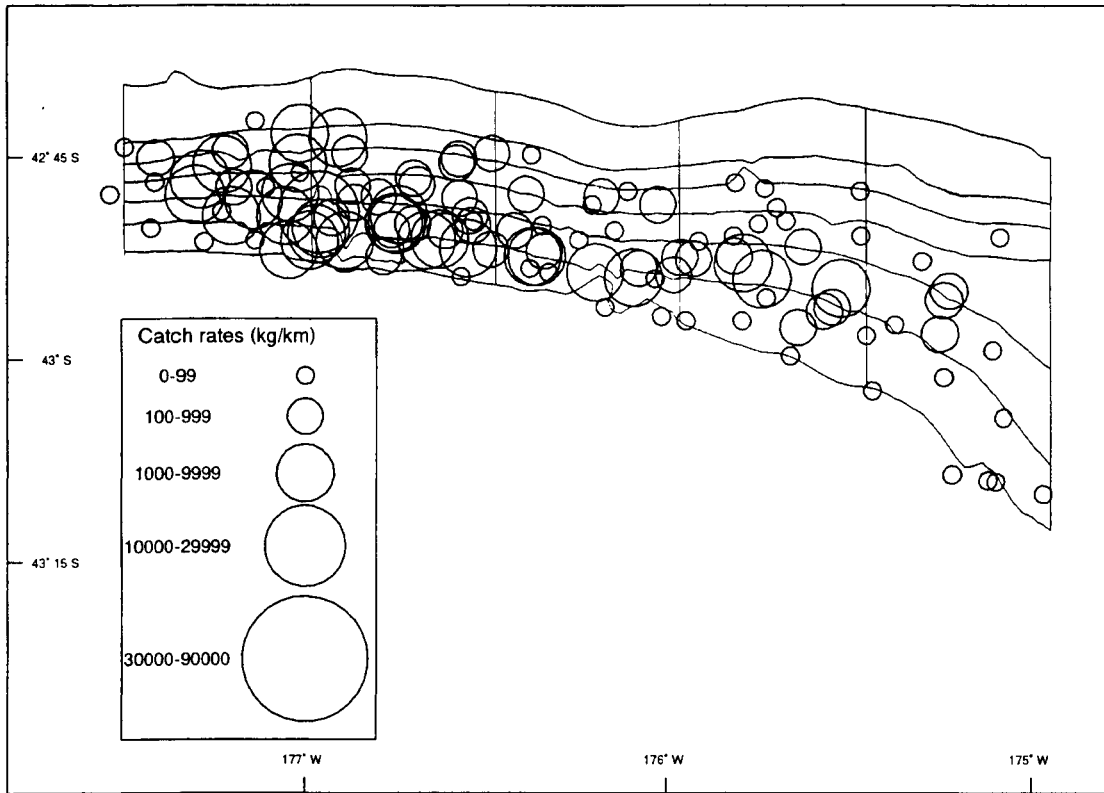


Figure 5: Catch rates (kg/km) of orange roughy in the spawning box. (BUC8501)

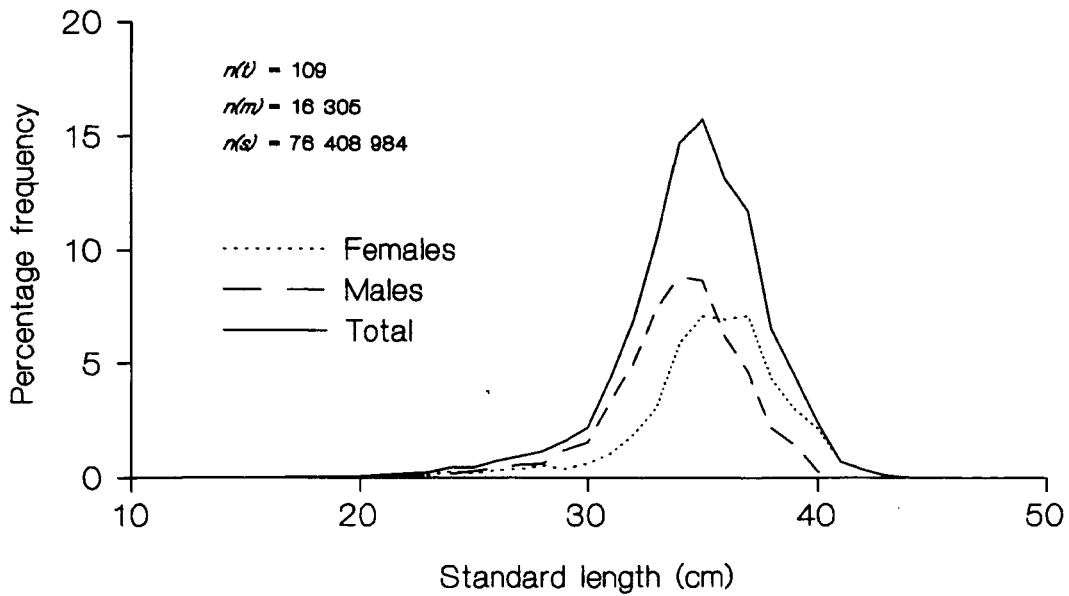


Figure 6: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (BUC8501)

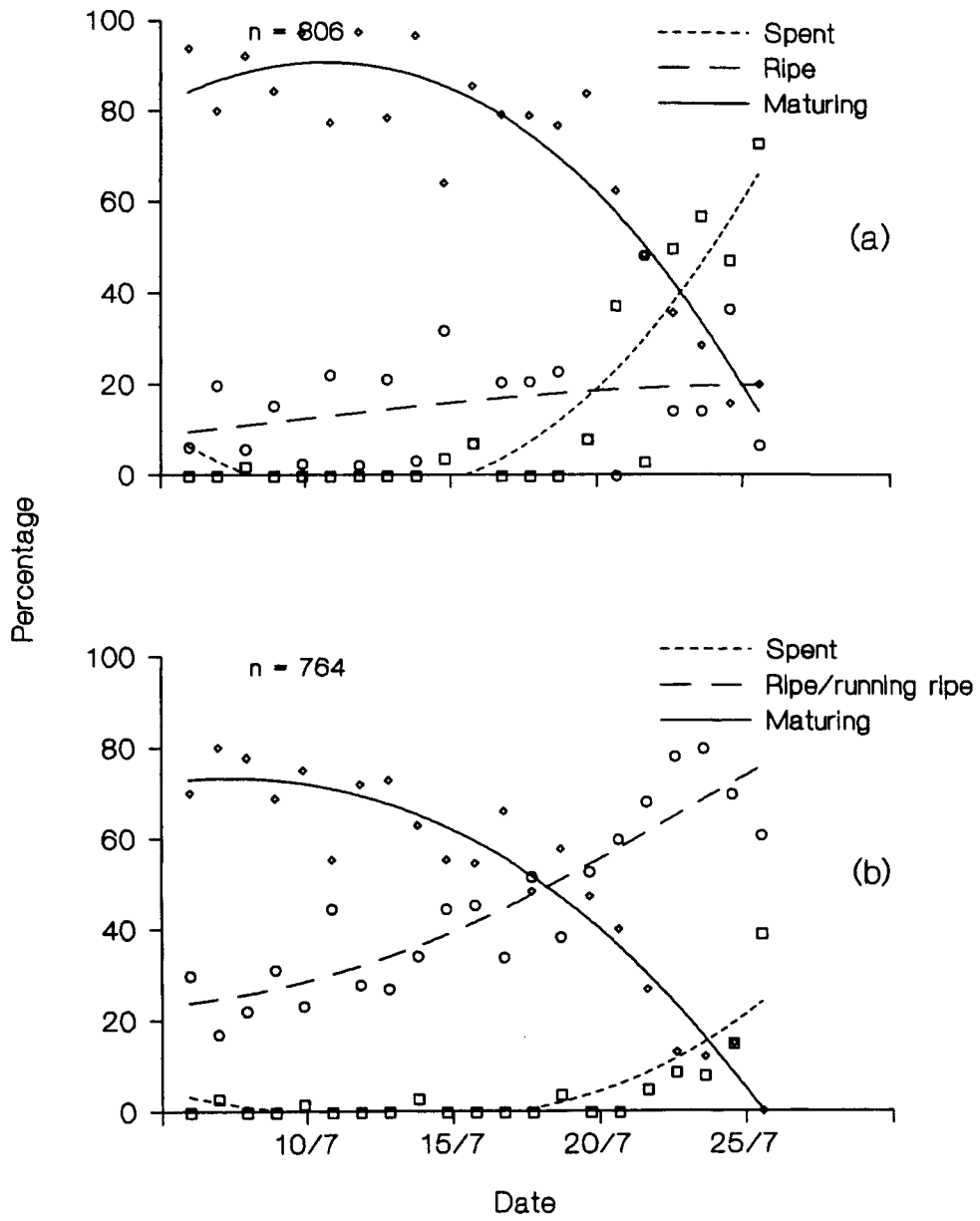


Figure 7: Gonad state of (a) male and (b) female orange roughy during the survey. Percentage refers to percent of mature fish only. (BUC8501)

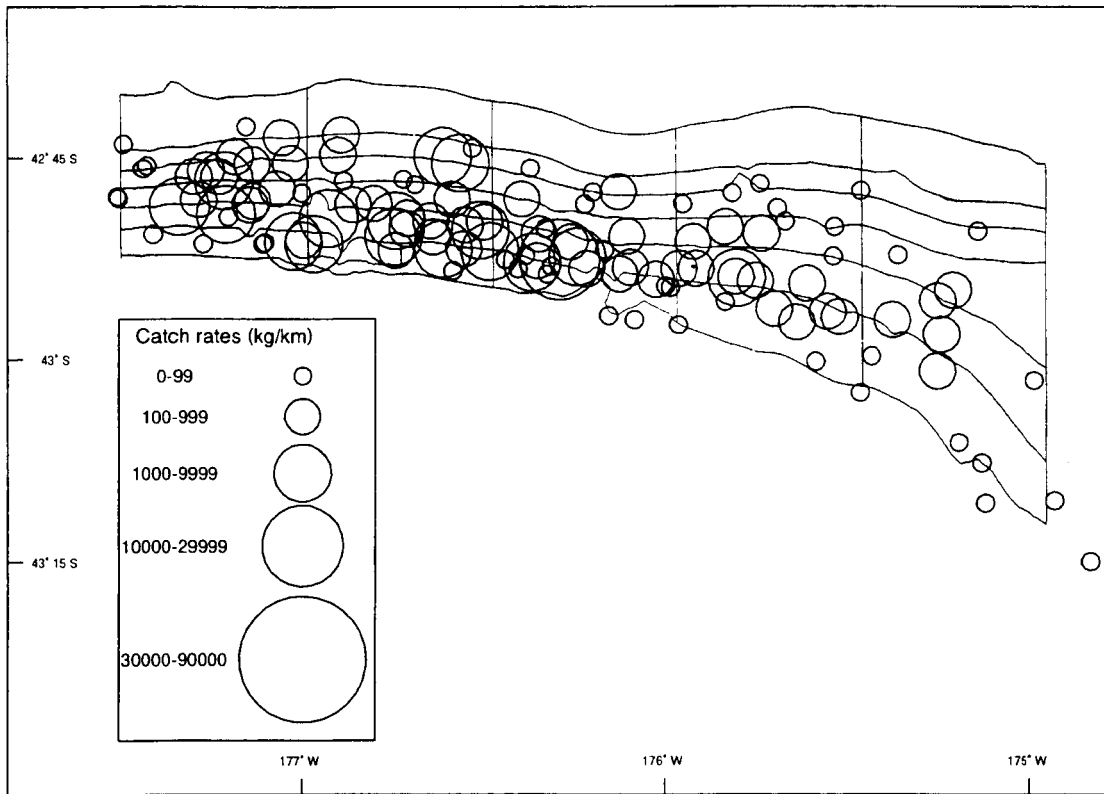


Figure 8: Catch rates (kg/km) of orange roughy in the spawning box. (BUC8601)

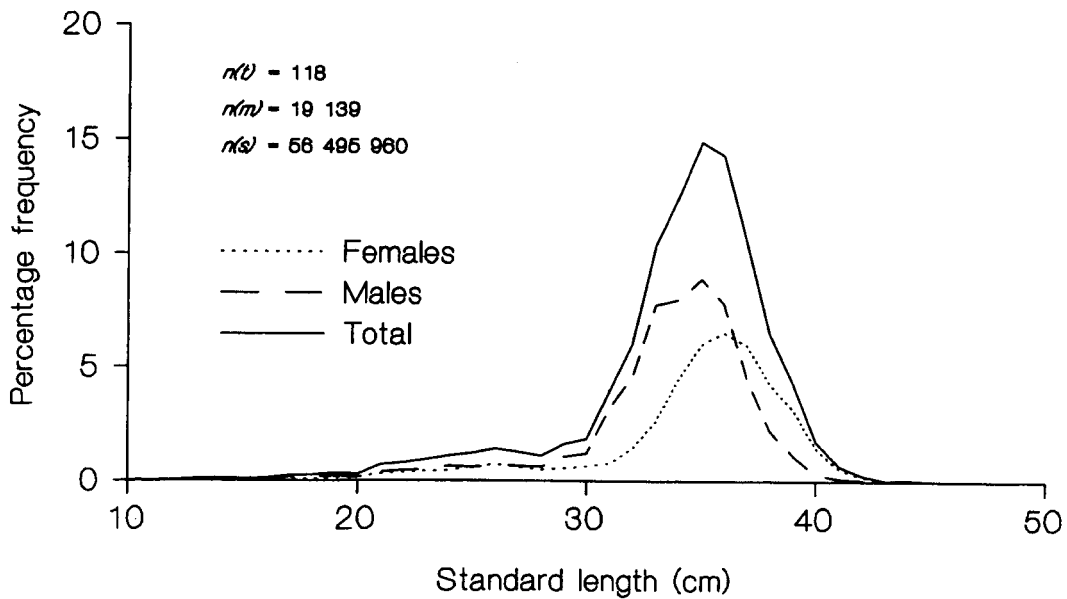


Figure 9: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (BUC8601)

