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ISSN 0110-1765

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Published by the New Zealand Ministry of Agriculture and Fisheries
Wellington
1984

ISSN 0110-1765

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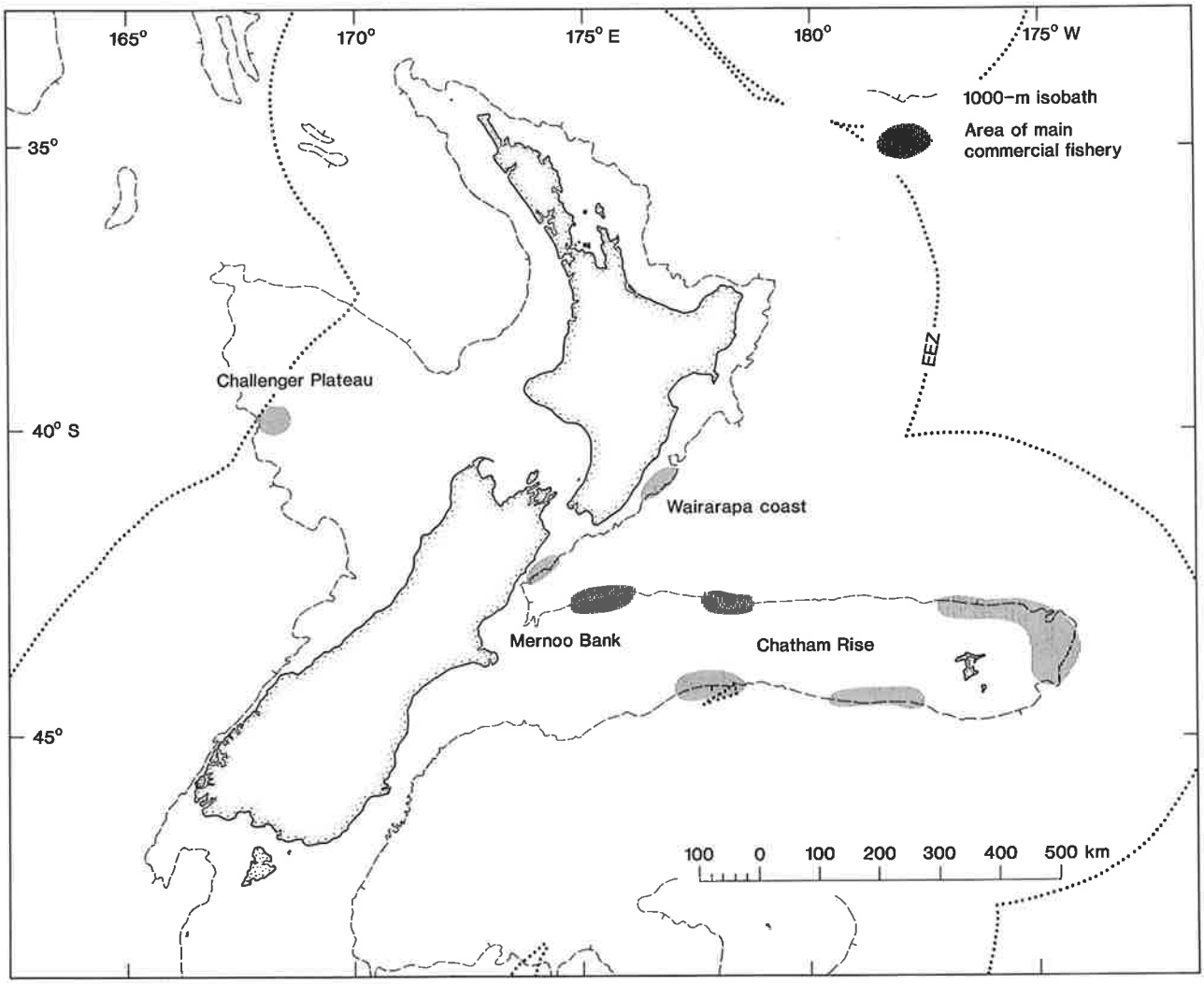


Fig. 1: Main fishing areas for orange roughy around New Zealand.

Introduction

A feature of the developing trawl fisheries around New Zealand has been the changing prominence of various species in the total landings each year. One species which has become important since 1979 is the deepwater berycoid *Hoplostethus atlanticus* (orange roughy).

Orange roughy occurs in slope waters from about 750 to about 1300 m deep in most of the New Zealand 200-mile Exclusive Economic Zone (EEZ) and has been found in abundance on Chatham Rise and Challenger Plateau and off the Wairarapa coast (Fig. 1).

High prices for fillets of this fish, and the prospect of a valuable oil by-product (Buisson, Body, Dougherty, Eyres, and Vlieg 1982), have resulted in the fishing industry showing increasing interest in the species.

Little is known of the fishery before the declaration of the EEZ in 1978. The Soviets reported taking small quantities of a berycoid fish, assumed by us to be orange roughy, from 1972 to 1977. During this period the maximum reported annual catch was 3500 t in 1977. In 1976 a few large catches of orange roughy were reported during exploratory trawling. For the next 3 years catches were negligible and little notice was taken of the species. In 1979–80*, 10 500 t were reported caught and, with unrestricted effort, the landings in 1980–81 increased to 27 540 t, with reports of exceptionally large catches.

The developing fishery had all the characteristics of a "boom-bust" situation and, with no real knowledge of the resource size, a total catch quota of 25 000 t was put on orange roughy for 1981–82. The quota was reached in July, and by 31 July 1981 the fishery was closed.

Although there was a lack of basic information on the orange roughy population size in any area, the New Zealand Ministry of Agriculture and Fisheries (MAF) prepared a more detailed management plan in 1982–83. This comprised an increased total allowable catch (30 000 t), a shortened season, and quotas by areas. Further, as MAF had no appropriate research vessel or funds for charter, fishing companies were offered the opportunity of tendering for 1000 t of additional quota in exchange for a vessel to conduct a trawl survey on Chatham Rise.

This publication describes the results of the "charter for quota" research cruise on the northern and eastern Chatham Rise from 31 July to 7 September 1982.

* In this publication the fishery year is from 1 April to 31 March.

Methods

Survey area

On the basis of commercial fishing data for 1979–82, it appeared that the northern and eastern slopes of Chatham Rise were the most important fishing areas for orange roughy. An area that could be sampled in 42 days of ship's time was selected. This survey area was divided into 5 subareas (A–E), and depths between 700 and 1150 m were sampled (Fig. 2).

Survey design

Within each subarea depth strata were selected at 100-m intervals in the depth range from 700 to 1150 m. Sampling was stratified by area and bottom depth, and random trawl positions were allocated to strata. This method was described by Francis (1981). Available time enabled sampling at 22 of the 25 strata. Maximum fishing depth was restricted to 1150 m because of limited warp length on the vessel.

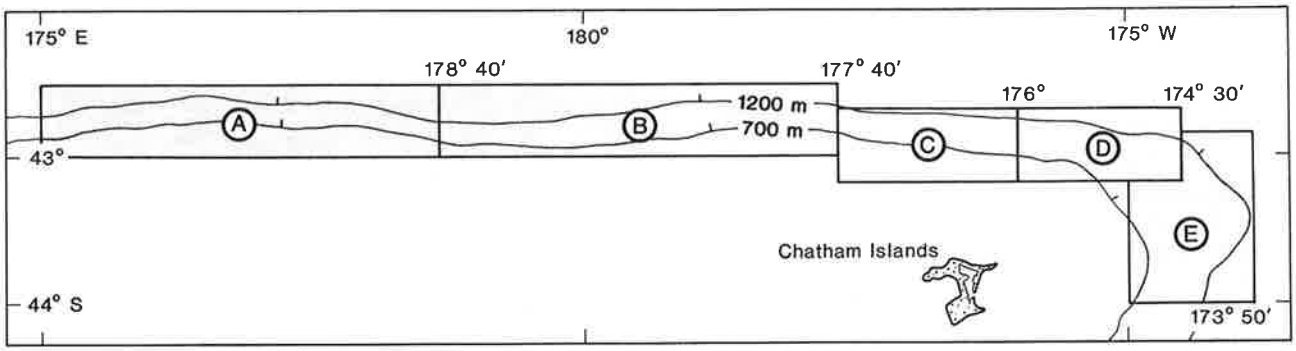


Fig. 2: Division of survey area into subareas A–E.

Random station positions were generated by computer program. The density of stations per stratum was weighted according to our understanding of existing fish distribution; that is, more stations were allocated to strata where fish density (and thus catch rate variance) was expected to be high (Francis 1981).

Data from research and commercial fishing showed that the largest catches occurred in the depth range from 800 to 1100 m, and catches were mainly in sampling areas A, C, and D. A weighting of 4 was given to strata where the chance of taking good catches was believed to be high (that is, 800–1100 m in areas A, C, and D). A weighting of 2 was given where the chance was thought to be intermediate (that is, 800–1100 m in areas B and E and less than 800 m and greater than 1100 m in A, C, and D). A weighting of 1 was given where the chance was believed to be low (that is, less than 800 m and greater than 1100 m in areas B and E). The number of stations allocated to each stratum was proportional to the product of stratum area and weighting.

During the survey there were minor changes to this original allocation when stations were rejected owing to foul trawl ground or insufficient warp. Replacement stations were chosen sequentially from the generated lists of positions where earlier choices had to be abandoned.

Bathymetry

Existing charts of Chatham Rise were inadequate and it was necessary to collect reliable (to $\pm$ 1.5 nautical miles (n. miles)) satellite-navigator positions and depths from vessels which had fished the area. By use of this information a provisional bathymetrical chart was drawn, and it was used in the definition of the sampling strata. Data from this survey and other cruises have been added to prepare a detailed bathymetry for the northern and eastern Chatham Rise.

Vessel

The vessel used during the survey, f.v. *Kaltan*, is a Soviet Atlantik-class stern trawler operated by Fletcher-Sovrybflot Fishing Limited, a co-operative fishing venture based in Dunedin, New Zealand. It has the following specifications: overall length 82 m; beam 13.6 m; tonnage 2100 GRT; horsepower 2320; service speed 10 knots; maximum fishing depth 1150 m; navigation equipment Furuno satellite navigator.

Net features

Two trawls were used; both were two-panel bottom trawls, one slightly larger than the other (Fig. 3). The port trawl was used for most stations, but when it needed repairs, or was full of fish, the starboard trawl was used. The port trawl (cod-end mesh size 106 mm) was used for 134 stations and the starboard trawl (cod-end mesh size 140 mm) for 26. The difference in net capability due to the different mesh sizes of the two nets has been ignored.

On both nets the sweeps were 90 m long, and on the groundrope wingtips each net had 500-kg weights. The groundropes had heavy steel bobbins.

During fishing, attempts were made to calculate the net mouth width by the method of Koyama (1974). This involved measuring the increment in distance between the trawl warps from the stern rollers to 1 m aft of the stern rollers. This distance was difficult to measure because the warps vibrated so much that the actual distance through which they moved, up to 10 cm, was greater than the incremental distance we were trying to measure. Two estimates for this increment were about 2.5 and 3.5 cm, but our confidence in these measurements was low.

