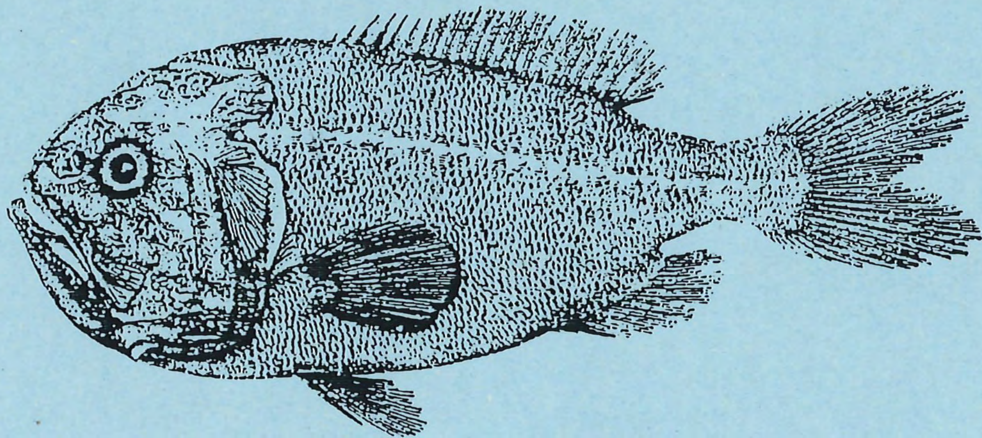
An Assessment of the Orange Roughy Resource off the Coast of Tasmania

Final Report to the Fishing Industry Research and Development Council Project 87/65



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SUMMARY

A stratified random trawl survey of the mid-slope region off Tasmania was conducted between 1988 and 1989. In conjunction with the trawl surveys, a programme of commercial catch sampling and monitoring was undertaken from late 1987 to 1990.

Trawl survey coverage was restricted to areas of smooth, readily trawlable bottom. Results suggest that the biomass of orange roughy off north-western and north-eastern Tasmania is of a low order, with biomass indices generally below 1 500 tonnes in each area, and little evidence of seasonal or interannual variability. Extrapolation to include the unsampled areas of rough bottom produced biomass indices of 4 000 - 11 500 tonnes for the entire Tasmanian region, though little confidence can be attributed to these estimates.

Since 1989, commercial catches of orange roughy have expanded dramatically. The bulk of the catch is now taken in areas which were excluded from the trawl surveys, i.e. off St Helens (north-east Tasmania) and off southern Tasmania. The total catches from waters adjacent to Tasmania were approximately 26 000 tonnes in 1989 and 42 000 tonnes in 1990, significantly greater than the trawl survey estimates. The high catches achieved by the commercial fleet indicate that orange roughy are not evenly distributed over smooth and rough bottom.

Not withstanding the obvious limitations of the trawl surveys, they may be of some value in detecting relative changes in absolute biomass for the whole stock. A longer time series of trawl surveys would, however, be required to test this. Other methods of biomass estimation, including acoustic and egg production surveys, may be more suitable for orange roughy.

Combined biomass indices for warty and spiky oreos were generally below 460 tonnes for north-western Tasmania. Smooth and black oreos show considerable commercial potential but were only rarely taken in the surveys. Results of commercial fishing operations indicate that these species favour areas of rough bottom.

The size distribution of orange roughy taken by trawl survey was strongly bimodal, with one mode represented by juvenile (generally < 30 cm) and the other by adult fish. Information from other studies suggests that orange roughy are extremely slow growing and long-lived and it seems probable that the mode of adult fish represents the accumulation of a very large number of age classes.

There was some evidence for a size depth relationship for orange roughy off western Tasmania, with smaller fish tending to predominate in the shallower depths.

Commercial catches were almost exclusively comprised of adult fish, most measuring between 30 - 40 cm. There were only minor differences in length frequency distributions for the major fishing areas around Tasmania, though sex ratios varied between fishing areas. Comparison of Tasmanian fish with those from other localities, namely the Cascade Plateau and New South Wales, indicated marked differences in size structure which possibly reflect differences in stock structure.

Orange roughy are group synchronous spawners which form large winter spawning aggregations. The only major spawning site known in Australian waters is located east of St Helens. The spawning aggregation appears to be associated with a single pinnacle and the timing of spawning was consistent in 1989 and 1990. Spawning occurs from mid-July to early August, a period of just over three weeks. There is evidence of localised segregation of the sexes within the spawning aggregation but it

is not clear whether the sexes are distributed in a consistent manner in relation to factors such as depth or position on the pinnacle. By the end of August the aggregation had effectively dispersed and it seems probable that there is some dispersal into deeper water.

A significant finding of this study has been that not all post-mature females spawn each year. Some fish fail to either initiate or maintain vitellogenesis in a given year. The proportions of non-reproductive females was found to vary spatially and temporally. At the St Helens spawning site, the proportion of non-reproductive females decreased from about 45% in March and April 1990 to about 2% immediately prior to the onset of spawning, presumably reflecting the movement of spawners into the area. By contrast, immediately prior to and during the spawning season over half of the adult females examined from southern Tasmania were found to be non-reproductive. It is suggested that there may be some movement of spawners away from these sites. These findings have relevance in understanding possible migration patterns and are of importance if population biomass estimates are to be derived from spawning aggregations.

Orange roughy feed opportunistically on benthopelagic and mesopelagic organisms. Crustaceans (mostly prawns) were the most commonly eaten prey, with fish and cephalopods (squid) of secondary importance. Orange roughy do not feed heavily during the spawning season.

Warty oreo length frequencies were basically bimodal and spiky oreo size distributions indicated several distinct modes. In the absence of validated ageing data for either species, the significance of the size structure is unknown.

Our data suggest that warty oreos spawn during winter whereas spiky oreos spawn in spring. The onset and duration of the spawning event for both species could not be determined and it is not known whether they aggregate to spawn. Macroscopic staging of gonads suggests synchronous ovarian development.

Warty oreos fed principally on prawns as well as fish and cephalopods. The main food item eaten by spiky oreos were salps, with fish, crustaceans and cephalopods of lesser importance.

1 INTRODUCTION

1.1 Background

Orange roughy, *Hoplostethus atlanticus*, are distributed throughout the Atlantic Ocean, western Mediterranean Sea, southern Indian Ocean and Southern Ocean around New Zealand and southern Australia. The species inhabits depths of greater than about 750 m and has been recorded to at least 1 400 m in Australian waters. The lower depth limit around Australia is not yet known, though orange roughy been recorded to 1 800 m in other parts of the world (Merret and Wheeler, 1983).

A major demersal trawl fishery for orange roughy has existed off New Zealand since 1979, with annual catches exceeding 40 000 tonnes in recent years. The fishery is based largely on winter spawning aggregations found on the Chatham Rise, Challenger Plateau and off the east coast of the North Island (Robertson, 1991).

The Australian fishery has a shorter history. The first promising catches were taken by the RV *Challenger* off Tasmania in 1981 (Wilson, 1982). Recognizing the significance of this find, the then Tasmanian Fisheries Development Authority, in conjunction with the Commonwealth government, undertook a series of surveys designed to assess the commercial potential of the resource and to identify suitable trawl grounds (Anon, 1982; Wilson and Evans, 1983;1984; Wilson *et al.*, 1984; Evans and Pullen, 1986; Pullen *et al.*, 1986). Biological data collected as part of these surveys have been summarised by Lyle *et al.* (1989a).

Commercial fishing for orange roughy began in 1982, initially as an adjunct to traditional shelf and upper slope fishing operations. Although catch statistics are incomplete, annual catches prior to 1986 are unlikely to have exceeded 400 tonnes. It was not until the latter part of 1986 that the first large (non-spawning) aggregation was discovered and substantial catches were taken. Subsequent to this, a number of other aggregations have been fished. Between 1986 and 1988 annual landings for the South East Trawl (SET) fishery ranged between 4 600 and 6 000 tonnes, most of which was taken from non-spawning aggregations.

The discoveries of a major spawning aggregation off St Helens (north-eastern Tasmania) and aggregations off southern Tasmania during 1989 have resulted in a dramatic expansion of the fishery (Lyle *et al.*, 1989b). The total reported catch from waters adjacent to Tasmania exceeded 26 000 tonnes in 1989 and 42 000 tonnes in 1990. In 1990 orange roughy represented Australia's largest finfish fishery, with a landed value in the order of $60 million.

Since 1988 there have also been substantial, but spasmodic, catches of orange roughy in the Great Australian Bight (Newton, 1988; Newton and Burnell, 1989; Newton *et al.*, 1990). Annual catches from that area ranged from 1 000 to 3 700 tonnes for the period 1988 - 1990.

Despite considerable research in New Zealand and Australia over the past decade, many fundamental aspects of the biology of orange roughy remain poorly understood. For instance, it has only been in the past year or so that significant advances have been made in understanding basic population parameters; the species appears to be extremely slow growing, long lived and has very low productivity (see Mace *et al.*, 1990, Fenton *et al.*, 1991). In the light of this and uncertainty about the size of the Australian resource, concern has been expressed over the ability of the stock(s) to sustain the current high catch levels. Pending better information about potential sustainable yields, interim management arrangements for orange roughy have been introduced for the SET fishery, including catch limits in management zones off eastern and southern Tasmania (Anon., 1990).

1.2 Present Study

The present study represents one segment of a major co-operative research effort, initiated in 1987, which was intended to assess the size of the orange roughy resource, its population parameters, potential yields and stock structure (Williams, 1987). The primary objective of the present study was to determine the abundance, distribution and biology of orange roughy on the continental slope around Tasmania. Specific objectives were to:

- determine the size of the orange roughy resource on the continental slope (between 800 and 1 200 m depths) around Tasmania

- investigate the spatial and temporal distribution and relative abundance patterns of orange roughy, i.e. the occurrence, size and distribution of spawning and non-spawning aggregations

- investigate factors (both biotic and abiotic) which affect the distribution and abundance patterns

- investigate the biology and determine population parameters of orange roughy

- estimate potential sustainable yield of the orange roughy resource

- determine the distribution, resource sizes and potential yields of other commercial species occurring on the slope.

Two field sampling programmes were established to achieve these objectives, the first a systematic trawl survey and the second, a commercial catch sampling programme. The trawl surveys were undertaken on a seasonal basis over a two year period (1988 and 1989) while commercial catch monitoring continued throughout the duration of the study (1987 - 1990) and is on-going.

In late 1987 the various groups working on orange roughy met to ensure that the research was properly co-ordinated and duplication minimised. As a consequence, some of the objectives listed above were tasked to other organisations. For instance, the Victorian Marine Science Laboratories (MSL) and University of Tasmania assumed responsibility for the ageing of orange roughy (essential for the estimation of population parameters) and the NSW Fisheries Research Institute (FRI) undertook histological examination of gonads and estimation of fecundity. An important secondary function of the present study became the collection of biological material for these and other programmes. A breakdown of the numbers and types of samples collected during the course of the study is presented in Table 1.

TABLE 1. Details of samples collected for other organizations.

Organization	Study	Sample type	No. samples
	Stock discrimination		
Uni of Tasmania	mitochondrial DNA (FIRTA 87/92)	ovary	185
Uni of NSW	allozyme electrophoresis (FIRTA 87/131)	whole fish	100
Uni of Queensland	parasite load (FIRTA 88/25)	viscera	920
	Ageing		
MSL	otolith annuli (FIRTA 86/39)	otoliths	1 227
Uni of Tasmania	radioisotope (FIRTA 87/94)	otoliths	188
	Reproductive biology		
FRI	histology (FIRTA 87/131)	gonad	745
FRI	fecundity (FIRTA 87/131)	ovary	213

2 MATERIALS AND METHODS

2.1 Study Area

The study area encompassed mid-slope waters (between 800 - 1 200 m) south of latitude 41°S off the east and west coasts of Tasmania, an estimated area of 4 346 km^2. The west coast boundary of 41°S represents the southern most limit of the Western Bass Strait Trawl Fishery Assessment project (FIRTA 86/39).

2.2 Research Surveys

2.2.1 Survey design

A stratified random trawl survey design was adopted, with seasonal surveys conducted over a two year period (1988 and 1989)[1]. Stratified random trawl surveys have been used widely in the assessment of abundance of demersal fish stocks (Grosslein, 1969; Doubleday, 1981; Francis, 1981; Robertson *et al.*, 1984; Tracey *et al.*, 1990). The underlying principle of such surveys is that the mean catch rate from a number of trawls accurately reflects the fish density in the area swept by the trawl net. This is in turn assumed to be representative of the fish density throughout the survey area.

The random allocation of trawl stations gives every location within the survey area an equal chance of being selected and thereby enables statistically valid estimates of variance for the biomass indices to be produced (Grosslein, 1969). As fish are seldom uniformly distributed, stratification of the survey area may give much more precise estimates of abundance (i.e. reduce sampling variance). Stratification is usually by depth and area. When knowledge is available about the distribution of the fish, sampling density can also be increased in those strata where fish abundance is high. This will further reduce sampling error and is the basis of the two phase survey design of Francis (1984).

In this study no prior knowledge of fish abundance was assumed. However, experience gained from earlier trawl surveys and analysis of the distribution of commercial fishing effort had indicated that the availability of bottom suitable for a random trawl survey was limited. Relatively smooth bottom was known to occur off the west coast between about 41°00' and 42°30'S and on the St Patricks Head ground between 41° 25' and 41°50'S, off the north-east coast. Outside of these areas the ground is hard and very uneven and the likelihood of hooking up or causing major gear damage is high. The 1988 and 1989 CSIRO orange roughy trawl surveys generally confirm these observations (Bulman *et al.*, 1991).

In order to avoid a high proportion of trawl stations abandoned because of unsuitable bottom, two areas known to contain trawlable bottom were defined:

1. North-western Tasmania (NW Tas) - between 41°00' to 42°30'S, a bottom area of 1 025.9 km^2; and
2. North-eastern Tasmania (NE Tas) - between 41°25' to 41° 50'S, a bottom area of 412.5 km^2.

Four 100 m depth strata were recognised: 800-899 m, 900-999 m, 1 000-1 099 m and 1 100-1 199 m.

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[1] The year was split into quarters which correspond to the seasons - summer (December to February); autumn (March to May); winter (June to August); spring (September to November).

Isolated patches of trawlable ground also exist outside of these areas and in an effort to extend the spatial coverage, some non-random tows were also attempted. In such circumstances, the decision to trawl was based solely on the presence of trawlable bottom and not on the appearance of fish marks on the echo sounder or results of previous trawls. A small number of targeted tows were also made when fish marks suspected of being orange roughy were observed. The latter have not been included in the calculation of biomass.

Charts of the bottom bathymetry within the survey area (Wilson *et al.*, 1984) were electronically digitized according to 100 m depth contours to determine area within each depth interval. Random positions were generated using a computer program developed by the CSIRO for their orange roughy trawl survey (Bulman *et al.*, 1991). A condition that stations within each depth stratum must be greater than 4 km apart was imposed and a sampling density of 1 station per 50 km^2 in the two areas of trawlable bottom was intended. A different series of random positions was generated for each survey.

2.2.2 Vessels and gear

The research vessel *Challenger* was used to survey the east coast and the commercial fishing vessel *Petuna Endeavour* was chartered for the west coast surveys.

The *Challenger* has the following specifications: overall length 21.3 m; beam 5.85 m: horse power 500. The *Challenger* was fitted with Krupp Atlas 791DS and Echoscope 322 echosounders; a JRC JLR-4100 global positioning system (GPS) navigator and a Magnavox satellite navigator (SATNAV).

The specifications for the *Petuna Endeavour* are: overall length 24.0 m; beam 7.51 m; gross tonnage 200 t; horse power 550. The vessel was fitted with Simrad ET100 and Koden 884 echosounders; Trimble 10X and Furuno GP500 GPS navigators and a Magnavox MX4102 SATNAV.

The net used by the *Challenger* was a modified Atlantic Western trawl with a headline length of 34.9 m, vertical opening of 3.7 m and codend mesh of 11 cm (knot to knot). The *Petuna Endeavour's* net was a Milligan orange roughy trawl with a headline length of 36.6 m, vertical opening of 6 m and codend mesh of 11 cm. Net plans and gear specifications are given in Appendix I.

Under normal trawling conditions the wing tip distance generally ranges between 50 - 60% of the headline length, with a reasonable average being about 55% (K. J. Graham, pers. comm.). Accordingly, wing tip distance has been assumed to be 55% of the headline length for the purposes of this study, i.e. 19.2 m and 20.1 m for the nets used by the *Challenger* and *Petuna Endeavour*, respectively. Attempts were made to measure wing spread and the results generally agree with the assumed values:

> Door spread and wing tip distance were measured by Scanmar for the *Challenger's* net. At a depth of 98 - 100 m and trawl speed of 2.5 knots, the door spread was 68 - 70 m and wing tip distance 18 - 19 m.
>
> Door spread on the *Petuna Endeavour* was estimated by determining the increment in distance between the trawl warps from the trawl blocks to 2 m aft of the blocks and then extrapolating for the quantity of wire out. At a depth of 158 m and trawl speed of 3 knots the distance between the doors was 84 m. Based on a sweep angle of 165^{o} (assessed by attaching a small sheet of lead around one of the sweeps and estimating the angle produced by bottom scouring), the wing tip measurement was 18.5 m.

2.2.3 Sampling procedure

Tows were intended to be of 60 minutes duration but this had to be reduced where suitable bottom was limited. Tows were considered invalid when bottom time was less than 15 minutes or where substantial net damage was sustained. Invalid tows have not been included in calculations of biomass. A sampling station was abandoned if bottom suitable for trawling could not be located after one hours search around the predetermined position.

The following station data were recorded: start and finish positions, start time of tow and duration, tow direction, trawl speed, height of the net opening, sea conditions, surface and bottom temperatures and trawl depth (minimum and maximum). Trawl duration was recorded as actual bottom contact time as indicated by net sonde. On those occasions when the net sonde malfunctioned, bottom times were estimated by the master of the vessel. Position fixing was by SATNAV or, when available, GPS.

Catches were not weighed directly. The total weight of the each catch was estimated by the fishing master. The weights for orange roughy and oreos were calculated using length frequency data and known length-weight relationships or, when catches were large (> 500 kg), by multiplying the number of fish bins by the average weight of a fish bin. The remainder of the catch was sorted by species and numbers of individuals recorded. In a few instances, catches were sub-sampled and the numbers scaled up accordingly. When this occurred care was taken to ensure that all rare species were noted.

2.2.4 Biomass index estimation

The following assumptions were made regarding the performance of the sampling gear and the behaviour and distribution of the fish:

1. fish did not extend above the headline height of the net
2. all fish in the path of the net were caught; i.e. there was no escapement or avoidance
3. there was no concentrating or herding effect by the sweeps and trawl doors; i.e. the distance between the wing tips was the effective sampling width.
4. there was no movement of fish into or out of the survey area during each survey period.

Assumptions 1 and 2 will tend to be conservative whereas assumption 3, if wrong and herding does occur, will over-estimate abundance. Biomass values, therefore, should be regarded as indices of abundance rather than absolute quantities of fish. As long as catchability remains constant between and within surveys, comparison between surveys is valid and any changes in biomass index will reflect relative changes in actual abundance.

Biomass and standard errors of biomass were calculated using the following formulae (based on Francis, 1981). For each station the catch rate was determined as weight of fish per swept area (kg/km^2) according to the formula:

$$X_{ij} = W_{ij} \ / a_{ij} c$$

where X_{ij} is the catch rate (kg/km^2), W_{ij} is the weight (kg) caught from station j in stratum i, a_{ij} is the swept area of station j in stratum i (km^2), and c is the catchability coefficient (i.e. an estimate of the proportion of fish available to the net which is caught) which is assumed to equal 1 (refer to assumptions 1-3 above). The swept area was determined by multiplying trawl speed (converted to kilometres per hour) by tow duration (in hours) and wing spread (in kilometres). No attempt has been made to standardise results for the relative fishing power of the two vessels.

The mean catch rate, $\overline{X}_i$, and standard error, S_i, for stratum i were calculated as:

$$\overline{X}_i = \sum_{j=1}^{n_i} X_{ij} / n_i$$

$$S_i = \sqrt{[\sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2 / n_i (n_i - 1)]}$$

where n_i is the number of tows in stratum i.

The biomass estimate, B, was obtained by summing the products of the mean catch rate for each stratum by stratum area, A, where T is the total number of strata:

$$B = \sum_{i=1}^{T} \overline{X}_i A_i$$

and the standard error as:

$$S_B = \sqrt{[\sum_{i=1}^{T} (S_i^2 A_i^2)]}$$

The 95% confidence limits for the biomass estimates, CL_{95}, and coefficients of variation, *c.v.*, were obtained in the following manner:

$$CL_{95} = B \pm 2S_B$$

$$c.v. = S_B / B \times 100$$

Trawl catch rates are generally distributed according to a lognormal distribution (Francis, 1981). In order to test for seasonal and depth effects on catch rates, analysis of variance was performed (via regression) on $\log_e(1 + X_{ij})$.

2.2.5 Biological observations

(i) Orange roughy

Standard lengths were measured to the nearest centimetre rounded down. At each station where the orange roughy catch was less than about 250 kg, all fish were sexed and measured. With larger catches, a randomly selected sub-sample of at least 200 fish was measured. Size distributions were scaled up when sub-sampling occurred.

Between 25 and 50 fish from each tow were retained for detailed biological examination. The following observations were made - standard length (± 0.1 centimetre), body weight (± 1.0 gram), sex, gonad stage (after Pankhurst *et al.*, 1987), gonad weight (± 0.1 gram), presence of food in the stomach and principal prey categories (fish, cephalopod, crustacea). Easily recognisable prey were identified to family or genus. Sagittal otoliths were removed and stored dry.

(ii) Oreos

Biological information was collected from three species of oreo - warty (*Allocyttus verrucosus*), spiky (*Neocyttus rhomboidalis*) and smooth (*Pseudocyttus maculatus*). Sampling strategy was similar to that for orange roughy except that the oreos were measured for total length. Smooth oreos were rarely caught and as a result sample sizes were too small to permit detailed biological analysis.

2.2.6 Miscellaneous

(i) Codend Escapement

A 5 cm mesh liner was attached outside of the final 1 m of the codend to assess the level of escapement of small orange roughy from the codend. The use of the liner was discontinued after 32 trials since very few orange roughy actually passed through the codend meshes. The liner did, however, retain large numbers (not quantified) of small whiptails (Macrouridae) and basket-work eels (*Diastrobranchus capensis*).

(ii) Plankton Tows

Several deep plankton tows were undertaken in an attempt to determine the presence of orange roughy eggs and larvae. During the 1988 winter and spring surveys a one metre diameter plankton net (500 µm mesh) was attached to the warp in front of the trawl door.

Oblique tows of the plankton net were also made in the vicinity of the St Helens spawning site during July and August 1989. Temperature and depth profiles were attained using a temperature/depth probe.

(iii) Bathymetric Charts

The bottom bathymetry of the Port Davey, Maatsuyker and Pedra Branca aggregation sites were investigated. Each site was surveyed by a number of north-south and east-west transects, with accurate depth and position data recorded at regular intervals along each transect. Depth contour maps were generated using the National Center for Atmospheric Research (NCAR) contouring package and are presented as Appendix II.

2.3 Commercial Catch Monitoring

2.3.1 On board sampling

On board monitoring of commercial fishing operations was undertaken opportunistically. Size and sex composition information were recorded on a per tow basis. Where possible a random sample of at least 150 fish was measured from each trawl shot. Catch weights were estimated by the master of the vessel and size compositions were scaled up to account for sub-sampling.

Prior to and during the spawning season particular attention was given to the assessment of reproductive condition. Our ability to correctly assess gonad condition by macroscopic staging was validated using histology. Between April and July 1990 ovarian tissue from 133 fish was retained for histological examination. In the laboratory the tissue was embedded in paraffin, sectioned at 7 µm and stained with haematoxylin and eosin. Each fish was attributed a stage on the basis of the diagnostic histological features given in Pankhurst *et al.* (1987) and this was compared with the macroscopic stage given to it in the field. Macroscopic stages were correctly attributed in just over 95% of cases.