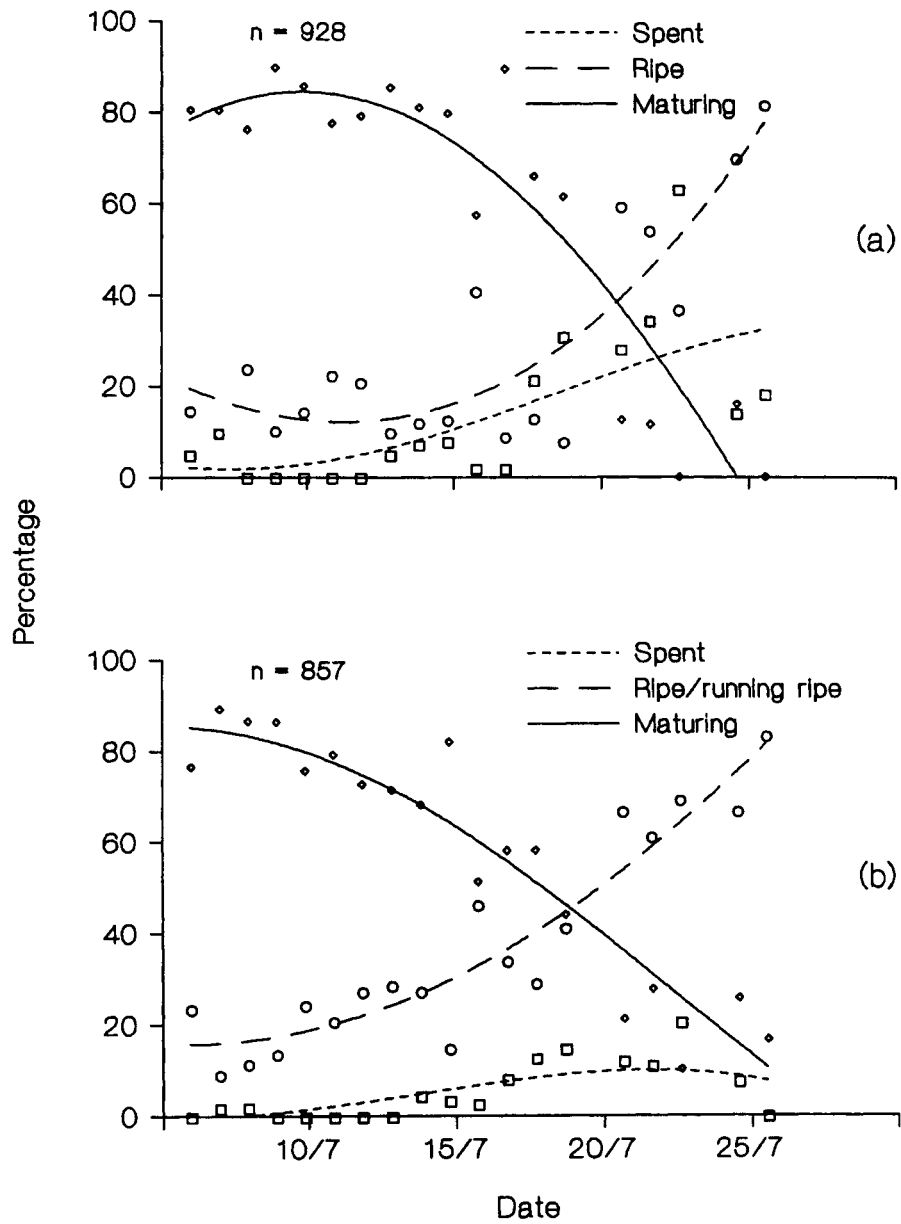


Figure 10: Gonad state of (a) male and (b) female orange roughy during the survey. Percentage refers to percent of mature fish only. (BUC8601)

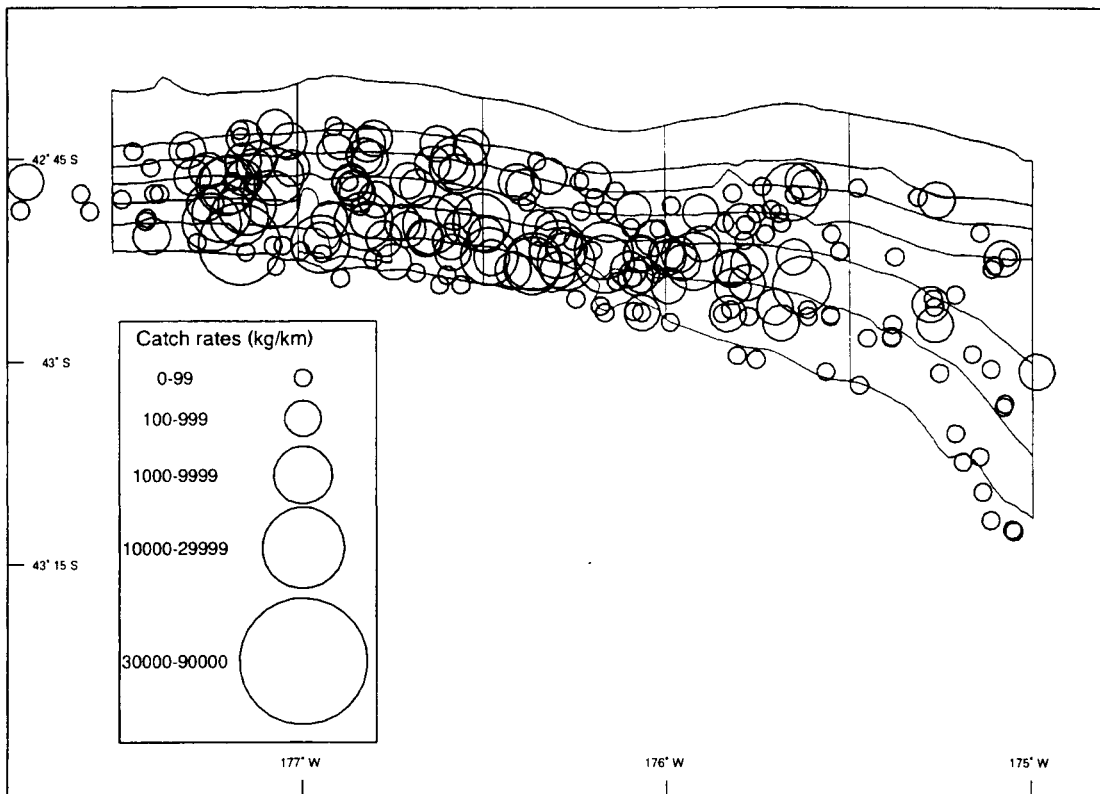


Figure 11: Catch rates (kg/km) of orange roughy in the spawning box.  
(BUC8701)

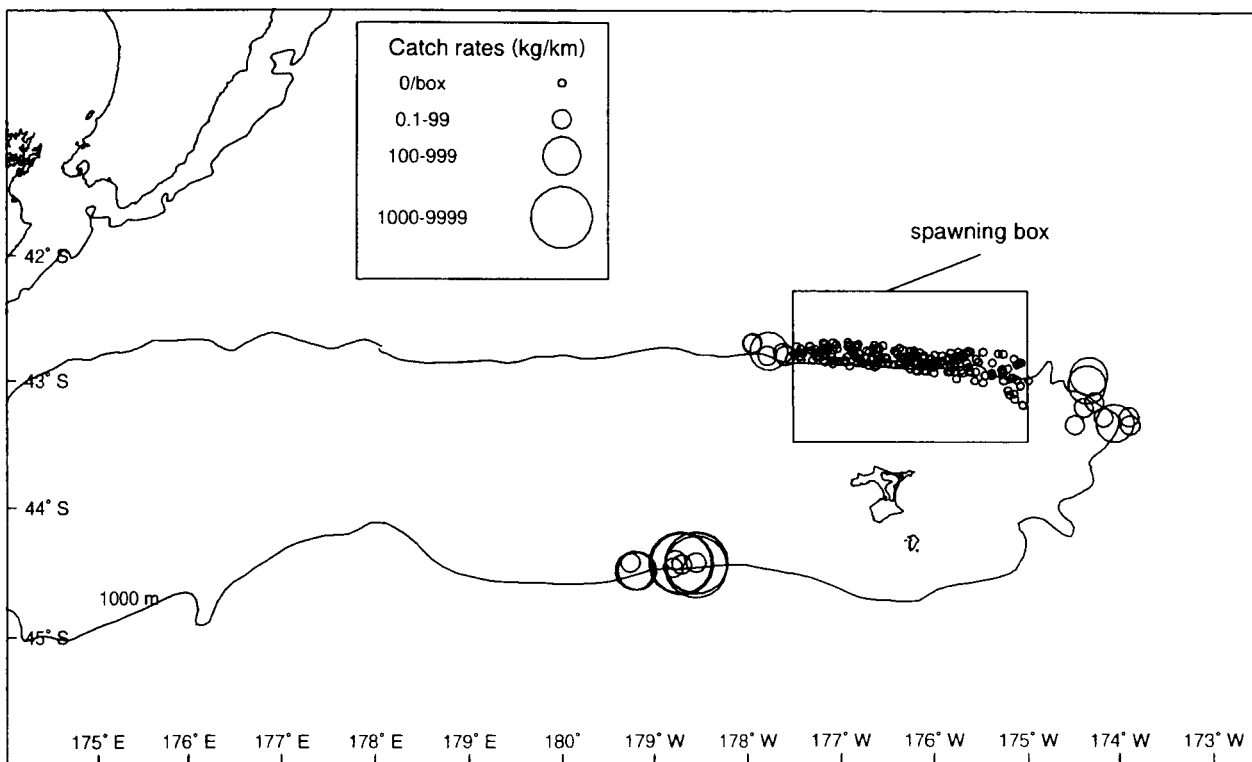


Figure 12: Catch rates (kg/km) of orange roughy at stations outside the spawning box.  
Symbols within the spawning box represent station positions only.  
(BUC8701)

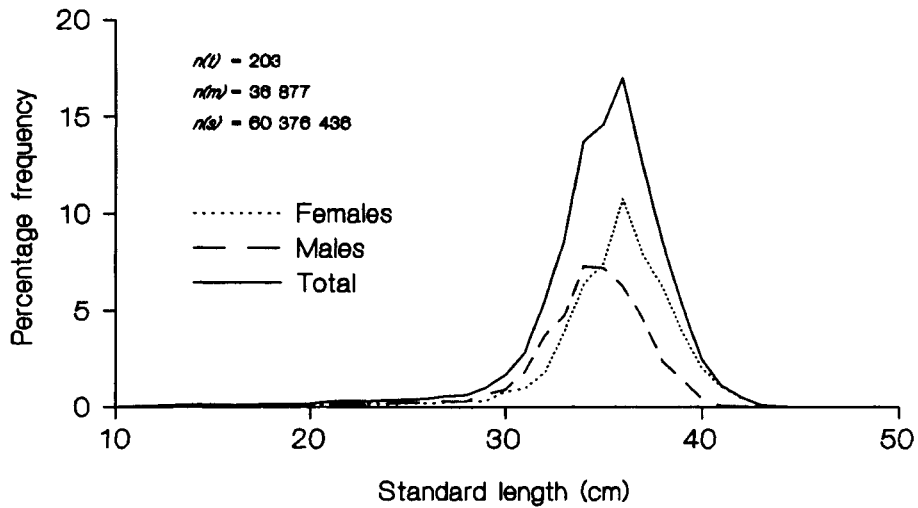


Figure 13: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (BUC8701)

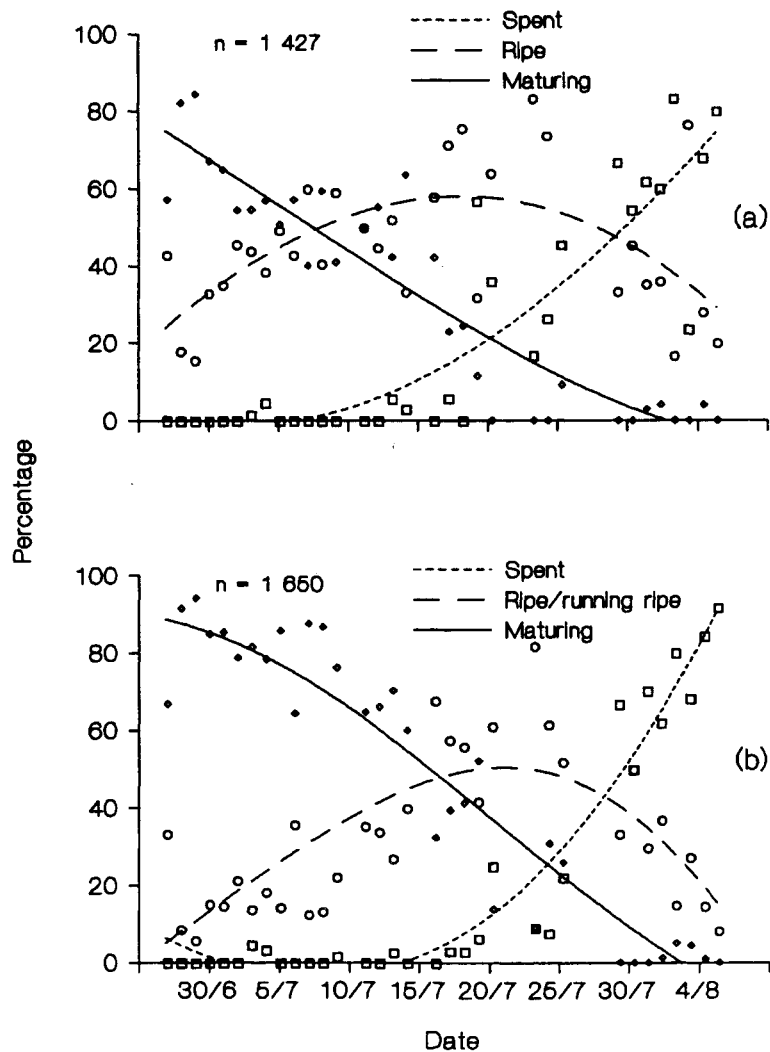


Figure 14: Gonad state of (a) male and (b) female orange roughy in the spawning box during the survey. Percentage refers to percent of mature fish only. (BUC8701)