These figures gave values of wingtip distances for the port net of 18.7 and 25.2 m and distances between the otter boards of 59 and 74 m. Instead of using these values we accepted the advice of the

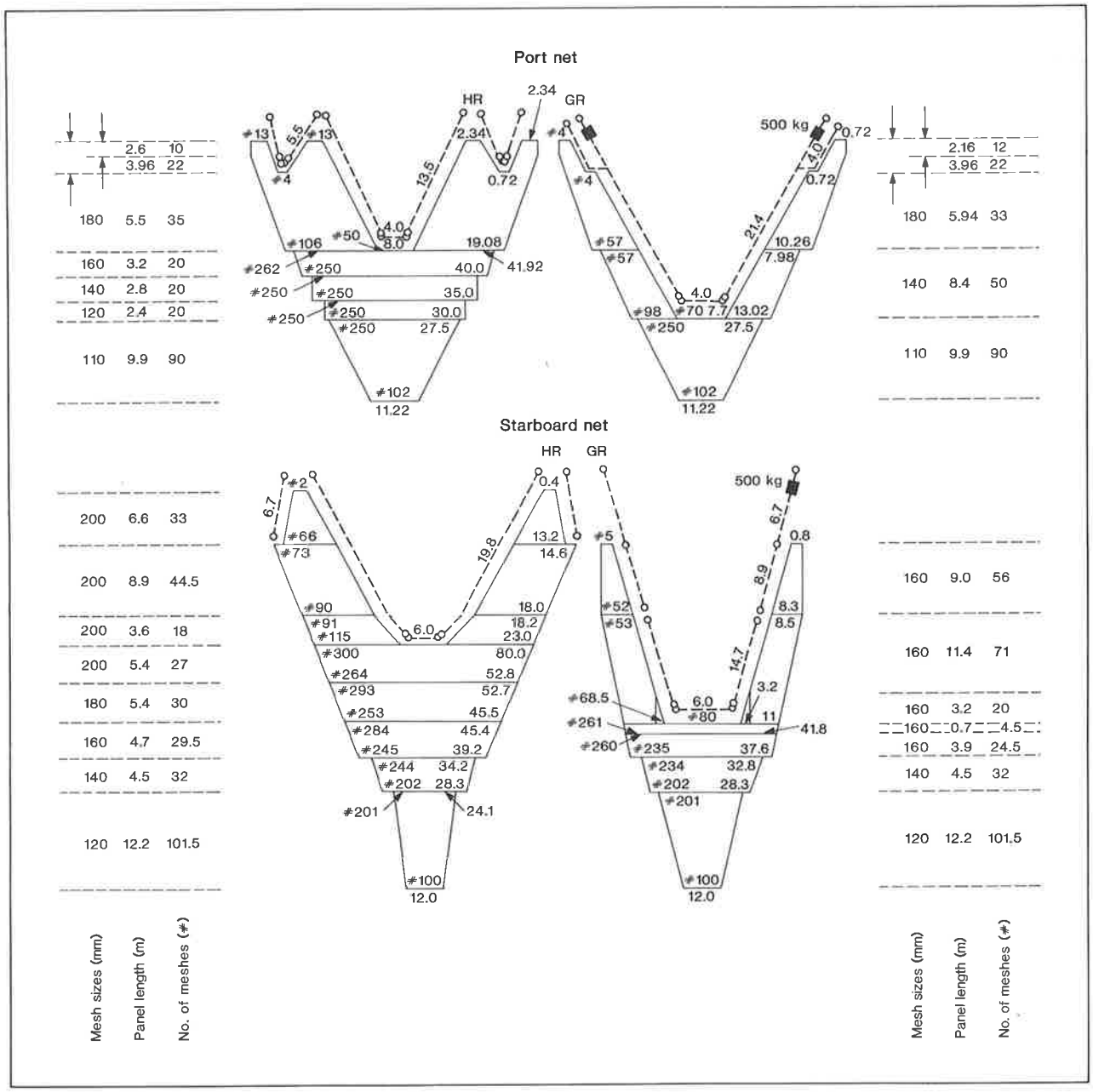


Fig. 3: Nets used on the *Kaltan* survey.

trawl master, who said that the port net was designed to fish with a mouth opening of about 21 m and the starboard net with a mouth opening of about 23.5 m. The trawl master also advised that the distance between the otter board doors for these trawls was expected to be 3–4 times the distance between the wingtips. Before the netsonde malfunctioned, the vertical net mouth opening was 6 m.

Trawling procedure

During the first week of the survey (that is, stations 1–35) research trawls were carried out between 0630 and 2230 hours. There was no restriction during the rest of the survey.

When the bottom was trawlable, shooting of the trawl gear usually began (on the appropriate depth

contour) about 2 n. miles from the actual chart position. This distance allowed time for the gear to reach the bottom at, or close to, the chart position.

A Furuno single-channel satellite navigator was used to locate trawl positions. The accuracy of these positions, under the conditions during the survey period, can normally be expected to be within 1.5 n. miles. A root mean square error of between 1.5 and 2.0 n. miles would be expected 2 hours of dead reckoning after a satellite fix. The mean time between position fixes at 43° S was about 70 minutes.

Fishing was conducted with a warp length to bottom depth ratio of about 2 : 1. It took 35–45 minutes to pay out warp and allow the trawl gear to settle on the bottom. The net was on the bottom for 45 minutes and took another 35–45 minutes to haul.

A towing speed of 2.6 knots was aimed for, but the actual speed across the ground was calculated from the trawling time and the distance between the satellite navigator positions at the start and end of the haul.

Catch size estimation

Small catches, about 5 t or less, were emptied on deck, sorted by species, and weighed. It was impractical to hand sort catches larger than about 5 t, and so the following method of estimating catch size was used:

Catch weight (t) = LAD

where L = total length (m) of the cod-end filled with fish,

A = mean cross-sectional area of the cod-end (m^2). Assuming the bag was elliptical in section, A was calculated from

$$A = \frac{\pi}{4}(a_{i1}b_{i1} + a_{i2}b_{i2} + \ldots a_{in}b_{in})/n$$

where a_{in} and b_{in} are principal axes at points 1, 2, ... n on the net, and n is the number of measurements (usually 4 or 5) taken midway between the bulges and constrictions caused by the ropes encircling the cod-end.

D = density of fish packed in the net (t/m^3) and was estimated by weighing fish tightly packed into a fish box of known volume (0.0517 m^3). Observed weights from five sets of observations were 37.15, 36.70, 37.25, 39.00, and 37.30 kg for 27, 27, 27, 26, and 27 fish respectively, with a mean of 37.48 kg. Therefore, $D = 0.03748/0.0517 = 0.725$ t/m^3.

This method was used to assess catch weight or check product weight at 18 stations in areas C and D. We intended to use the product weight of each haul to back-calculate catch weight if the catch was greater than 5 t. In areas C and D catch rates were so high that all four stern bunkers were continuously full and there was a constant flow of orange roughy through the factory. It was difficult to keep subsequent hauls separate on the factory deck under these conditions. Catch weights for stations 12, 15, 19, 20, and 25 were estimated "by eye".

At one station (K01/33/82) a comparison was made of all methods used to estimate a large catch (Table 1).

By-catch estimation

Weights of by-catch species for trawls greater than 5 t (that is, catches where total weight of catch was estimated) were calculated by use of a set of mean catch rate figures (kilograms per kilometre trawled). These figures were used to make estimates for 23 stations in strata 12, 13, 17, and 18. The mean catch rates were obtained by adding the weighed by-catch species and then dividing by the total distance trawled for the 15 remaining stations in these strata.

Biological observations

Orange roughy

A total of 160–180 fish (six 40-kg fish boxes) were taken from the catch at each station, and standard lengths were measured to the nearest centimetre below actual length. All the fish were measured in catches where there were fewer than six fish boxes. Fish were not sexed.

A further 20 specimens were chosen at random from each catch, and the following were recorded or collected for each specimen: standard length (± 1 mm); weight of whole fish (± 1 g); sex; gonad stage for females (eight stages: 1, juvenile; 2, first maturation or resting; 3–5, maturing; 6, mature; 7, running ripe; and 8, spent); ovary weight (± 0.1 g); stomach fullness and degree of digestion of contents (if they were in good condition, contents were retained for later identification); otoliths (stored in 70% isopropyl alcohol).

TABLE 1: Comparison of methods used to estimate a large catch

Method of estimation	Catch (t)*	% departure from product weight
From product weight (10.32 × 2.12)†	21.878	
From volume and density measurements (LAD)	20.759	−5.1
By eye	19.3	−11.8

* By-catch would decrease the estimates by about 0.5%.

† 10.32 = weight of headed and gutted fish. 2.12 = conversion factor to convert product weight to green weight. This value is based on measurements from the factory on *Kaltan*.

Flesh samples were taken for mercury analysis from up to 10 specimens for each centimetre size group for the whole trip.

Samples of liver, muscle, and heart tissue from 81 fish were collected for electrophoretic protein comparison with other orange roughy populations on the west coast of New Zealand and from Tasmania. All were stored in liquid nitrogen at −196 °C.

Other species

Length and sex data were collected from other species (for example, smooth oreo dory (*Pseudocyttus maculatus*) and spiky oreo dory (*Neocyttus rhomboidalis*)) at opportune times.

Biomass index estimations

Biomass values should not be used as absolute estimates of the actual quantity of fish in the survey area. Instead, they should be regarded as an index of abundance both to provide a comparative basis for future surveys and to quantify the relative abundance of orange roughy and the by-catch species, as available to bottom trawls.

We are aware of the controversy over the use of net wingtip spread as opposed to door spread in stock size estimations. For orange roughy there are two phases of availability to trawls: low density scattering and high density spawning and feeding schools. Fish response to the net is likely to be very different for each situation.

Before use is made of the biomass index in any sense more related to absolute biomass, all values should be reduced by a factor of 0.29, the approximate ratio of net wingtip spread to door spread.

Biomass index estimates with upper and lower bounds were calculated as by Francis (1981). The following assumptions were made:

1. That orange roughy did not extend further than 6 m above the bottom (6 m was the headline height of *Kaltan*'s nets). This implies no significant diurnal vertical migration.
2. That there was no escapement or avoidance.
3. That there was no herding effect by the doors and sweeps; that is, that the distance between the net wings was the effective sampling width.
4. That orange roughy were not actively migrating along Chatham Rise or into deeper water during the survey.
5. That there was no gear saturation effect with large catches; that is, fish were not lost from an overfull net.

Although orange roughy do not have a gas-filled swim bladder, and are usually not detected by most 2-kW echo-sounders in general use, there have been reports that the fish are "visible" to echo-sounders when in large concentrations. For example, the vessels *Otago Buccaneer* and *Otago Galliard* reported dense echotraces up to 80 m off the sea bed during the peak of the spawning season in July 1982 (P. Robins pers. comm.). Similar reports of interrupted echotraces up to 100 m off the bottom were recorded on Challenger Plateau during the same period (W. L. F. van den Broek pers. comm.). Fishermen using 10-kW, 28-kHz colour echo-sounders claim to be able to detect orange roughy schools and have successfully fished such schools in several areas where they appear to be more than 100 m high. Thus, it is likely that the first assumption—that fish are within 6 m of the bottom—would lead to an underestimate of the biomass index in areas where the fish are aggregated to spawn.

The fact that orange roughy were taken in all of the deeper stations suggests that in most of the areas surveyed their distribution extends down beyond 1150 m. The use of 1150 m as the maximum sampling depth will also result in an underestimate of the biomass index.

Assumptions 1 and 2 were adopted to give conservative estimates of biomass index. We have no information on the behaviour of orange roughy during trawling. If assumption 3 is wrong, there will be an overestimation of biomass index values by a factor of 3–4 if all fish which pass between the doors are actually caught.

Trawling by commercial vessels, on both spawning and non-spawning aggregations, seems to be equally successful at night or during the day, which indicates little or no diurnal vertical migration.

The aggregations of spawning orange roughy north and north-west of Chatham Islands during winter (May to August) suggest that fish migrate to that area and migrate away after spawning. The likely time for the dispersal of the aggregations coincided with the second half of the survey.

Hydrology

Continuous vertical temperature and salinity profiles were collected along Chatham Rise by staff on the fisheries research vessel *James Cook* between 7 and 14 August 1982. The instrument used was a Guildline Instruments Model 8705 digital conductivity-temperature-depth (CTD) probe with the Model 87102 control unit.

Precision for salinity, temperature, and depth is quoted in the handbook as ± 0.005‰, ± 0.005 °C, and ± 3 m respectively.

Along the Chatham Rise northern and eastern slopes, between 700 and 1200 m bottom depth, CTD casts were made to about 20 m above the bottom (Fig. 4).

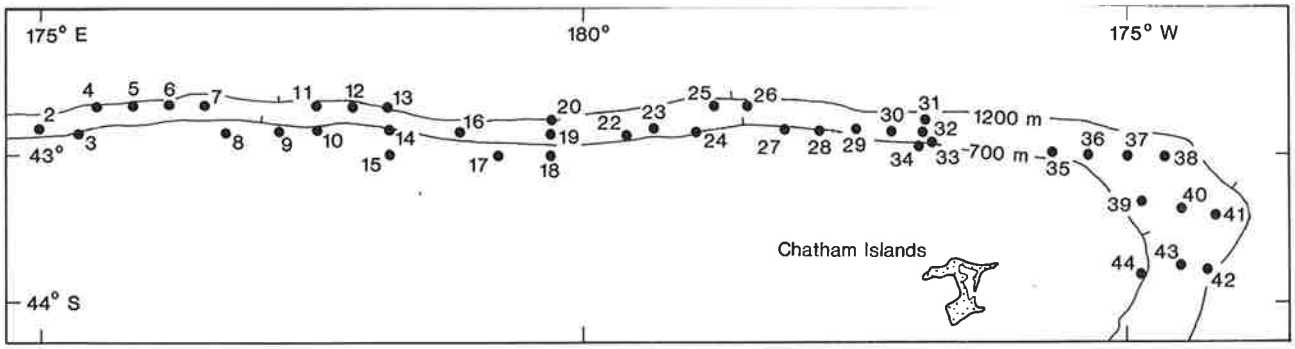


Fig. 4: Hydrological stations on the Chatham Rise occupied by *James Cook*, 7–14 August.

Results

Biomass

A total of 160 trawl stations were successfully completed. Including orange roughy, 106 species of fish and squid were recorded (Appendix 1). A total area of 25 538 km² was covered by the 22 strata sampled, and the station density was 1 per 160 km².

Orange roughy dominated the catches, with a calculated biomass index of 792 800 t, 90.4% of all species by weight (Table 2). Values for the 15 major by-catch species were calculated and had a total of 67 110 t, 7.6% of the total for all species. The remaining 90 species contributed 2%, or 17 320 t. This figure does not represent a true index of biomass for the minor species because many small or slender species (such as rattails or basketwork eels) escaped through the cod-end meshes.