2.3.2 Shore-based sampling

Further size and biological information was collected through the sampling of catches at fish processors. Sampling was undertaken on a regular basis depending upon availability. A minimum of 200 fish from each catch were chosen at random, measured and sexed. The locality (or aggregation) fished, vessel, date and total catch weight were recorded. If ambiguity existed regarding where or when the fish had been caught, the sample was excluded from further analysis. In some instances the date of capture had to be approximated as fish were caught over several days of fishing. Assigned dates are considered accurate to within ± 3 days of the actual capture date.

During the spawning season, samples were examined from vessels that were known to have caught their fish within a specified 24 - 36 hour period. This level of precision was necessary to assess the precise timing of the spawning event.

Biological information was also collected from up to 100 fish per landing and this has been used to supplement data collected from the research surveys.

2.3.3 SET logbook data

SET logbook data for the period July 1986 - April 1990 were examined for trends in catch and effort for orange roughy in the South West sector. Logbook coverage was, however, incomplete for the latter part of 1989 and early 1990 so catches for this period will be underestimates. For the purposes of analysis, the main fishing grounds adjacent to Tasmania have been treated separately and are defined in Figure 1. They are:

- St Helens, including the spawning hill;
- St Patricks Head ground;
- Pedra Branca, including several sites of aggregations;
- Maatsuyker, including several sites of aggregations;
- South-west Tasmania, including several sites of aggregations; and
- Sandy Cape, including the Sandy Cape aggregation site.

Commercial fishing operations can be divided into two distinct types of operation, target and non-target fishing. Target fishing occurs when fishing aggregations and/or fishing on rough ground and trawl duration is short (usually less than 20 minutes). Non-target fishing or 'prospecting' occurs when fishing over smooth bottom (usually in the absence of definite fish marks) and trawls can take up to several hours to complete. Effective effort is, therefore, difficult to define and, for the purposes of this analysis, has been expressed as number of tows rather than as a function of tow duration.

For species such as orange roughy catch per unit effort (CPUE) as an index of abundance is of limited value. Provided the fish are aggregated and accessible to trawls, catch rates will remain high even when the biomass has been substantially reduced. CPUE analysis is further complicated by the effects of gear saturation, i.e. where nets become overfilled and there is loss of fish, and the use of net 'windows' or burst panels to regulate the size of the catches. Notwithstanding these limitations, CPUE trends will provide an indication of changes in vulnerability and aggregating behaviour.

Note: in accordance with Australian Fisheries Service (AFS) policy regarding the presentation of logbook information, summary statistics in which less than five vessels fished have not been presented in this report.

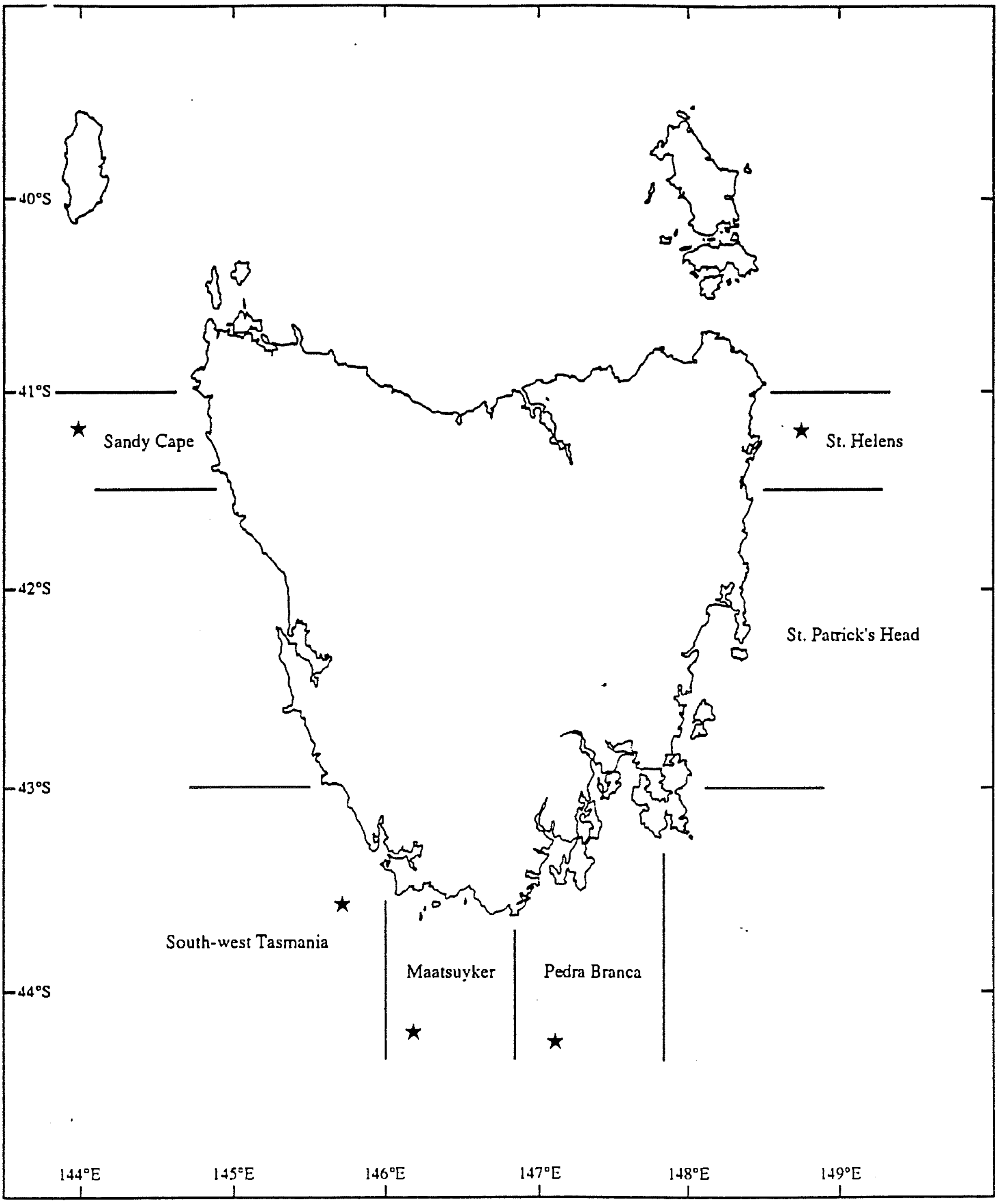


Figure 1: Map showing main fishing grounds adjacent to Tasmania.
(★ indicates major aggregation sites)

3 RESULTS

3.1 Research Surveys

3.1.1 General

A total of 238 tows were attempted, 50 and 188 off the east and west coasts, respectively. Of these, 195 were valid, 23 were non-random and 4 were targeted tows. A summary of station and catch details is provided in Appendix III.

An average sampling density of 1 tow per 54 km^2 was achieved for NW Tas, with a range 1 per 45 to 68 km^2. The average station density for NE Tas was 1 tow per 77 km^2, with a range of 1 per 37 to 206 km^2. Difficulties were encountered in achieving the desired coverage for NE Tas, with considerable ship time lost to bad weather and as a result of gear damage.

Up to 141 species of fish, representing 59 families, were caught during the surveys (Appendix IV). The most common by-catch to orange roughy were squalid sharks (brier shark, golden dogfish, owston's dogfish and rough deep-sea shark), basketwork eels, slickheads, several species of whiptails (especially serrulate and long-rayed whiptails), warty and spiky oreos and Johnson's deep-sea cod. Squid and crustaceans (spider crabs, prawns and bugs) were also caught. The structure of the fish community on the mid-slope region is considered elsewhere (Koslow *et al.*, in prep).

3.1.2 Catch rates and biomass estimates

(i) Orange Roughy

Catches of orange roughy were generally low with no high density aggregations sampled (Appendix III). Just over half of the tows produced catch rates of less than 100 kg/h and exceeded 1 000 kg/h on only three occasions (refer to Figure 2a-h). The highest recorded catch rates were 2 421 and 1 267 kg/h for the east and west coasts, respectively. Catch rates were on average higher off eastern Tasmania, 264 kg/h compared with 138 kg/h for western Tasmania. (Note: no adjustment has been made to account for differences in vessel or gear characteristics)

Standardised catch rates (kg/km^2) are compared by depth and season in Table 2. Orange roughy density tended to higher in the 800 and 1 100 m depth strata than the 900 and 1 000 m depth strata in most seasons for NW Tas. Winter was the exception when lowest densities were found in the 1 100 m stratum. Analysis of variance of catch rates showed that while there were no significant differences between seasons, there was a significant depth effect (Table 3). Biomass indices for NW Tas ranged between 785 - 2 709 tonnes, with most estimates falling between 1 000 and 1 475 tonnes (Table 4). The 95% confidence limits on all estimates overlapped, providing no evidence for seasonal or interannual variability. Coefficients of variation were generally less than 30%.

Owing to the poor coverage achieved off NE Tas, the two years of data have been combined (Table 2). Apart from winter when there was a clear trend of increasing densities with depth, data for the other seasons do not suggest obvious depth relationships. Despite pooling the data, two strata remained unsampled, i.e. 900 m and 1 100 m depth strata in spring and summer, respectively. Since it is unreasonable to assume that there would be no fish in these strata, catch rates, calculated as the mean of all stations sampled in that season, were assigned to them

TABLE 2: Mean catch rates (kg/km^2) by season and depth for NW and NE Tas. Standard errors are presented in parentheses; *N* is number of tows.

Depth	*N*	Summer	*N*	Autumn	*N*	Winter	*N*	Spring
NW Tas								
1988								
800	2	3 018.8	3	1 575.5 (549.6)	4	1 769.1 (898.5)	4	2 384.6 (472.3)
900	6	576.2 (136.1)	4	364.5 (75.0)	5	1 810.9 (1 010.6)	6	870.0 (284.3)
1000	3	572.3 (280.0)	6	687.8 (221.5)	5	1 168.8 (443.4)	6	508.2 (239.6)
1100	4	834.4 (246.8)	4	1 463.5 (572.2)	3	970.9 (655.6)	5	2 021.5 (545.1)
1989								
800	5	1 260.7 (478.2)	4	6 406.5 (3 037.1)	5	2 464.5 (839.7)	5	1 061.3 (508.4)
900	7	395.2 (95.7)	5	355.1 (50.2)	5	1 127.0 (233.7)	6	895.6 (291.0)
1000	6	632.1 (281.2)	6	2 516.8 (1 623.6)	5	873.9 (222.5)	5	1 236.3 (388.0)
1100	5	833.3 (331.2)	4	1 562.9 (725.7)	4	265.6 (63.8)	5	2 366.5 (171.3)
NE Tas								
800	4	3 234.3 (2 638.3)	2	741.2	3	270.4 (143.0)	1	569.2
900	8	4 332.8 (1 689.9)	2	1 545.5	3	2 984.6 (1 825.5)	-	
1000	3	2 270.5 (1 481.7)	4	1 778.1 (203.8)	3	3 600.3 (2 769.8)	2	2 621.2
1100	-		2	752.5	3	13 164.9 (7 075.3)	3	657.5 (135.8)

TABLE 3: Analysis of variance of log(catch rate +1) by season and depth for NW Tas. n.s., not significant; * P<0.05.

Source of variation	df	ss	ms	F-ratio	Sig.
Season	7	11.92	1.70	1.07	n.s.
Depth	3	18.94	6.31	3.95	*
Season x Depth	21	53.02	2.53	1.58	n.s.
Residual	120	191.83	1.60		

TABLE 4: Biomass index estimates (tonnes) with 95% confidence limits and coefficients of variation (c.v.) for orange roughy for NW Tas. *N* is the number of tows.

Season	*N*	Lower bound	Biomass estimate	Upper bound	c.v. (%)
1988					
Summer	15	0	1 245	2 577	53.4
Autumn	17	616	1 018	1 421	19.8
Winter	17	666	1 473	2 280	27.4
Spring	21	1 036	1 438	1 840	14.0
1989					
Summer	23	461	785	1 109	20.6
Autumn	19	956	2 709	4 462	32.3
Winter	19	761	1 207	1 652	18.4
Spring	21	1 033	1 403	1 773	13.2

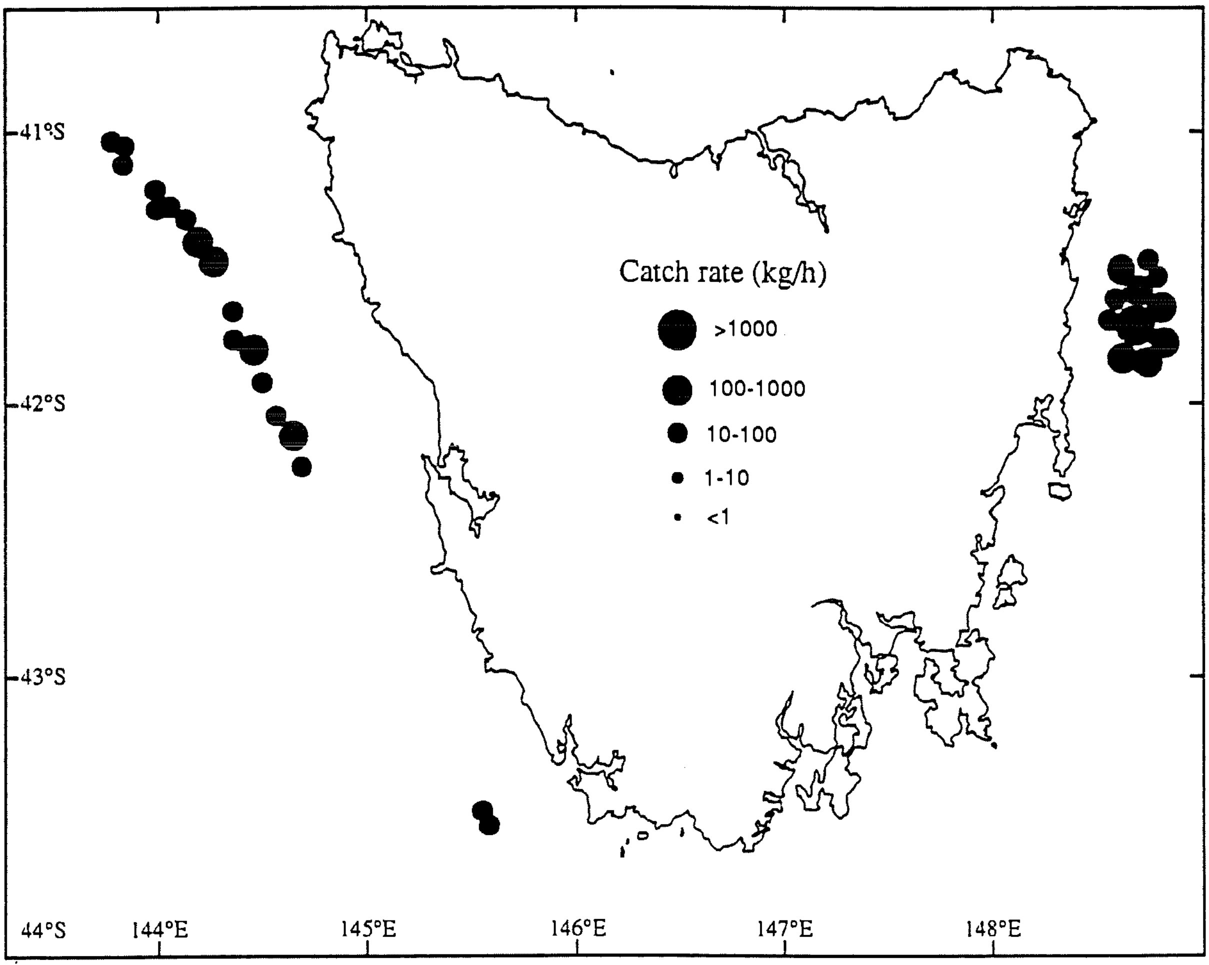


Figure 2a: Orange roughy catch rates (kg/h) for all survey stations in summer 1987/88.

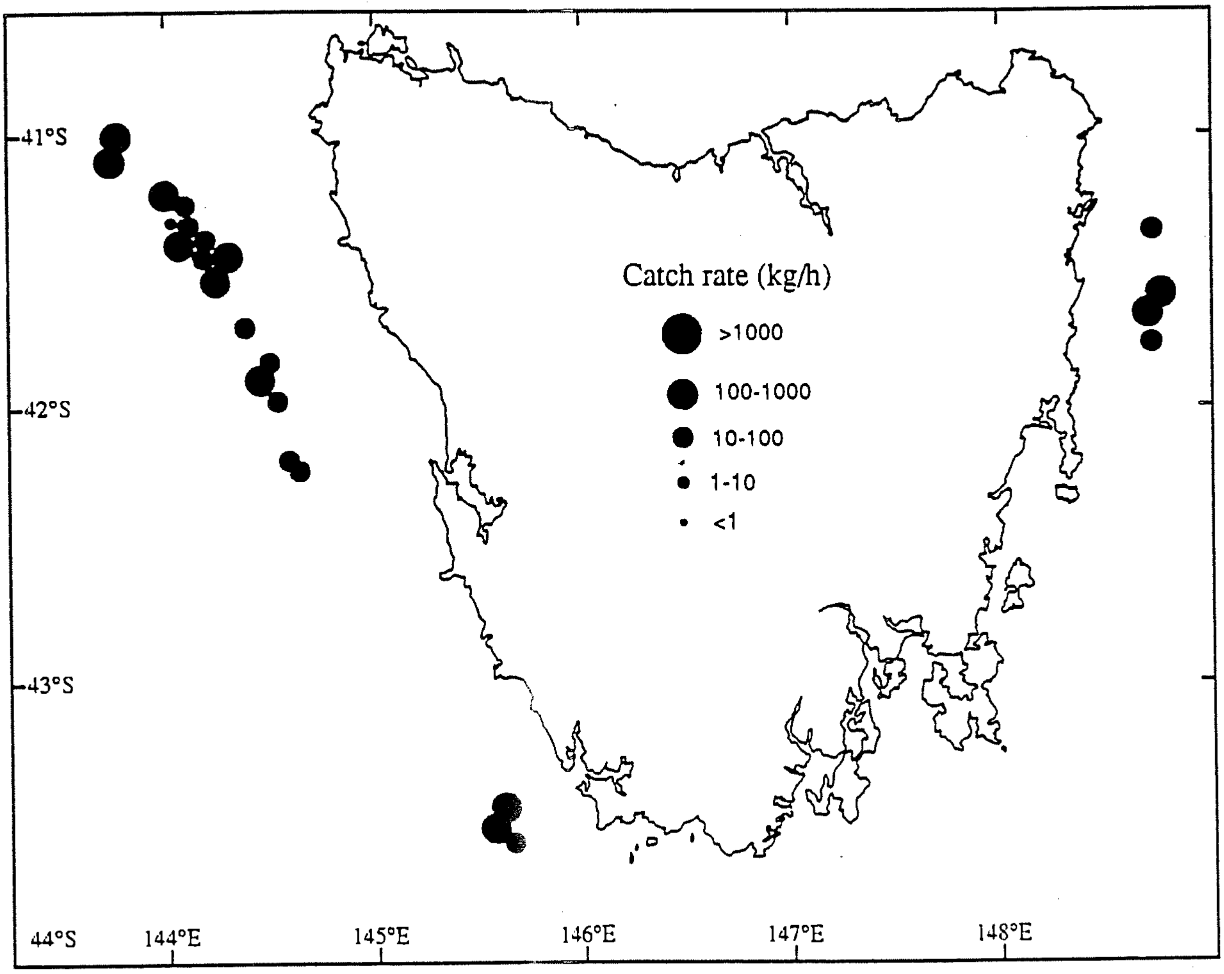


Figure 2b: Orange roughy catch rates (kg/h) for all survey stations in autumn 1988.

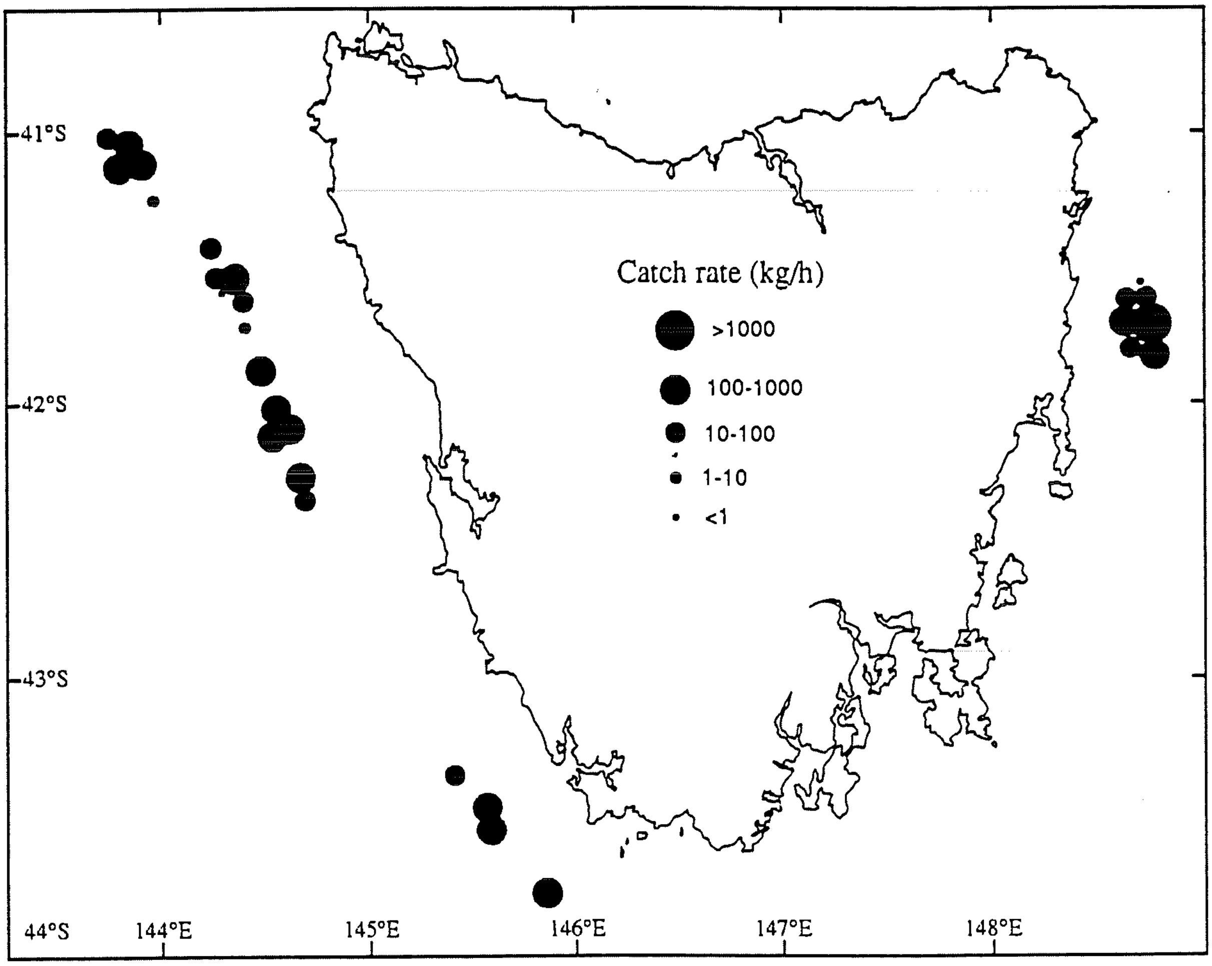


Figure 2c: Orange roughy catch rates (kg/h) for all survey stations in winter 1988.