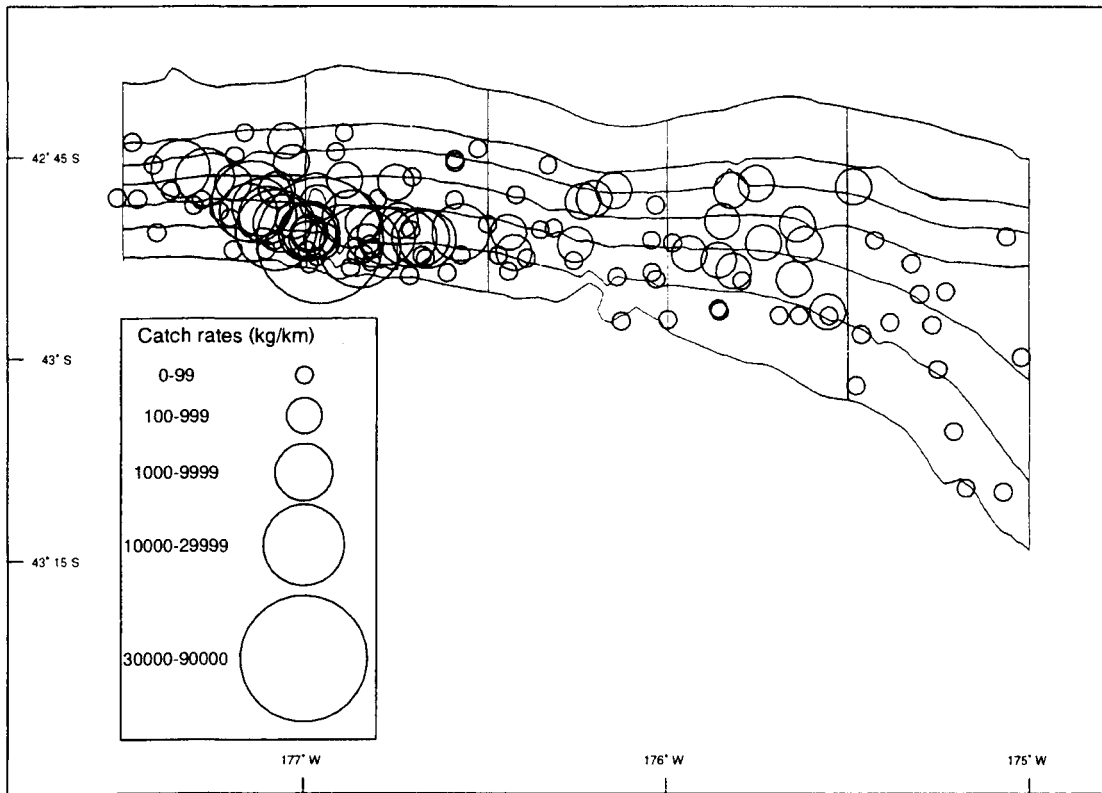


Figure 15: Catch rates (kg/km) of orange roughy in the spawning box. (COR8801)

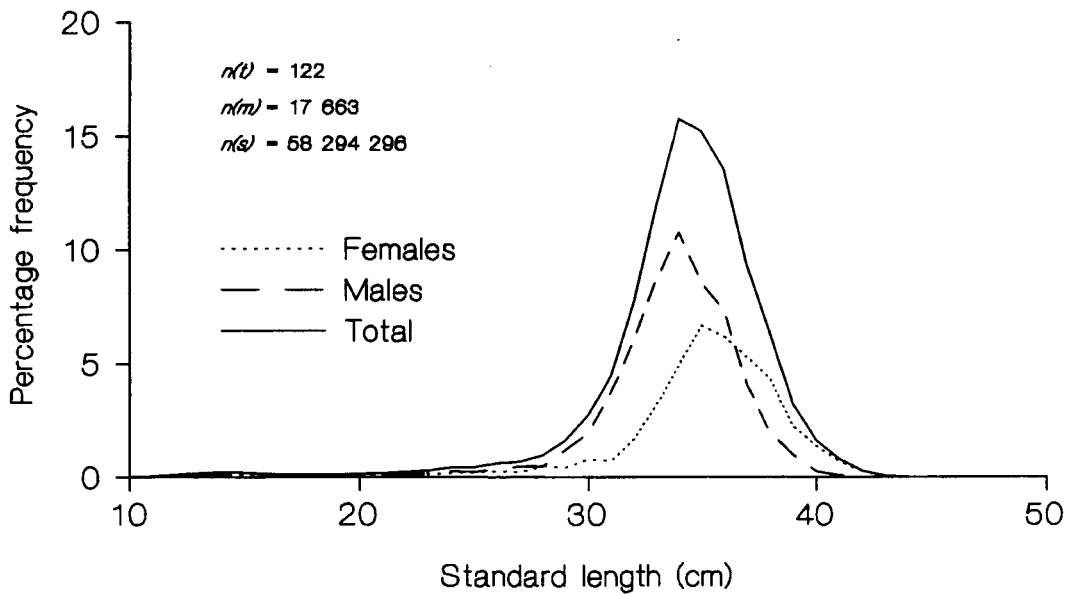


Figure 16: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (COR8801)

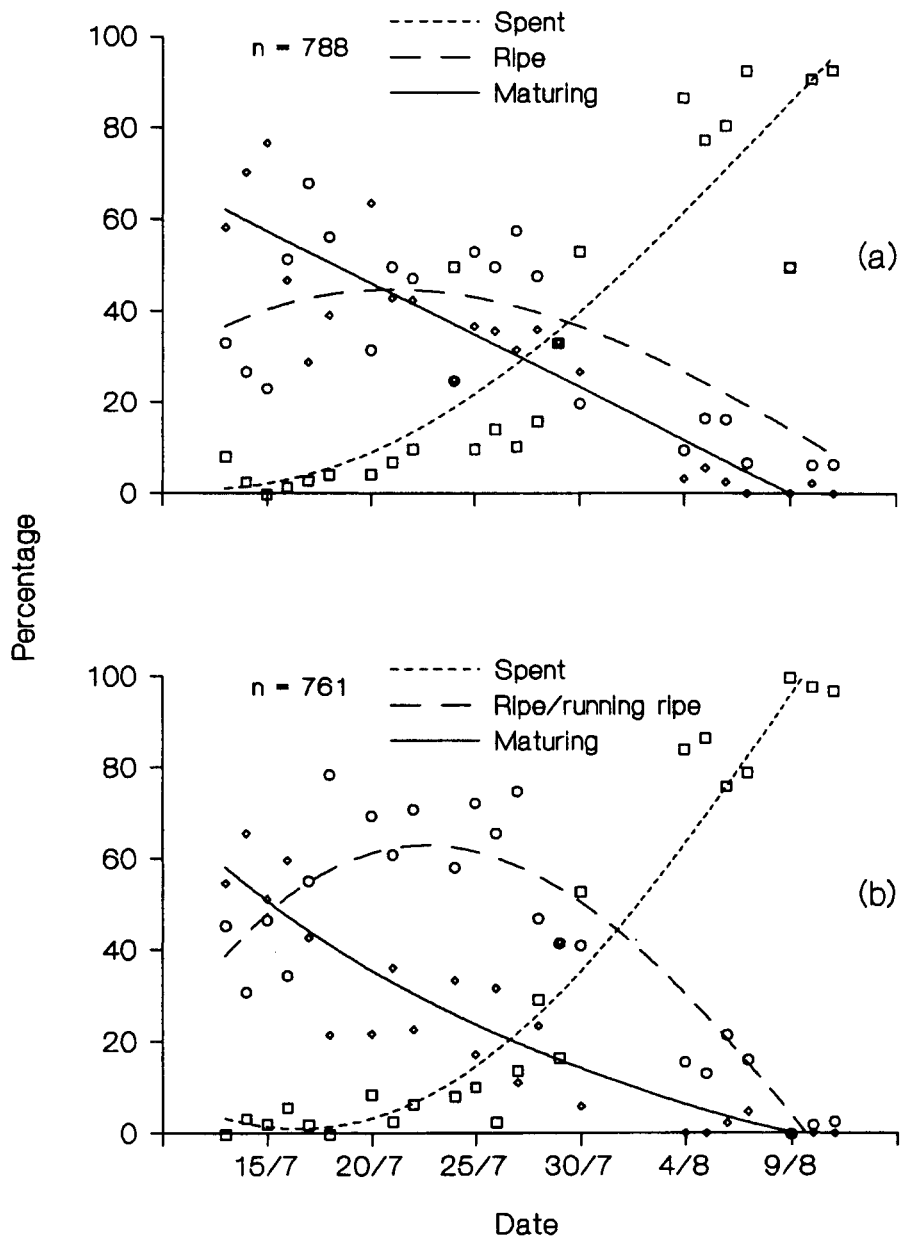


Figure 17: Gonad state of (a) male and (b) female orange roughy in the spawning box during the survey. Percentage refers to percent of mature fish only. (COR8801)

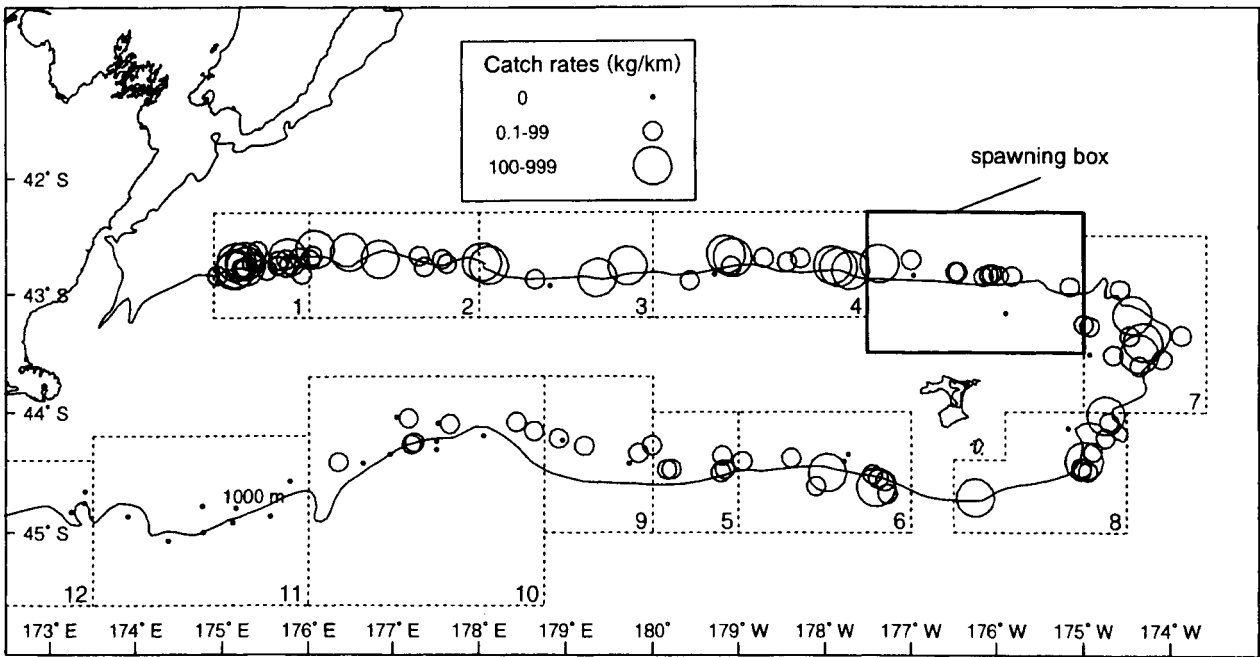


Figure 18: Catch rates (kg/km) of orange roughy in the survey area.  
(COR8802)

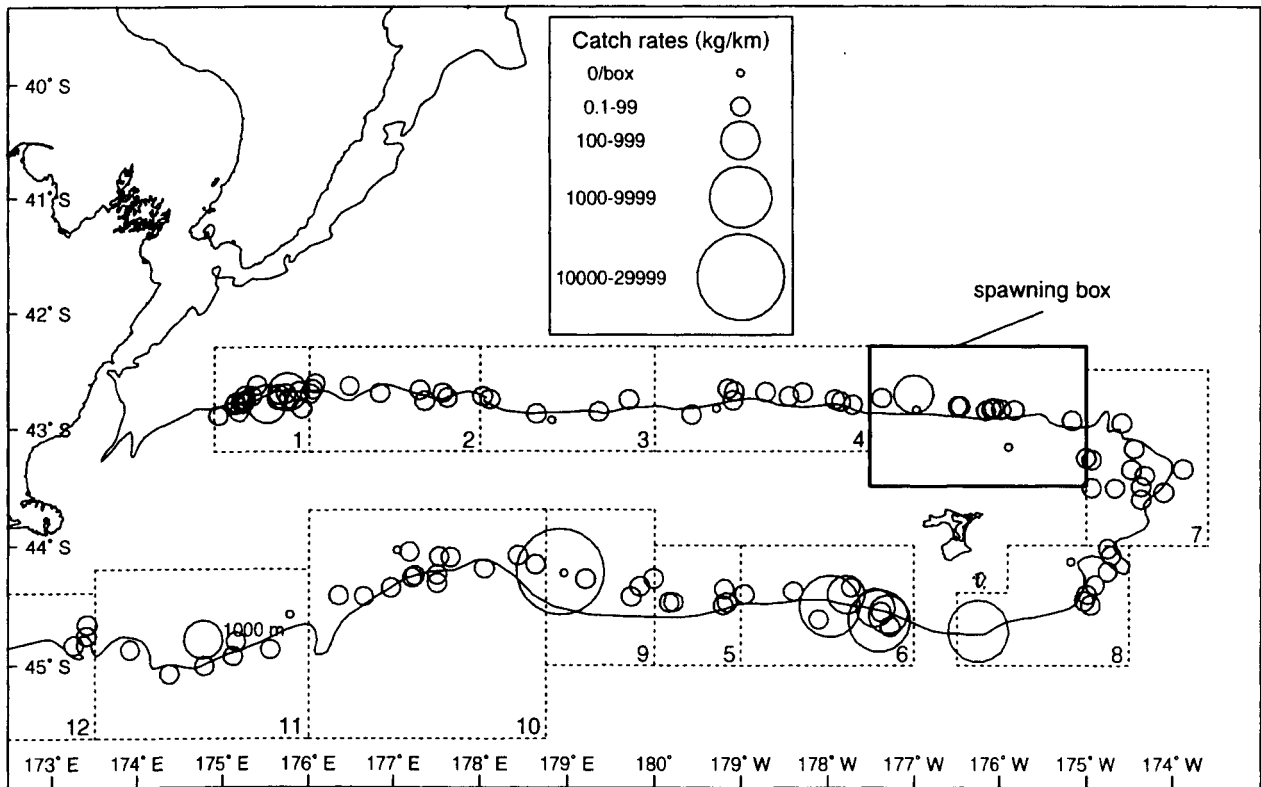


Figure 19: Catch rates (kg/km) of smooth oreo in the survey area.  
(COR8802)