The distribution of orange roughy was uneven along Chatham Rise (Figs. 5 and 6). The proportions of the total biomass index (and the proportions of the total area) for each subarea were:

Subarea	% of biomass index	% of area
A	5.5	25.6
B	1.9	26.1
C	45.4	14.2
D	38.0	14.5
E	9.2	19.5

Biomass index estimates for individual strata ranged from 0 to 238 200 t, and mean catch rates ranged from 0 to 21.8 t/h (Table 3). The maximum catch rate was 47.8 t/h. Areas C and D contributed 83.4% of the total value from only 28.8% of the total survey area.

For areas C and D the main concentration of spawning fish was mapped by contouring catch rates as tonnes per kilometre trawled (Fig. 7). This shows the approximate extent and shape of the largest known aggregation of orange roughy. The aggregation with catch rates greater than 3 t/km is 83 n. miles long by about 5 n. miles wide.

Distribution by depth

Orange roughy were not taken from hauls shallower than 750 m, but occurred in all other stations down to 1150 m. The survey did not extend deep enough to define the lower limit, but commercial vessels have reported catches down to 1300 m.

The highest catch rates recorded were about 12 t/km trawled (at two stations at depths of 860 and 920 m). High catch rates (over 3 t/km trawled) were reached between 835 and 990 m. Combined mean catch rates declined steeply as sampling depth increased (Fig. 8).

The dependence of catch rate on depth varied in different parts of Chatham Rise (Fig. 9). In areas

TABLE 2: Biomass index estimates (with approximate 95% confidence limits and coefficients of variation) for orange roughy and 15 major by-catch species and for all species taken during the survey

	Lower bound (t)	Biomass index (t)	Upper bound (t)	Coefficient of variation (%)	% of total biomass index (all species)
Hoplostethus atlanticus	591 890	792 800	993 710	13	90.4
Deania calcea	8 160	12 730	17 300	18	1.5
Pseudocyttus maculatus	4 510	8 410	12 310	23	1.0
Trachyrincus longirostris	7 220	8 200	9 180	6	0.9
Mora moro	5 470	6 680	7 900	9	0.8
Etmopterus baxteri	4 070	5 790	7 510	15	0.7
Centroscymnus spp.*	3 680	4 800	5 930	12	0.5
Alepocephalus australis	2 780	4 200	5 620	17	0.5
Hydrolagus sp.	2 460	3 050	3 640	10	0.4
Dalatias licha	1 880	2 600	3 330	14	0.3
Merluccius australis	1 570	2 210	2 850	14	0.3
Macruronus novaezelandiae	1 150	2 210	3 270	24	0.3
Rhinochimaera pacifica	1 770	2 170	2 570	9	0.2
Neocyttus rhomboidalis	890	1 630	2 370	23	0.2
Harriotta raleighana	890	1 230	1 571	14	0.1
Moroteuthis ingens	990	1 190	1 390	8	0.1
	658 310	859 910	1 061 500	12	98.0
All species	675 440	877 230	1 079 020	12	

* Mostly *Centroscymnus crepidator*, but also *C. owstoni* and *C. coelolepis*.

TABLE 3: Area, weighting, and number of tows and estimated biomass index and mean catch rates for orange roughy by stratum

Area	Stratum No.	Depth interval (m)	Stratum area (km²)	Weighting of station density	No. of tows	Estimated orange roughy biomass index (t)*	Mean orange roughy catch rates (kg/km)	Mean orange roughy catch rates (t/h†)
A	1	700–800	1 181	2	3	1 190	21.6	0.18
	2	800–900	1 073	4	10	1 440	28.7	0.19
	3	900–1 000	1 170	4	11	7 520	137.5	0.83
	4	1 000–1 100	2 726	4	27	30 540	239.8	1.29
	5	1 100–1 150	397	2	4	3 310	178.6	0.95
B	6	700–800	1 436	1	2	110	1.6	0.01
	7	800–900	1 616	2	7	3 320	43.9	0.25
	8	900–1 000	1 678	2	6	5 490	70.1	0.38
	9	1 000–1 100	1 244	2	5	5 120	88.1	0.38
	10	1 100–1 150	680	1	2	820	25.8	0.14
C	11	700–800	809	2	4	0	0	0
	12	800–900	990	4	9	238 200	5 150.4	2.16
	13	900–1 000	763	4	7	106 200	2 979.4	5.04
	14	1 000–1 100	1 077	4	9	15 840	314.8	1.22
D	16	700–800	600	2	3	10	0.4	0
	17	800–900	1 119	4	7	79 150	1 514.0	8.63
	18	900–1 000	1 046	4	12	197 410	3 857.3	21.8
	19	1 000–1 100	947	4	10	24 640	557.0	2.83
E	21	700–800	910	1	1	440	10.4	0.07
	22	800–900	1 916	2	9	26 370	294.7	1.62
	23	900–1 000	1 206	2	7	13 080	232.2	1.48
	24	1 000–1 100	954	2	5	33 060	741.7	3.17
			25 538		160	793 260	858.2	4.78

* Based on a mean net mouth width of 21.4 m.
† At 3 knots.

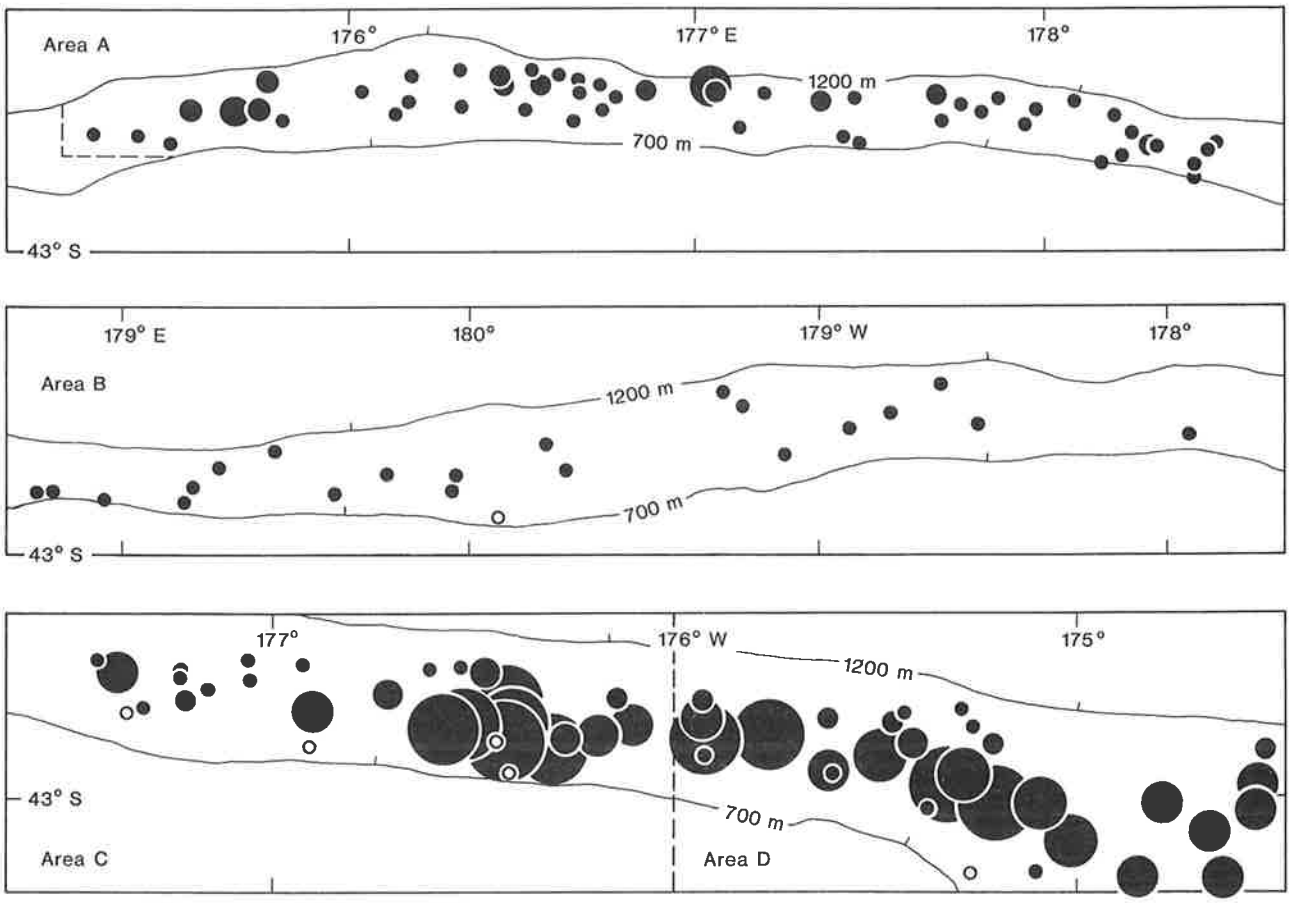


Fig. 5: Catch rates for orange roughy in areas A–D. (See key on page 13.)

A and B the catch rate was low at all depths sampled, with a slight peak in area A at 1050 m. For areas C and D the mean catch rate was highest between 840 and 990 m, where values were up to 25 times higher than in areas A and B. In area E catch rates were highest in the deepest water sampled; mean catch rates increased with mean sampling depth.

Catch rates in tonnes per kilometre trawled were contoured on a depth-longitude grid, and in areas C and D the depth of maximum catch rate increased towards the east from about 860 m at 176° 30′ W to 950 m at 175° 20′ W (Fig. 10).

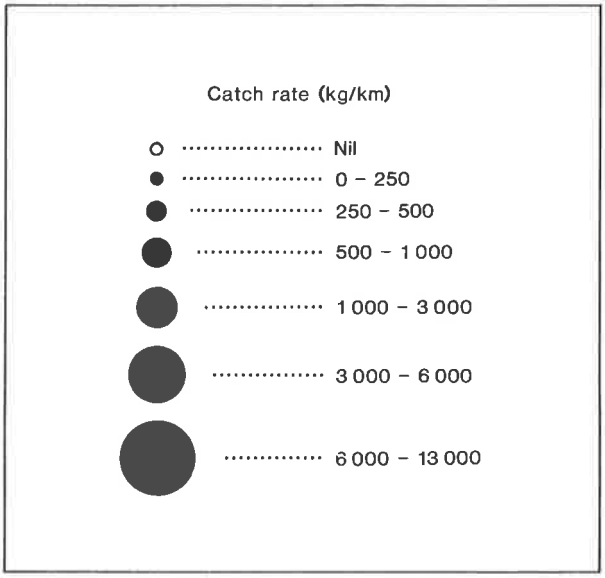
Length and weight

A histogram showing the length distribution of all fish measured during the survey is bimodal at 26 and 34 cm (Fig. 11). Fish measured ranged in size from 14 to about 42 cm standard length (SL).

The length-distribution data for each catch were then weighted by the catch rate and combined to give a histogram representing all fish caught (Fig. 12). This shows the predominance of large fish, modal length 34 cm SL, in large catches. The influence of small fish, generally taken in small trawl catches, has been greatly reduced. The modal size for fish measured during the collection of detailed biological data (20 fish per trawl) was 35 cm SL, which suggests a subsampling bias towards larger fish (Fig. 13). The size range was from 14 to about 44 cm SL.

Figure 14 shows length-frequency histograms of orange roughy by stratum. These have several features, including the following:

1. There was a predominance of large fish, of modal lengths 34 or 35 cm SL, in areas C, D, and E at depths of 800–1100 m. These strata had large concentrations of spawning or post-spawning fish.
2. In contrast, at 800–900 m in areas A and B there was a predominance of small fish, with modal lengths of 25 and 26 cm SL respectively.
3. Small fish occurred in shallow strata; for example, at 700–800 m in areas A and E,



modal lengths were 24 and 16 cm SL respectively.

4. In moderate to deep strata, 900–1200 m in areas A and B, and 1000–1100 m in area C, there was a wide range of fish sizes.

Weights of 2379 orange roughy were taken during the survey, and length-weight relationships were calculated for males, females, and all fish combined (Table 4). There was little difference between the length-weight relationships for males and females.

Feeding

Of the 2349 stomachs examined, 70% were empty, 23% half full, and 7% full (Table 5). Small or juvenile fish had a lower frequency of empty stomachs: for example, 48% of the fish under 25 cm SL, compared with 73% of fish over 25 cm SL, but less than 35 cm SL (Table 6).