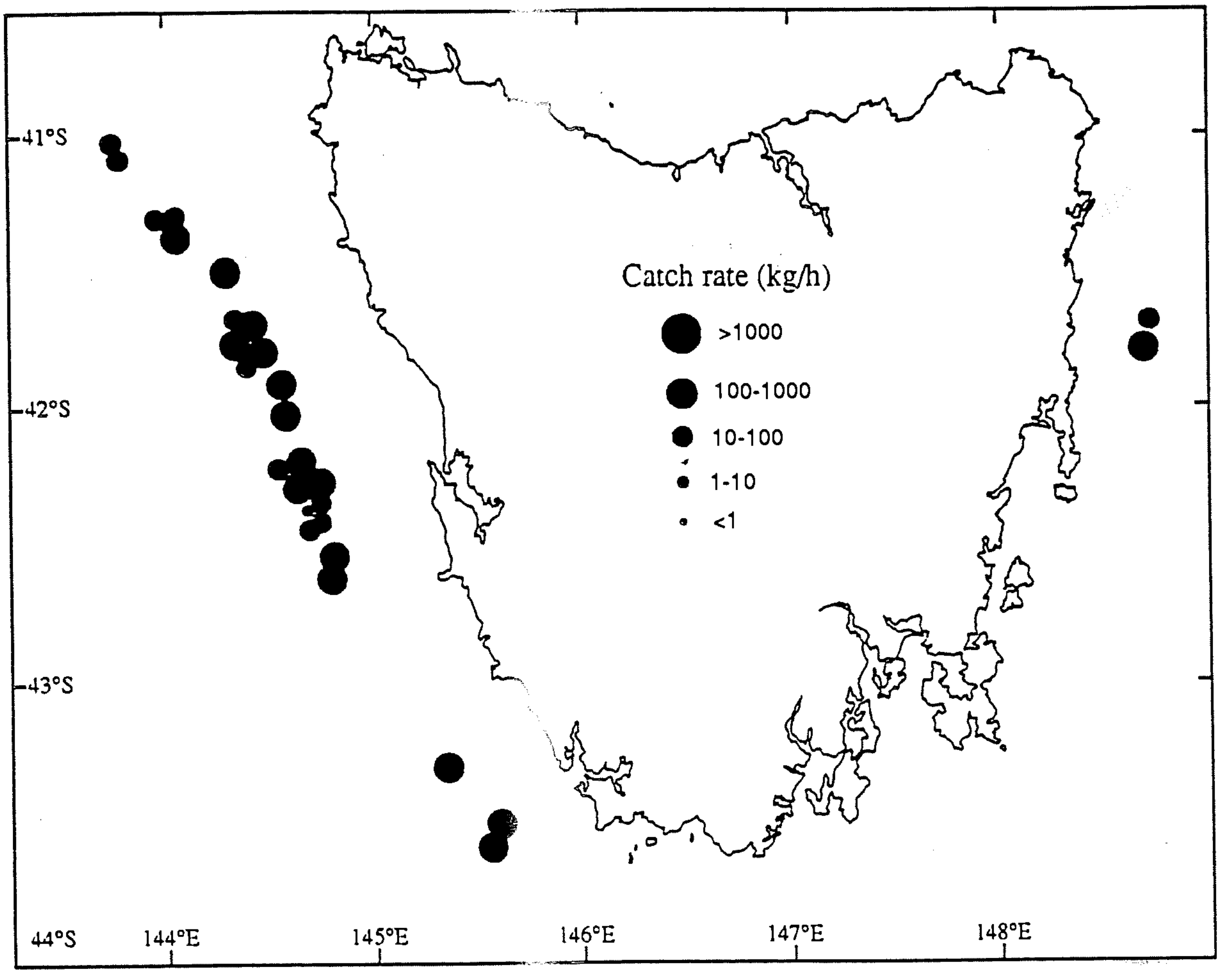


Figure 2d: Orange roughy catch rates (kg/h) for all survey stations in spring 1988.

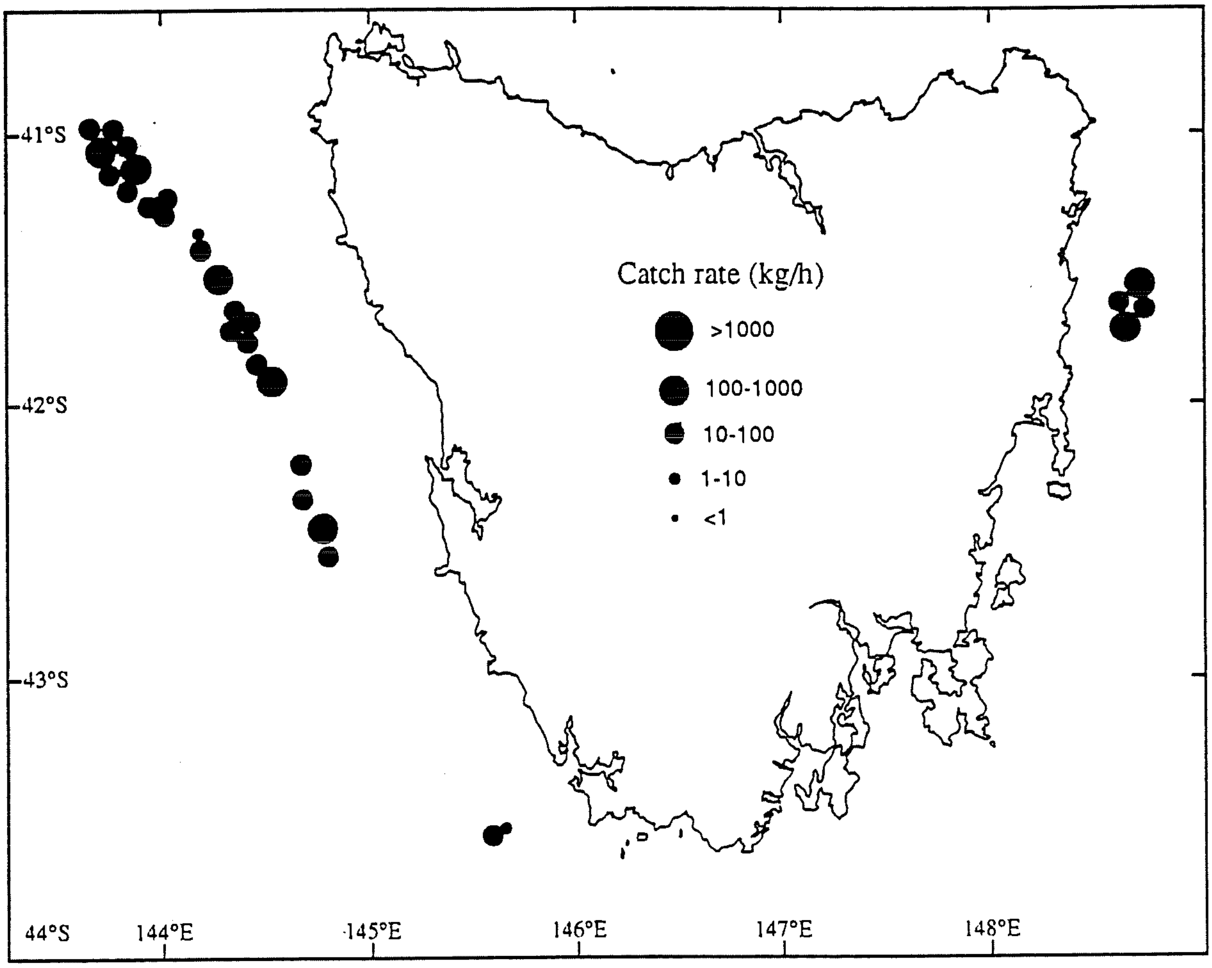


Figure 2e: Orange roughy catch rates (kg/h) for all survey stations in summer 1988/89.

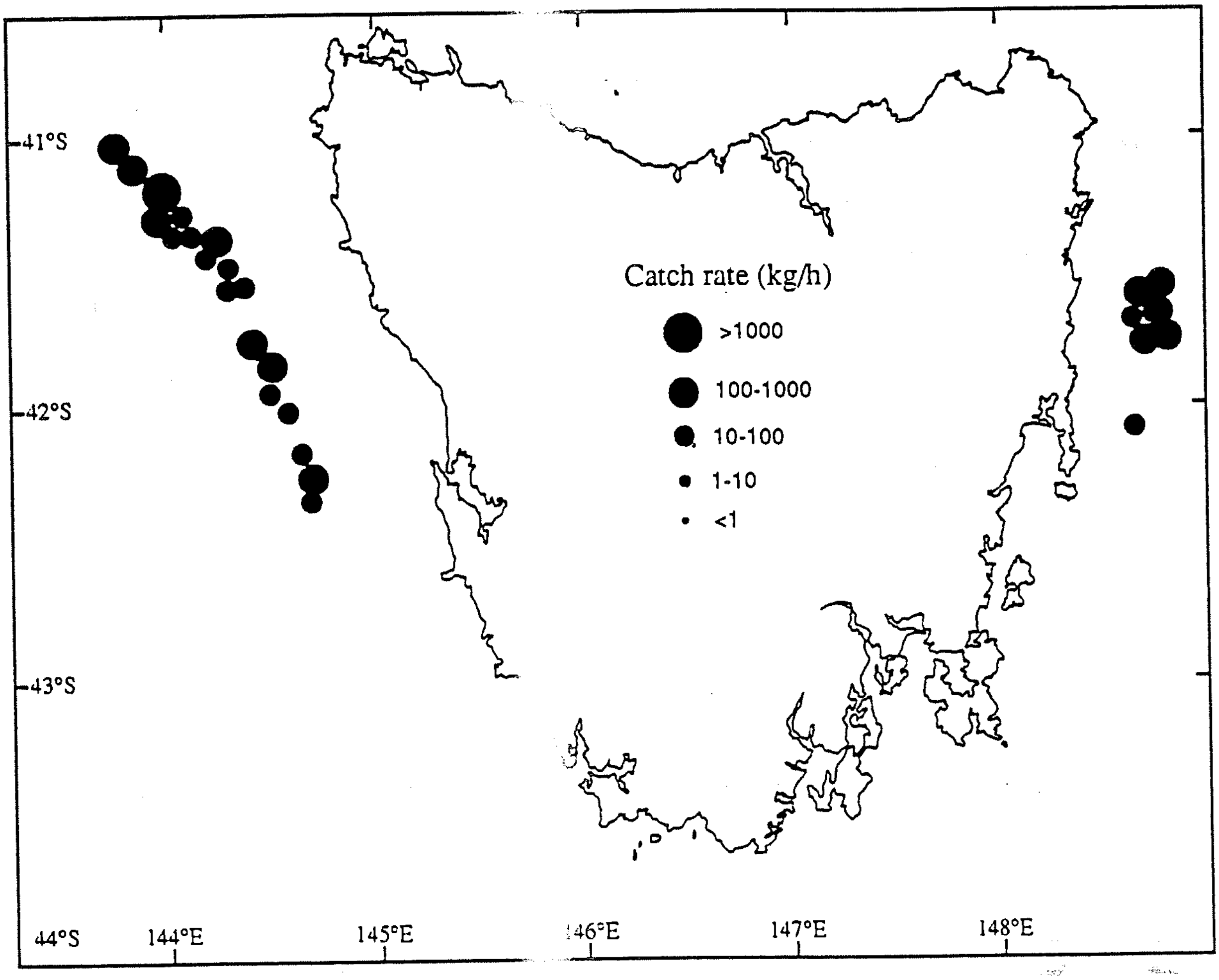


Figure 2f: Orange roughy catch rates (kg/h) for all survey stations in autumn 1989.

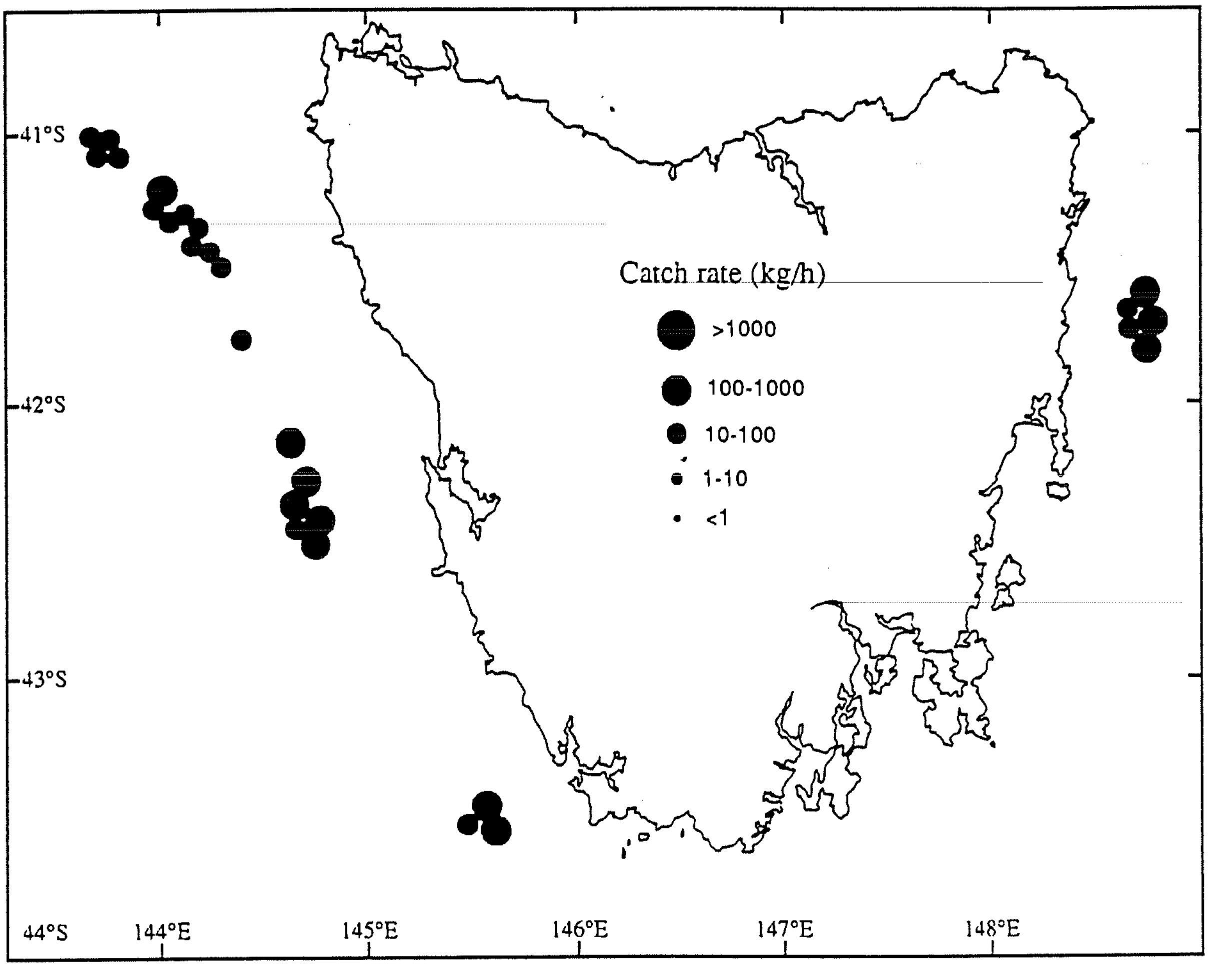


Figure 2g: Orange roughy catch rates (kg/h) for all survey stations in winter 1989.

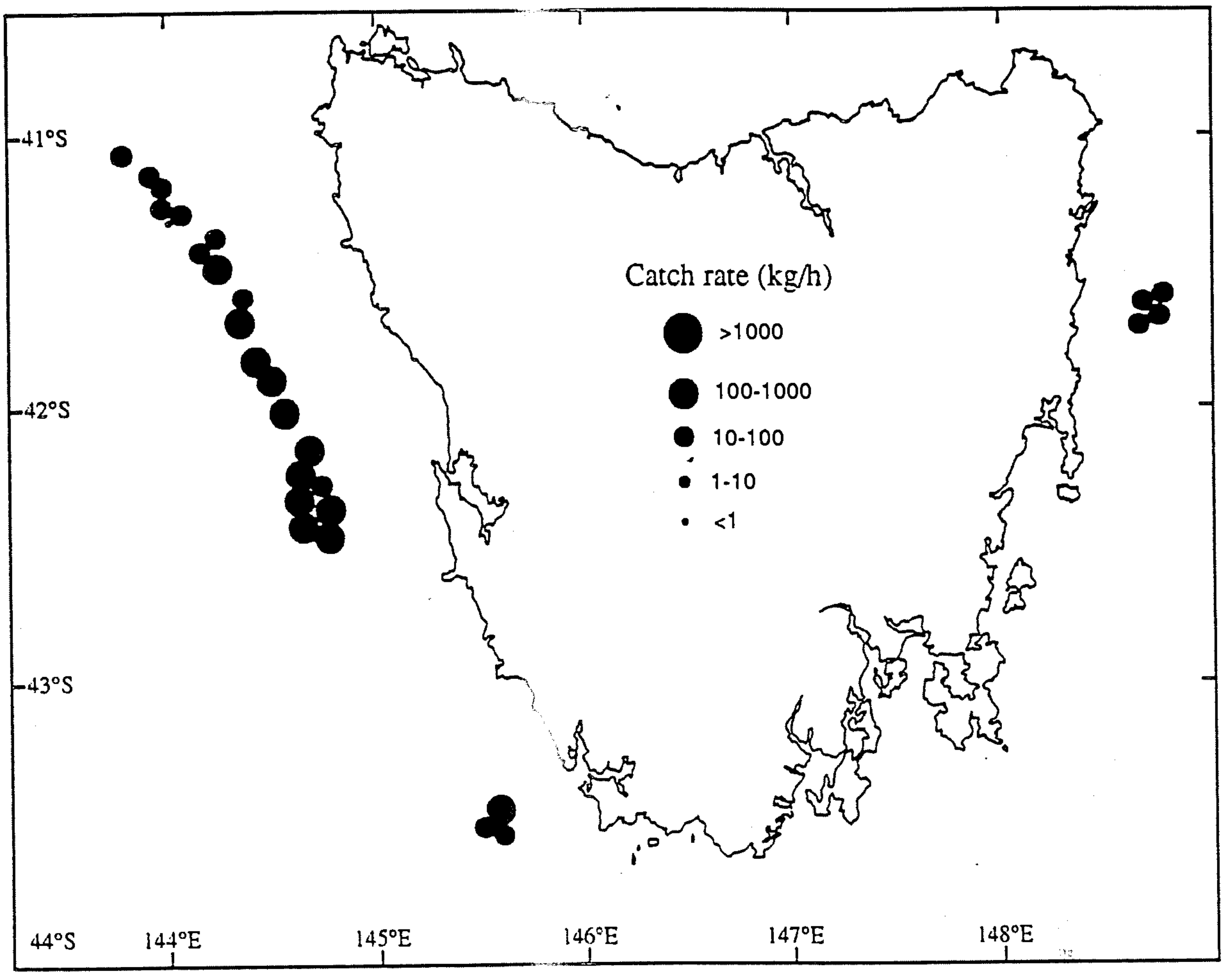


Figure 2h: Orange roughy catch rates (kg/h) for all survey stations in spring 1989.

when estimating biomass. Biomass index estimates were between 499 and 2 131 tonnes,the peak occurring during winter (Table 5). Coefficients of variation were high in winter and spring (> 39%) and confidence limits on all estimates overlapped.

Estimation of biomass for the entire Tasmanian region is complicated by the large area off southern and south-eastern Tasmania that was not sampled. However, *post hoc* stratification was attempted with the entire region treated as a single area (comprised of the four depth strata) and all valid and non-random (but not targeted) trawls were used in the analysis. Statistically this approach is not rigourous since non-random trawls are included, sampling density is low and patchy and it is necessary to make the further assumption that orange roughy are equally distributed between areas of smooth and rough bottom. Estimates ranged between about 4 000 and 11 500 tonnes with no consistent seasonal pattern (Table 6). Confidence limits were broad and overlapping.

(ii) Oreos

Spiky and warty oreo biomass indices have been calculated for NW Tas only as catches off NE Tas were small and spasmodic. Warty oreos were the more abundant species, with biomass estimates generally below 350 tonnes (Table 7). The high summer 1988/89 estimate is heavily influenced by two large catches (PE104/17 and PE104/20) which when excluded from the analysis reduce the estimated biomass to only 95 tonnes (c.v. of 18.7%). This clearly demonstrates how a few particularly large (and conversely poor) catches can significantly influence the biomass estimates.

In most seasons spiky oreo biomass did not exceed 125 tonnes, being only slightly higher than this during summer (Table 7).

3.1.3 Codend escapement

Out of 1 449 orange roughy that were caught whilst using the small mesh liner, 52 had escaped into the liner. That is an escapement rate equivalent to 3.6% by number (or approximately 2.0% by weight). Orange roughy retained by the liner measured 12 - 38 cm, with a mean length of 25.2 cm. The large size of some of the fish retained suggests that not all escapement occurred through the meshes - it is possible that the larger fish passed through the hole created when the codend draw-rope was tied off. Nevertheless these results suggest that under normal circumstances, codend escapement was unlikely to have been significant.

3.1.4 Population size structure

In an attempt to reconstruct the population size structure, catch size compositions for each depth stratum where combined and adjusted by the proportion of the stratum sampled (i.e. stratum area divided by swept area). Size compositions for each stratum where then summed. (Note: no attempt has been made to take account of mesh selectivity in this analysis)

(i) Western Tasmania

For the purposes of analysis the area off the west coast has been expanded to encompass the mid-slope region between 41°00' and 43°40'S (a total area of 1 911 km^2) thereby including non-random tows. This area is defined here as 'western Tasmania'.

Fish ranged in size from 5 - 44 cm with the majority of individuals measuring between 15 - 40 cm. Size distributions were strongly bimodal, with modes at 23 - 24 cm and 33 - 35 cm and a trough at 28 - 30 cm (Figure 3). The mode of small fish

TABLE 5: Biomass index estimates (tonnes) with 95% confidence limits and coefficients of variation (c.v.) for orange roughy for NE Tas. *N* is the number of tows.

Season	*N*	Lower bound	Biomass estimate	Upper bound	c.v. (%)
Summer	15	678	1 410	2 143	26.0
Autumn	10	382	499	615	11.7
Winter	12	464	2 131	3 799	39.1
Spring	6	62	525	987	44.1

TABLE 6: Provisional biomass index estimates (tonnes) with 95% confidence limits and coefficients of variation (c.v.) for orange roughy for the Tasmanian region. *N* is the number of tows.

Season	*N*	Lower bound	Biomass estimate	Upper bound	c.v. (%)
1988					
Summer	28	3 496	8 722	13 949	30.0
Autumn	24	2 888	4 748	6 608	19.6
Winter	28	2 733	11 502	20 271	38.1
Spring	28	5 946	10 910	15 875	22.7
1989					
Summer	29	2 214	3 993	5 772	22.2
Autumn	25	4 355	10 327	16 299	28.9
Winter	27	4 466	8 877	13 291	24.9
Spring	28	3 685	5 153	6 621	14.2

TABLE 7: Biomass index estimates (tonnes) with 95% confidence limits and coefficients of variation (c.v.) for spiky and warty oreos for NW Tas. *N* is the number of tows.

		Spiky oreo				Warty oreo			
Season	*N*	Lower bound	Biomass estimate	Upper bound	c.v. (%)	Lower bound	Biomass estimate	Upper bound	c.v. (%)
1988									
Summer	15	42	152	262	36.1	133	313	494	28.8
Autumn	17	64	75	86	7.1	189	350	512	23.0
Winter	17	30	67	104	27.6	90	187	284	25.9
Spring	21	38	64	91	20.4	50	100	150	24.9
1989									
Summer	23	122	177	231	15.5	0	1 497	3 331	61.3
Autumn	19	0	123	291	68.0	168	294	420	21.5
Winter	19	27	40	53	16.6	117	213	308	22.5
Spring	21	33	57	81	21.1	82	153	223	23.1

was comprised largely of juveniles while the upper mode was mainly adults (refer to section 3.3.2).

The relative heights of the modes varied seasonally - the adult mode was dominant in autumn, spring and summer 1987/88; the two modes were of approximately equal size in winter; and the mode of juvenile fish was dominant in summer 1988/89 (Figure 3). There was no obvious modal progression throughout the year and the position of the trough remained constant over the two year period.

There were some differences in size structure by sex for adult fish - the modal peak of females (35 - 37 cm) was between 1 and 3 cm greater than that for males (33 - 34 cm) and females attained larger maximum sizes (Figure 3).

Size compositions by 100 m depth strata suggest a weak size depth relationship in some seasons, with mean lengths tending to increase with depth and large fish (≥ 30 cm) predominating in the deepest stratum (Figure 4).