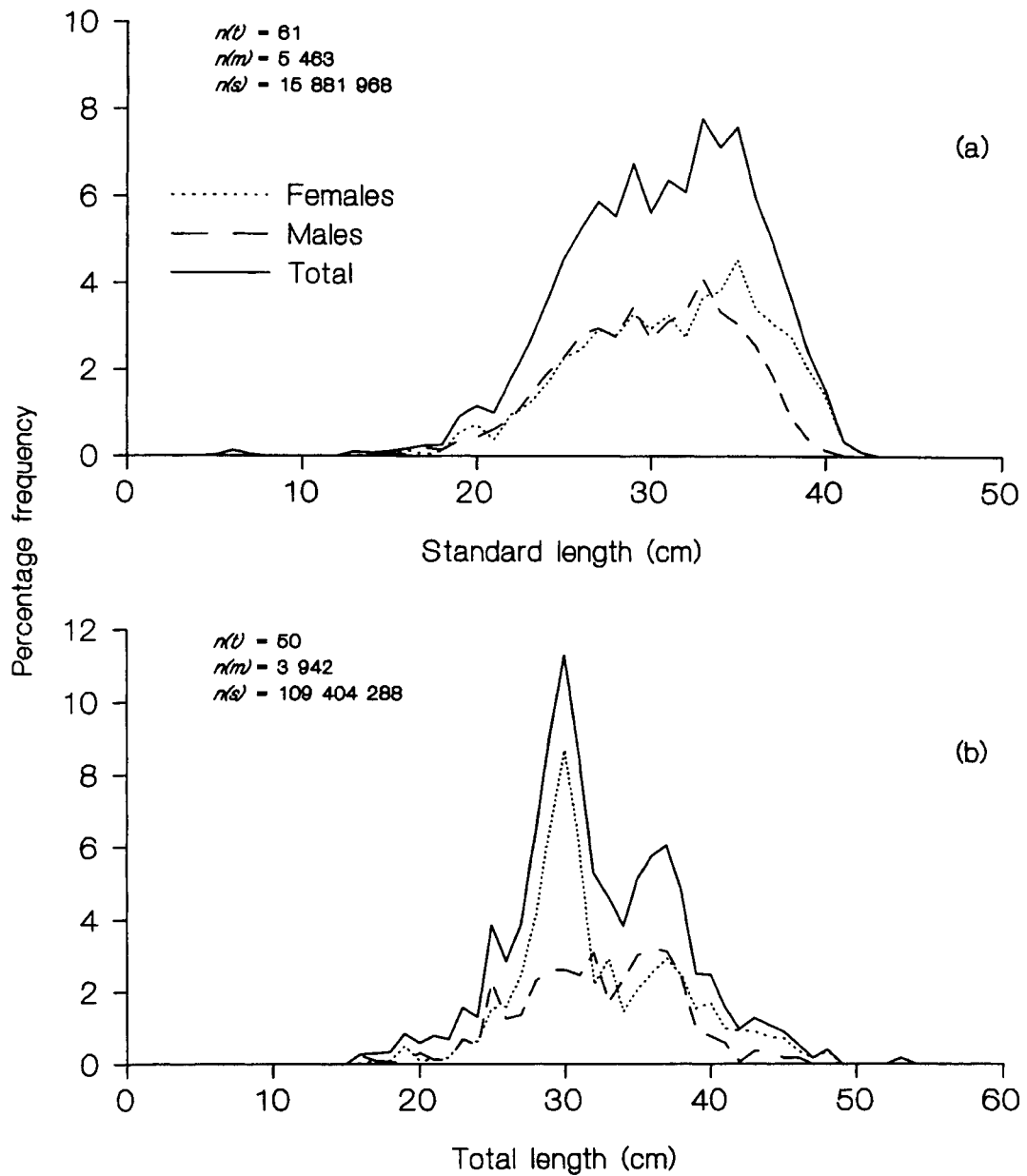


Figure 20: Length frequency distribution of (a) orange roughy and (b) smooth oreo on the Chatham Rise, scaled to represent the total population. Percentage refers to the percentage of all fish. (COR8802)

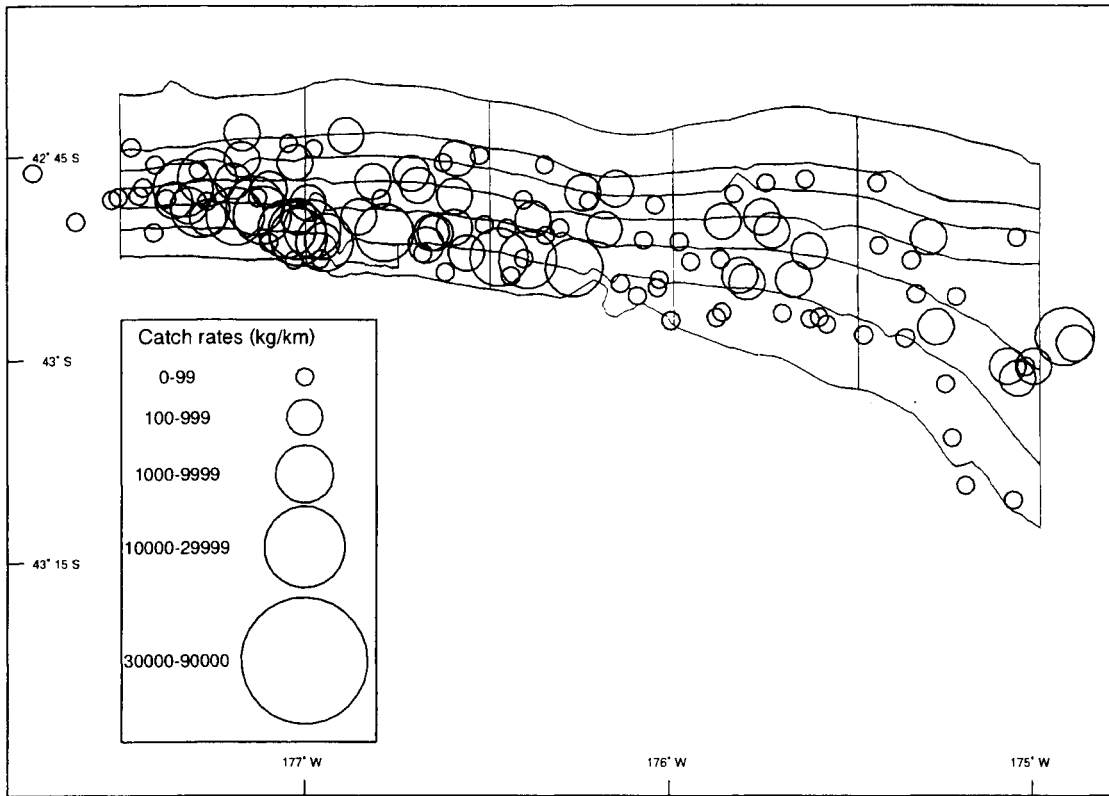


Figure 21: Catch rates (kg/km) of orange roughy in the spawning box.  
(COR8901)

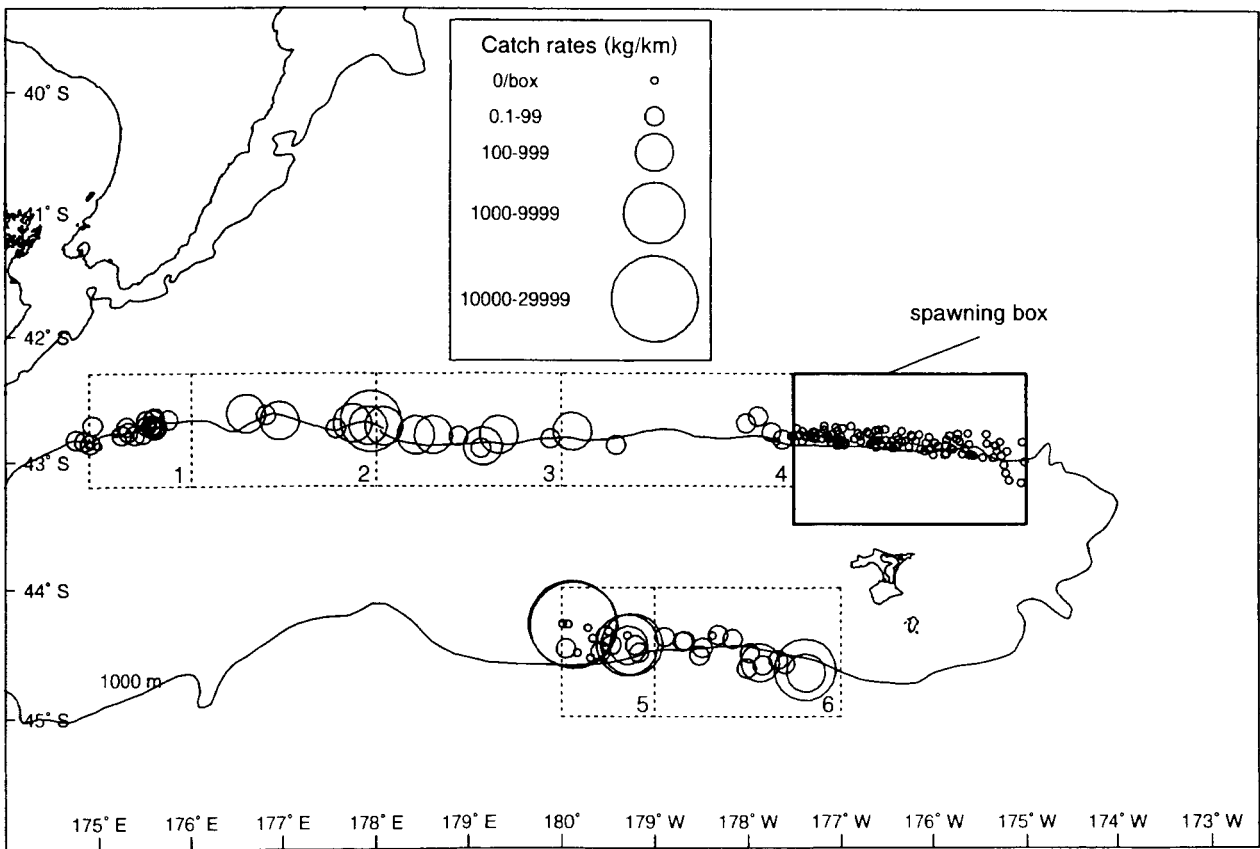


Figure 22: Catch rates (kg/km) of orange roughy at stations outside the spawning box.  
Symbols within the spawning box represent station positions only.  
(COR8901)

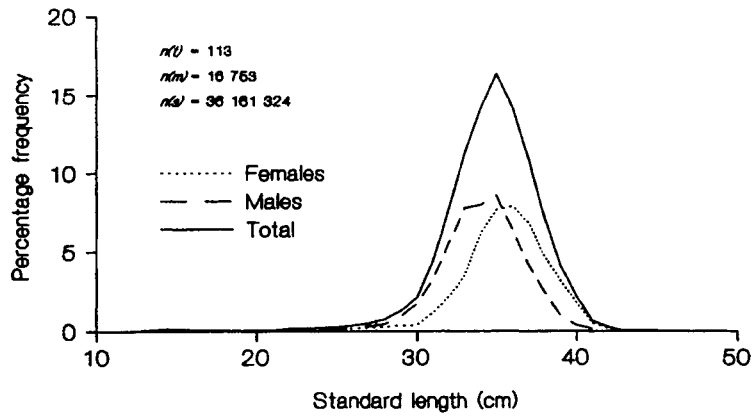


Figure 23: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (COR8901)

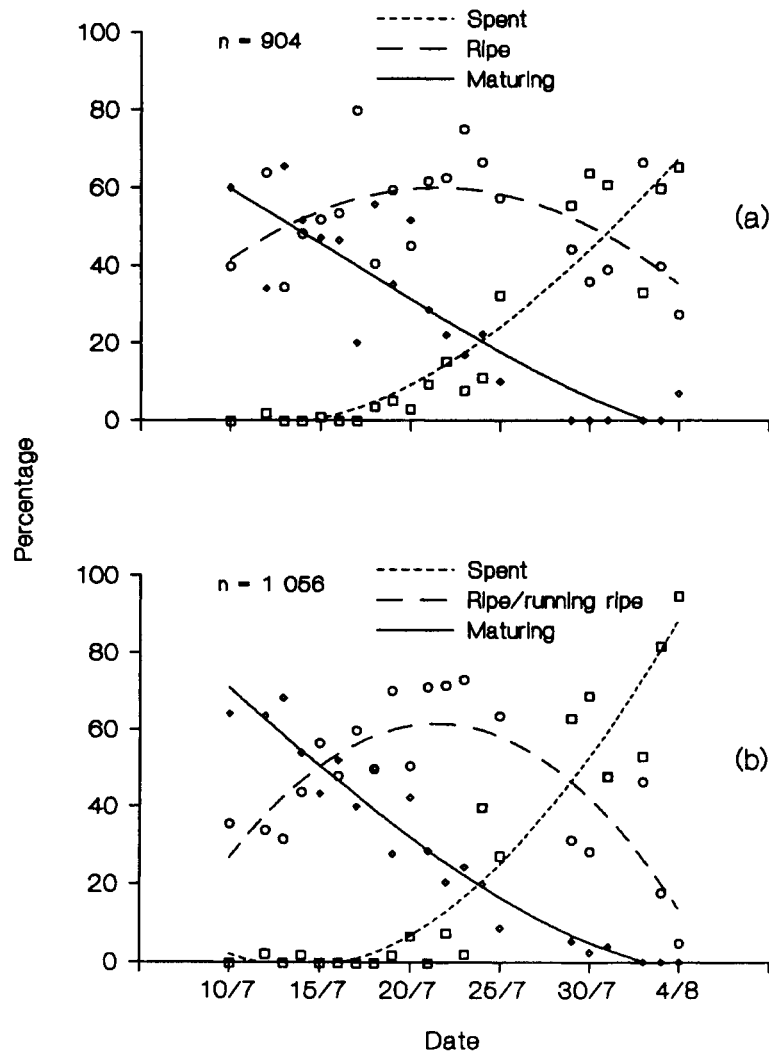


Figure 24: Gonad state of (a) male and (b) female orange roughy in the spawning box during the survey. Percentage refers to percent of mature fish only. (COR8901)