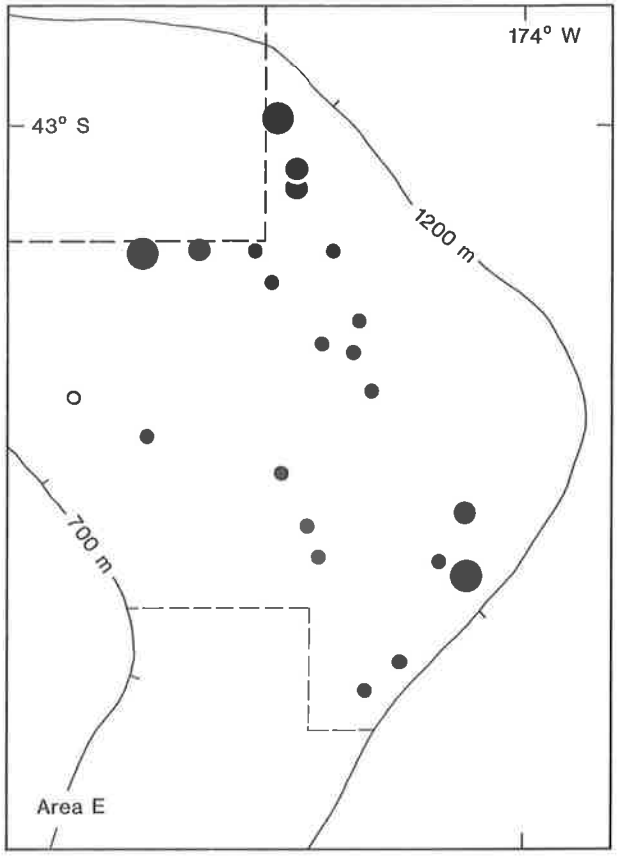


Fig. 6: Catch rates for orange roughy in area E.

The main spawning area (in areas C and D) and the area east of Chatham Islands (area E) had the highest percentage of fish with empty stomachs; 85%, 88%, and 81% respectively. Area A had the lowest, with 34% empty, and area B was intermediate, with 64%.

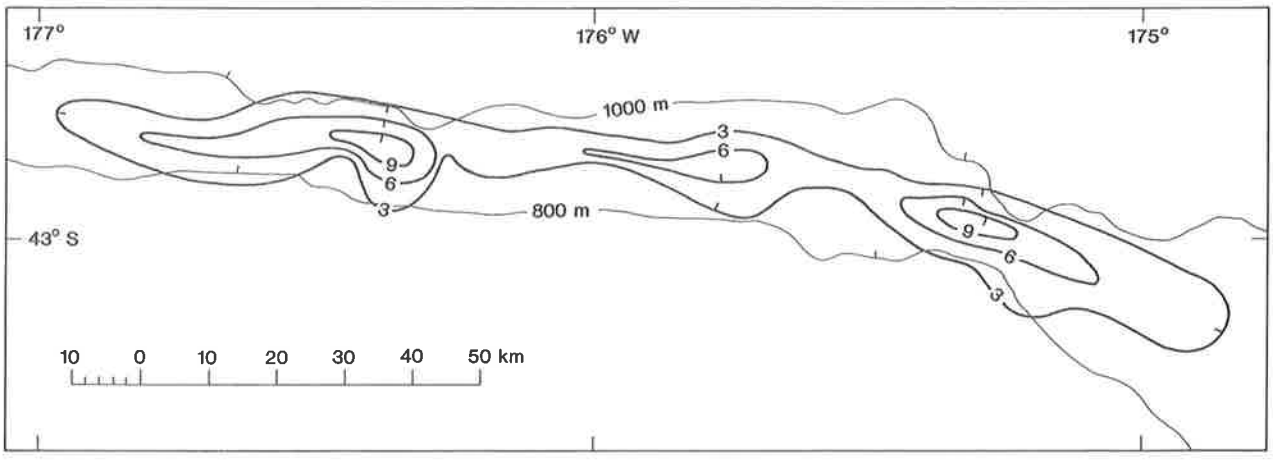


Fig. 7: Catch rates (tonnes per kilogram) for orange roughy in areas C and D.

All identifiable stomach contents were initially categorised by major taxa (Table 7). There was a relatively high incidence of fish and crustaceans in stomachs from area A, but levels of fish were low in areas C, D, and E. Highest crustacean levels were found in small orange roughy in shallow strata 1, 2, 7, 16, and 21. For all orange roughy examined, 30% had food in the stomach; 17% was fish, 12% crustaceans, 2% squid, and 1% unidentified.

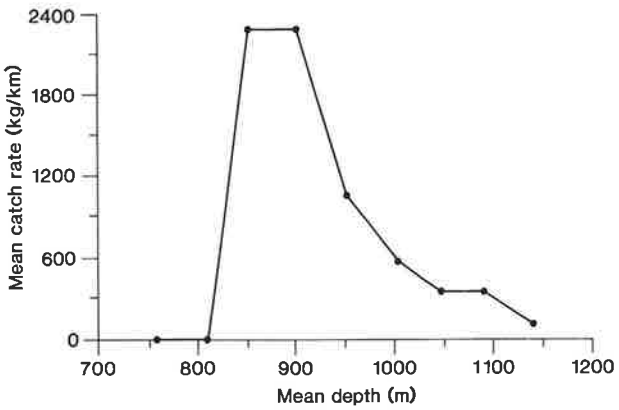


Fig. 8: Mean catch rates of orange roughy by depth.

Reproductive state

Of 1024 sets of female gonads examined, 77.1% were spent, 8.8% juvenile, 10.0% first maturation or resting, 2.1% maturing, 0.4% mature, and 1.8% running ripe (Table 8).

Of the 22 mature or running ripe fish, 21 were taken in areas C and D, during the first 12 days of the survey. The other was caught in stratum 2 in area A.

Male gonads were not staged or weighed because of the difficulty in establishing a stage scale for males. Many of the testes examined were spent posteriorly, but were maturing anteriorly.

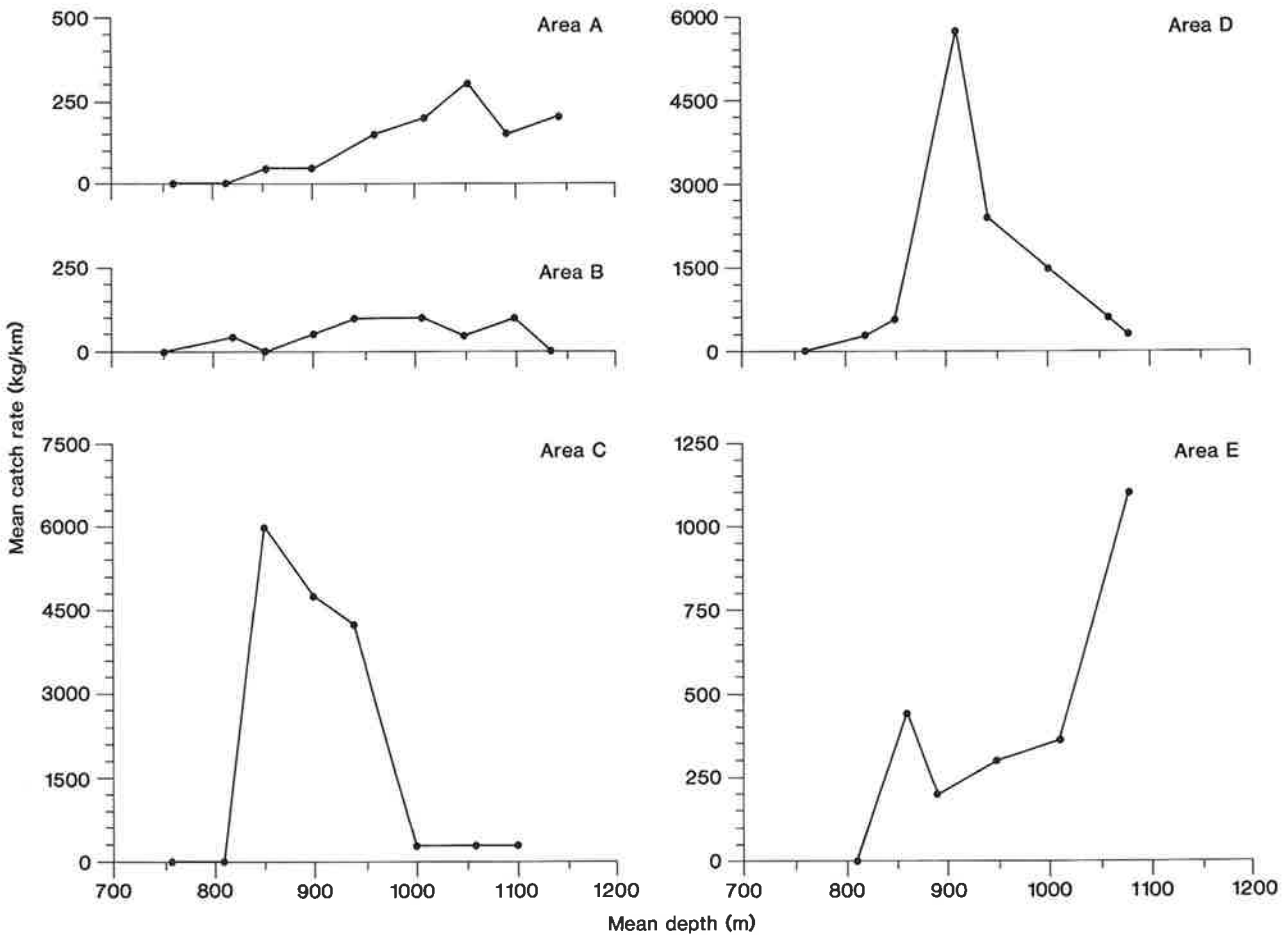


Fig. 9: Mean catch rates of orange roughy by depth in areas A–E.

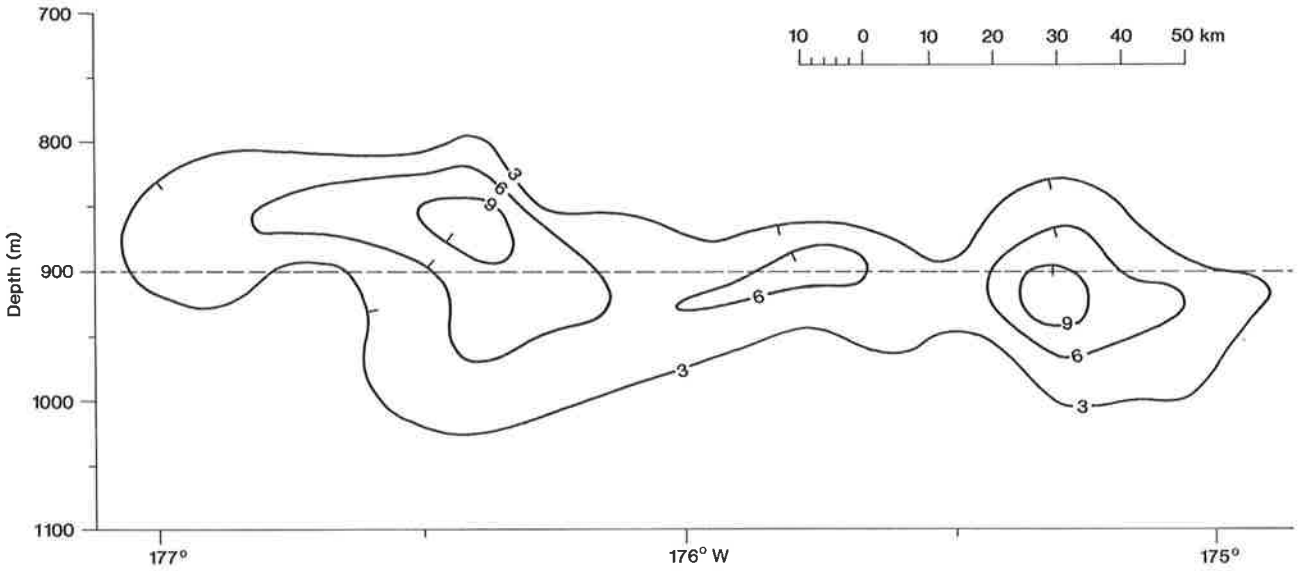


Fig. 10: Catch rates of orange roughy by depth and longitude in areas C and D.

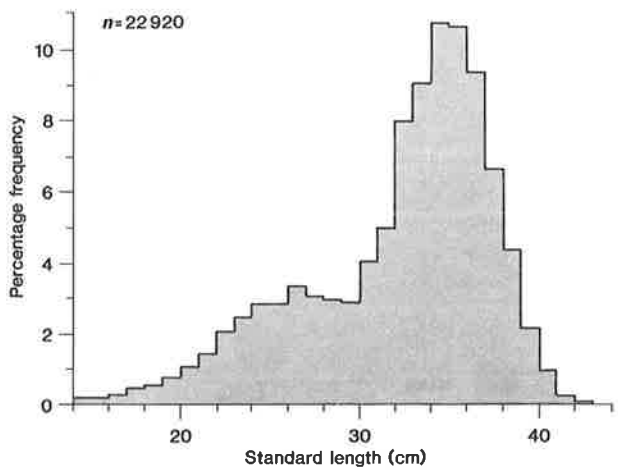


Fig. 11: Length-frequency histogram for all measured orange roughy.