(ii) North-eastern Tasmania

Some of the size distributions for north-eastern Tasmania are based on a small number of successful tows and as a consequence sample sizes are small. By comparison with western Tasmania, the juvenile mode was weak and the peak occurred at a slightly smaller size, 17 - 20 cm (Figure 5). The modal peak for adults ranged between 34 - 37 cm, with the mode of males (34 - 36 cm) generally 1 to 2 cm smaller than that for females (35 - 37 cm).

There was no obvious relationship between size and depth (Figure 6).

3.1.5 Sex ratios

Overall females accounted for just over half of the fish from the west coast whereas males were more abundant off north-eastern Tasmania (Table 8). Juvenile sex ratios (fish < 30 cm) in the two areas were, however, close to 1:1. Between 30 - 35 cm, sex ratios were either equal or showed a significant excess of males for western Tasmania, with females more abundant in the larger size classes. By contrast, males predominated in the 30 - 39 cm size range off north-eastern Tasmania. Sex ratios were either equal or favoured females only among fish of 40 cm or longer.

TABLE 8: Sex ratios by length class and season for orange roughy from western and north-eastern Tasmania. Sex ratios differing significantly from 50% are indicated (based on Chi-square test). n.s., not significant; * $p<0.05$; ** $p<0.01$; N is the number of fish.

Size class	Summer N	Summer % female	Autumn N	Autumn % female	Winter N	Winter % female	Spring N	Spring % female
Western Tasmania								
1988								
<20	372	46.0 n.s.	303	54.8 n.s.	282	43.6 *	508	53.5 n.s.
20-24	485	47.0 n.s.	486	49.4 n.s.	720	56.7 **	988	51.3 n.s.
25-29	241	44.4 n.s.	304	46.1 n.s.	743	49.3 n.s.	859	52.3 n.s.
30-31	82	36.6 *	126	43.6 n.s.	310	49.0 n.s.	300	45.7 n.s.
32-33	139	36.0 **	236	40.2 **	373	47.7 n.s.	458	44.1 *
34-35	257	53.7 n.s.	372	52.4 n.s.	427	55.0 *	706	54.7 *
36-37	219	66.7 **	269	68.8 **	345	77.1 **	690	65.7 **
38-39	112	76.8 **	122	87.7 **	159	83.7 **	287	78.7 **
≥40	30	93.3 **	51	98.0 **	41	85.4 **	80	93.7 **
Total	1 937	50.8 n.s.	2 269	54.3 **	3 400	55.8 **	4 876	55.5 **
1989								
<20	359	49.9 n.s.	377	51.7 n.s.	314	47.5 n.s.	404	55.7 *
20-24	670	50.1 n.s.	608	51.6 n.s.	722	50.6 n.s.	648	48.3 n.s.
25-29	486	49.6 n.s.	376	48.9 n.s.	807	52.2 n.s.	456	47.2 n.s.
30-31	91	41.8 n.s.	134	44.8 n.s.	273	54.9 n.s.	162	45.7 n.s.
32-33	127	47.2 n.s.	344	34.9 **	312	53.5 n.s.	313	44.1 *
34-35	216	44.4 n.s.	733	42.8 **	388	64.7 **	456	56.1 **
36-37	175	70.9 **	668	64.2 **	259	73.7 **	361	72.9 **
38-39	95	80.0 **	364	78.9 **	144	82.6 **	153	85.0 **
≥40	34	91.2 **	101	87.1 **	34	82.3 **	35	91.4 **
Total	2 253	52.4 *	3 705	53.7 **	3 253	56.6 **	2 988	55.1 **
North-eastern Tasmania								
1988								
<20	153	60.1 *	98	51.0 n.s.	85	48.2 n.s.	1	
20-24	222	46.0 n.s.	90	54.4 n.s.	86	58.1 n.s.	0	
25-29	204	40.2 **	54	42.6 n.s.	39	61.5 n.s.	6	
30-31	146	28.8 **	21	42.9 n.s.	147	21.1 **	22	18.2 **
32-33	357	28.3 **	31	35.5 n.s.	340	21.8 **	56	16.1 **
34-35	543	23.4 **	38	34.2 n.s.	590	18.3 **	99	25.3 **
36-37	551	24.5 **	28	35.7 n.s.	638	19.6 **	85	8.2 **
38-39	304	39.1 **	33	51.5 n.s.	261	31.4 **	50	38.0 n.s.
≥40	75	60.0 n.s.	8	62.5 n.s.	93	74.2 **	13	53.9 n.s.
Total	2 555	33.1 **	401	46.6 n.s.	2 279	26.5 **	332	22.9 **
1989								
<20	45	57.8 n.s.	47	40.4 n.s.	7	28.6 n.s.	25	44.0 n.s.
20-24	38	52.6 n.s.	32	46.9 n.s.	39	33.3 *	6	
25-29	25	44.0 n.s.	15	46.7 n.s.	42	47.6 n.s.	9	
30-31	25	40.0 n.s.	29	34.5 n.s.	46	28.3 **	5	
32-33	53	37.7 n.s.	65	41.5 n.s.	199	28.1 **	16	31.2 n.s.
34-35	94	33.0 **	102	30.4 **	330	33.3 **	27	18.5 **
36-37	86	30.2 **	116	44.8 n.s.	290	42.8 *	21	19.0 **
38-39	69	42.0 n.s.	82	52.4 n.s.	150	58.0 n.s.	13	38.5 n.s.
≥40	23	52.2 n.s.	23	65.2 n.s.	36	77.8 **	1	
Total	458	40.4 **	511	42.9 *	1 139	39.8 **	123	29.3 **

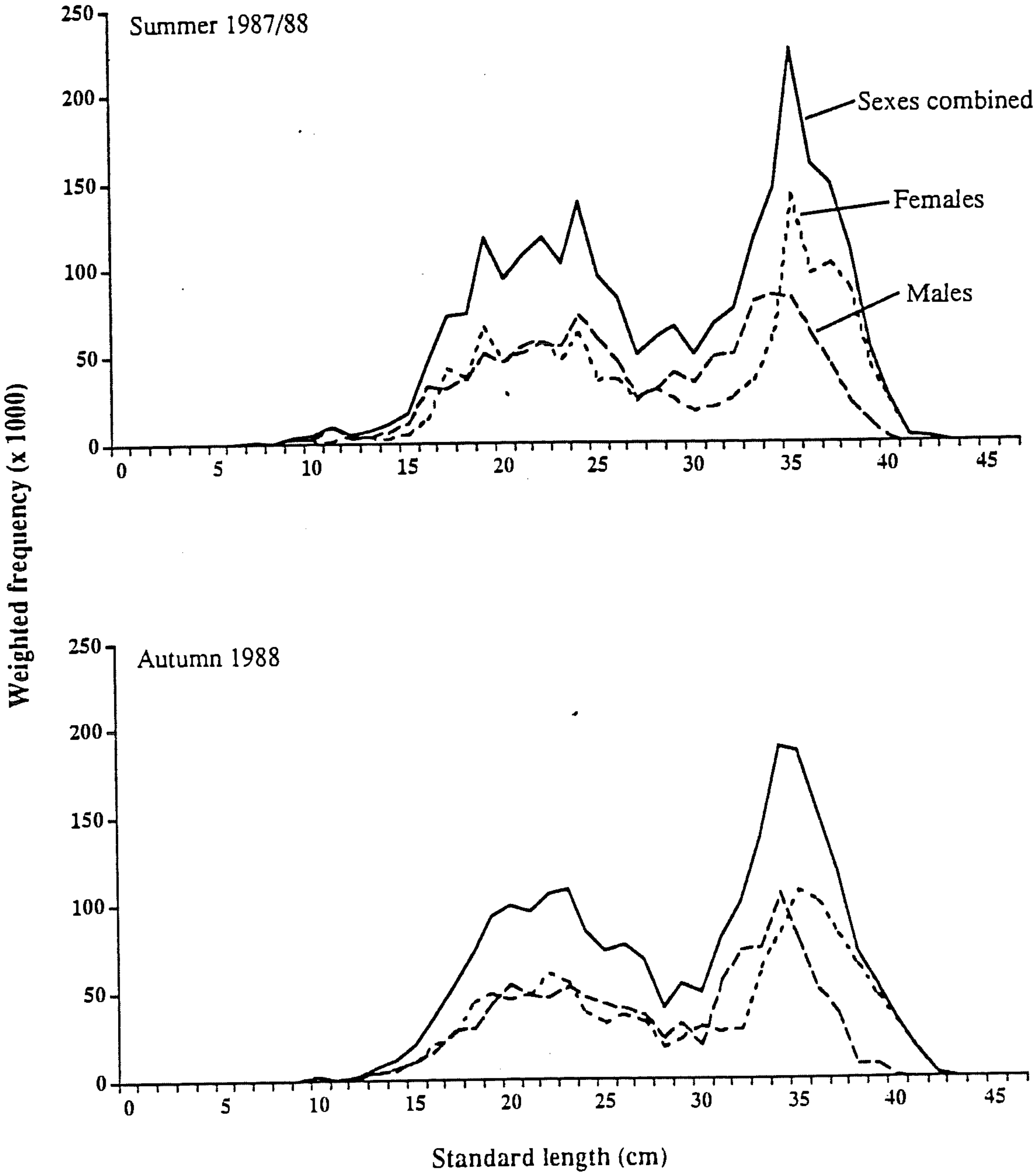


Figure 3: Weighted (by proportion of survey area sampled) length frequency distributions of orange roughy by season for western Tasmania.

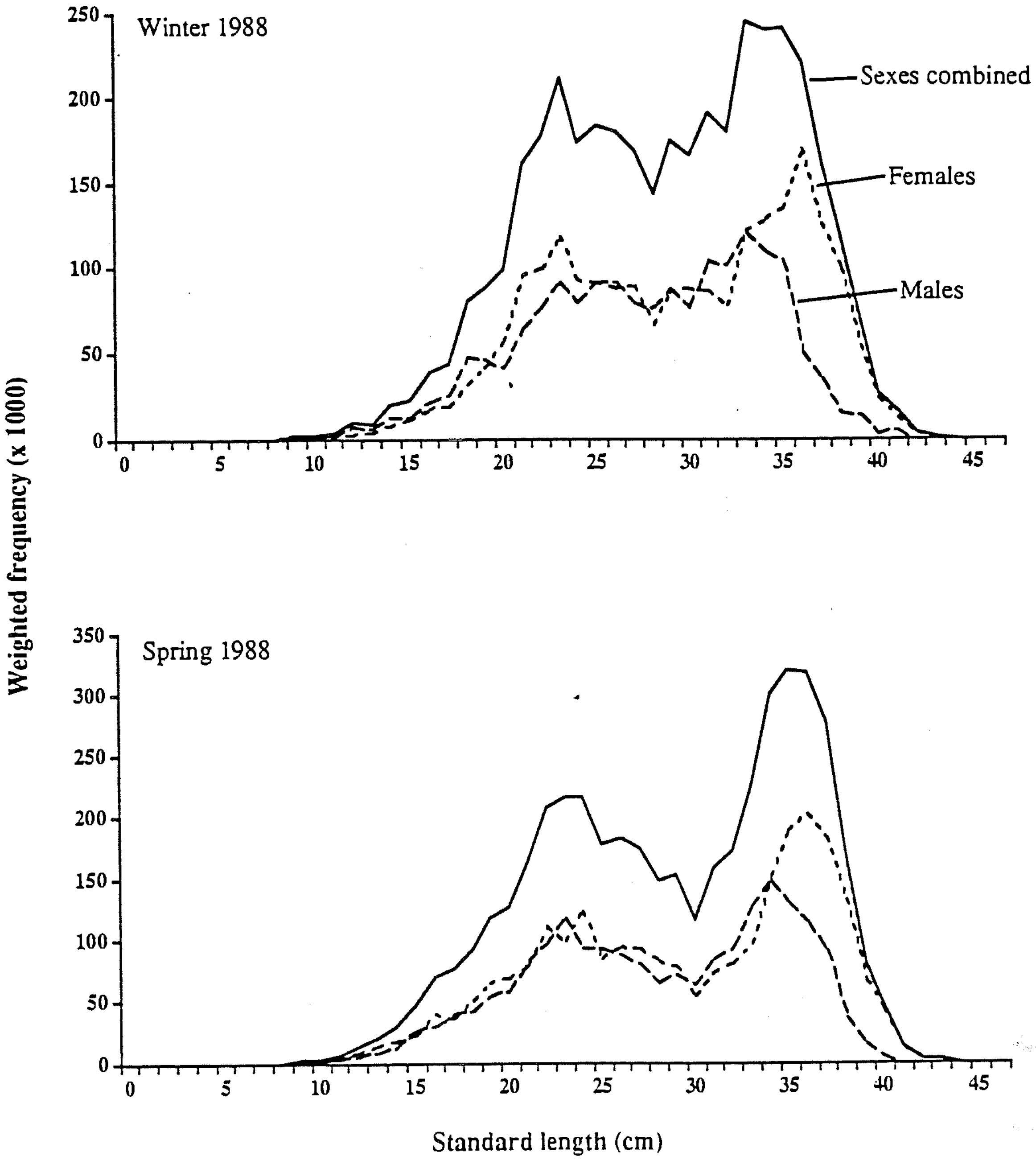


Figure 3: (cont.)

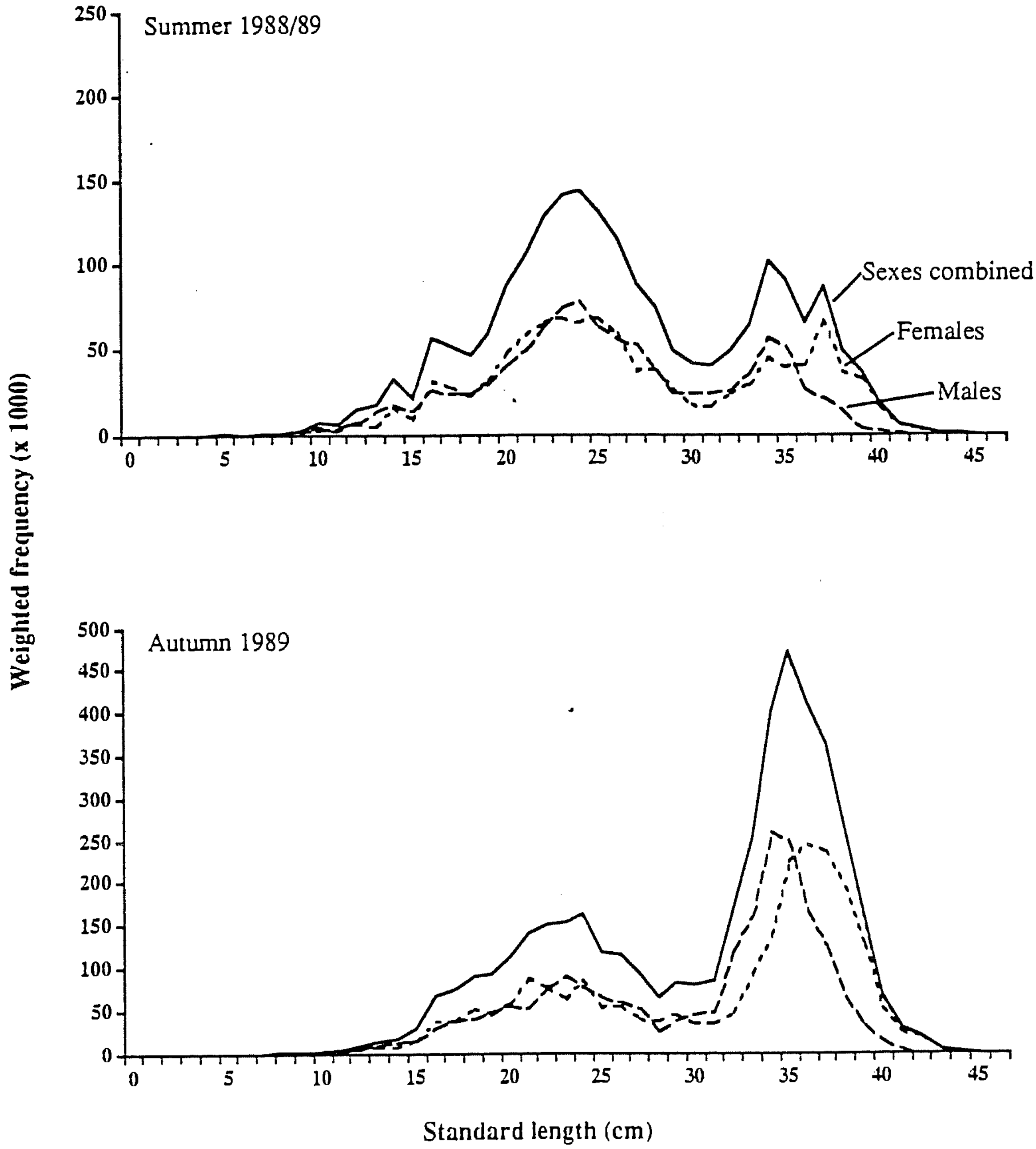


Figure 3: (cont.)

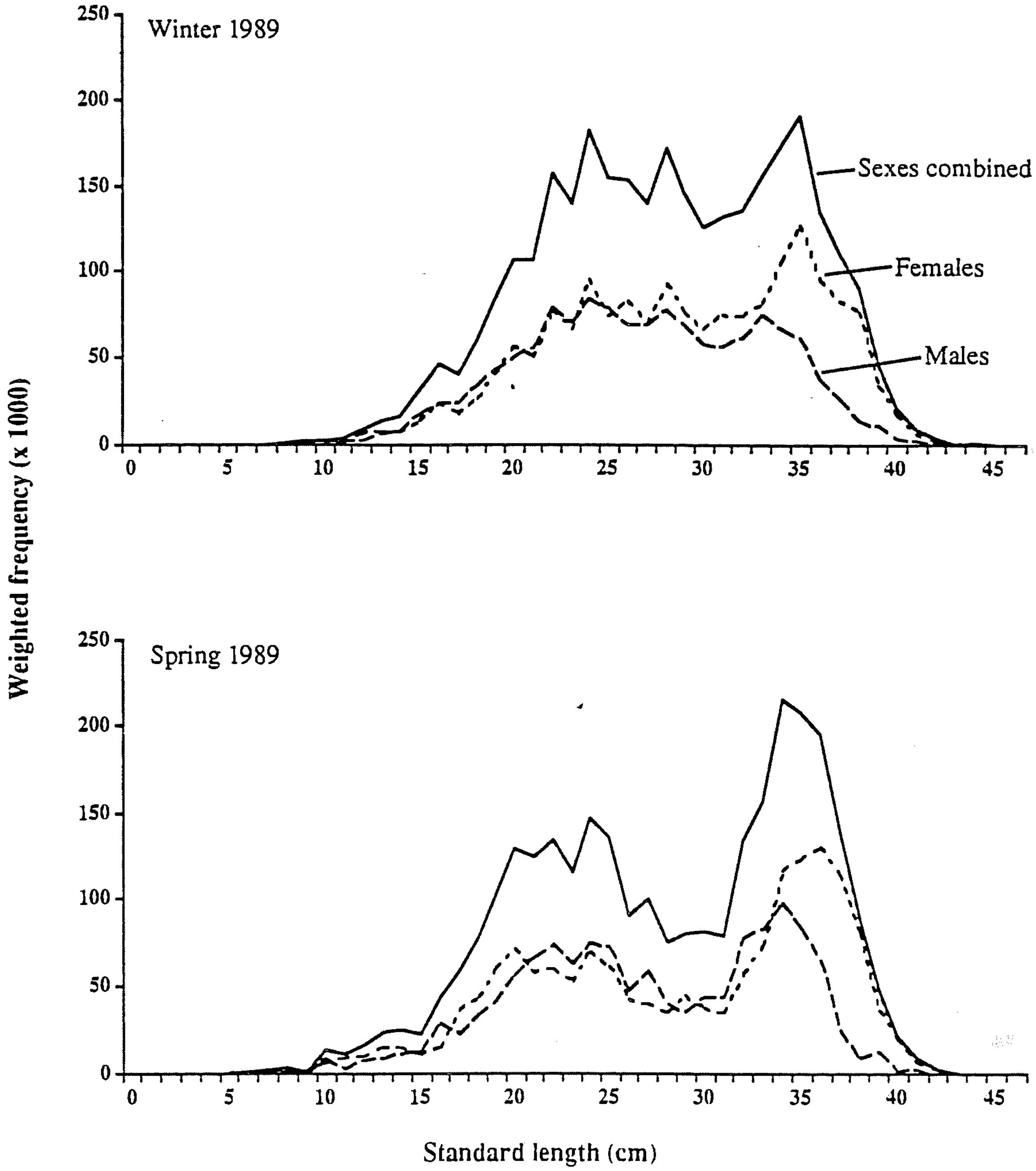


Figure 3: (cont.)