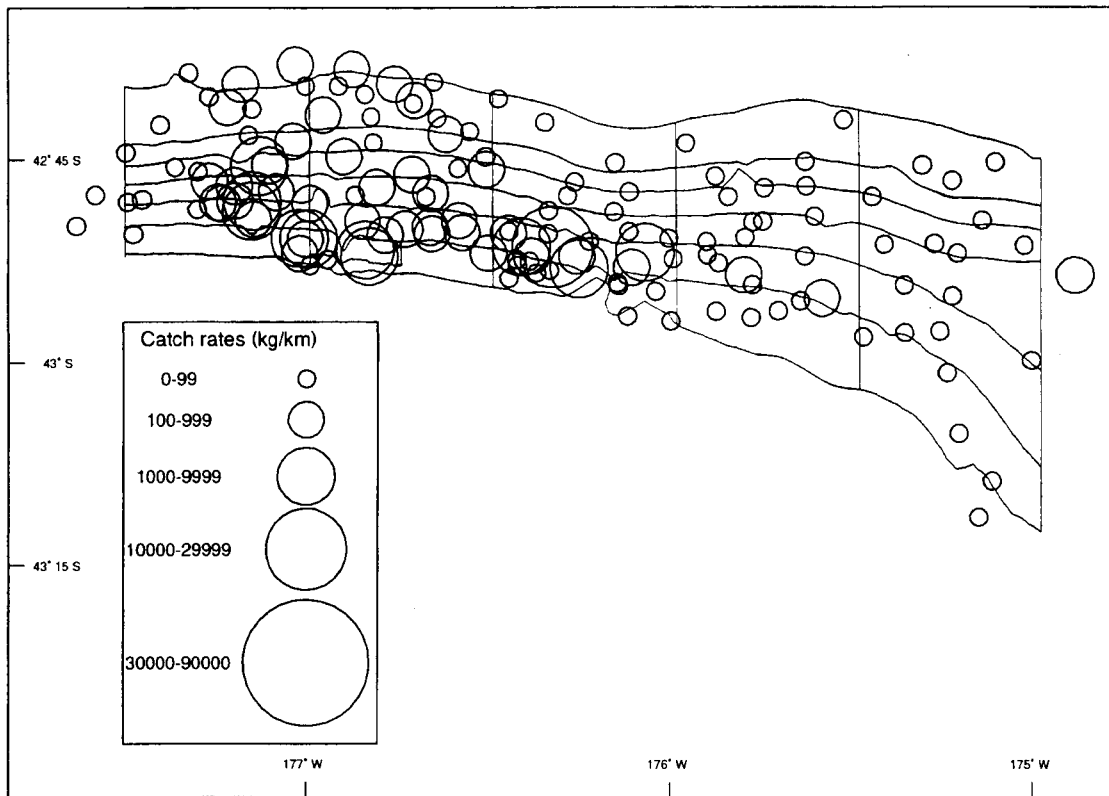


Figure 25: Catch rates (kg/km) of orange roughy in the spawning box. (COR9002)

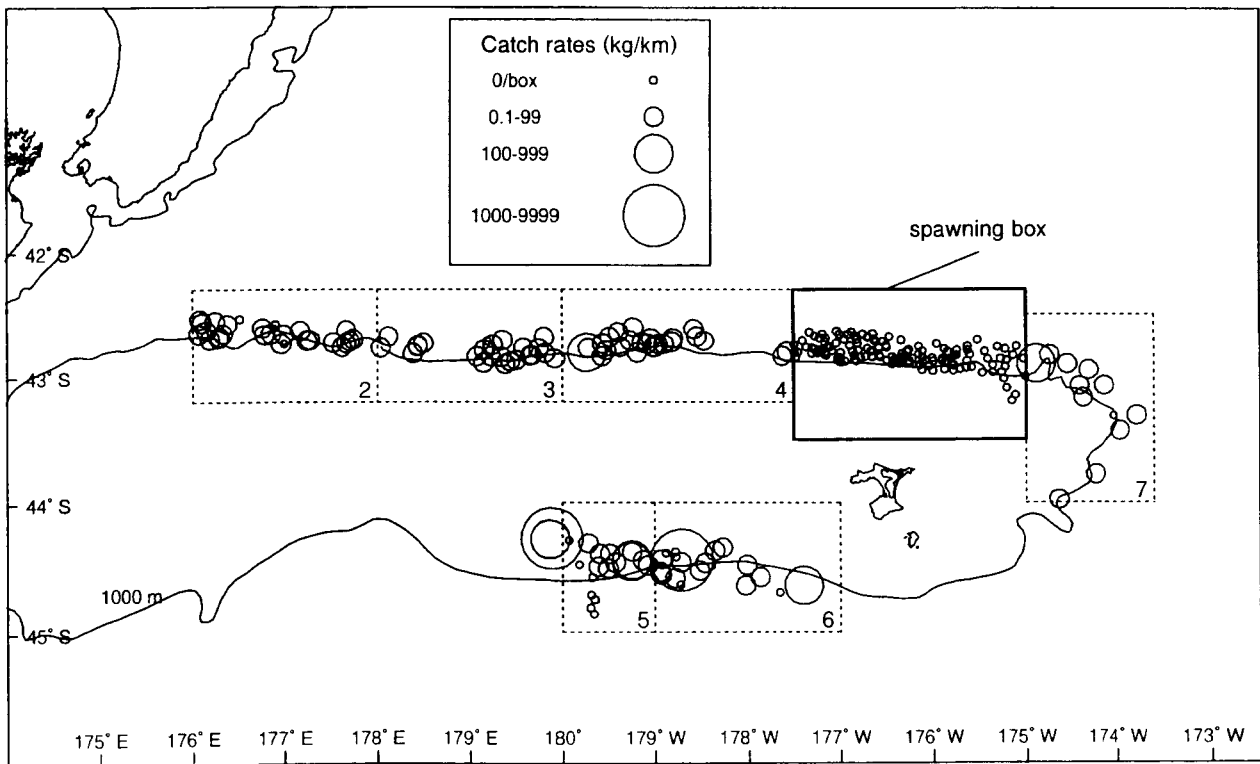


Figure 26: Catch rates (kg/km) of orange roughy at stations outside the spawning box. Symbols within the spawning box represent station positions only. (COR9002)

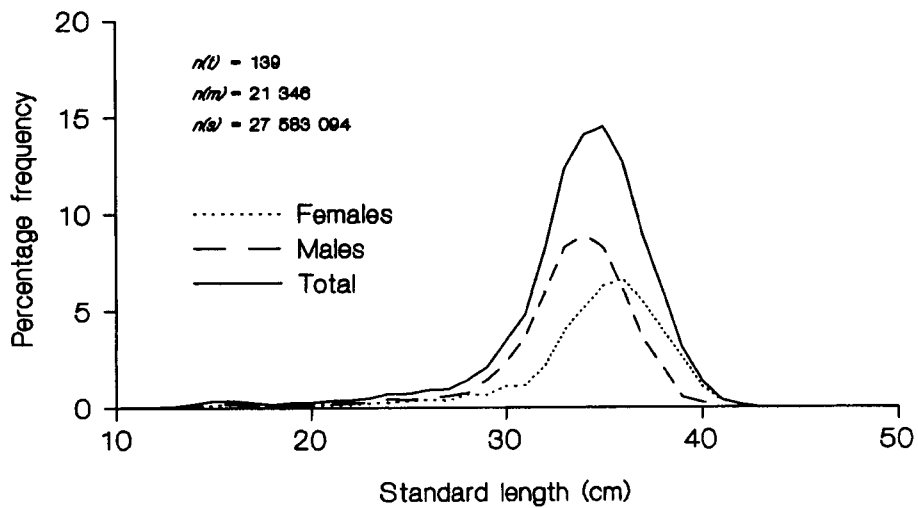


Figure 27: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (COR9002)

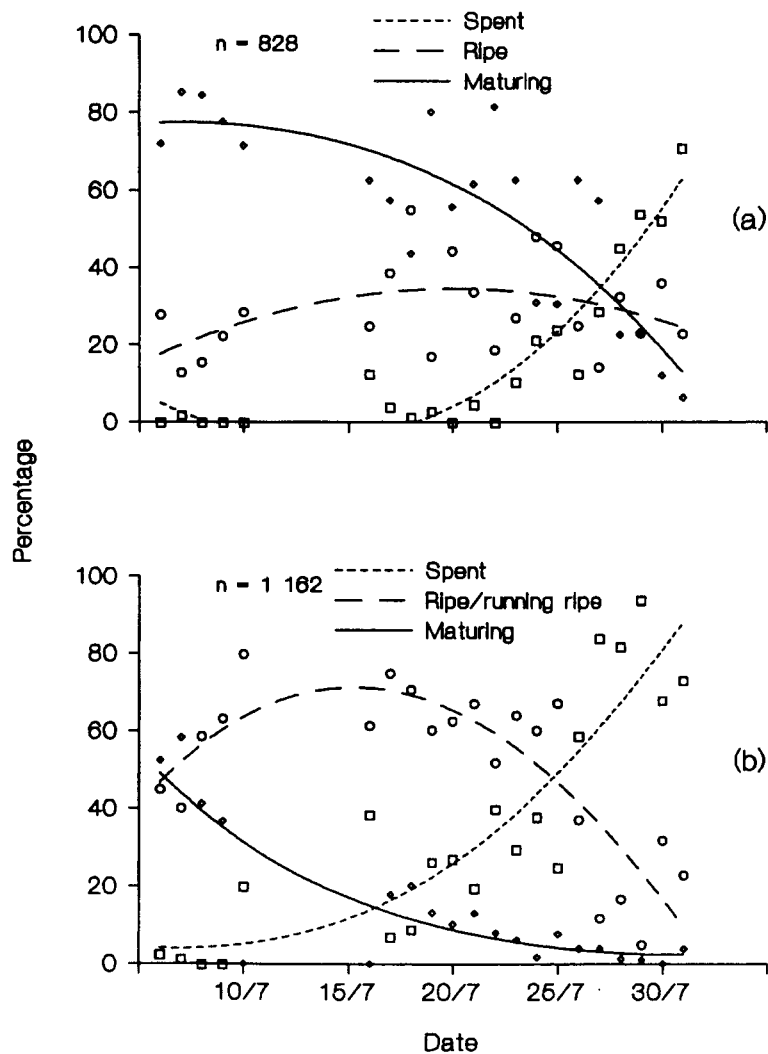


Figure 28: Gonad state of (a) male and (b) female orange roughy in the spawning box during the survey. Percentage refers to percent of mature fish only. (COR9002)



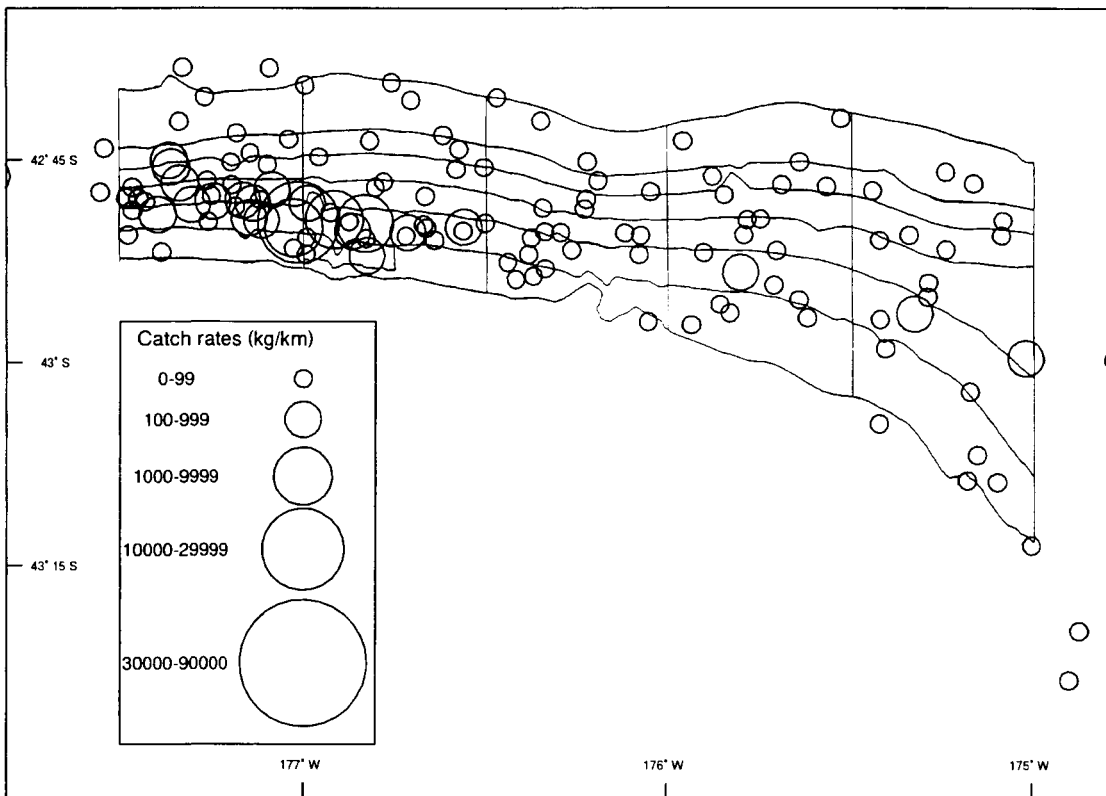


Figure 29: Catch rates (kg/km) of orange roughy in the spawning box.  
(TAN9206)