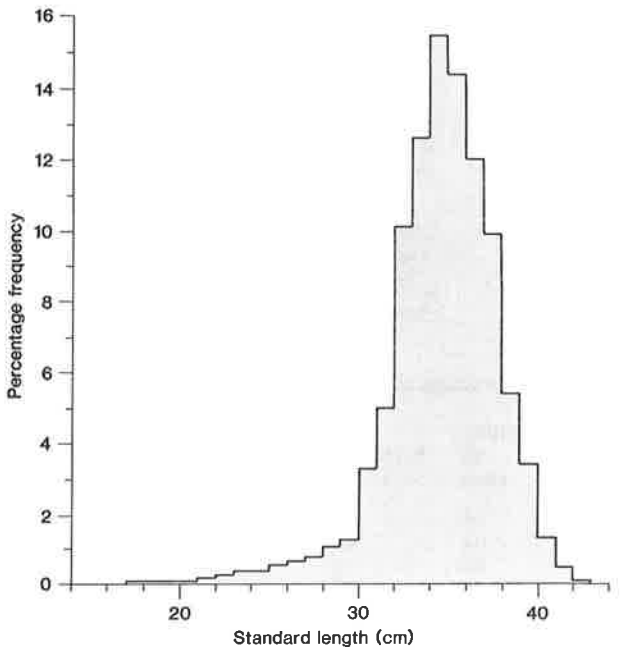


Fig. 12: Length-frequency histogram for all orange roughy caught.

Sex ratio

Of the 2367 fish sexed, 57% were male (Table 9). For most size groups the sex ratio was close to this. However, most fish over 40 cm SL were females (see Fig. 13).

There is evidence of segregation by sex from the wide variations in the proportions of males (25–90%) from all stations (Appendix 2). This effect is patchy and does not correspond closely with stratum boundaries, depth range, or proximity to known spawning areas. However, the clusters of stations with a predominance of males or females suggest that schooling by sex occurs in the spawning season.

Hydrology

Forty-two CTD stations were occupied, at depths between 358 and 1380 m. Recorded temperatures and salinities at the surface and also at depths inhabited by orange roughy are summarised in Table 10.

Vertical temperature and salinity sections on selected transects are shown in Figs. 15–21. Values were taken from continuous vertical profiles.

TABLE 4: Length-weight relationships for orange roughy

	No.	Length range (cm)	Weight range (g)	Equation*	Regression coefficient r
Males	1 348	13.2–41.6	85.0–2 541	$W = 0.0973 \times SL^{2.68}$	0.98
Females	1 018	14.4–45.2	107.0–2 800	$W = 0.1003 \times SL^{2.68}$	0.98
All fish	2 379	9.8–45.2	39.5–2 800	$W = 0.0963 \times SL^{2.68}$	0.98

* W is weight in grams and SL is standard length in centimetres.

TABLE 5: Orange roughy feeding status by stratum

Stratum	No.	% empty stomachs	% half full stomachs	% full stomachs	% everted stomachs
1	20	10	90	0	0
2	80	32	58	8	0
3	97	38	45	16	0
4	318	32	49	17	0
5	60	43	50	6	0
7	79	49	44	8	3
8	119	61	26	12	0
9	79	82	11	6	0
10	40	75	15	10	0
12	154	90	8	0	1
13	112	87	10	1	0
14	175	80	18	1	0
16	8	50	12	37	0
17	159	68	20	11	0
18	215	96	3	0	0
19	200	96	2	2	0
21	40	40	50	10	0
22	178	77	16	5	1
23	138	92	4	2	0
24	78	89	8	1	0
	2 349	70	23	7	0

TABLE 6: Percentage of empty stomachs by size of orange roughy

Area	% empty, all sizes	% empty, < 25 cm	% empty, ⩾ 25 to < 35	% empty, ⩾ 35 cm
A	34	30	34	25
B	64	63	66	72
C	85	73	86	88
D	88	47	93	96
E	81	44	88	93
	69	48	73	76

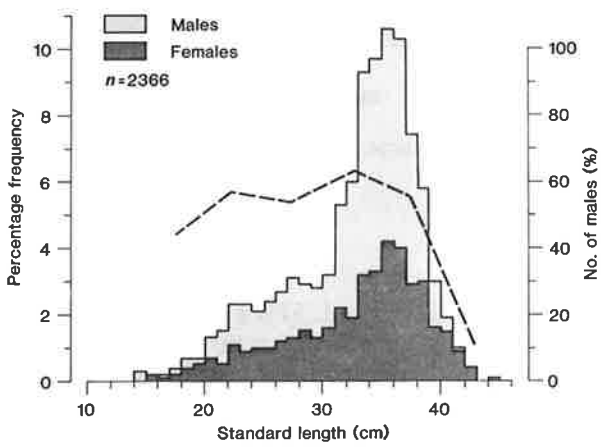


Fig. 13: Length-frequency histogram for all orange roughy selected for biological observations.

Bottom temperatures and salinities between 700 and 1200 m ranged from 4.37 °C to 7.63 °C and from 34.43‰ to 34.59‰. Bad weather prevented hydrological casts in part of the area of highest concentration of orange roughy around 176° W, but bottom temperatures and salinities at the western and eastern ends of this area were 6.69 °C and 34.50‰, and 7.22 °C and 34.53‰, at bottom depths of 775 and 700 m respectively. The core of "Antarctic Intermediate Water", defined by a salinity minimum, is normally at 1000–1200 m, north of the Chatham Rise (Heath 1981). A salinity minimum occurred at depths of about 700 m in two transects, which probably represented extensions of Antarctic Intermediate Water (see transects across stations 18, 19, and 20 and 27, 28, 29, 30, and 31).

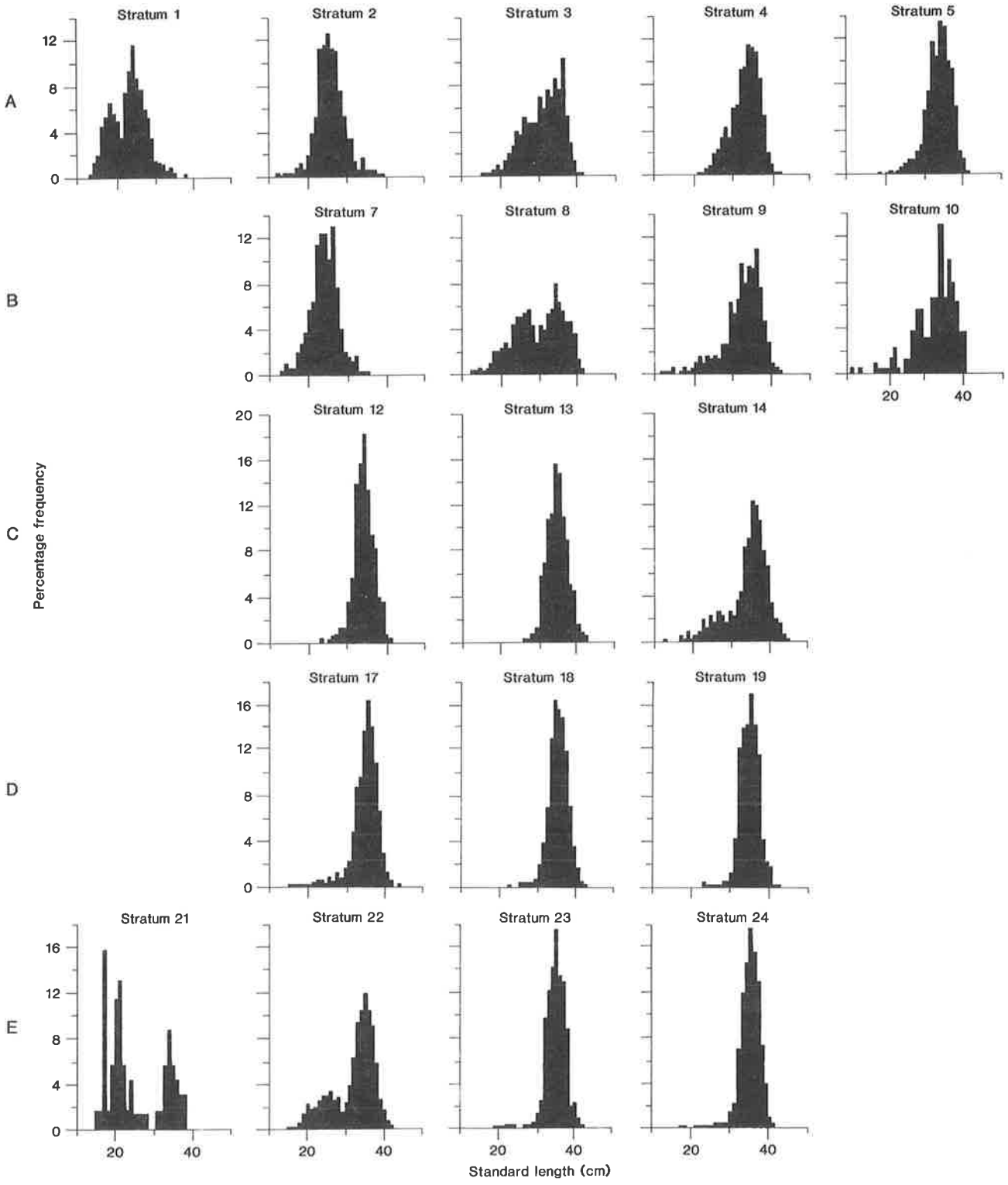


Fig. 14: Length-frequency histograms of orange roughy by stratum.

For all sections, except that across stations 35–38, there was subtropical water (that is, water with temperatures 10 °C or over and salinities 34.7‰ or over (Heath 1981)) in the upper 350–400 m overlying Antarctic Intermediate Water in which salinity decreased to a minimum of 34.4‰ and temperature to a minimum of 4.1 °C.

TABLE 7: Percentage occurrence of orange roughy dietary components by stratum

Stratum	Area	No.	% empty	% fish	% crustaceans	% squid	% unidentified	Mean length of fish (cm, SL)
1	A	20	10	20	90	0	0	20.7
2		80	29	29	49	3	0	28.4
3		99	39	48	13	4	0	32.6
4		318	33	60	9	2	0	34.0
5		60	43	48	3	7	0	33.4
7	B	79	48	22	33	5	0	24.6
8		120	62	19	17	3	0	28.2
9		80	81	9	6	1	3	32.1
10		40	78	15	8	0	0	33.5
12	C	168	91	1	4	2	2	33.8
13		114	88	5	5	0	3	34.4
14		180	81	9	5	2	3	32.2
16	D	8	50	0	50	0	0	24.4
17		160	68	4	27	3	1	30.2
18		217	97	1	1	1	0	36.2
19		200	96	3	1	0	0	34.9
21	E	40	48	5	48	0	3	23.0
22		179	78	7	15	1	1	32.0
23		139	93	1	4	1	1	35.2
24		78	90	5	5	0	0	35.0
		2 349	70	17	12	2	1	
Mean length of fish by category (cm, SL)			33.4	33.4	26.8	31.2	31.2	32.6

TABLE 8: Percentage of female gonad stages by stratum for orange roughy

		Gonad stage (%)							
Stratum	No.	1	2	3	4	5	6	7	8
1	11	36	55	0	0	0	0	0	9
2	41	0	46	0	0	0	0	3	51
3	46	2	11	0	0	0	0	0	87
4	102	0	6	0	0	0	0	0	94
5	23	0	4	0	0	0	0	0	96
7	36	14	33	17	6	0	0	0	30
8	63	10	22	0	0	0	0	0	68
9	39	3	8	0	0	0	0	0	89
10	26	4	8	0	0	0	0	0	88
12	45	4	2	0	0	0	0	25	69
13	40	3	3	3	0	0	0	0	91
14	104	4	15	3	2	2	1	1	76
16	1	0	0	0	0	0	0	0	100
17	86	42	9	5	0	0	1	2	41
18	75	0	0	0	0	0	1	3	96
19	84	6	0	1	0	0	1	1	91
21	15	73	0	0	0	0	0	0	27
22	79	14	8	0	0	0	0	0	78
23	74	3	3	0	0	0	0	0	94
24	34	0	3	0	0	0	0	0	97
	1 024	8.8	10.0	1.5	0.4	0.2	0.4	1.7	77.0

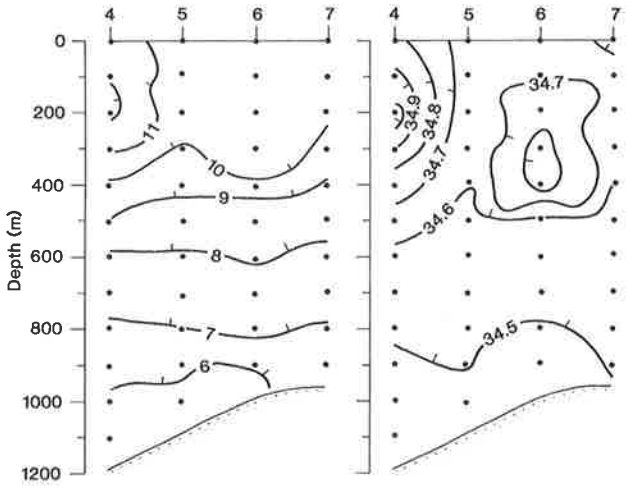


Fig. 15: Vertical sections of temperature and salinity, stations 4–7.