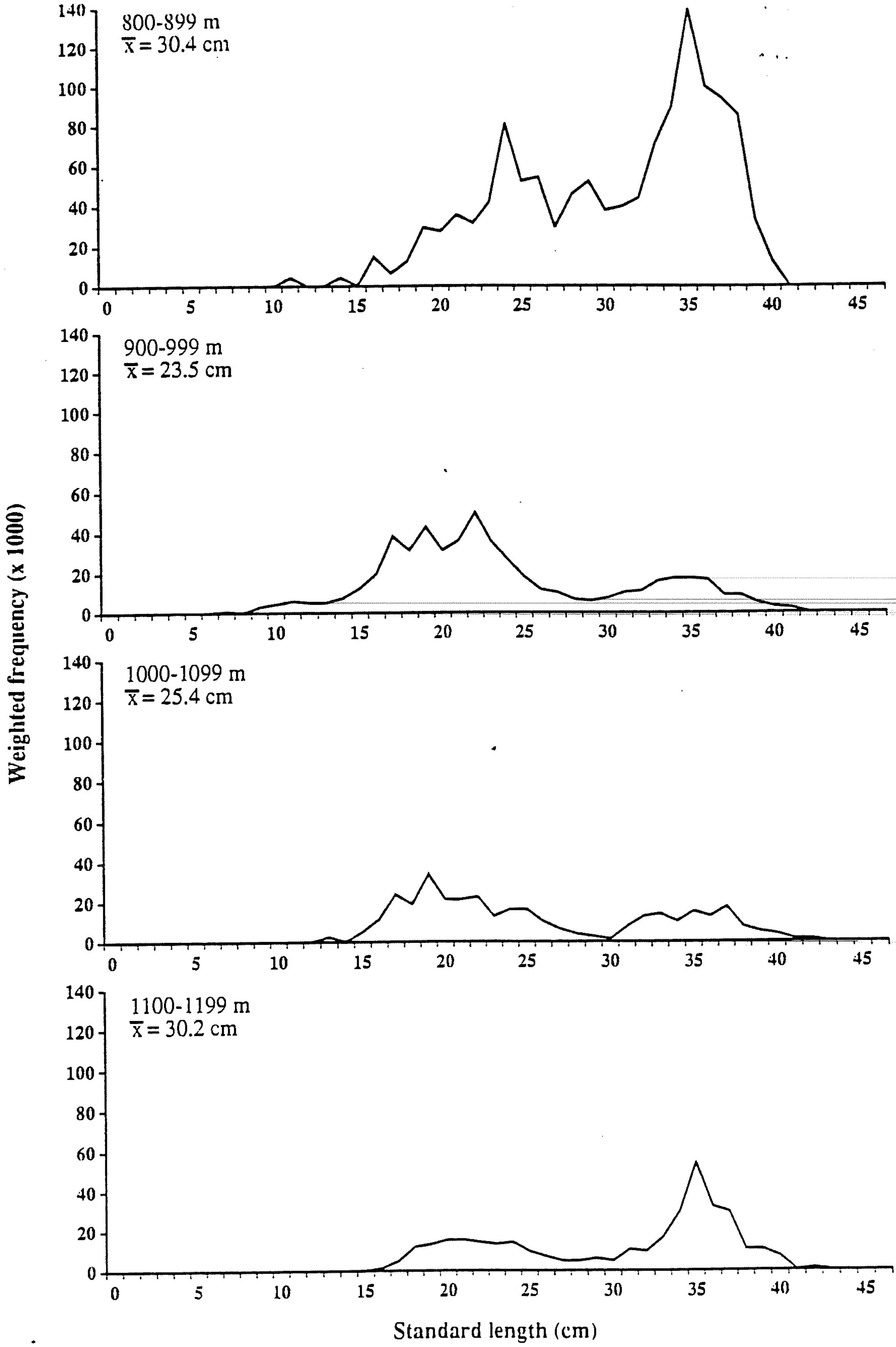


Figure 4a: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in summer 1987/88. ($\overline{x}$ = mean length)

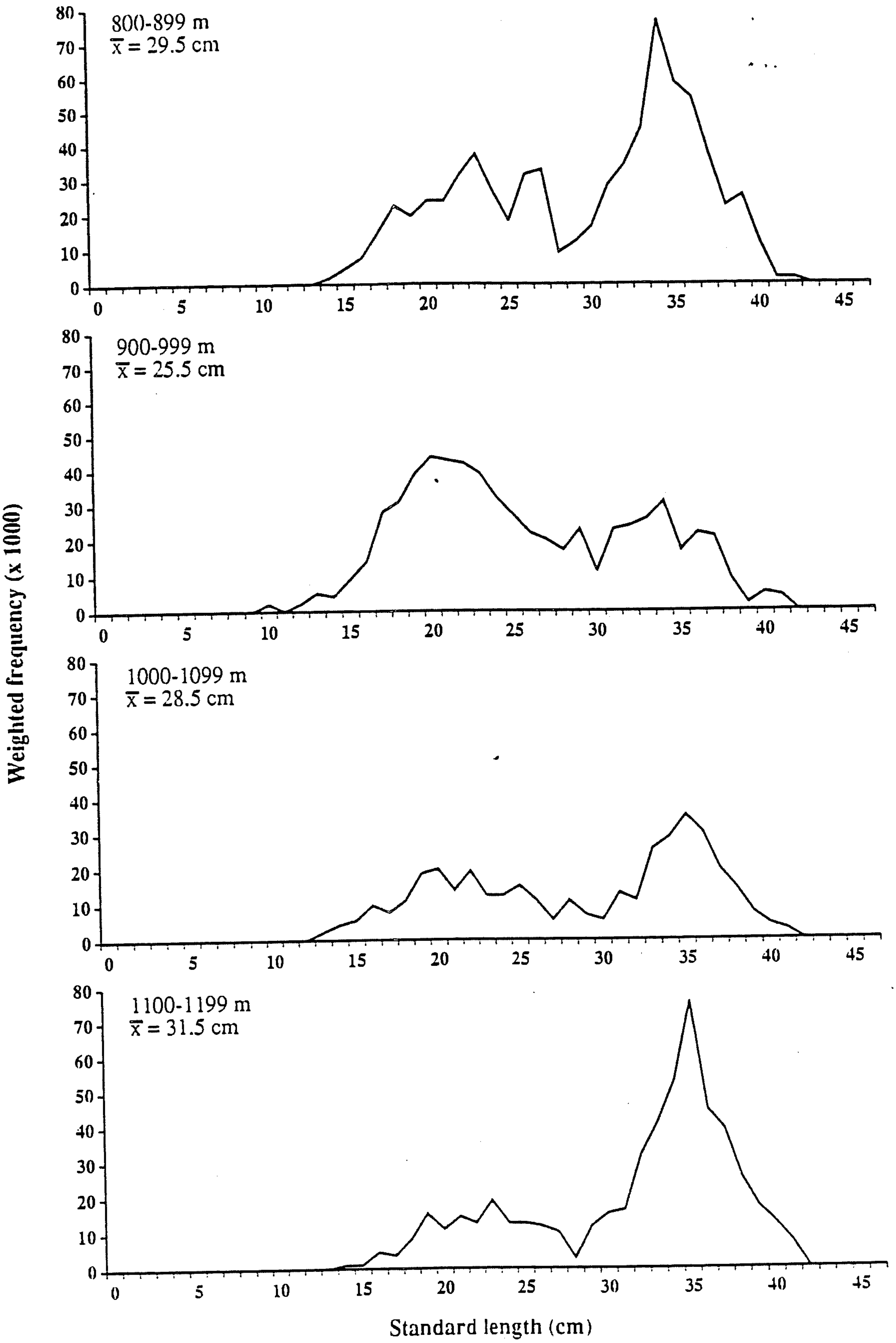


Figure 4b: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in autumn 1988. ($\overline{x}$ = mean length)

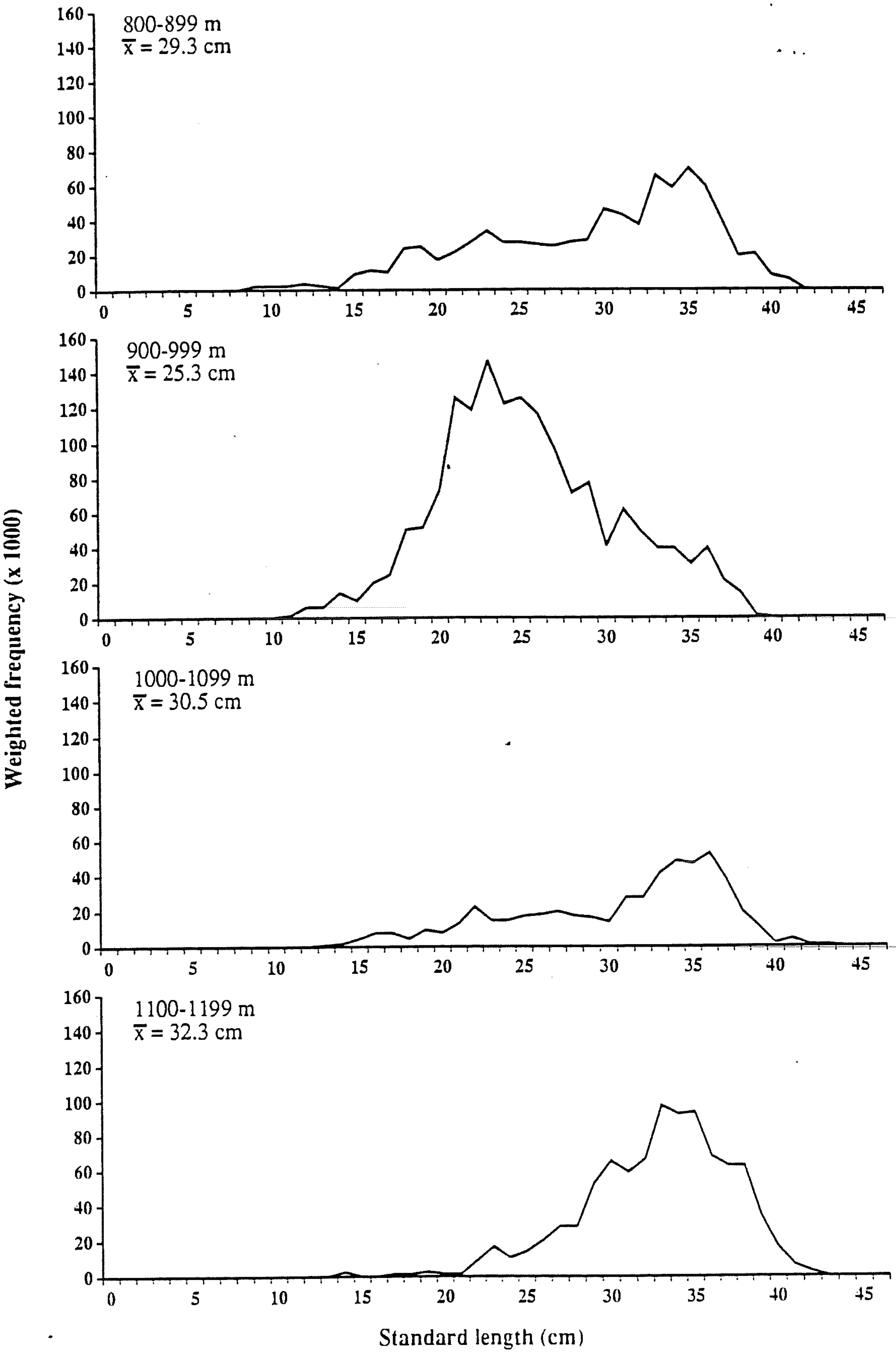


Figure 4c: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in winter 1988. ($\overline{x}$ = mean length)

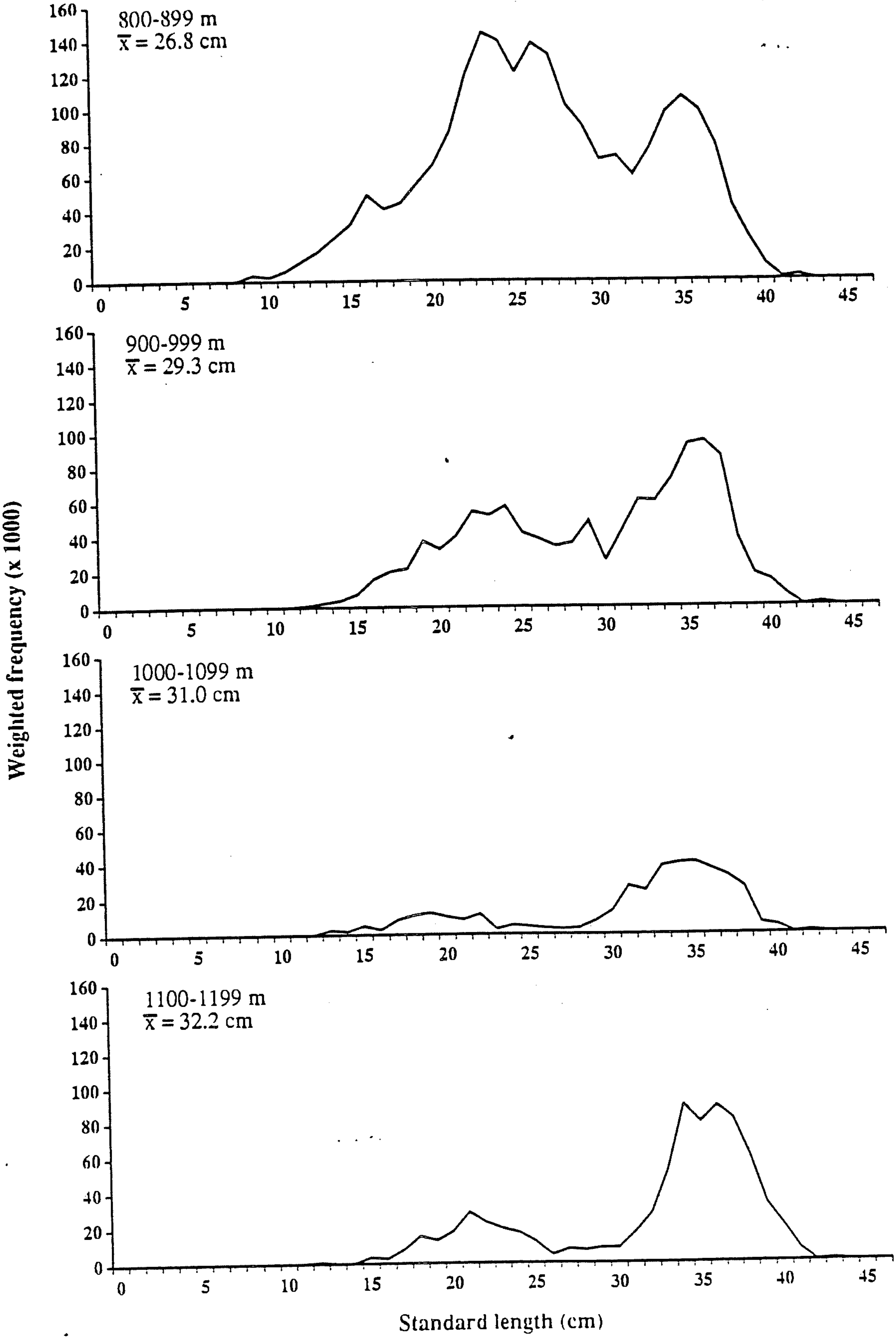


Figure 4d: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in spring 1988. ($\overline{x}$ = mean length)

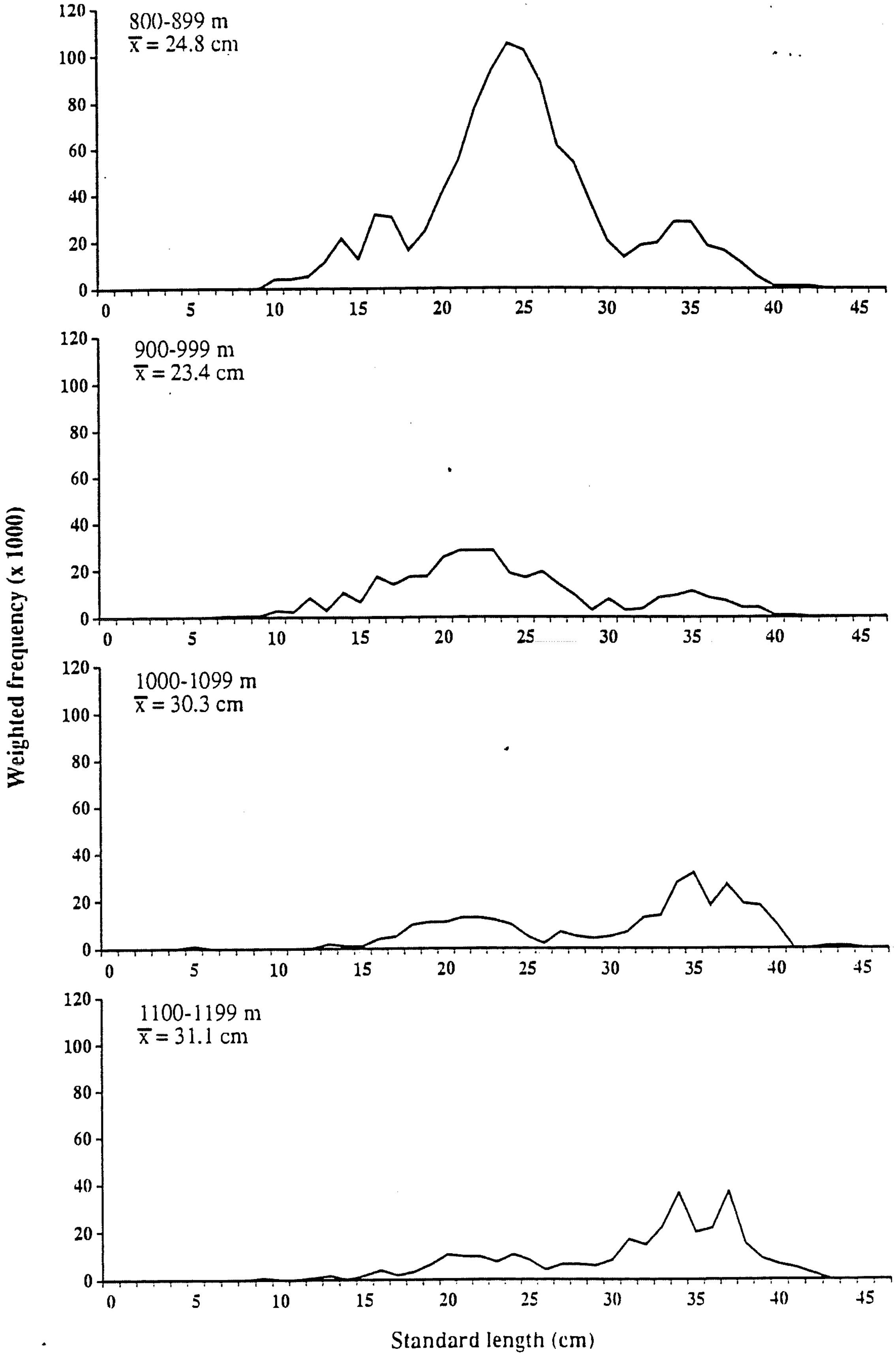


Figure 4c: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in summer 1988/89. ($\overline{x}$ = mean length)

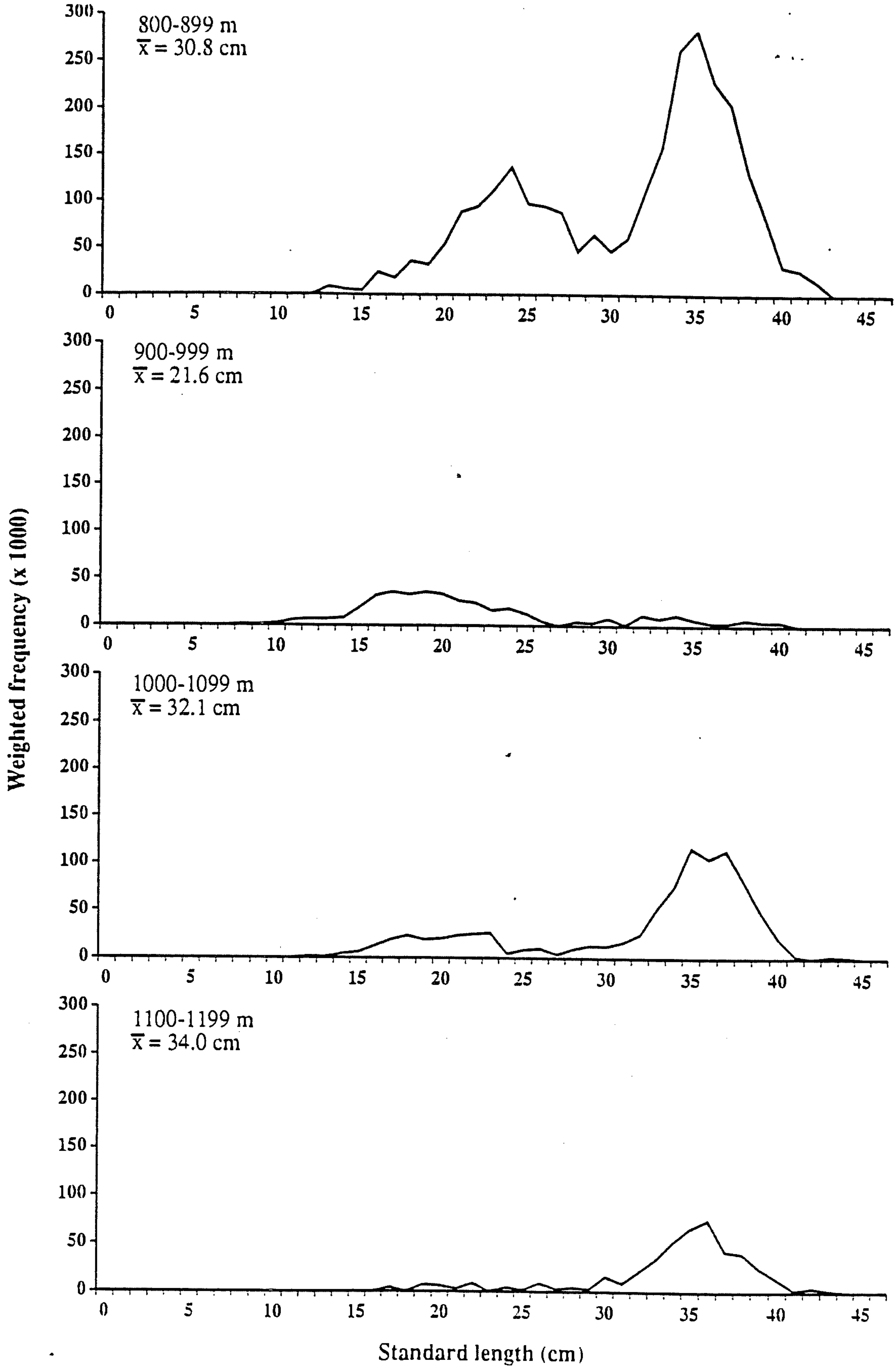


Figure 4f: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in autumn 1989. ($\overline{x}$ = mean length)

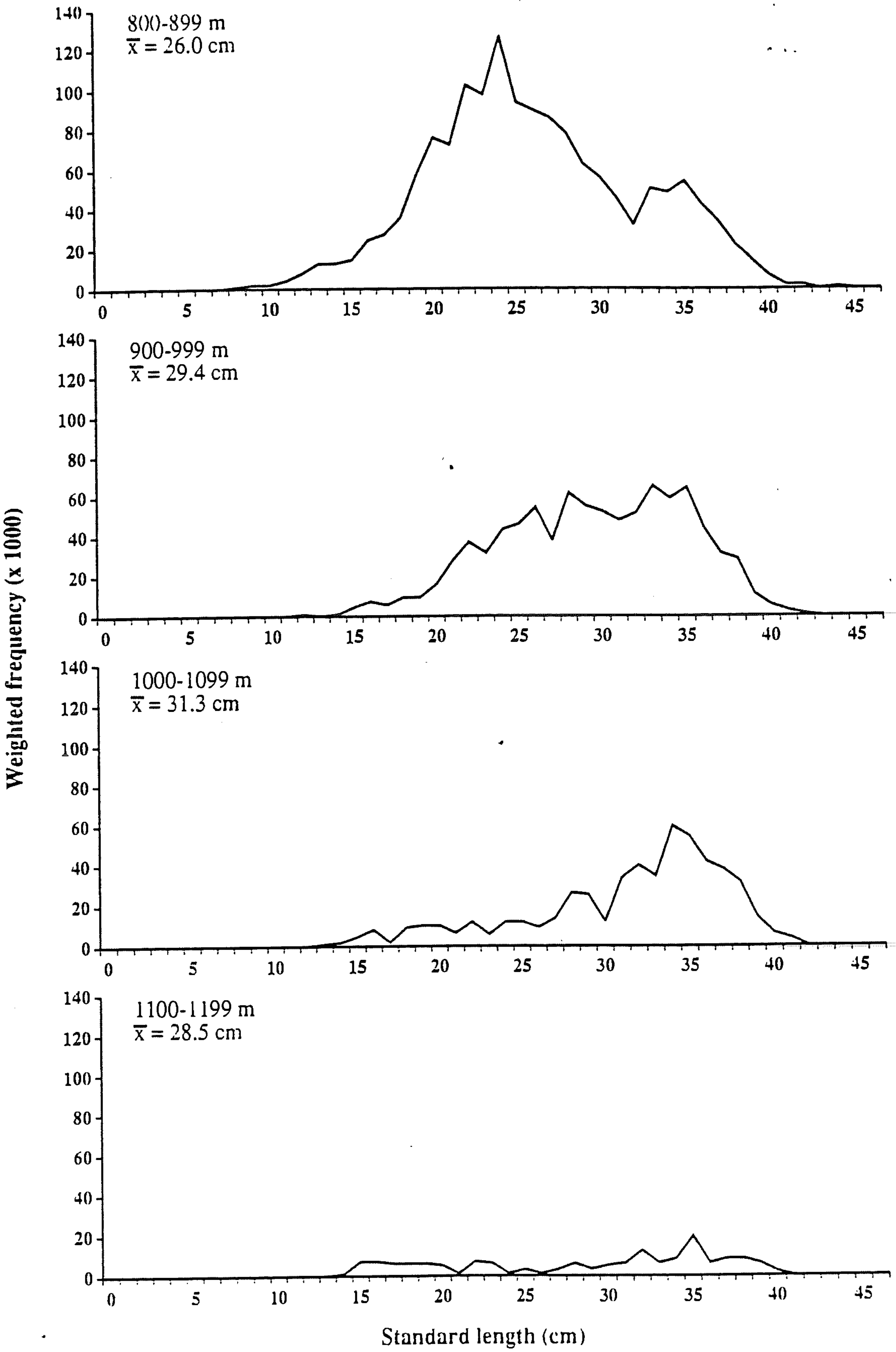


Figure 4g: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in winter 1989. ($\overline{x}$ = mean length)