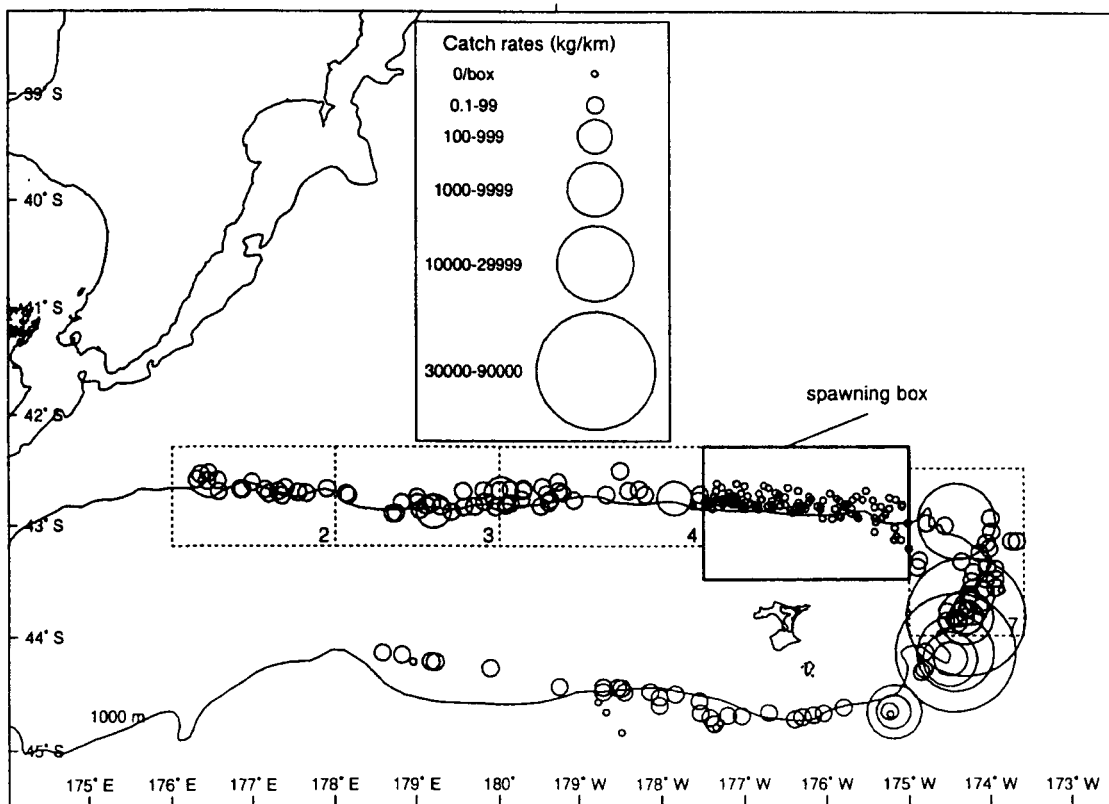


Figure 30: Catch rates (kg/km) of orange roughy at stations outside the spawning box.  
Symbols within the spawning box represent station positions only.  
(TAN9206)

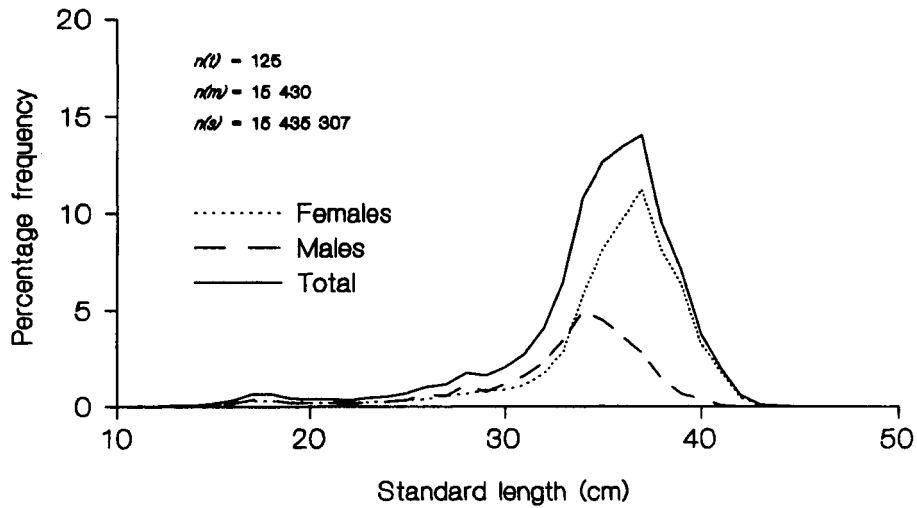


Figure 31: Length frequency distribution of orange roughy in the spawning box, scaled to represent the total population. The percentage frequency refers to the percentage of all fish.  $n(t)$ , number of tows;  $n(m)$ , number of fish measured;  $n(s)$ , scaled total number of fish. (TAN9206)

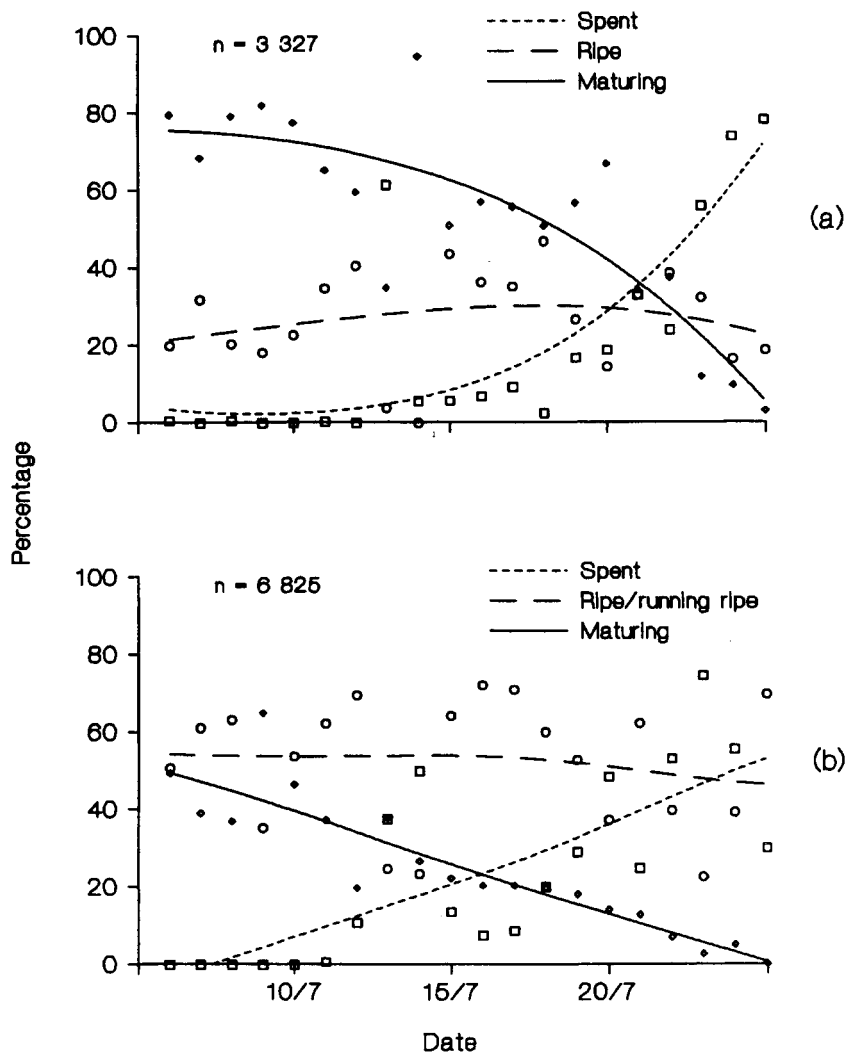


Figure 32: Gonad state of (a) male and (b) female orange roughy in the spawning box during the survey. Percentage refers to percent of mature fish only. (TAN9206)

## Appendix 1: Vessel specifications and trawl net plans

### *Otago Buccaneer*

Type	Stern trawler
Overall length	87 m
Breadth	13 m
Gross tonnage	1660 t

### *Cordella*

Type	Stern trawler
Overall length	76 m
Breadth	13 m
Gross tonnage	1534 t

### *Tangaroa*

Type	Research stern trawler
Overall length	70 m
Breadth	14 m
Gross tonnage	2282 t

## Gear specifications

### *Otago Buccaneer*

Modified Alfredo trawls without lower wings, using a nominal 125 mm codend mesh, were used at all stations on all surveys with this vessel except for midwater tows during the 1985 and 1987 surveys, when a Dutch P58 trawl was used. Windows set at about 40 t, either open or made of a loosely stitched panel, were commonly used to prevent catching too much fish for the net or hauling gear to safely handle. Sweeps were 91.5 m, bridles 25.6 m, and the total length of the running wires was 123.7 m including a 1 m Danleno assembly. The doors used were Polyvalents No. 9.5 (3.25 x 1.95 m, 5.4 m<sup>2</sup> area).

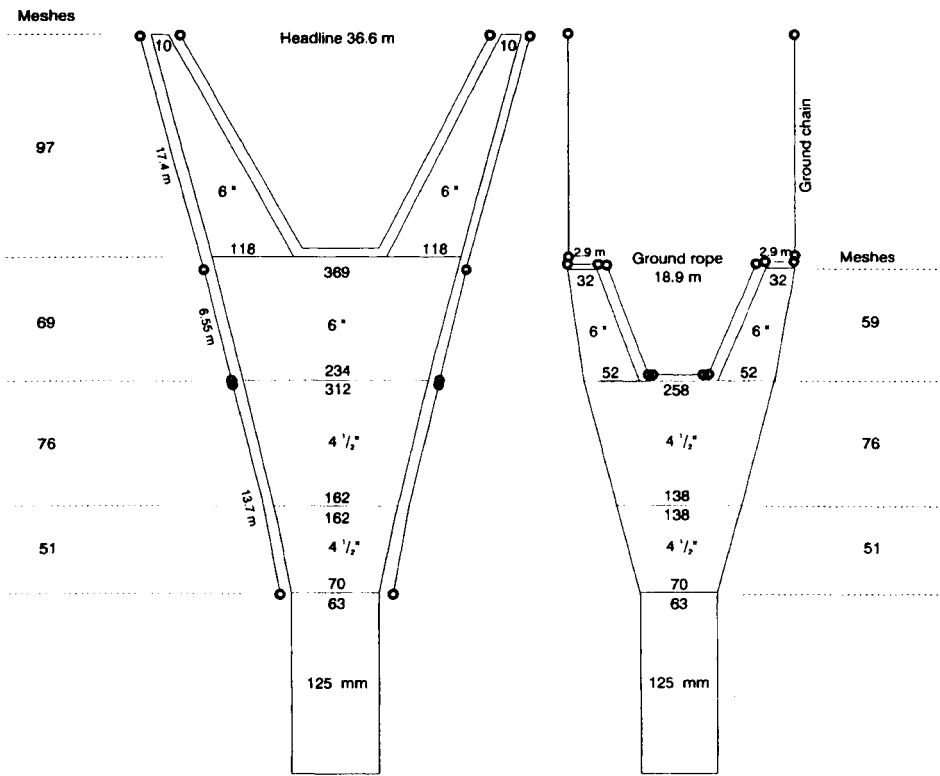
### *Cordella*

For the main spawning area surveys a six-panel rough-bottom trawl with no lower wings and a 100 mm codend was used. For surveys conducted outside the main spawning box (1988(2), 1989, and 1990) a standard six-panel rough-bottom trawl with a 40 mm mesh codend was used except at stations 79 to 94 on the south Rise in 1990. At these stations a 100 mm mesh codend was used to test for differences in catches due to escapement or changes in the pressure wave caused by the codend. Windows, used in the same way and for the same reasons as *Otago Buccaneer*, were usually installed in the trawl net. Sweeps were 91.5 m and bridles 45.8 m for stations within the spawning box, but sweeps were reduced to 45.8 m for some south Rise stations. Super-V doors (6.5 m<sup>2</sup>, weight in air 1.8 t) were used for all shots in 1988 and 1990. High aspect Korean Superkrub type doors were used for all stations in 1989.

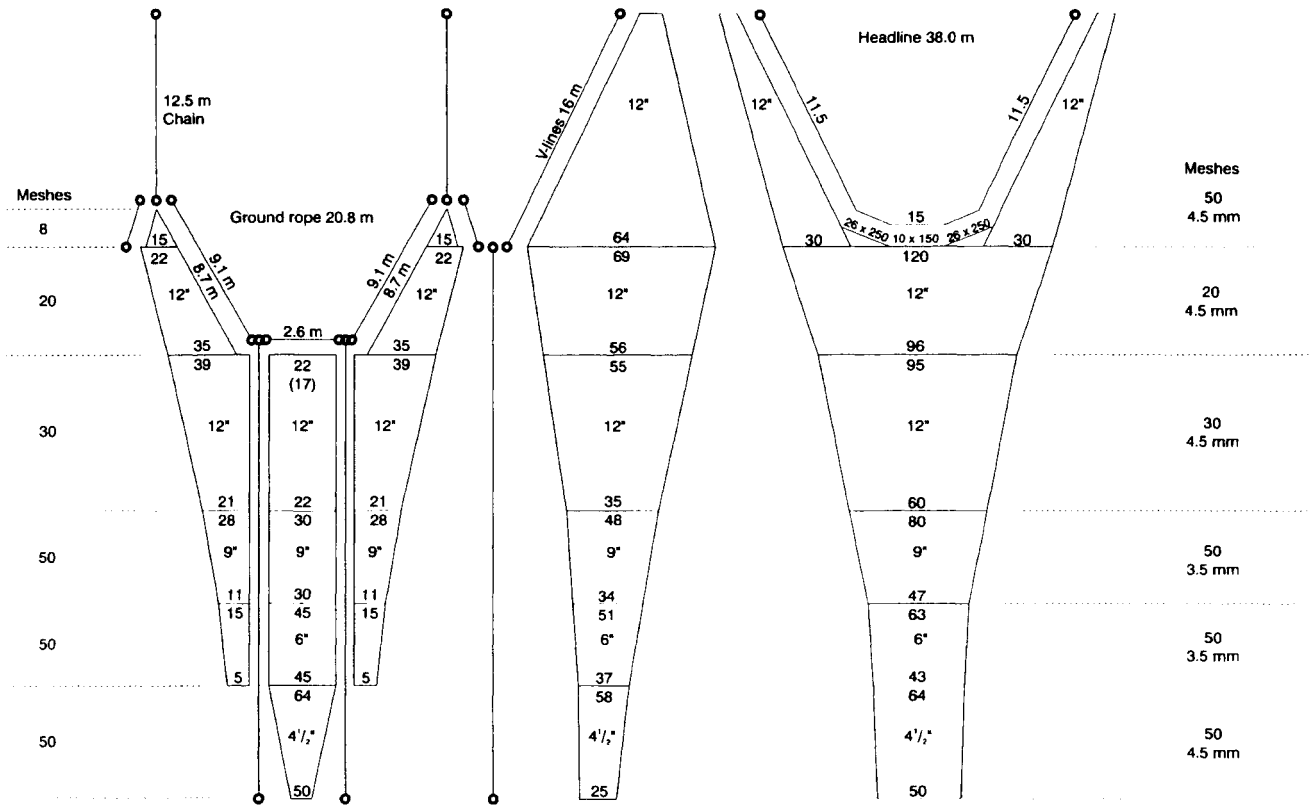
### *Tangaroa*

A six-panel rough-bottom trawl almost identical to that used by *Cordella* was used for all trawl stations in the 1992 survey. Sweep and bridle lengths were 50 m and doors 6.1 m<sup>2</sup> WV type. A 100 mm mesh codend was used at all stations.