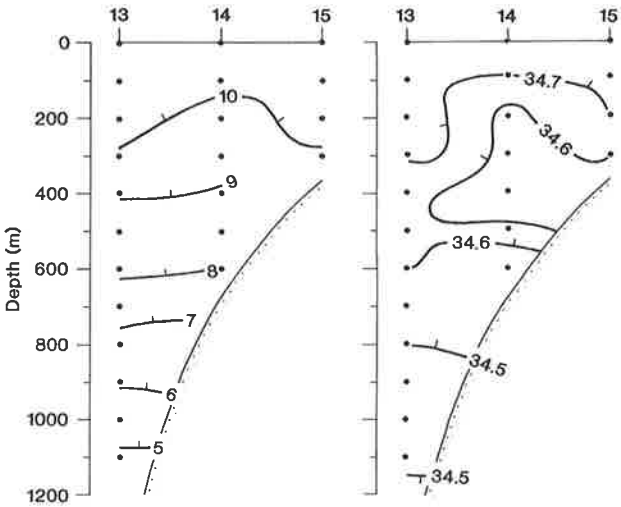


Fig. 16: Vertical sections of temperature and salinity, stations 13–15.

TABLE 9: Percentage of males by stratum and area for orange roughy

No. of fish sexed	Stratum	% males by stratum	Area	% males by area
20	1	45	A	61
80	2	47		
99	3	55		
318	4	68		
60	5	60		
79	7	56	B	51
120	8	48		
80	9	53		
40	10	35		
167	12	74	C	59
113	13	65		
176	14	41		
6	16	50	D	59
157	17	50		
216	18	65		
200	19	58		
40	21	53	E	53
179	22	56		
139	23	47		
78	24	56		
2 367		57		

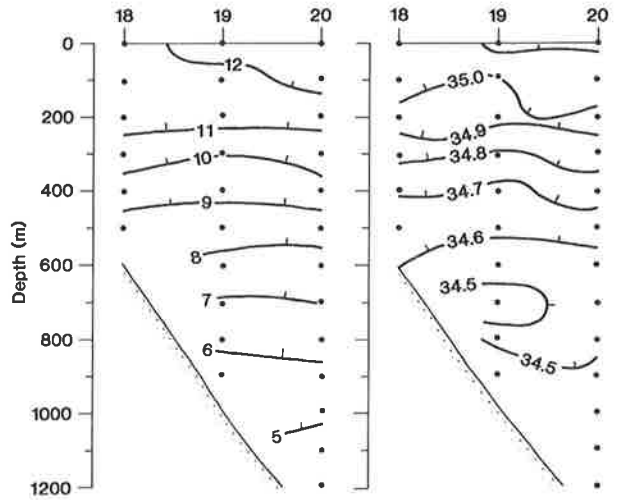


Fig. 17: Vertical sections of temperature and salinity, stations 18–20.

TABLE 10: Summary of temperatures and salinities by depth on Chatham Rise, 7–14 August 1982

Depth (m)	Temperature (°C) Range	Temperature (°C) Mean	Salinity (‰) Range	Salinity (‰) Mean	No. of observations
Surface	10.50–12.30	11.24	34.64–35.10	34.88	42
700	6.78– 7.63	7.25	34.44–34.59	34.52	33
800	6.00– 7.20	6.66	34.47–34.53	34.50	24
900	5.73– 6.45	6.10	34.44–34.50	34.48	16
1 000	5.18– 5.80	5.48	34.39–34.49	34.47	9
1 100	4.71– 5.22	4.95	34.43–34.49	34.48	7
1 200	4.37– 4.71	4.49	34.43–34.50	34.48	3
1 300	4.10– 4.24	4.17	34.52	34.52	2

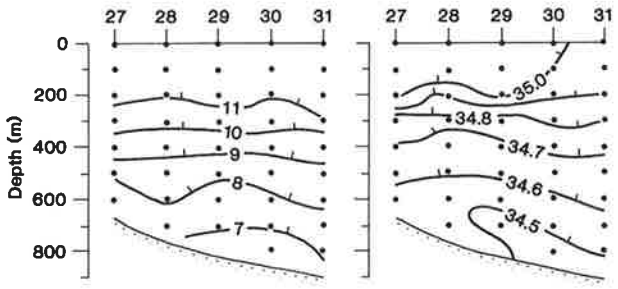


Fig. 18: Vertical sections of temperature and salinity, stations 27–31.

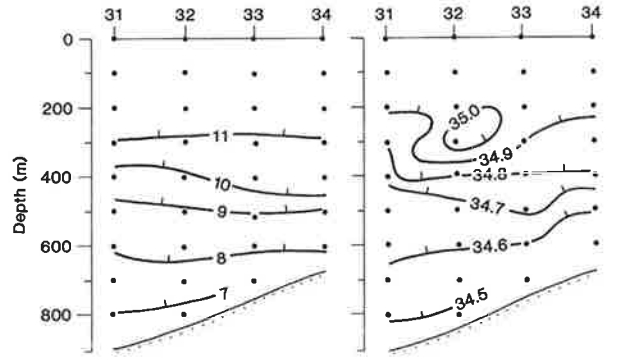


Fig. 19: Vertical sections of temperature and salinity, stations 31–34.

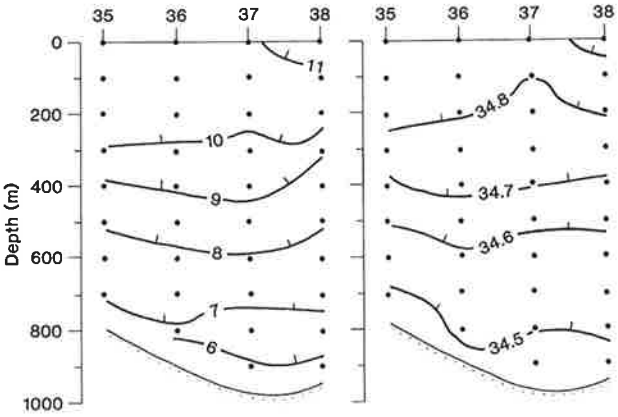


Fig. 20: Vertical sections of temperature and salinity, stations 35–38.

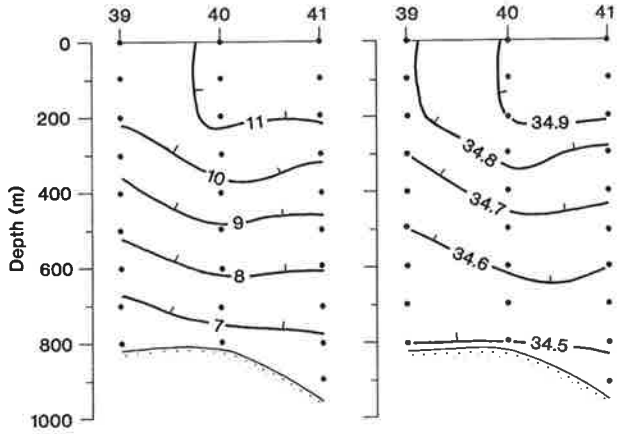


Fig. 21: Vertical sections of temperature and salinity, stations 39–41.

Discussion

Commercial and research trawls in 800–1300 m around New Zealand have taken orange roughy from Three Kings Islands (34° S) in the north to the southern limits of Campbell Plateau (54° S) (Shuntov 1979, Kerstan and Sahrhage 1980, Fisheries Research Division, MAF unpublished data). Within this 20° latitude range the main fishing areas lie between 39° S and 45° S.

The principal orange roughy fishery is north of Chatham Islands, but several other areas are also important: these are the southern Chatham Rise, the Wairarapa coast, and the southern Challenger Plateau. The relationship between the northern and southern Chatham Rise and the Wairarapa coast populations is not known, but it is possible that they form one spawning stock. West of New Zealand the Challenger Plateau orange roughy are probably one spawning stock. During winter and spring Challenger Plateau commercial catch rates are comparable with those on the northern and eastern Chatham Rise. Fishing depths are similar in both areas, but modal standard lengths are smaller on Challenger Plateau.

No other substantial fisheries for orange roughy have been recorded outside the New Zealand region, but the species has occasionally been caught in quantity elsewhere. For example, Freytag (1979) reported that a German vessel fishing for blue ling in Rockall Trough, west of Ireland caught 20 t of orange roughy in one haul (and smaller quantities of about 1 t/h in other hauls) at 800–900 m. Ehrich (1983) described the results of a series of research cruises also in the Rockall Trough area. Small catches of orange roughy were reported and distribution was described. The net width used was similar to those used on *Kaltan*, but maximum catch rates were only 0.25% of the maximum Chatham Rise catch rates. The reported temperature of 7.5 °C at 1000 m was higher than temperatures at the same depth on Chatham Rise (5.18–5.80 °C). Rockall Trough orange roughy were reported at depths less than 750 m and at a maximum depth of 1525 m.

Experimental trawling off southern Tasmania around 40–44° S at 800–1050 m has also revealed small-scale commercial concentrations, but no fishery has developed in the area and only limited observations have been published on catch rates, depth range, and distribution (Wilson 1982).

As a first attempt at a survey of orange roughy, the *Kaltan* cruise was successful because the area and depth ranges investigated probably covered most of the distribution of the species on the northern and eastern Chatham Rise. However, it was unfortunate that the spawning aggregations were dispersing during the first half of the survey (when areas C, D, and E were sampled) and it seems likely that this dispersal was almost complete by the time of the second half of the cruise, when areas A and B were sampled. Evidence of a dispersal comes from the small or negligible catches of orange roughy that were taken by *Kaltan* during commercial fishing on 15–18 August and 19–20 August in areas C and D, where large catches had been taken earlier in the survey. No other areas of major fish concentration were found during the survey. This also supports the suggestion of general dispersal, because fish densities were low in other important fishing areas, near the western end of the sampling area.

In the last few years fishing for orange roughy on the northern Chatham Rise has been centred in areas C, D, and A, with relatively little fishing in areas B and E. Although catch rates in areas C and D were typical of those experienced during normal commercial fishing, catch rates in area A were not comparable with those expected in this area during June and July. We assume that orange roughy in areas A, B, and E were dispersing from spawning concentrations and that some may have moved out of these areas, or may have moved into them from adjacent areas already sampled (C and D). The absence of orange roughy from water shallower than 750 m suggests that there is no migration to shallower depths. Because fish were caught in the deepest trawls (1150 m), and in areas A and E catch rates increased with increasing depth, the entire depth range of orange roughy may not have been sampled and dispersal to deeper water may have been occurring.

Thus the orange roughy biomass index values must be used with caution in the establishment of harvesting and management strategies. The optimum utility of surveys of this type is not in their absolute values, but in year-to-year comparisons between surveys which are as similar as possible.

From the data collected on this survey, and from some information from the commercial fishery, the following generalities may be made:

1. Orange roughy are found between 750 and 1150 m along the northern and eastern Chatham Rise and probably extend down at least another 200 m, to 1350 m.

2. During winter (mid June to mid August) there are at least three areas of spawning aggregation on fairly smooth sea bottom: north of Mernoo Bank about 175° 30′ E, at 178° E, and a larger one at 175–177° W. Spawning has been confirmed in the last area.
3. Catch rates are highest from June to mid August, between 850 and 1000 m. Catches consist mainly of fish about 35 cm SL.
4. These large aggregations disperse about mid August. There is evidence of a dispersal to deeper water and to rougher ground. In the 1982 season, during October, very high catch rates were experienced in an area south-west of Chatham Islands, on the southern Chatham Rise. Thus, aggregations of orange roughy are present at other times of the year in some areas. They do not appear to be spawning aggregations.
5. During the spawning and dispersal periods, orange roughy is the dominant member of the fish fauna in 750–1150 m. During this survey it represented 90% by weight of all species caught. The next most abundant species by weight were shovelnose dogfish (1.5%) and smooth oreo dory (1.0%).
6. There was little evidence that adult orange roughy had been feeding in areas C, D, and E during the early part of the survey, but there was a higher incidence of food in the stomachs of immature fish (smaller than 25 cm). On the second half of the cruise, in areas A and B, there was a relatively high incidence of food in the stomachs examined, possibly because of a high level of feeding after spawning. Prey items were mainly midwater fishes, prawns, and squids.
7. Spawning was almost completed when the survey began. Most (77%) of the females were spent.
8. Temperature preferences were not conclusively demonstrated in this study. Bottom temperatures between 700 and 1200 m ranged from 4.37 °C to 7.63 °C, and in the area of highest fish concentration (175–177° W) bottom temperatures were 5.89 °C and 6.90 °C at depths of 950 and 800 m respectively. The entire study area had bottom temperature and salinity properties typical of Antarctic Intermediate Water.

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Acknowledgments

We wish to thank Messrs J. Searle, A. Lachev, and N. Evans of Fletcher-Sovrybflot Fishing Limited, Dunedin for their assistance with the survey; Captain A. Poloshevet, Chief Mate S. Galenko, officers and crew of *Kaltan* for their help and hospitality; and Ms J. Gootjes of the Russian Department, University of Otago for interpreting services.