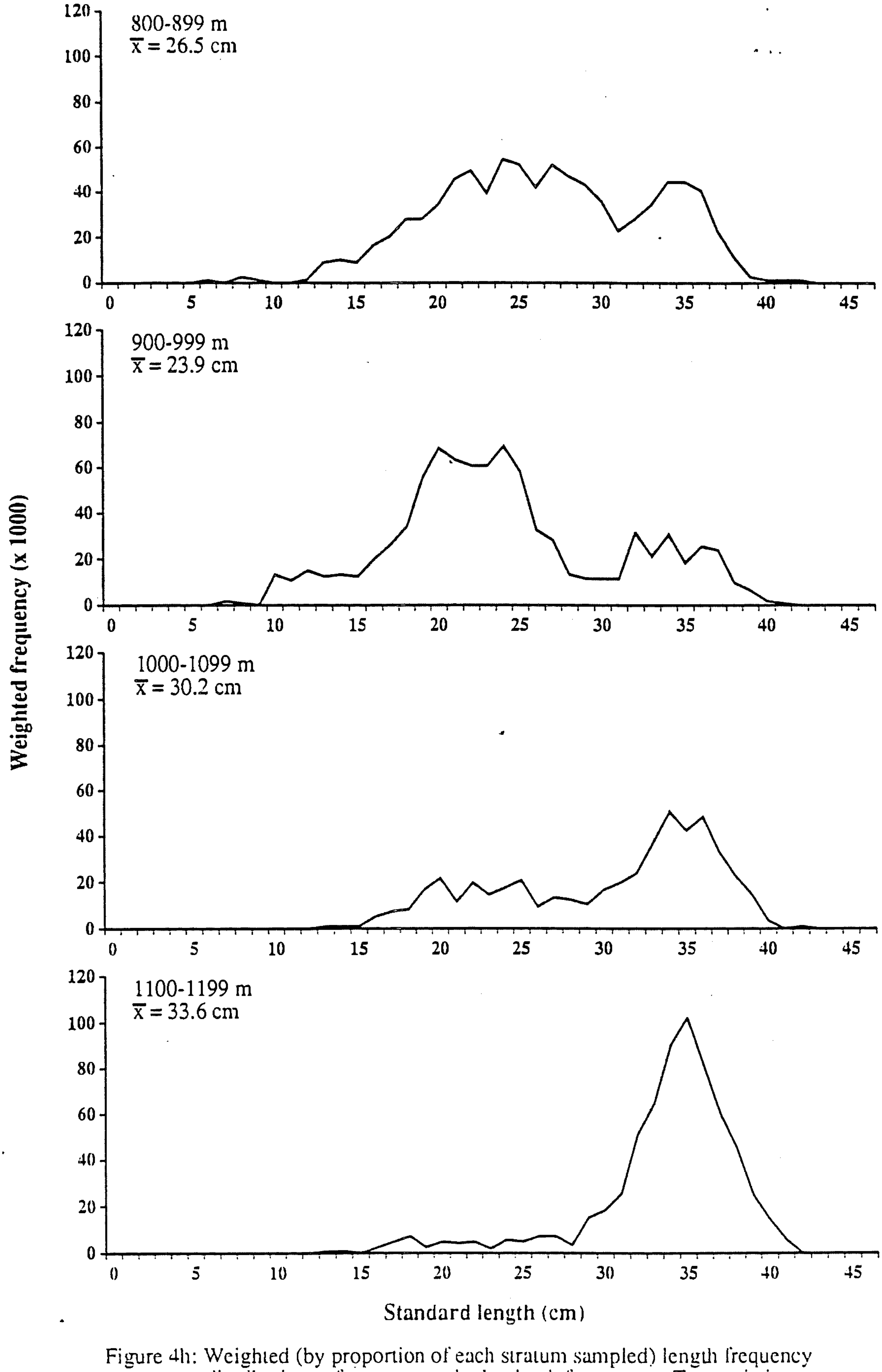


Figure 4h: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for western Tasmania in spring 1989. ($\overline{x}$ = mean length)

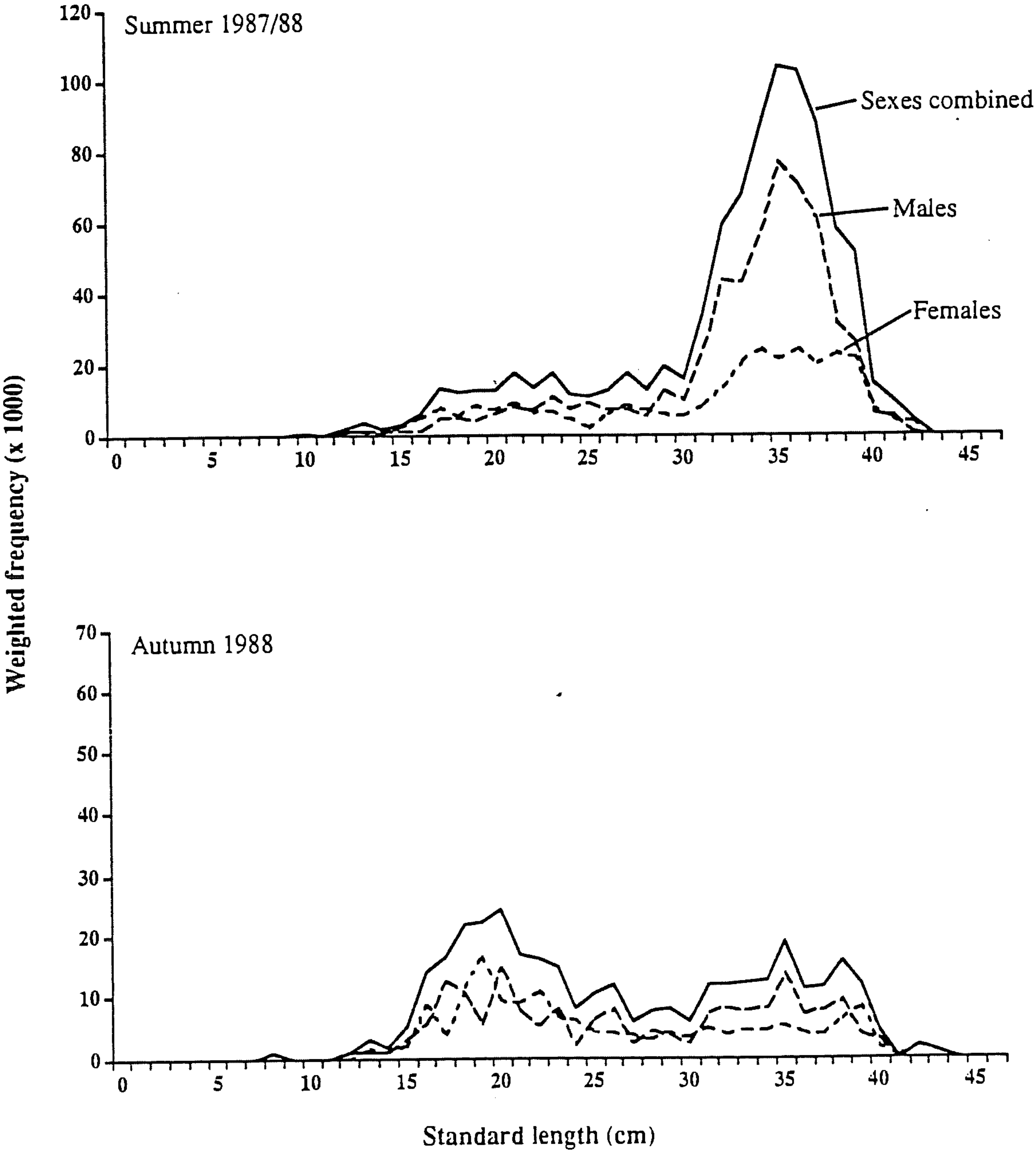


Figure 5: Weighted (by proportion of survey area sampled) length frequency distributions of orange roughy by season for north-eastern Tasmania.

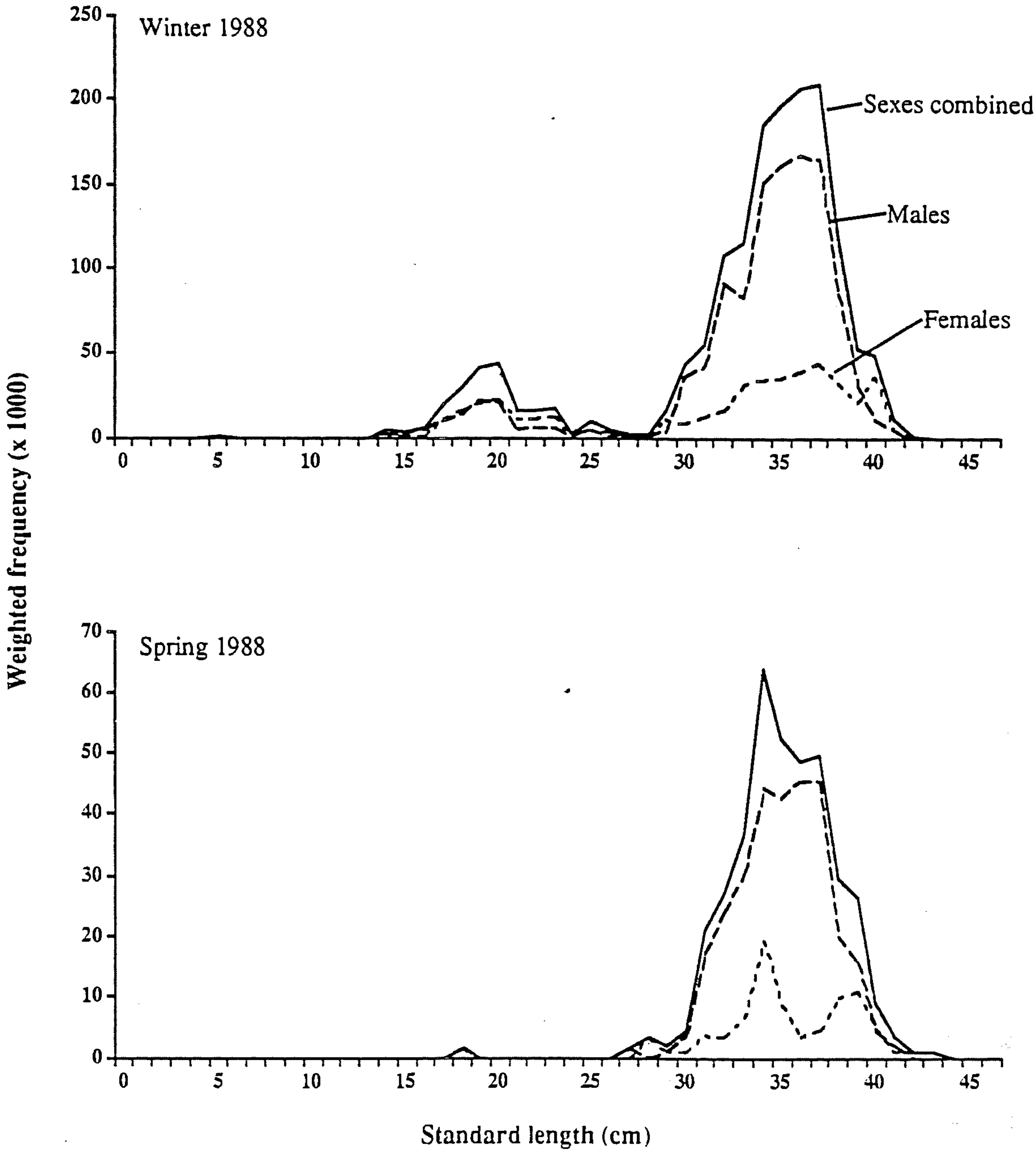


Figure 5: (cont.)

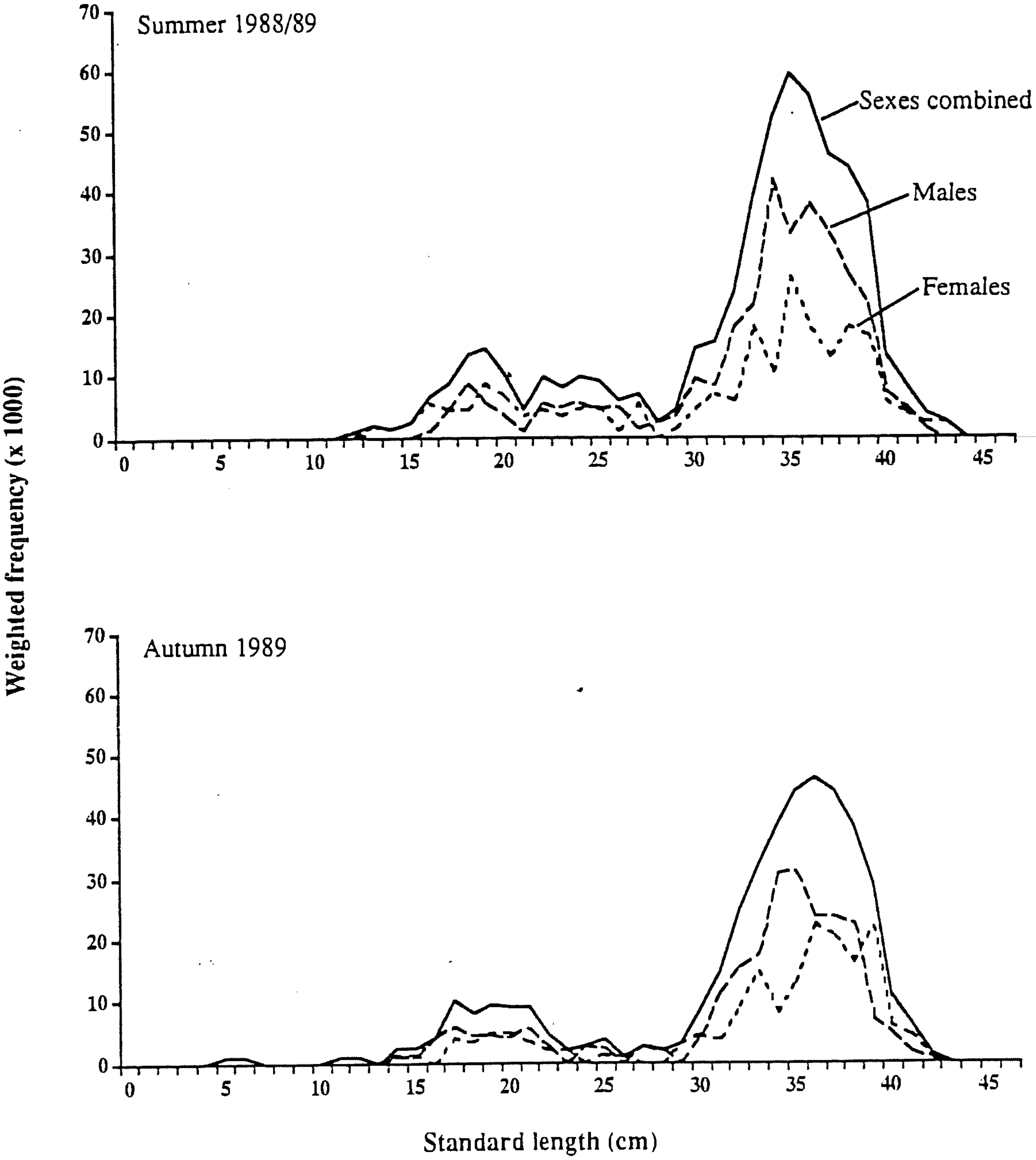


Figure 5: (cont.)

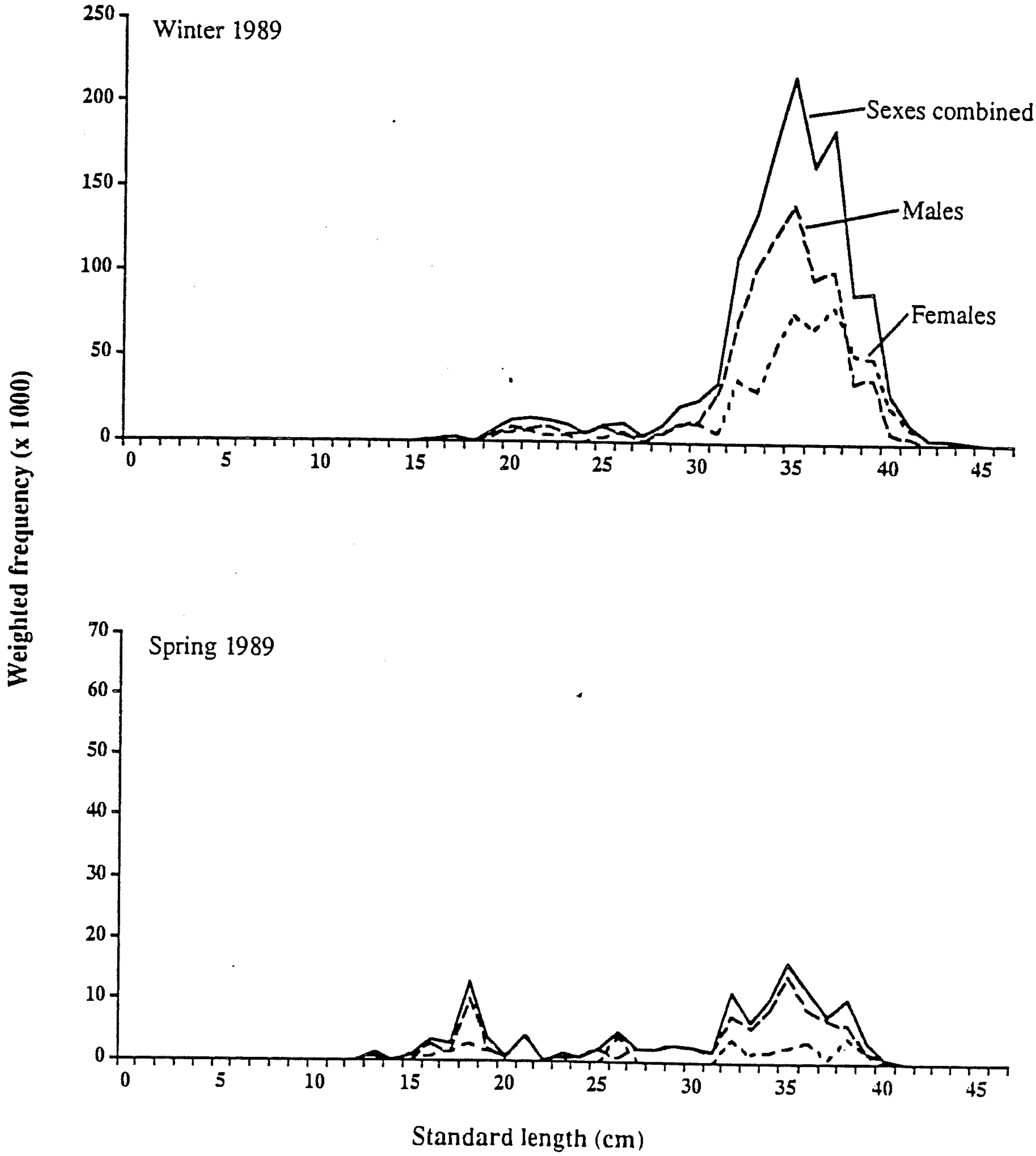


Figure 5: (cont.)

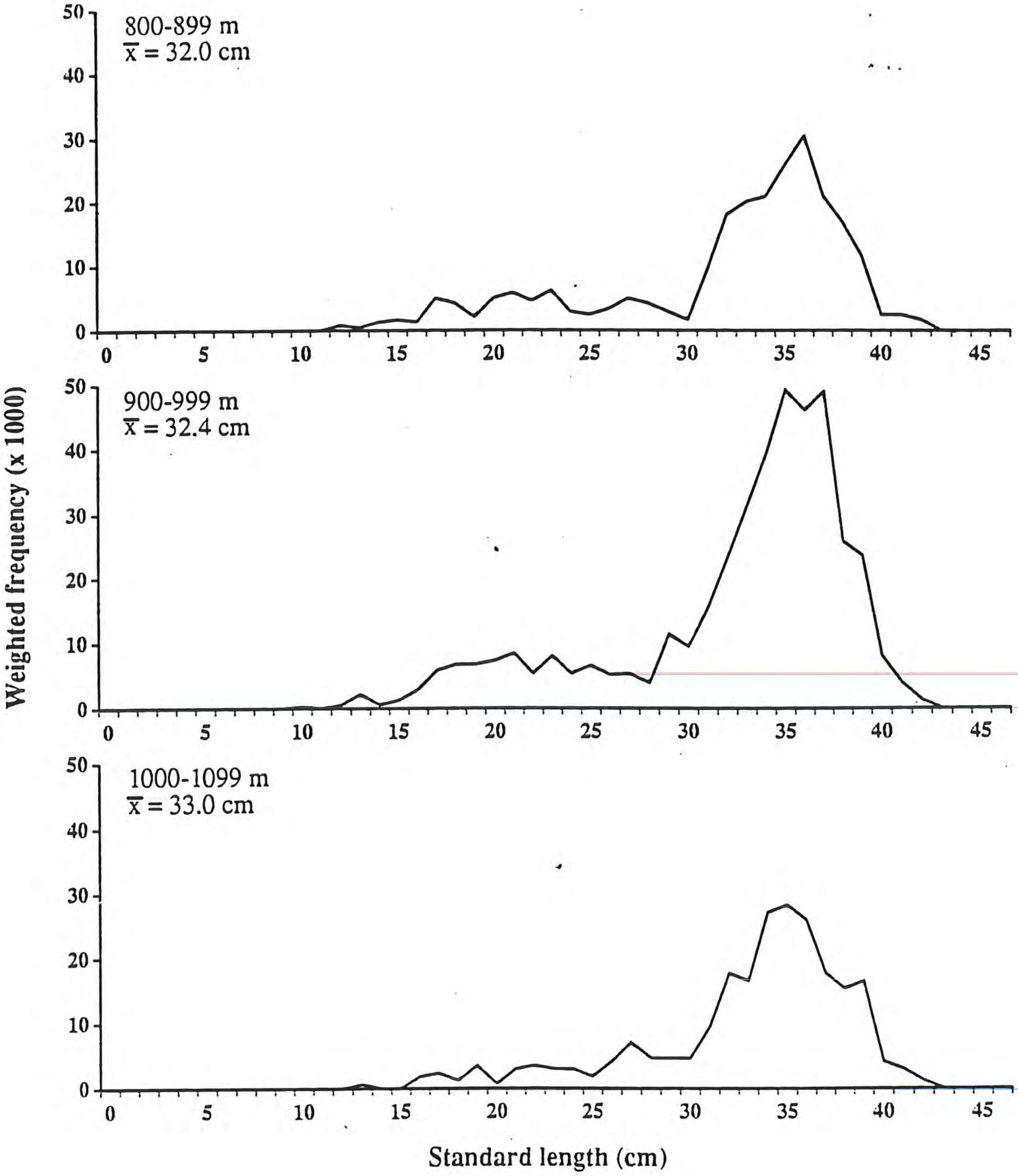


Figure 6a: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for north-eastern Tasmania in summer 1987/88. ($\overline{x}$ = mean length)