**Appendix 1 – continued**  
**Trawl net plans – Otago Buccaneer**



**Trawl net plans – Cordella and Tangaroa**



**Appendix 2: Species caught; voyages 1, BUC8401; 2, BUC8501; 3, BUC8601; 4, BUC8701; 5, COR8801; 6, COR8901; 7, COR9002; 8, TAN9206; 9, COR8802**

	Voyages on which caught
<b>Crustacea</b>	
<i>Acantheephyra pelagica</i>	78
<i>A. quadrispinosa</i>	6
<i>Aristaeomorpha foliacea</i> (royal red prawn)	7
<i>Gnathophausia</i> sp.	7
<i>Ibacus alticrenatus</i> (prawn killer)	89
<i>Lipkius holthuisi</i> (omega prawn)	678
<i>Lithodes murrayi</i> (southern stone crab)	13678
<i>Neolithodes brodiei</i> (southern stone crab)	2456789
<i>Notopandalus magnoculus</i>	7
<i>Notostomus auriculatus</i>	7
<i>Oplophorus novaezeelandiae</i>	67
<i>Pasiphaea</i> spp.	689
<i>P. barnardi</i>	378
<i>Plesiopenaeus edwardsianus</i> (scarlet prawn)	7
<i>Sergia potens</i>	8
spider crab	7
<b>Cephalopoda</b>	
<i>Amphitretus</i> sp. (deepwater octopod)	2
<i>Architeuthis</i> spp. (giant squid)	4678
Cranchiidae (cranchiid squid)	789
<i>Graneledone</i> spp. (deepwater octopus)	13456789
<i>Histioteuthis</i> spp. (violet squid)	1234789
<i>Moroteuthis ingens</i> or <i>M. robsoni</i> (warted squid)	123456789
<i>Nototodarus sloanii</i> or <i>N. gouldi</i> (arrow squid)	346789
Octopoteuthiidae	3
<i>Todarodes filippovae</i>	123456789
<i>Opisthoteuthis</i> sp. (umbrella octopus)	1458
<b>Chondrichthyes</b>	
<b>Geotriidae</b>	
<i>Geotria australis</i> (lamprey)	29
<b>Selachiformes</b>	
<i>Apristurus</i> spp. (catsharks)	123456789
<i>Centrophorus squamosus</i> (leafscaled gulper shark)	123456789
<i>Centroscymnus</i> spp. (deepsea sharks)	2
<i>C. coelolepis</i>	7
<i>C. crepidater</i> (longnosed velvet dogfish)	123456789
<i>C. owstoni</i> (smooth skin dogfish)	123456789
<i>Chlamydoselachus anguineus</i> (frill shark)	47
<i>Deania calcea</i> (shovelnosed spiny dogfish)	123456789
deepwater dogfish	7
<i>Etmopterus</i> sp.	7
<i>E. baxteri</i> (Baxter's lantern dogfish)	123456789
<i>E. lucifer</i> (Lucifer dogfish)	5689
<i>E. molleri</i> (blackbelly lantern shark)	7
<i>E. pusillus</i>	48
<i>E. villosus</i>	6
<i>Galeorhinus galeus</i> (school shark)	6
<i>Mustelus lenticulatus</i> (rig)	48
<i>Oxynotus bruniensis</i> (prickly dogfish)	4679
<i>Prionace glauca</i> (blue shark)	2
<i>Scymnodon plunketi</i> (Plunket's shark)	123456789

<i>Scymnorhinus licha</i> (sealshark)	123456789
<i>Squalus acanthias</i> (spiny dogfish)	9
<i>Zameus squamulosus</i>	7
<b>Rajiformes</b>	
<i>Bathyraja</i> sp. (bluntnose skate)	123456789
<i>B. shuntovi</i> (longnosed deepsea skate)	1234789
<i>Pavoraja asperula</i>	23456789
<i>P. spinifera</i>	234
<i>Raja</i> ( <i>Amblyraja</i> ) sp. (deepwater spiny skate)	68
<i>R. innominata</i> (smooth skate)	23467
<i>R. nasuta</i> (rough skate)	478
<i>Torpedo fairchildi</i> (electric ray)	1578
<i>Typhlonarke</i> spp. (numbfish)	5
<b>Chimaeriformes</b>	
<i>Chimaera</i> sp.	347
<i>Chimaera</i> sp. (purple chimaera)	12456789
<i>C. phantasma</i> (giant chimaera)	13478
<i>Harriotta raleighana</i> (longnosed chimaera)	123456789
<i>Hydrolagus</i> spp.	356789
<i>Hydrolagus</i> sp. A (black hydrolagus)	12456789
<i>Hydrolagus</i> sp. B (pale ghost shark)	123456789
<i>Hydrolagus</i> sp. C (purple finned hydrolagus)	6789
<i>H. novaezealandiae</i> (ghost shark)	38
<i>Rhinochimaera pacifica</i> (widenosed chimaera)	123456789
<b>Osteichthyes</b>	
<b>Notacanthiformes</b>	
<i>Halosauropsis macrochir</i> (abyssal halosaur)	5678
<i>Halosaurus pectoralis</i> (common halosaur)	123456789
<i>Notacanthus chemnitzii</i>	78
<i>N. sexspinis</i> (spineback)	123456789
<b>Anguilliformes</b>	
<i>Avocettina</i> spp. (black snipe eel)	56
<i>Bassanago bulbiceps</i> (swollenhead conger)	123456789
<i>B. hirsutus</i> (hairy conger)	123456789
<i>Brotulotaenia crassa</i> (blue cusk eel)	389
deepwater eel	34
<i>Diastobranchus capensis</i> (basketwork eel)	123456789
<i>Gnathophis habenatus</i> (silver conger)	8
<i>Lepidion microcephalus</i> (smallheaded cod)	123456789
<i>Nemichthys scolopaceus</i> (slender snipe eel)	69
<i>Nettastoma parviceps</i> (duckbill eel)	7
<i>Serrivomer</i> sp. (sawtoothed eel)	56789
<i>Simenchelys parasiticus</i> (snubnosed eel)	12456789
Synaphobranchidae (cutthroat eels)	7
<b>Salmoniformes</b>	
<i>Alepocephalus</i> sp. (bigscaled brown slickhead)	123456789
<i>A. australis</i> (smallscaled brown slickhead)	123456789
<i>Argentina elongata</i> (silverside)	6
<i>Bathylagus</i> spp. (deepsea smelt)	146789
<i>Persparsia kopua</i> (tubeshoulder)	89
Platyroctidae (tubeshoulders)	679
<i>Rouleina</i> sp. (large headed slickhead)	78
<i>Xenodermichthys</i> spp. (black slickhead)	123456789
<b>Stomiiformes</b>	
<i>Argyropelecus gigas</i> (giant hatchetfish)	17
<i>A. hemigymnus</i> (common hatchetfish)	67
Astronesthidae (snaggletooths)	5678
<i>Chauliodus sloani</i> (viper fish)	1356789

<i>Cyclothone</i> spp.	6
<i>Diplophos</i> spp.	78
<i>Gonostoma elongatum</i> (elongate lightfish)	9
<i>Idiacanthus</i> spp.	23456789
Malacosteidae (loosejaw)	56789
<i>Malacosteus niger</i> (loosejaw)	7
Melanostomiidae (scaleless black dragonfishes)	678
<i>Photichthys argenteus</i> (lighthouse fish)	123456789
Sternoptychidae (hatchetfish)	679
<i>Stomias</i> spp.	79
Aulopiformes	
<i>Alepisaurus brevirostris</i> (shortsnouted lancetfish)	23456789
<i>A. ferox</i> (lancetfish)	1458
<i>Bathysaurus ferox</i> (deepsea lizardfish)	789
<i>Chlorophthalmus nigripinnis</i> (cucumber fish)	49
<i>Evermanella indica</i> (sabretooth)	7
<i>Magnisudis prionosa</i> (barracudina)	134679
<i>Scopelarchus</i> sp.	278
<i>Scopelosaurus</i> sp.	7
Myctophiformes	
<i>Ceratoscopelus warmingi</i>	4
<i>Diaphus</i> spp.	7
<i>Gymnoscopelus</i> spp.	8
<i>Lampadena</i> spp.	9
<i>Lampanyctus</i> spp.	789
Myctophidae (lantern fish)	3456789
Gadiformes	
<i>Antimora rostrata</i> (violet cod)	12456789
<i>Austrophycis marginata</i> (dwarf cod)	679
<i>Bathygadus cottoides</i> (codheaded rattail)	7
<i>Caelorinchus acanthiger</i> (spottyfaced rattail)	123456789
<i>C. bollonsi</i> (Bollons's rattail)	123456789
<i>C. cookianus</i> (Cook's rattail)	3
<i>C. fasciatus</i> (banded rattail)	123456789
<i>C. innotabilis</i> (notable rattail)	123456789
<i>C. kaiyomaru</i> (Kaiyomaru rattail)	134689
<i>C. matamua</i> (Mahia rattail)	123456789
<i>C. oliverianus</i> (Oliver's rattail)	346789
<i>Cetonurus crassiceps</i> (globosehead rattail)	789
<i>Coryphaenoides</i> sp. A (slender rattail)	47
<i>Coryphaenoides</i> sp. B	123456789
<i>C. mcmillani</i>	378
<i>C. murrayi</i> (abyssal rattail)	13456789
<i>C. serrulatus</i> (serrulate rattail)	123456789
<i>C. subserrulatus</i> (four-rayed rattail)	123456789
<i>C. striatura</i> (abyssal rattail)	8
<i>Euclichthys polynemus</i> (eucla cod)	67
<i>Gadomus aoteanus</i> (filamentous rattail)	35679
<i>Halargyreus johnsonii</i> (Johnson's cod)	123456789
<i>Idiolorhynchus andriashevi</i> (pineapple rattail)	78
<i>Laemonema</i> spp.	78
<i>Lepidion schmidti</i> or <i>L. inosimae</i> (giant lepidion)	3456789
<i>Lepidorhynchus denticulatus</i> (javelinfish)	123456789
<i>Lyconus</i> sp.	123456789
<i>Macrourus carinatus</i> (ridge scaled rattail)	123456789
<i>Macruronus novaezelandiae</i> (hoki)	123456789
<i>Melanonus gracilis</i>	4689
<i>M. zugmayeri</i>	7

<i>Merluccius australis</i> (hake)	123456789
<i>Mesobius antipodum</i> (black javelinfish)	123456789
<i>Mora moro</i> (ribaldo)	123456789
Moridae (morid cods)	7
<i>Nezumia bubonis</i> (bulbous rattail)	9
<i>Nezumia namatahi</i> (squashed face rattail)	13456789
<i>Nezumia leonis</i> (false bulbous rattail)	2
<i>Odontomacrus murrayi</i> (large fang rattail)	789
<i>Pseudophycis bachus</i> (red cod)	67
<i>Trachonurus</i> sp. B (velvet rattail)	68
<i>Trachonurus villosus</i>	2378
<i>Trachyrincus aphyodes</i> (unicorn rattail)	123456789
<i>Tripteryphycis gilchristi</i> (grenadier cod)	678
<i>Ventrifossa nigromaculata</i> (blackspot rattail)	3456789
<b>Ophidiiformes</b>	
<i>Cataetyx niki</i> (brown brotula)	5
<i>Cataetyx</i> sp. (white brotula)	124
<i>Diplacanthopoma</i> sp.	7
<i>Echiodon cryomargarites</i> (messmate fish)	26789
<i>Genypterus blacodes</i> (ling)	123456789
<b>Lampriformes</b>	
<i>Agrostichthys parkeri</i> (ribbonfish)	789
<i>Regalecus glesne</i> (oarfish)	9
<i>Trachipterus trachipterus</i> (dealfish)	14789
<i>Zu elongatus</i> (scalloped dealfish)	78
<b>Beryciformes</b>	
<i>Anoplogaster cornuta</i> (fangtooth)	346789
<i>Beryx splendens</i> (alfonsino)	12456789
<i>Diretmus argenteus</i> (discfish)	9
<i>Diretmoides parini</i> (spinyfin)	7
<i>Hoplostethus atlanticus</i> (orange roughy)	123456789
<i>H. mediterraneus</i> (silver roughy)	356789
Melamphidae (bigscaled fish)	6789
<i>Paratrachichthys trailli</i> (common roughy)	348
<b>Lophiiformes</b>	
black anglerfish	246789
<i>Chaunax pictus</i> (pink frogmouth)	2346789
<i>Cryptopsaras couesi</i> (seadevil)	589
<i>Gigantactis</i> sp. (slender anglerfish)	7
<i>Melanocetus johnsonii</i> (humpbacked anglerfish)	8
<b>Zeiformes</b>	
<i>Alloctytus niger</i> (black oreo)	123456789
<i>A. verrucosus</i> (warty oreo)	123456789
<i>Capromimus abbreviatus</i> (capro dory)	49
<i>Cyttus traversi</i> (lookdown dory)	123456789
<i>C. novaezealandiae</i> (silver dory)	4
<i>Neocyttus rhomboidalis</i> (spiky oreo)	123456789
<i>Pseudocyttus maculatus</i> (smooth oreo)	123456789
<b>Syngnathiformes</b>	
<i>Centriscops humerosus</i> (redbanded bellowsfish)	589
<i>Notopogon lilliei</i> (crested bellowsfish)	9
<b>Scorpaeniformes</b>	
<i>Cottunculus nudus</i> (bonyskulled toadfish)	45789
<i>Helicolenus</i> sp. (sea perch)	123456789
<i>Hoplichthys haswelli</i> (deepsea flathead)	249
<i>Neophrynichthys angustus</i> (pale toadfish)	12345789
<i>Neophrynichthys</i> sp. (toadfish)	145679
<i>Psychrolutes</i> sp. (blobfish)	123456789