We are grateful to D. J. Gilbert and R. I. C. C. Francis for advice on computing techniques and to R. I. C. C. Francis and W. L. F. van den Broek who refereed the manuscript.

We also thank F. Saxton, Fishery Officer, Chatham Islands, who assisted greatly with the changeover of staff at Chatham Islands.

Appendix 1

Species taken in the study area

Scientific name	Common name
Elasmobranchs	
Apristurus sp.	Catshark
Bathyraja sp.	Skate
Bathyraja spinifera	Prickly deepsea skate
Centrophorus squamosus	Deepwater spiny dogfish
Centroscymnus coelolepis	Deepwater dogfish
C. crepidator	Deepwater dogfish
C. owstonii	Owston's spiny dogfish
Chimaera phantasma	Giant ghost shark
Chimaera sp.	Purple ghost shark
Dalatias licha	Seal shark
Deania calcea	Shovelnose dogfish
Etmopterus baxteri	Baxter's dogfish
E. lucifer	Lucifer dogfish
Harriotta raleighana	Long-nosed chimaera
Hydrolagus sp.	Pale ghost shark
Oxynotus bruniensis	Prickly dogfish
Raja sp.	Pale long-nosed skate
Rhinochimaera pacifica	Wide-nosed chimaera
Scymnodon plunketi	Plunket's dogfish
Torpedo fairchildi	Electric ray
Teleosts	
Alepisaurus brevirostris	Shortnose lancetfish
Alepocephalus australis	Brown slickhead
Allocyttus sp.	Black oreo dory
A. verrucosus	Warty oreo dory
Antimora rostrata	Violet cod
Argyropelecus gigas	Giant hatchetfish
Austrophycis marginatus	Dwarf cod
Bassanago bulbiceps	Swollenheaded conger
B. hirsutus	Hairy conger
Beryx splendens	Alfonsino
Brama brama	Ray's bream
Cataetyx sp.	Ophidiid
Centriscops obliquus	Crested bellowsfish
Centrolophus niger	Rudderfish
Chaunax picta	Pink frogmouth
Coelorinchus bollonsi	Big-eye rattail
C. cookianus	Rattail
C. fasciatus	Banded rattail
C. innotabilis	Notable rattail
C. kaiyomaru	Kaiyomaru rattail
C. matamua	Rattail
C. oliverianus	Rattail
C. sp.	Rattail
Coryphaenoides rudis	Rattail
C. serrulatus	Rattail
C. sp.	Rattail
C. subserrulatus	Rattail
Cottunculoides sp.	Bony skull toadfish
Cryptosaurus couesi	Black anglerfish
Cyttus traversi	Lookdown dory
Diastobranchus capensis	Basketwork eel
Diretmoides parini	Spinyfin
Epigonus lenimen	Bigeye cardinal fish
E. robustus	Robust cardinal fish
E. telescopus	Deepsea cardinal fish
Gadomus aoteanus	Filamentous rattail
Genypterus blacodes	Ling
Halargyreus johnsonii	Slender cod
Halosaurus pectoralis	Deepwater halosaur
Helicolenus sp.	Sea perch
Hoplichthys haswelli	Deepsea flathead
Hoplostethus atlanticus	Orange roughy
H. mediterraneus	Silver roughy
Hyperoglyphe antarctica	Bluenose
Idiacanthus sp.	Black dragonfish
Kathetostoma giganteum	Monkfish
Lepidion microcephalus	Small-headed cod
L. schmidti	Giant lepidion
Lepidorhynchus denticulatus	Javelin fish
Lycenchelys sp.	Eelpout
Macrourus carinatus	Ridge-scaled rattail
Macruronus novaezelandiae	Hoki
Malacosteus sp.	Loosejaw
Mancopsetta milfordi	Finless flounder
Melanostigma gelatinosum	Limp eelpout
Merluccius australis	Hake
Mesobius antipodum	Black javelin fish
Mora moro	Ribaldo
Nansenia sp.	Deepsea smelt
Nemichthys sp.	Snipe eel
Neocyttus rhomboidalis	Spiky oreo dory
Neophrynichthys angustus	Pale toadfish
Nezumia namatahi	Small-headed rattail
N. sp.	Rattail
Notacanthus sexpinis	Spineback eel
Odontomacrurus murrayi	Rattail
Opostomias micripnus	Giant black dragonfish
Persparsia kopua	Searsid
Photichthys argenteus	Lighthouse fish
Polyprion oxygeneios	Hapuku
Pseudocyttus maculatus	Smooth oreo dory
Psychrolutes sp.	Blobfish
Pterycombus petersii	Fanfish
Rouleina sp.	Black slickhead
Seriolella caerulea	White warehou
Synaphobranchus affinis	Grey cutthroat eel
Taractichthys longipinnis	Big-scale pomfret
Trachonurus villosus	Rattail
Trachyrincus longirostris	White rattail
Trachyscorpia capensis	Pink scorpionfish
Tubbia tasmanica	Centrolophid
Ventrifossa nigromaculata	Black spotted rattail
Cephalopods	
Moroteuthis ingens	Warty squid
Octopus sp.	Blue deepwater octopus
Ommastrephes bartrami	Red squid
Opisthoteuthis sp.	Umbrella octopus

Appendix 2
Individual station data

Station No.	Start position Latitude ° ′ S	Start position Longitude ° ′	Stratum No.	Depth at start (m)	Distance (n. mile)	Orange roughy Catch (kg)	Orange roughy Catch rate (kg/km)	Biological sample n	Biological sample Mean length (cm)	Biological sample Mean body weight (g)	Biological sample Mean gonad weight (g)	Biological sample % male
1	42 51.1	177 21.7W	11	775	2.7	0.0	0.0	0	*	*	*	*
2	42 50.8	177 19.1W	12	810	3.0	17.8	3.2	12	32.6	1 081.1	29.8	83.3
3	42 49.5	177 12.9W	12	846	2.2	1 353.5	332.2	36	33.2	1 161.0	57.3	88.8
4	42 45.5	177 26.0W	14	1 070	1.2	407.2	183.2	20	30.5	1 051.0	22.3	33.3
5	42 46.7	177 22.9W	14	1 000	1.5	2 963.4	1 066.7	20	32.4	1 126.3	18.5	35.0
6	42 47.2	177 13.7W	13	980	1.8	179.3	53.8	20	32.9	1 216.3	6.3	75.0
7	42 48.5	177 09.7W	13	940	2.1	324.1	83.3	20	34.1	1 299.0	53.2	80.0
8	42 46.5	177 13.5W	14	1 015	3.0	76.6	13.8	0	*	*	*	*
9	42 45.4	177 03.6W	14	1 100	2.3	347.9	81.7	20	31.7	1 016.7	23.1	57.8
10	42 47.5	177 03.1W	13	990	1.1	350.8	172.2	14	33.5	1 317.2	32.2	69.2
11	42 46.1	176 55.1W	14	1 050	2.5	350.3	75.7	20	34.0	1 258.6	24.9	30.0
12	42 50.9	176 53.9W	12	875	1.9	20 000.0†	5 683.8	20	34.0	1 291.8	25.3	90.0
13	42 54.8	176 54.8W	11	765	1.9	0.0	0.0	0	*	*	*	*
14	42 49.1	176 42.5W	13	910	2.3	2 638.0	619.3	0	*	*	*	*
15	42 52.4	176 34.8W	12	850	2.2	35 000.0	8 590.2	0	*	*	*	*
16	42 46.5	176 36.6W	14	1 070	1.6	254.6	85.9	40	32.6	1 224.5	26.0	37.5
17	42 46.4	176 32.5W	14	1 100	2.9	1 328.9	247.4	20	30.5	1 017.3	19.7	35.0
18	42 46.5	176 28.6W	14	1 090	0.9	1 165.0	698.9	20	32.0	1 100.9	18.4	45.0
19	42 52.1	176 31.7W	12	870	1.7	25 000.0†	7 940.5	20	35.1	1 368.3	36.1	80.0
20	42 53.5	176 25.0W	12	835	1.2	18 000.0‡	8 099.4	20	32.9	1 156.5	*	40.0
22	42 58.0	176 24.9W	11	740	2.2	0.0	0.0	0	*	*	*	*
23	42 54.2	176 26.9W	11	770	2.5	0.0	0.0	0	*	*	*	*
24	42 52.8	176 24.5W	12	860	1.2	25 970.0‡	11 685.6	20	34.3	1 283.8	46.4	75.0
25	42 50.5	176 24.7W	13	955	1.7	20 000.0†	6 352.4	20	35.5	1 471.2	34.7	45.0
26	42 49.9	176 03.2W	14	1 050	2.2	1 328.9	326.2	20	32.8	1 218.2	42.6	63.1
27	42 54.5	176 18.4W	13	900	2.2	34 132.0†	8 377.2	20	34.8	1 329.1	30.3	50.0
28	42 53.3	176 11.4W	12	880	2.1	21 500.0	5 528.1	20	35.1	1 349.2	36.7	85.0
29	42 54.0	176 16.1W	12	840	2.4	3 130.0	704.2	20	33.0	1 159.3	25.8	36.8
30	42 52.3	176 06.7W	13	930	2.0	21 331.0‡	5 758.9	20	35.0	1 318.7	25.3	75.0
31	43 02.3	175 42.9W	16	745	2.2	0.0	0.0	0	*	*	*	*
32	42 55.1	175 56.6W	17	840	2.0	47.6	12.9	40	24.0	537.3	6.8	46.1
33	42 53.5	175 56.5W	18	920	1.9	21 878.0‡	6 217.5	20	35.4	1 438.7	46.2	80.0
34	42 51.4	175 53.2W	18	990	1.8	4 961.0	1 488.2	20	35.2	1 348.0	24.6	65.0
35	42 49.9	175 55.6W	19	1 055	1.8	2 475.0	742.5	20	29.8	950.5	8.9	80.0
36	42 53.2	175 46.1W	17	890	2.2	29 797.0‡	7 313.2	20	38.1	1 695.4	42.9	60.0
37	42 51.7	175 37.0W	19	1 010	2.2	1 456.0	357.4	20	35.1	1 347.9	31.7	65.0
38	42 52.1	175 27.5W	19	1 025	2.1	1 043.0	268.2	20	37.7	1 626.0	31.4	35.0
39	42 51.4	175 26.0W	19	1 075	1.5	509.6	183.4	20	36.2	1 509.0	35.7	25.0
40	42 55.1	175 30.5W	18	930	2.7	16 270.0	3 253.7	20	37.2	1 494.8	33.3	60.0
41	42 50.8	175 18.3W	19	1 075	1.7	710.6	225.7	20	34.2	1 303.8	37.7	65.0
42	42 54.3	175 24.3W	18	990	2.7	3 029.0	605.8	20	34.7	1 322.8	37.7	70.0
43	42 55.2	175 29.8W	18	920	2.4	17 130.0	3 853.9	20	37.1	1 530.8	67.8	80.0
44	42 57.4	175 36.5W	17	825	3.0	860.2	154.8	20	25.6	642.5	7.5	52.6
45	42 57.0	175 37.1W	17	860	2.4	7 120.0	1 601.9	20	34.4	1 333.7	38.4	50.0
46	42 58.2	175 19.0W	18	920	1.2	27 132.0	12 208.4	0	*	*	*	*
47	42 52.3	175 15.5W	19	1 080	3.4	1 010.0	160.4	20	33.2	1 221.2	29.0	80.0
48	42 54.4	175 12.5W	19	1 040	3.0	1 421.0	255.8	20	35.2	1 320.2	27.5	60.0
49	42 57.7	175 17.6W	18	990	2.5	17 440.0	3 766.7	20	36.3	1 512.9	51.9	75.0
50	43 00.3	175 12.2W	18	925	2.4	35 835.0	8 062.2	20	36.0	1 401.3	28.9	70.0
51	43 02.5	175 23.5W	16	790	2.5	4.9	1.1	8	24.3	679.6	47.2	50.0
52	43 00.3	175 06.0W	18	980	1.9	12 460.0	3 541.0	20	36.7	1 487.9	31.0	60.0
53	43 07.6	175 14.5W	16	775	2.4	0.0	0.0	0	*	*	*	*
54	43 07.9	175 06.5W	17	840	2.1	106.9	27.5	20	24.2	526.4	4.5	36.8
55	43 14.0	174 54.8W	17	870	1.9	3 829.0	1 088.2	20	34.6	1 322.7	22.7	55.0
56	43 05.5	175 00.3W	18	920	3.5	28 934.0	4 463.7	20	36.3	1 488.7	34.3	68.4
57	43 10.4	174 45.0W	22	870	2.3	4 467.0	1 048.8	20	36.2	1 461.1	33.2	45.0
58	43 00.8	174 47.7W	18	960	2.6	6 082.0	1 263.0	17	36.3	1 448.0	28.2	35.2
59	43 03.3	174 40.0W	18	920	2.0	6 015.0	1 623.9	20	36.4	1 453.8	31.0	50.0
60	43 09.0	174 38.2W	17	885	1.5	3 566.0	1 283.8	20	36.5	1 496.7	31.5	55.0

* No biological data.
† Estimated by eye.
‡ Estimated from product weight.