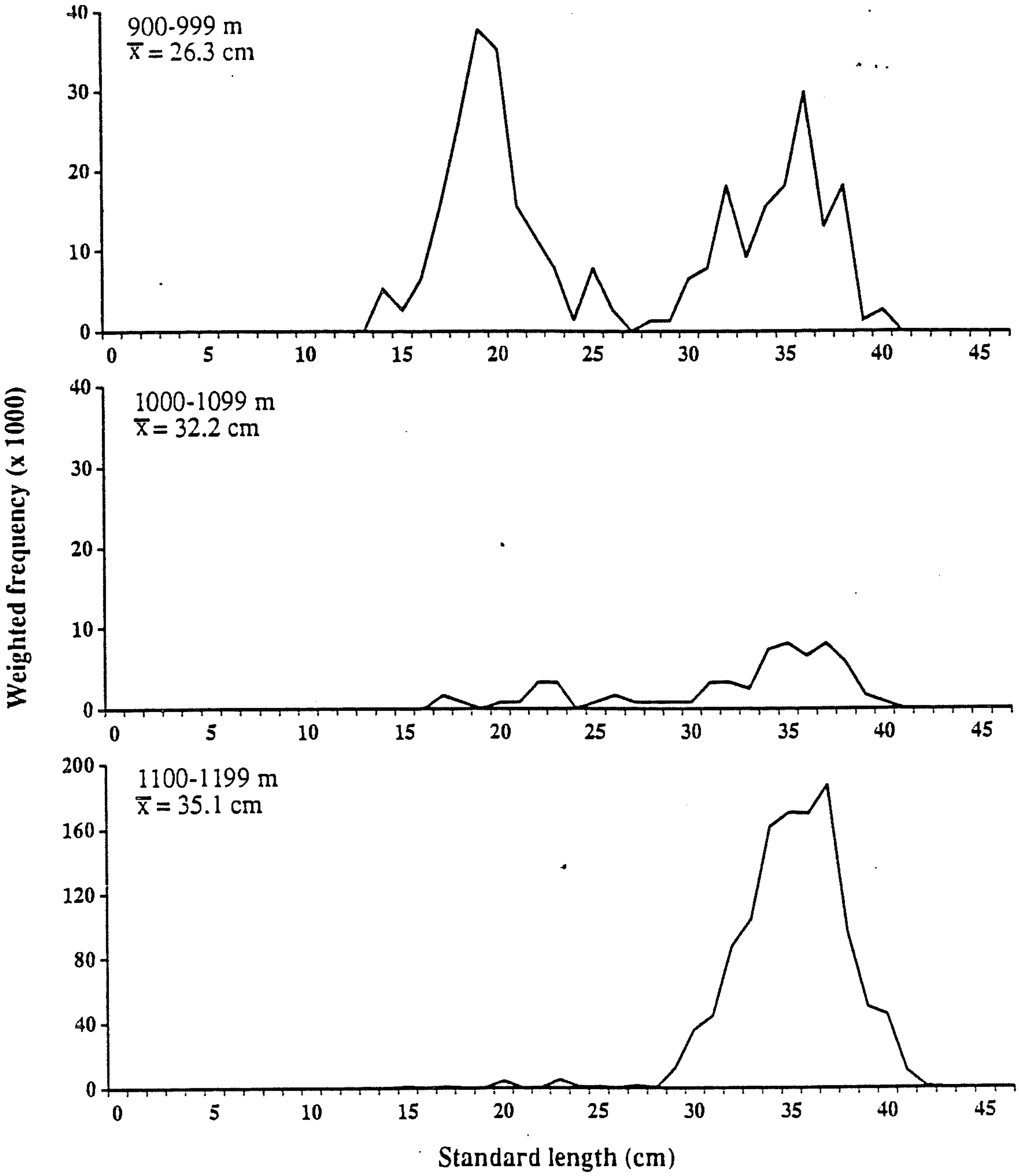


Figure 6b: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for north-eastern Tasmania in winter 1988. ($\overline{x}$ = mean length)

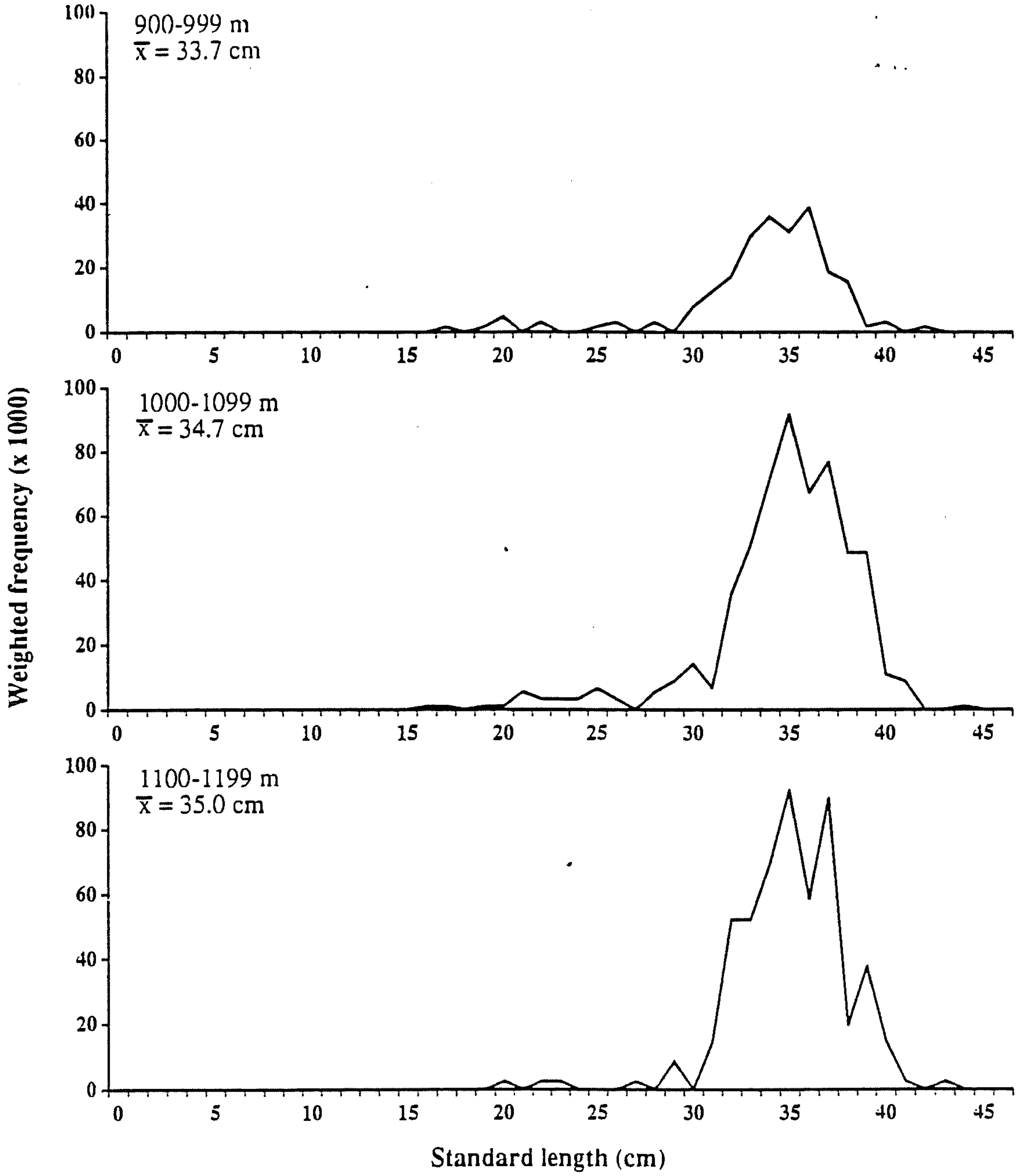


Figure 6c: Weighted (by proportion of each stratum sampled) length frequency distributions of orange roughy by depth for north-eastern Tasmania in winter 1989. ($\overline{x}$= mean length)

3.2 Commercial Fishery

3.2.1 Catch and effort data

Following the first substantial catches of orange roughy from an aggregation off Sandy Cape in late 1986 and early 1987, good catches were taken from a number of aggregations located off western Victoria (Figure 7). Since mid 1988 the fishery has been centred off Tasmania. Catch, effort and CPUE for the main fishing areas around Tasmania are presented in Figures 8 - 13.

Between September 1986 and March 1987 over 5 500 tonnes were taken from Sandy Cape, with a marked peak in catches and CPUE from November to February (Figure 8). Despite considerable fishing effort during the spring/summer of 1987/88, and to a lesser extent in subsequent years, catches and catch rates have remained low. An aggregation has apparently failed to form again in the general area suggesting that localised depletion may have occurred. The total catch from the Sandy Cape area since March 1987 is reported to be about 1 200 tonnes.

The first significant catches (approximately 1 600 tonnes) off eastern Tasmania were taken from the St Patricks Head ground during the winter and spring of 1988 (Figure 9). Anecdotal reports indicate that between August and September some good catches were taken in deep water (at depths of 1 250 - 1 350 m). In April/May 1989 approximately 500 tonnes were taken from St Patricks Head but by late May fishing activity was concentrated on an aggregation situated east of St Helens (Figure 10). This later proved to be the site of a major spawning aggregation. Between May and early August just over 16 000 tonnes were caught, almost 85% of which was taken in June and July. CPUE peaked at around 19 tonnes/shot in July and remained high (14 tonnes/shot) up until the ground was closed to trawling in early August. Fishing then resumed on the St Patricks Head ground, some 20 nautical miles to the south, and during August and September a further 1 000 tonnes were caught (Figure 9). CPUE during this period was slightly down on that for 1988. Significant catches were again taken from the St Helens spawning aggregation in 1990 (Lyle *et al.*, 1990) and in 1991.

Since late 1988, fishing activity has become increasingly directed off southern Tasmania outside of the winter months. The ability to target trawl over rough ground has facilitated the exploitation of numerous aggregations distributed throughout the area. The earliest significant catches were from an aggregation located on a ridge off Port Davey (refer to Appendix II for bottom bathymetry). The aggregation yielded just over 600 tonnes between November 1988 and February 1989 (Figure 11). In May 1990 almost 600 tonnes was caught from the Maatsuyker and Pedra Branca grounds (refer to Appendix II for bottom bathymetry of the main aggregation sites) with a further 1 500 tonnes taken between June and August 1989 (Figures 12 & 13). (Note: winter catches are under-represented in the figures because less than five vessels fished in some months and these data are not shown). Peak catches from the three main areas off southern Tasmania have occurred during summer/autumn, with a total reported catch for December 1989 - April 1990 of 14 350 tonnes, 63% of which was taken from the Maatsuyker area. CPUE fluctuated between 5 - 10 tonnes/shot throughout most of this period, declining to about 2.5 - 4 tonnes/shot by April. Logbook data after April are incomplete, though good catches continued to be reported from the Maatsuyker and Pedra Branca areas throughout 1990 and into early 1991.

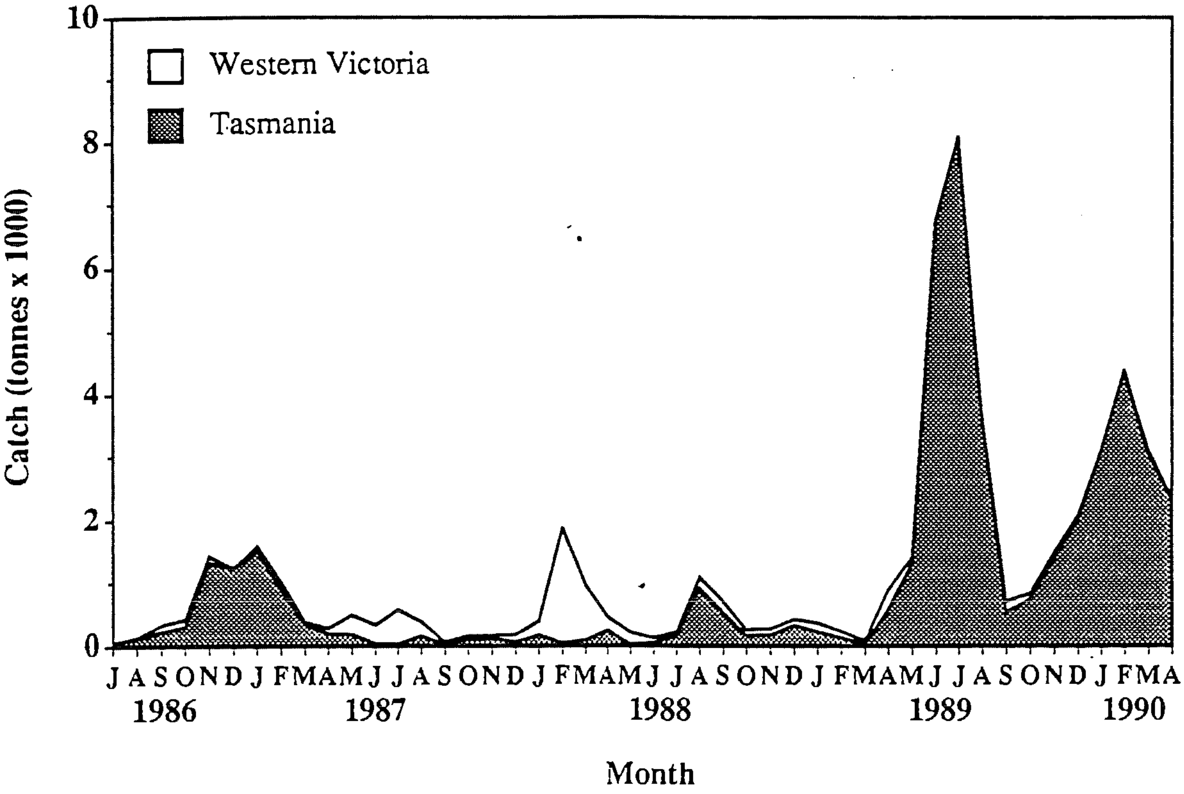


Figure 7: Monthly orange roughy catches for the South East Trawl fishery between July 1986 - April 1990 (based on SET logbook data).

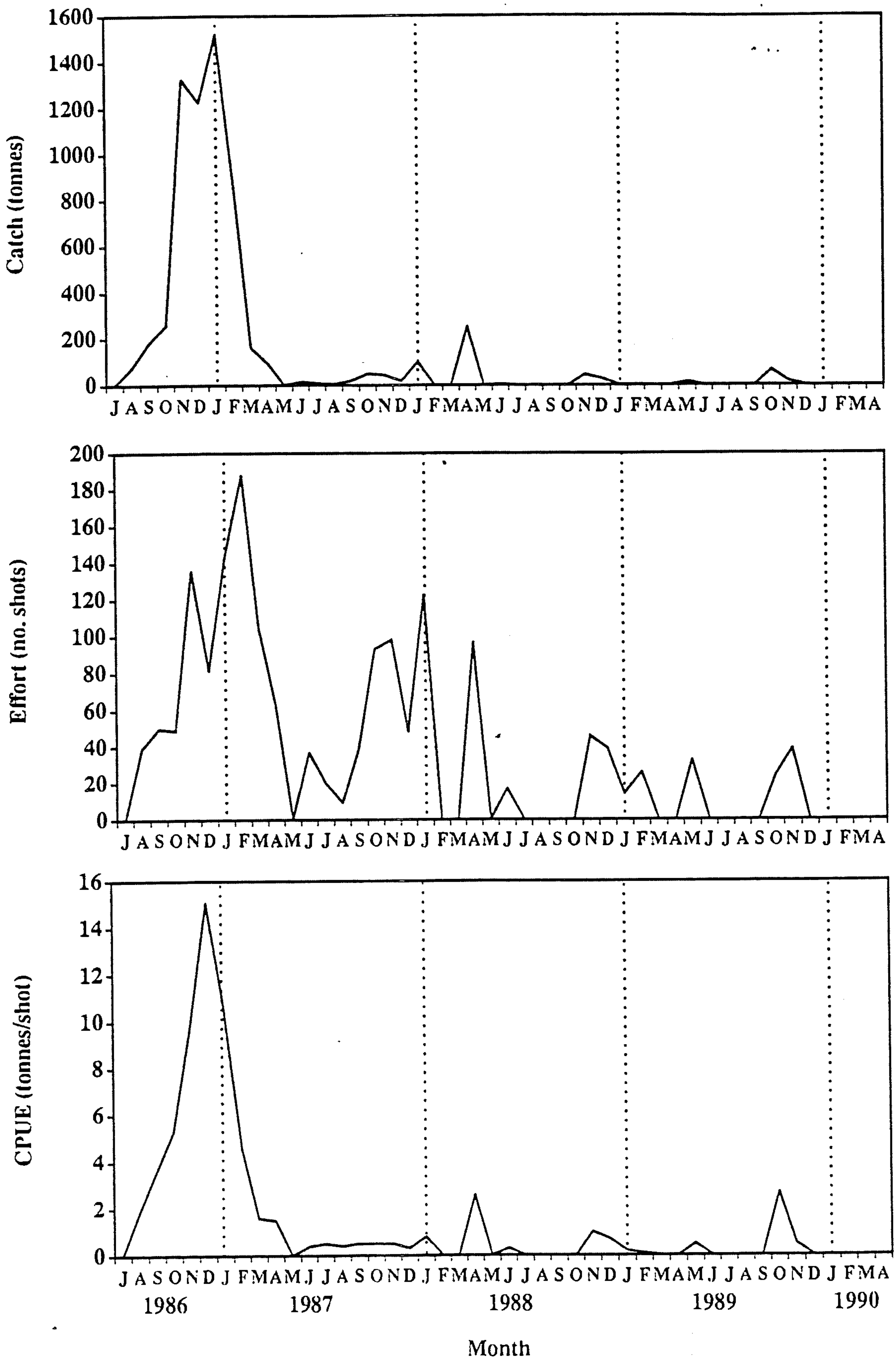


Figure 8: Orange roughy catch, effort and CPUE by month for Sandy Cape (based on SET logbook data).

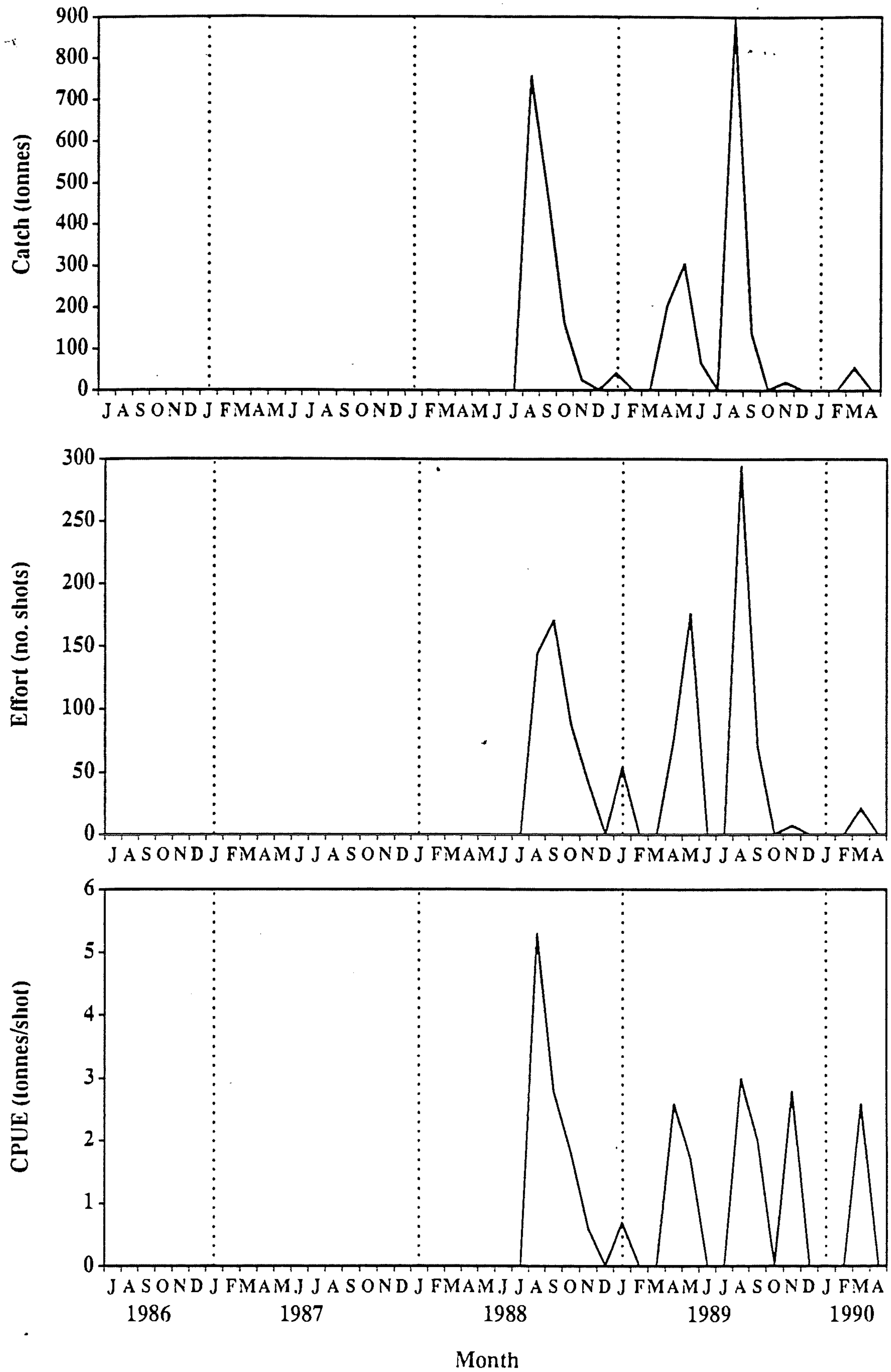


Figure 9: Orange roughy catch, effort and CPUE by month for St. Patrick's Head (based on SET logbook data).

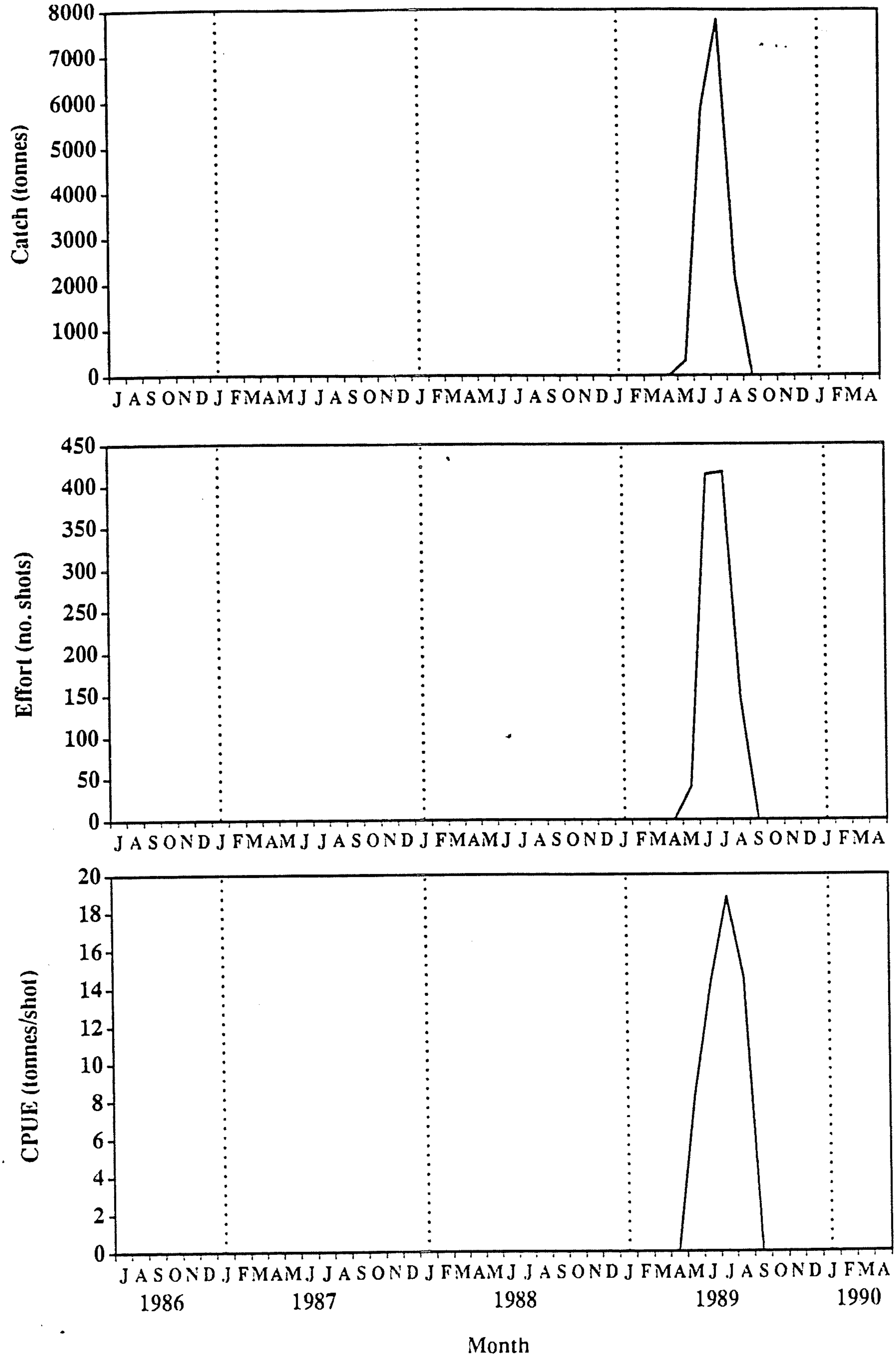


Figure 10: Orange roughy catch, effort and CPUE by month for St. Helens (based on SET logbook data).