<i>Trachyscorpia capensis</i> (Cape scorpionfish)	123456789
Perciformes	
Apogonidae (cardinalfish)	49
<i>Benthodesmus</i> spp. (scabbardfish)	4789
<i>Brama brama</i> (Ray's bream)	123479
<i>Caristius</i> sp. (manefish)	12378
<i>Centrolophus niger</i> (rudderfish)	45679
<i>Chiasmodon niger</i> (black swallower)	78
<i>Cubiceps</i> spp. (cubehead)	4678
<i>Epigonus lenimen</i> (bigeyed cardinalfish)	123456789
<i>E. robustus</i> (robust cardinalfish)	123456789
<i>E. telescopus</i> (deepsea cardinalfish)	123456789
<i>Hyperoglyphe antarctica</i> (bluenose)	47
<i>Icichthys australis</i> (ragfish)	4678
<i>Kali indica</i>	7
<i>Kathetostoma giganteum</i> (giant stargazer)	6789
<i>Lepidocybium flavobrunneum</i> (escolar)	9
<i>Melanostigma gelatinosum</i> (limp eel pout)	89
<i>Nesiarachus nasutus</i> (black barracouta)	8
<i>Paradiplospinus gracilis</i> (false frostfish)	5
<i>Paranotothenia angustata</i> (Maori chief)	3
<i>Platyberyx</i> sp.	7
<i>Pterycombus petersii</i> (fanfish)	5
<i>Rosenblattia robusta</i>	26789
<i>Schedophilus huttoni</i>	8
<i>Schedophilus</i> sp.	7
<i>Seriolella labyrinthica</i>	7
<i>S. caerulea</i> (white warehou)	9
<i>S. punctata</i> (silver warehou)	9
stargazer	9
<i>Taratichthys longipinnis</i> (bigscaled pomfret)	14567
<i>Tetragonurus</i> sp. (squaretail)	567
<i>Tetrapturus angustirostris</i> (shortbill spearfish)	3
<i>Trachurus murphyi</i> (jack mackerel)	9
<i>Tubbia tasmanica</i>	12346789
<i>Xiphias gladius</i> (broadbill swordfish)	7
Pleuronectiformes	
<i>Achiropsetta tricholepis</i> (prickly flounder)	8
<i>Neoachirosetta milfordi</i> (finless flounder)	123456789

**Appendix 3: Total research catch (kg) of the most abundant species, including the major ITQ species, caught during each survey**

Species	1984	1985	1986	1987	1988(1)	1988(2)	1989	1990	1992
Orange roughy	527 091	726 560	413 957	657 255	518 785	13 964	372 834	328 792	216 667
Smooth oreo	1 462	1 635	1 762	78 933	3 389	28 554	35 143	36 970	113 945
Black oreo	10	1	2	7 802	5	2 729	2 146	3 176	20 302
Shovelnosed spiny dogfish	2 834	2 277	4 980	11 404	7 543	2 244	4 323	6 771	8 858
Longnosed velvet dogfish	743	856	1 564	2 731	4 549	1 744	3 169	6 112	8 285
Baxter's lantern dogfish	1 861	1 187	1 711	9 216	1 989	1 605	3 942	2 810	4 270
Four-rayed rattail	510	70	1 211	1 247	477	2 361	3 000	5 829	2 957
Smooth skin dogfish	426	748	1 491	2 627	926	1 153	1 521	3 755	2 710
Bigscaled brown slickhead	1 074	759	524	1 157	533	1 842	1 365	4 689	2 288
Johnson's cod	1 671	1 701	1 872	2 288	1 185	1 375	1 609	2 703	2 159
Hoki	337	383	419	1 429	161	1 821	2 981	3 631	2 139
Basketwork eel	3 294	3 418	1 872	2 759	940	3 543	2 409	3 610	1 814
Widenosed chimaera	834	929	916	1 289	1 074	710	1 220	1 783	1 496
Ribaldo	1 408	2 556	2 738	3 722	2 040	496	1 413	834	1 401
Unicorn rattail	1 637	1 233	1 247	2 203	1 077	1 926	1 842	1 741	1 371
Smallscaled brown slickhead	9	1	20	191	2	1 946	1 806	2 081	889
Hake	710	508	949	1 142	587	1 085	1 082	1 362	831
Pale ghost shark	823	613	624	1 449	1 024	1 105	1 606	730	555
Black javelinfish	1	15	1	2	0	147	77	417	428
Deepsea cardinalfish	45	68	146	97	75	20	199	79	353
Ling	37	98	195	321	206	189	122	147	138
Plunket's shark	94	31	38	460	94	77	145	129	40

**Appendix 4: Length-weight regressions for orange roughy caught in the spawning box.**

$W = aL^b$ , where  $W$  = weight (g) and  $L$  = standard length (cm).

$n$ , sample size;  $r^2$ , correlation coefficient

Voyage	Sex	$a$	$b$	$n$	$r^2$
BUC8401	Both	8.19	2.74	2 447	0.97
	M	9.62	2.69	1 239	0.98
	F	7.39	2.78	1 238	0.98
BUC8501	Both	8.33	2.74	2 424	0.97
	M	1.05	2.67	1 227	0.97
	F	7.75	2.77	1 196	0.97
BUC8601	Both	9.23	2.71	2 792	0.96
	M	1.27	2.62	1 537	0.96
	F	7.75	2.77	1 254	0.97
BUC8701	Both	8.48	2.73	5 649	0.98
	M	9.73	2.69	2 806	0.98
	F	8.08	2.75	2 840	0.98
COR8801	Both	1.02	2.68	2 848	0.98
	M	1.10	2.65	1 503	0.98
	F	9.81	2.69	1 345	0.98
COR8901	Both	8.90	2.72	4 103	0.95
	M	1.10	2.65	1 959	0.94
	F	8.69	2.73	2 144	0.95
COR9002	Both	8.14	2.75	4 586	0.96
	M	1.00	2.68	1 900	0.97
	F	7.38	2.78	2 684	0.96
TAN9206	Both	8.10	2.74	4 778	0.97
	M	1.00	2.67	2 089	0.98
	F	7.53	2.77	2 688	0.97

## Appendix 5: Repeat station positions and station numbers for spawning box surveys

Numbers in the table represent the station number of the tow for each year, a "-" indicates that the station was not sampled. Station numbers and positions were obtained by a deductive process from the TRAWL database and should be considered approximate. Details of catch, etc., at each station are available from the TRAWL database.

Stratum	1984	1985	1986	1987	1988	1989	1990	1992	Position	
									Latitude (S)	Longitude (W)
1	3	3	3	70	3	28	148	222	42°50.00'	182°33.00'
1	9	9	9	78	9	52	153	215	42°51.60'	182°54.00'
1	10	10	10	79	10	26	129	216	42°51.90'	182°46.20'
2	1	1	1	68	1	-	-	-	42°49.20'	182°49.50'
2	2	2	2	69	2	27	250	219	42°48.60'	182°41.40'
2	4	4	4	73	4	37	147	224	42°48.00'	182°31.20'
2	8	8	8	77	8	40	133	218	42°48.60'	182°53.40'
3	7	7	7	76	7	39	143	229	42°46.80'	182°45.00'
3	11	11	11	80	11	41	146	230	42°45.72'	182°42.90'
3	14	14	15	83	14	44	149	-	42°47.10'	182°49.80'
3	15	15	16	84	15	45	152	231	42°47.70'	182°58.50'
4	5	5	5	74	5	30	131	227	42°45.72'	182°34.50'
4	13	12	12	81	12	42	142	244	42°47.10'	182°50.40'
4	16	16	17	85	16	46	150	246	42°45.54'	182°56.40'
5	6	6	6	75	6	38	140	198	42°44.10'	182°33.60'
5	12	13	13	82	13	43	144	-	42°47.10'	182°48.60'
5	17	17	18	86	17	48	151	197	42°43.80'	182°58.50'
6	32	33	38	105	34	78	-	-	42°52.50'	183°17.40'
6	42	44	50	117	43	85	167	233	42°54.00'	183°27.00'
7	25	25	28	97	25	61	-	-	42°49.50'	183°07.20'
7	26	26	31	99	28	63	168	241	42°50.10'	183°17.10'
7	27	31	-	-	-	-	166	-	42°50.58'	183°22.20'
7	30	-	36	103	32	66	169	243	42°49.80'	183°20.52'
7	31	27	37	104	35	62	165	-	42°50.88'	183°17.70'
7	33	34	40	-	33	70	189	266	42°51.75'	183°24.60'
7	34	35	-	107	36	79	-	-	42°52.20'	183°30.60'
7	35	36	41	108	37	-	175	240	42°49.80'	183°29.10'
7	36	38	43	109	38	80	170	-	42°50.40'	183°25.08'
8	22	22	24	93	22	55	163	248	42°46.80'	183°10.20'
8	23	23	26	94	23	59	164	232	42°48.30'	183°09.90'
8	24	24	27	96	24	60	161	-	42°48.30'	183°05.10'
8	29	30	34	102	31	68	162	249	42°46.02'	183°14.70'
8	38	28	32	100	29	67	172	250	42°48.60'	183°33.00'
8	37	39	44	110	39	81	171	247	42°46.80'	183°16.80'
9	21	21	23	92	30	53	155	-	42°44.40'	183°04.50'
9	39	29	33	101	-	69	174	251	42°45.00'	183°23.40'
9	117	40	45	111	40	-	-	-	42°45.90'	183°27.90'
11	108	99	108	180	44	-	-	-	42°56.10'	183°47.10'
11	44	45	51	118	-	-	-	-	42°53.70'	183°37.50'
11	107	63	70	137	70	98	197	256	42°56.40'	183°56.40'
12	47	50	56	196	48	-	193	259	42°52.80'	183°41.70'
12	52	54	60	127	60	-	196	-	42°54.00'	183°52.20'
12	45	47	53	120	46	88	191	-	42°50.40'	183°33.00'
12	119	55	-	124	63	-	266	-	42°54.60'	184°00.30'
13	46	-	-	-	47	-	264	-	42°51.30'	183°42.00'
13	49	-	57	-	50	156	192	-	42°49.50'	183°38.40'
13	109	64	69	136	69	99	183	-	42°50.70'	183°57.00'
13	114	-	-	-	58	162	184	255	42°50.10'	183°50.10'

Stratum	1984	1985	1986	1987	1988	1989	1990	1992	Position	
									Latitude (S)	Longitude (W)
13	118	-	-	-	-	164	185	235	42°51.30'	183°46.80'
14	50	52	58	125	-	-	186	253	42°48.00'	183°34.80'
14	110	100	103	175	-	-	-	-	42°48.60'	184°00.00'
14	111	102	104	178	-	160	-	-	42°48.00'	183°47.40'
15	51	53	59	126	-	92	-	-	42°45.90'	183°39.60'
15	112	-	-	-	66	-	-	-	42°46.92'	183°55.20'
15	113	-	-	-	-	-	180	212	42°47.10'	183°48.60'
16	57	59	-	133	-	106	199	188	42°56.40'	184°10.50'
16	66	69	-	147	73	111	-	-	42°57.60'	184°23.40'
16	106	60	65	132	65	102	-	-	42°57.30'	184°02.40'
17	54	56	62	129	-	97	207	-	42°52.60'	184°00.60'
17	56	58	61	128	-	96	-	-	42°54.30'	184°03.00'
17	59	-	67	134	67	104	-	185	42°53.82'	184°10.20'
17	60	-	-	-	-	109	-	-	42°52.50'	184°15.00'
17	61	66	-	-	-	-	-	-	42°54.48'	184°18.00'
17	62	71	75	149	75	-	221	184	42°56.22'	184°20.10'
17	65	70	74	148	74	112	222	183	42°56.40'	184°25.80'
17	67	72	76	150	76	110	219	190	42°54.60'	184°24.90'
17	58	61	-	135	68	105	208	-	42°52.50'	184°09.30'
18	55	57	-	131	64	101	206	-	42°51.60'	184°03.30'
18	64	97	96	168	-	172	217	182	42°52.08'	184°24.60'
18	104	96	98	170	-	168	210	181	42°50.70'	184°14.40'
19	98	94	95	167	-	169	211	180	42°49.68'	184°20.70'
19	100	93	100	172	-	-	-	-	42°48.78'	184°15.90'
19	103	95	99	171	-	-	-	-	42°49.80'	184°12.00'
19	102	91	101	173	84	166	203	191	42°47.88'	184°12.60'
20	101	92	102	174	-	167	212	178	42°46.92'	184°16.50'
21	90	82	-	158	-	118	226	159	43°09.60'	184°55.32'
21	91	83	-	156	82	117	227	158	43°10.20'	184°50.40'
21	92	84	83	157	83	116	225	157	43°06.90'	184°49.38'
21	120	76	80	154	80	-	230	160	43°03.00'	184°35.40'
22	71	-	-	-	-	-	-	-	42°56.40'	184°37.44'
22	72	-	-	-	-	113	-	-	42°57.00'	184°35.10'
22	73	-	77	-	-	-	-	-	42°57.60'	184°34.80'
22	74	-	78	-	-	-	-	-	43°00.00'	184°36.00'
22	78	78	88	160	86	122	229	163	42°57.00'	184°42.96'
22	83	79	81	155	81	115	224	156	43°01.68'	184°48.00'
22	84	80	-	-	-	123	231	164	43°06.00'	184°57.90'
22	85	81	91	163	89	-	-	-	43°09.30'	184°59.70'
23	69	-	-	-	-	-	-	-	42°54.00'	184°38.10'
23	75	-	-	-	-	124	-	-	42°52.20'	184°39.60'
23	76	87	90	162	88	121	-	-	42°54.00'	184°45.42'
23	77	77	89	161	87	-	-	-	42°55.80'	184°46.80'
23	86	85	87	159	85	-	-	-	42°59.40'	184°58.50'
24	95	89	93	165	93	125	233	166	42°52.38'	184°46.20'
24	96	-	-	-	-	-	235	173	42°50.70'	184°32.10'
25	97	90	94	166	92	120	236	174	42°46.80'	184°32.10'
25	94	86	92	164	-	-	240	170	42°51.00'	184°54.60'
26	18	18	19	87	18	51	141	194	42°51.00'	183°01.80'
26	19	19	-	202	98	50	158	213	42°52.50'	183°01.20'