Appendix 2—*continued.*

Station No.	Start position Latitude ° ′ S	Longitude ° ′	Stratum No.	Depth at start (m)	Distance (n. mile)	Orange roughy Catch (kg)	Orange roughy Catch rate (kg/km)	Biological sample *n*	Mean length (cm)	Mean body weight (g)	Mean gonad weight (g)	% male
61	42 55.4	174 31.9W	19	1 080	2.4	1 614.0	363.2	20	34.7	1 319.5	23.4	60.0
62	42 59.0	174 33.5W	19	1 050	2.3	5 907.0	1 386.7	20	36.5	1 560.2	37.2	65.0
63	43 01.1	174 33.4W	19	1 020	1.6	5 044.0	1 702.2	20	35.7	1 431.3	43.6	45.0
64	42 59.2	174 28.8W	24	1 080	1.3	2 885.0	1 198.3	18	35.8	1 434.5	28.2	50.0
65	43 04.2	174 26.1W	24	1 025	2.2	3 160.0	775.6	20	36.5	1 535.6	33.6	55.0
66	43 05.6	174 26.0W	23	970	2.6	4 470.0	928.3	20	36.1	1 487.5	32.6	45.0
67	43 10.5	174 30.1W	23	940	2.1	1 276.0	328.1	19	34.6	1 374.7	26.4	52.6
68	43 10.4	174 37.5W	22	875	1.3	713.3	296.3	20	31.8	1 066.6	14.9	65.0
69	43 13.5	174 29.0W	22	890	2.0	638.2	172.3	20	34.8	1 342.2	20.1	65.0
70	43 10.9	174 22.1W	23	970	2.2	244.0	59.9	20	34.9	1 365.6	27.7	45.0
71	43 18.4	174 23.2W	22	885	3.7	450.5	65.7	20	35.2	1 396.0	32.6	75.0
72	43 16.4	174 19.8W	23	910	3.0	750.8	135.1	20	36.3	1 497.3	40.0	70.0
73	43 19.1	174 20.0W	22	890	2.1	1 614.0	415.0	20	31.0	1 057.0	20.1	35.0
74	43 22.7	174 17.7W	23	940	2.6	375.4	78.0	20	34.0	1 264.9	22.8	45.0
75	43 32.3	174 07.3W	24	1 020	1.8	1 501.6	450.4	20	34.6	1 277.1	25.3	60.0
76	43 37.7	174 07.0W	24	1 090	2.0	3 792.0	1 023.6	0	*	*	*	*
77	43 36.2	174 10.1W	23	980	2.0	262.8	71.0	20	35.3	1 385.4	33.9	30.0
78	43 44.5	174 14.4W	24	1 010	1.6	563.1	190.0	20	32.9	1 168.2	28.8	60.0
79	43 46.8	174 18.8W	23	950	2.4	412.9	92.9	20	34.5	1 349.0	24.6	40.0
80	43 33.4	174 24.9W	22	840	3.2	675.7	114.0	39	27.1	701.9	10.3	51.2
81	43 36.0	174 23.6W	22	885	2.7	1 201.0	240.2	20	33.3	1 168.5	33.5	80.0
82	43 29.0	174 27.6W	22	850	2.6	1 201.0	249.5	20	30.6	991.1	14.8	35.0
83	43 26.2	174 43.5W	21	795	2.7	51.0	10.2	40	22.9	496.3	10.6	52.5
84	43 22.9	174 52.3W	22	820	2.6	0.0	0.0	0	*	*	*	*
85	42 45.7	177 56.6W	8	935	1.4	561.0	216.4	20	34.2	1 308.5	19.0	25.0
86	42 44.4	178 32.6W	7	850	2.4	2.6	0.6	0	*	*	*	*
87	42 39.8	178 39.3W	9	1 070	1.0	63.8	34.4	20	31.1	1 046.3	15.0	65.0
88	42 48.0	179 06.0W	6	770	1.3	7.4	3.1	0	*	*	*	*
89	42 44.9	178 55.0W	8	960	1.7	23.4	7.4	20	29.0	927.8	17.3	40.0
90	42 42.9	178 48.6W	9	1 030	1.4	205.7	79.8	20	32.8	1 207.4	20.2	50.0
91	42 41.7	179 13.4W	9	1 020	3.3	112.2	26.3	20	30.3	1 005.3	14.8	45.0
92	42 40.7	179 16.6W	10	1 120	2.3	140.3	23.0	20	32.1	1 133.6	15.1	35.0
93	42 49.5	179 43.9W	8	915	3.0	76.7	13.8	20	27.4	712.8	9.4	45.0
94	42 46.8	179 47.6W	9	1 010	1.0	224.4	121.2	20	34.0	1 263.8	20.0	50.0
95	42 50.9	179 57.2E	7	870	2.0	43.7	11.8	19	25.1	605.9	5.5	57.8
96	42 55.8	179 55.3W	6	740	2.4	0.0	0.0	0	*	*	*	*
97	42 52.6	179 56.7E	7	820	2.6	8.4	1.7	0	*	*	*	*
98	42 50.2	179 45.4E	8	930	1.8	149.6	44.9	20	25.0	609.9	5.7	55.0
99	42 52.7	179 36.9E	7	830	2.1	112.2	28.8	20	23.3	513.1	2.6	40.0
100	42 47.2	179 26.2E	10	1 140	2.3	103.2	24.2	20	34.7	1 394.0	24.8	35.0
101	42 49.3	179 16.8E	9	1 080	2.4	785.4	176.7	0	*	*	*	*
102	42 51.4	179 11.6E	8	990	3.8	785.4	111.6	20	30.5	1 038.8	13.6	70.0
103	42 53.4	179 10.5E	7	880	2.2	392.7	96.4	0	*	*	*	*
104	42 53.2	178 56.2E	7	820	2.2	448.8	110.2	20	24.3	506.8	4.1	55.0
105	42 52.3	178 46.7E	7	835	2.9	280.5	52.2	20	25.3	604.8	5.0	70.0
106	42 52.3	178 44.5E	8	920	3.3	112.2	18.4	20	22.7	453.1	2.8	55.0
107	42 47.8	178 13.0E	2	860	3.2	112.2	19.0	20	25.7	597.5	3.8	45.0
108	42 48.4	178 09.7E	1	750	1.8	1.2	0.4	0	*	*	*	*
109	42 46.5	178 17.9E	4	1 010	2.7	766.7	153.3	0	*	*	*	*
110	42 46.7	178 17.3E	3	970	2.0	1 570.8	424.1	20	32.7	1 191.4	12.5	60.0
111	42 49.4	178 25.6E	3	910	2.4	149.6	33.7	19	27.7	767.9	5.2	63.1
112	42 50.5	178 25.3E	2	810	3.3	168.3	27.5	20	24.8	543.9	2.7	50.0
113	42 46.7	178 29.5E	5	1 110	3.6	486.2	72.9	20	32.1	1 100.0	13.8	65.0
114	42 47.6	178 27.7E	4	1 030	3.5	935.0	144.2	20	32.7	1 260.0	17.6	75.0
115	42 45.2	178 15.0E	4	1 050	2.1	822.8	211.6	20	33.4	1 284.3	15.7	65.0
116	42 43.3	178 11.6E	4	1 080	1.4	317.9	122.6	20	32.3	1 215.9	14.0	80.0
117	42 41.5	178 04.7E	5	1 140	1.9	448.8	127.5	0	*	*	*	*
118	42 42.5	177 58.5E	3	965	2.3	149.6	35.1	0	*	*	*	*
119	42 43.9	177 56.5E	3	910	2.1	149.6	38.5	0	*	*	*	*
120	42 42.8	177 49.9E	3	950	2.3	860.2	201.9	0	*	*	*	*
121	42 40.8	177 51.8E	4	1 090	2.7	60.2	12.0	20	33.4	1 249.3	15.0	80.0
122	42 41.8	177 45.6E	4	1 040	2.6	654.5	135.9	20	34.6	1 399.8	23.7	80.0
123	42 40.9	177 41.6E	4	1 075	1.7	1 009.8	320.7	20	34.6	1 360.0	21.2	65.0
124	42 43.7	177 42.5E	3	925	2.3	10.2	2.4	0	*	*	*	*
125	42 46.3	177 27.4E	1	755	3.4	390.5	62.0	20	20.7	350.7	2.7	45.0
126	42 45.6	177 24.5E	2	895	2.8	392.7	75.7	0	*	*	*	*
127	42 41.0	177 27.5E	4	1 060	1.2	542.3	244.0	0	*	*	*	*
128	42 41.3	177 21.4E	4	1 080	1.0	533.4	288.0	0	*	*	*	*
129	42 40.5	177 13.4E	4	1 020	2.0	1 271.6	343.3	0	*	*	*	*
130	42 44.7	177 07.4E	2	890	2.7	243.1	48.6	0	*	*	*	*

Appendix 2—*continued.*

Station No.	Start position Latitude ° ′ S	Longitude ° ′	Stratum No.	Depth at start (m)	Distance (n. mile)	Orange roughy Catch (kg)	Orange roughy Catch rate (kg/km)	Biological sample *n*	Mean length (cm)	Mean body weight (g)	Mean gonad weight (g)	% male
131	42 40.5	177 03.5E	4	1 010	2.3	1 252.9	294.1	0	*	*	*	*
132	42 40.6	177 06.8E	4	1 050	2.8	935.0	180.3	20	36.0	1 557.0	26.6	60.0
133	42 40.9	177 11.7E	4	1 075	3.4	673.2	106.9	20	33.6	1 259.6	14.4	65.0
134	42 39.8	177 02.5E	4	1 053	1.7	3 328.6	1 057.2	20	33.1	1 275.4	15.4	65.0
135	42 40.3	176 51.0E	4	1 020	2.7	1 496.0	299.2	20	33.6	1 338.8	14.7	55.0
136	42 41.0	176 46.5E	3	990	2.8	448.8	86.5	0	*	*	*	*
137	42 39.9	176 40.8E	4	1 010	3.1	280.5	48.9	0	*	*	*	*
138	42 42.2	176 44.6E	2	890	2.0	37.0	10.0	0	*	*	*	*
139	42 44.0	176 39.5E	1	770	1.8	4.3	1.3	0	*	*	*	*
140	42 42.6	176 30.6E	2	810	3.2	74.8	12.6	0	*	*	*	*
141	42 39.3	176 27.1E	3	980	2.9	2 281.4	424.8	20	32.9	1 223.5	12.8	45.0
142	42 39.3	176 33.9E	4	1 040	2.1	1 047.2	269.3	20	35.3	1 537.4	11.5	90.0
143	42 38.7	176 40.6E	4	1 050	2.0	448.8	121.2	19	32.8	1 192.2	10.5	63.1
144	42 39.3	176 44.0E	4	1 090	1.5	486.2	175.0	20	33.2	1 239.4	15.0	60.0
145	42 38.1	176 36.9E	5	1 140	2.2	598.4	146.9	20	33.9	1 576.3	22.6	55.0
146	42 37.8	176 31.9E	4	1 080	2.7	561.0	112.2	19	33.9	1 531.2	23.0	52.6
147	42 38.4	176 26.7E	4	1 050	2.4	1 327.7	298.7	0	*	*	*	*
148	42 42.1	176 19.7E	2	840	2.2	149.6	36.7	0	*	*	*	*
149	42 37.4	176 19.0E	4	1 070	2.2	878.9	215.7	0	*	*	*	*
150	42 38.3	176 10.1E	4	1 030	2.8	673.2	129.8	0	*	*	*	*
151	42 41.1	176 10.2E	2	890	2.4	74.8	16.8	0	*	*	*	*
152	42 43.9	176 08.0E	2	810	2.3	93.5	22.0	20	29.0	1 021.8	8.2	35.0
153	42 40.0	176 02.3E	3	950	1.7	149.6	47.5	20	34.9	1 408.1	22.7	50.0
154	42 39.1	175 46.1E	5	1 140	2.0	1 309.0	353.4	20	34.1	1 290.4	18.0	60.0
155	42 42.2	175 44.6E	4	1 010	2.5	1 346.4	290.8	20	35.6	1 451.1	23.2	80.0
156	42 43.5	175 48.5E	3	960	2.8	785.4	151.5	20	34.4	1 351.8	20.4	55.0
157	42 42.3	175 40.2E	4	1 045	2.2	2 618.0	642.5	0	*	*	*	*
158	42 42.3	175 32.6E	4	1 060	3.2	1 533.4	258.7	0	*	*	*	*
159	42 45.8	175 23.5E	3	940	1.7	261.8	83.2	0	*	*	*	*
160	42 45.7	175 15.7E	4	1 020	2.6	355.3	73.8	20	35.0	1 441.9	22.3	45.0
162	42 46.3	175 29.7E	2	890	1.7	44.4	14.1	20	34.0	1 345.5	19.0	60.0

P. D. HASSELBERG, GOVERNMENT PRINTER, WELLINGTON, NEW ZEALAND—1984

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