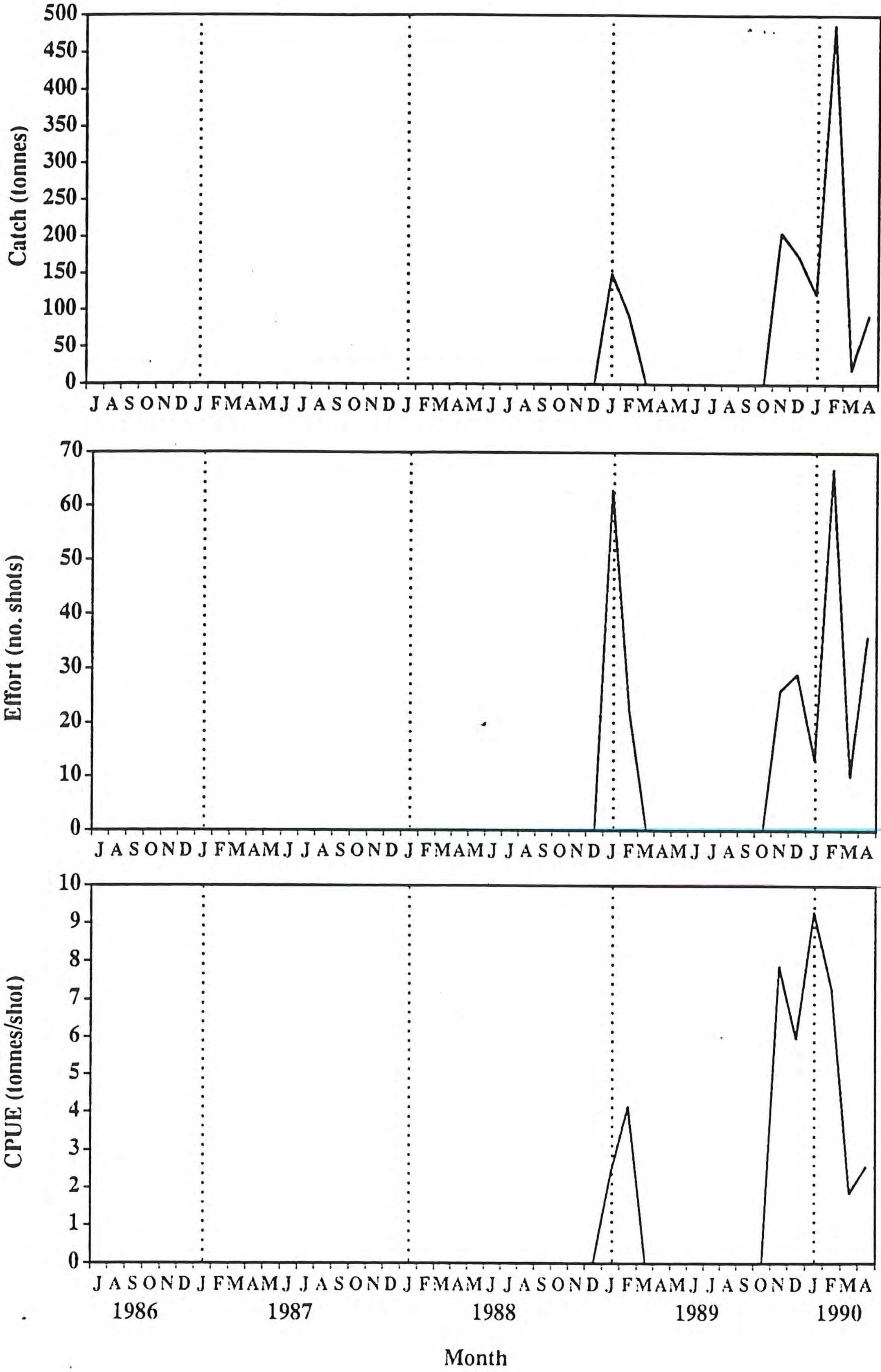


Figure 11: Orange roughy catch, effort and CPUE by month for south-west Tasmania (based on SET logbook data).

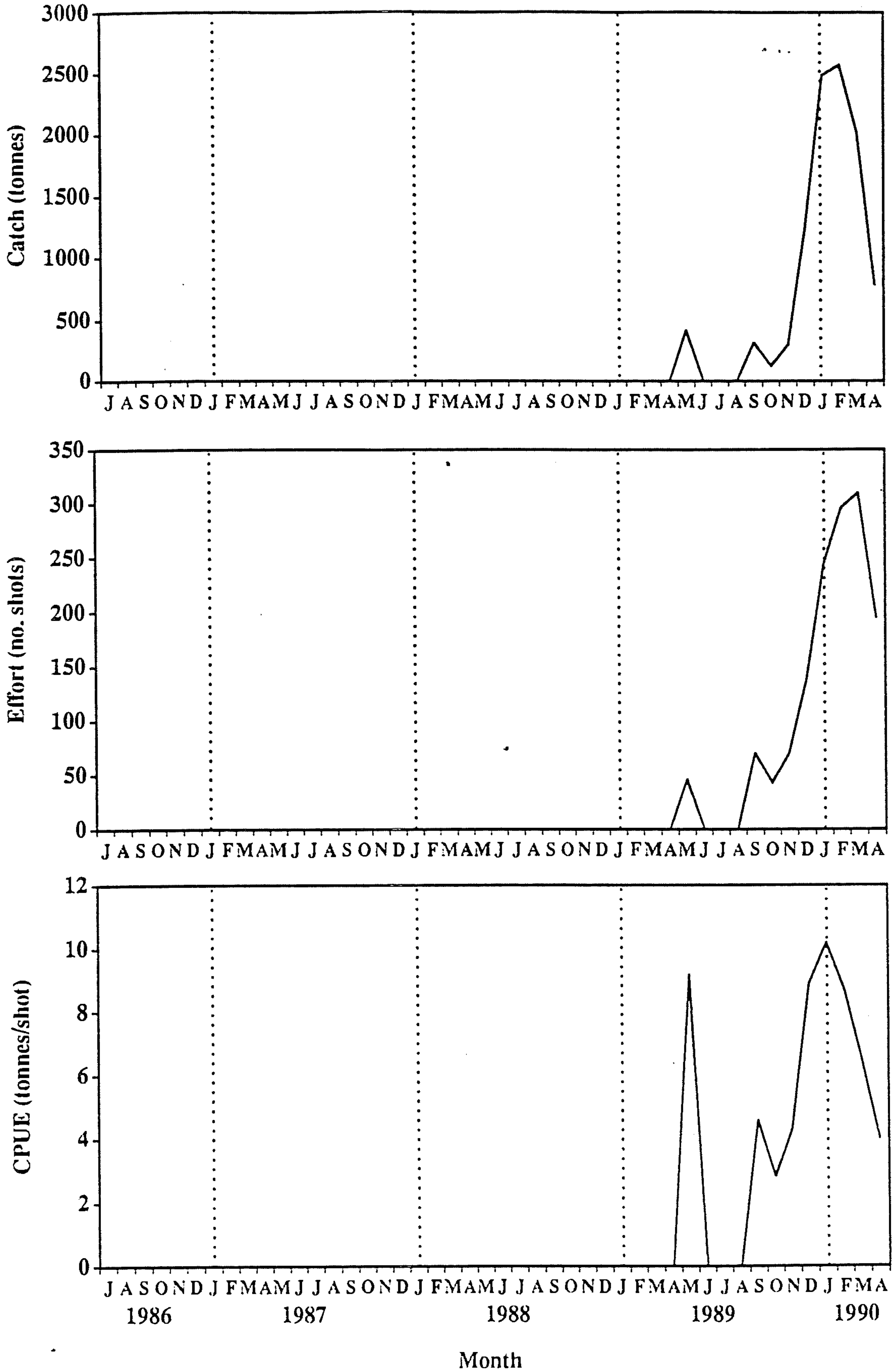


Figure 12: Orange roughy catch, effort and CPUE by month for Maatsuyker (based on SET logbook data).

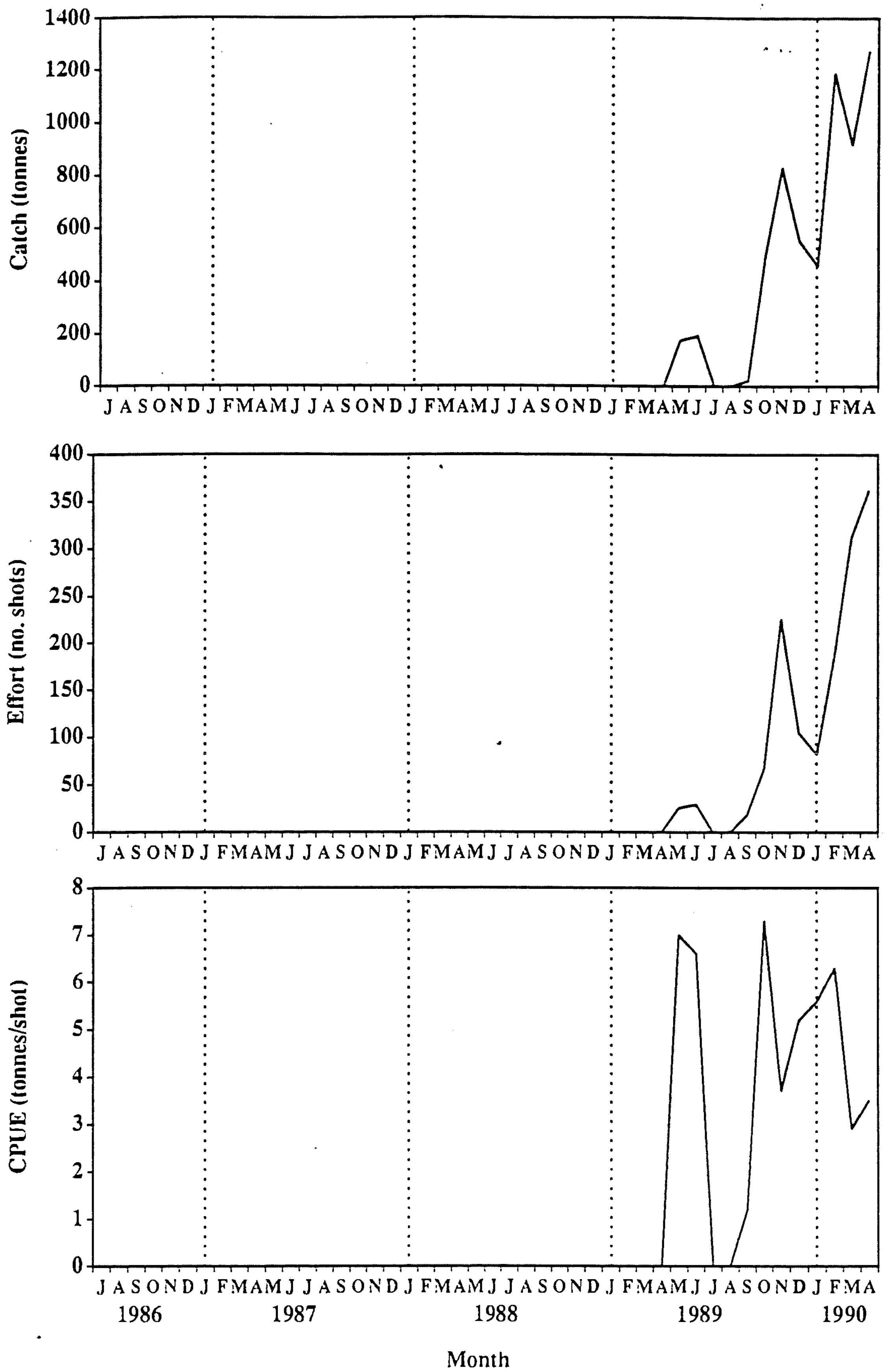


Figure 13: Orange roughy catch, effort and CPUE by month for Pedra Branca (based on SET logbook data).

3.2.2 Size and sex composition

When fishing aggregations there is little, if any, sorting of the catch by size and as a consequence shore-based measurements can be considered representative of the actual catch size composition. A comparison of length frequency distributions derived from on board and landed catch sampling support this observation (Figure 14).

Seasonal length frequency distributions for fish taken by the commercial fishery from the major fishing grounds adjacent to Tasmania are shown in Figure 15. Length frequency distributions are based on both shore-based and on board measurements. Mean sizes and sex ratios are presented in Table 9. The smallest fish examined were 18 cm and maximum sizes ranged from 41 - 48 cm, with fish over 44 cm being extremely rare. Size distributions were strongly unimodal, with peaks at 35 - 37 cm and the majority (>90% by number) of fish measuring between 30 - 40 cm. There were differences in size by sex with females attaining larger sizes than males and having greater mean lengths (Table 9). The modal lengths for females (most between 35 - 37 cm) also tended to be 1 - 2 cm larger than the peaks for males (most between 34 - 36 cm).

There were no obvious seasonal or interannual differences in size structure within each area. There was, however, a small but consistent difference in the mean size of males from north-eastern (St Patricks Head and St Helens) and southern Tasmania (Port Davey, Maatsuyker and Pedra Branca), the southern fish being slightly (< 1 cm) smaller than those from the north-east coast.

With the exception of Port Davey, males outnumbered females in most seasons (Table 9). Females generally accounted for less than one third of the numbers from St Patricks Head, St Helens and Pedra Branca and usually represented 45 - 48% of Maatsuyker catches.

The apparent consistency of the sex ratios within each area masks the variation observed between individual samples (i.e. tow or landing). The greatest variability in sex ratios was observed from the St Helens spawning aggregation during the period of peak spawning. For instance, the proportion of females ranged from 1.5 to 61.7% in July 1989 while in July 1990 females accounted for 14.1 to 76.6% of the numbers.

TABLE 9: Mean length, size range and sex ratios of commercial catches of orange roughy from the major fishing grounds adjacent to Tasmania. *N* is the unscaled sample size.

Year	Season	Month(s) sampled	*N*	Mean length (cm) Total	Male	Female	Range (cm)	% female
St Patricks Head								
1988	Winter	Jun-Aug	2 604	35.9	35.5	36.7	18 - 44	32.0
	Spring	Sept-Oct	1 244	35.5	35.1	36.3	22 - 42	33.6
1989	Autumn	Apr	1 076	35.8	35.6	36.3	27 - 43	32.7
St Helens								
1989	Autumn	May	550	35.5	35.1	36.3	22 - 43	35.3
	Winter	Jun-Aug	4 947	35.5	35.1	36.6	24 - 45	28.1
1990	Autumn	Mar-May	3 556	35.3	35.0	35.9	18 - 43	35.1
	Winter	Jun-Aug	12 893	35.7	35.1	36.8	18 - 48	38.3
Port Davey								
1989/90	Summer	Dec-Jan	1 534	36.1	34.8	36.7	25 - 44	68.0
Maatsuyker								
1989	Autumn	May	881	35.3	34.8	36.0	24 - 44	45.1
	Winter	Jun-Aug	4 011	35.5	34.8	36.1	24 - 43	48.4
	Spring	Oct-Nov	789	34.5	34.2	35.1	25 - 44	37.6
1989/90	Summer	Dec-Feb	1 873	34.9	34.4	35.5	26 - 42	47.3
1990	Autumn	Mar&May	821	34.6	34.0	35.3	26 - 43	46.3
	Winter	Jun&Aug	1 643	35.1	34.4	35.9	24 - 42	48.6
	Spring	Oct-Nov	1 183	35.2	34.4	35.9	23 - 44	52.4
Pedra Branca								
1989	Spring	Oct-Nov	508	34.9	34.9	34.8	25 - 41	25.6
1990	Summer	Jan-Feb	1 128	34.7	34.6	35.0	18 - 43	30.3
	Autumn	Mar-Apr	885	35.2	35.0	35.6	25 - 43	34.1
	Winter	Jun-Aug	1 588	35.0	34.7	35.9	25 - 43	26.8
	Spring	Sept-Nov	2 268	35.3	34.8	36.0	23 - 43	44.9

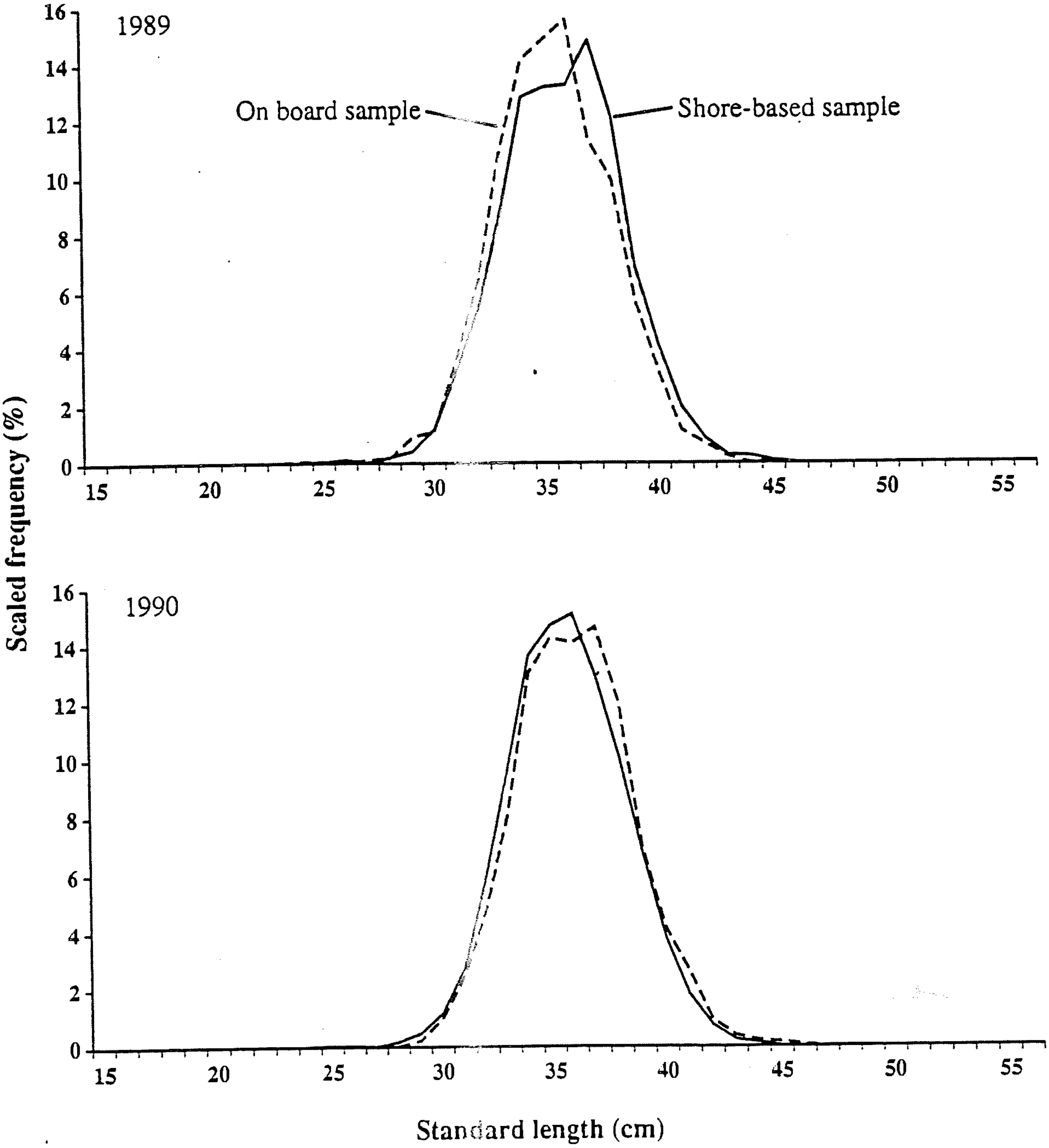


Figure 14: Scaled (by percentage sampled) length frequency distributions of orange roughy from the St. Helens spawning aggregation in June/July 1989 and 1990, showing comparison of shore-based and on board catch sampling.

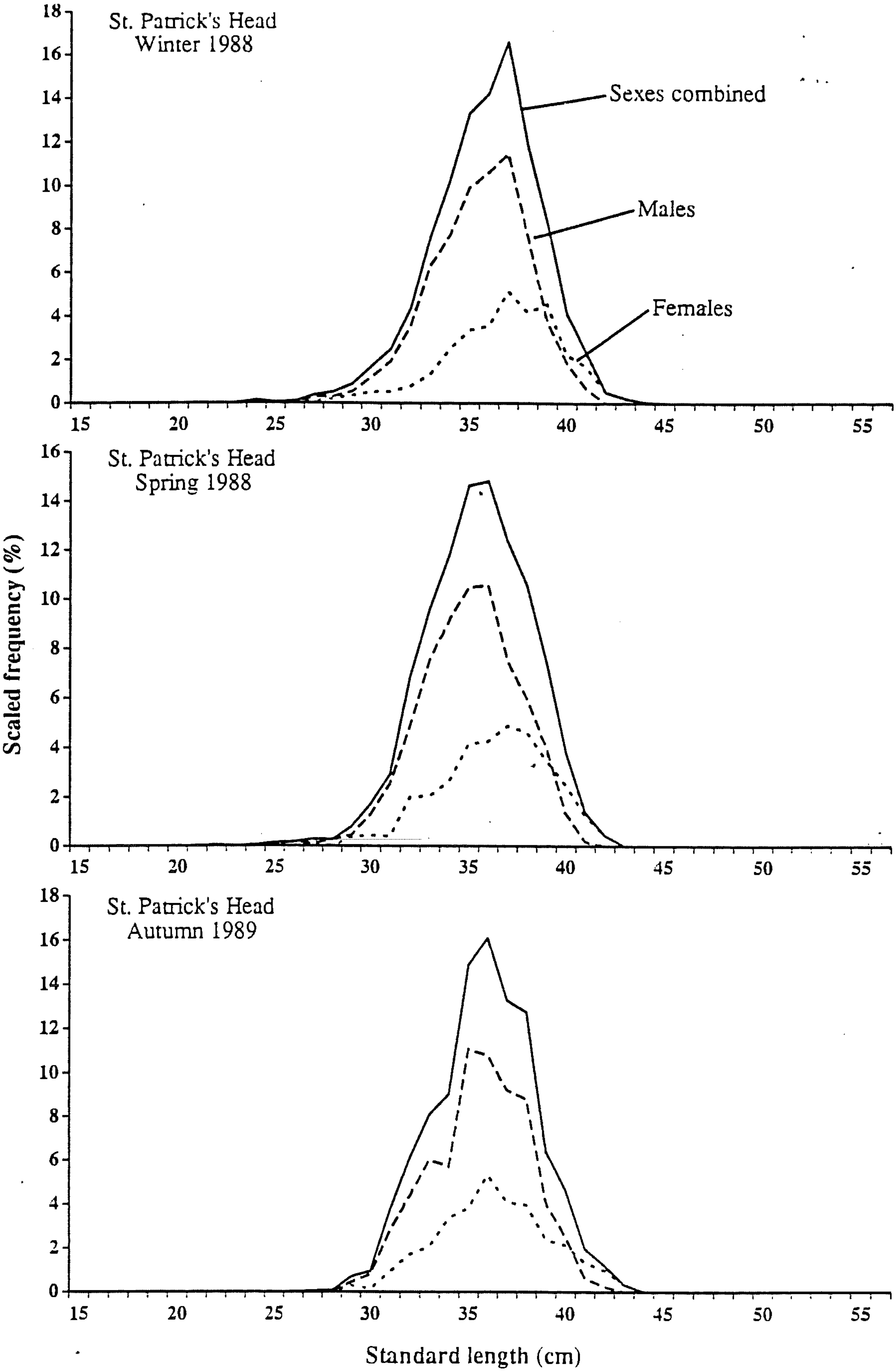


Figure 15: Scaled (by percentage sampled) length frequency distributions of orange roughy by season for the major commercial fishing grounds around Tasmania.

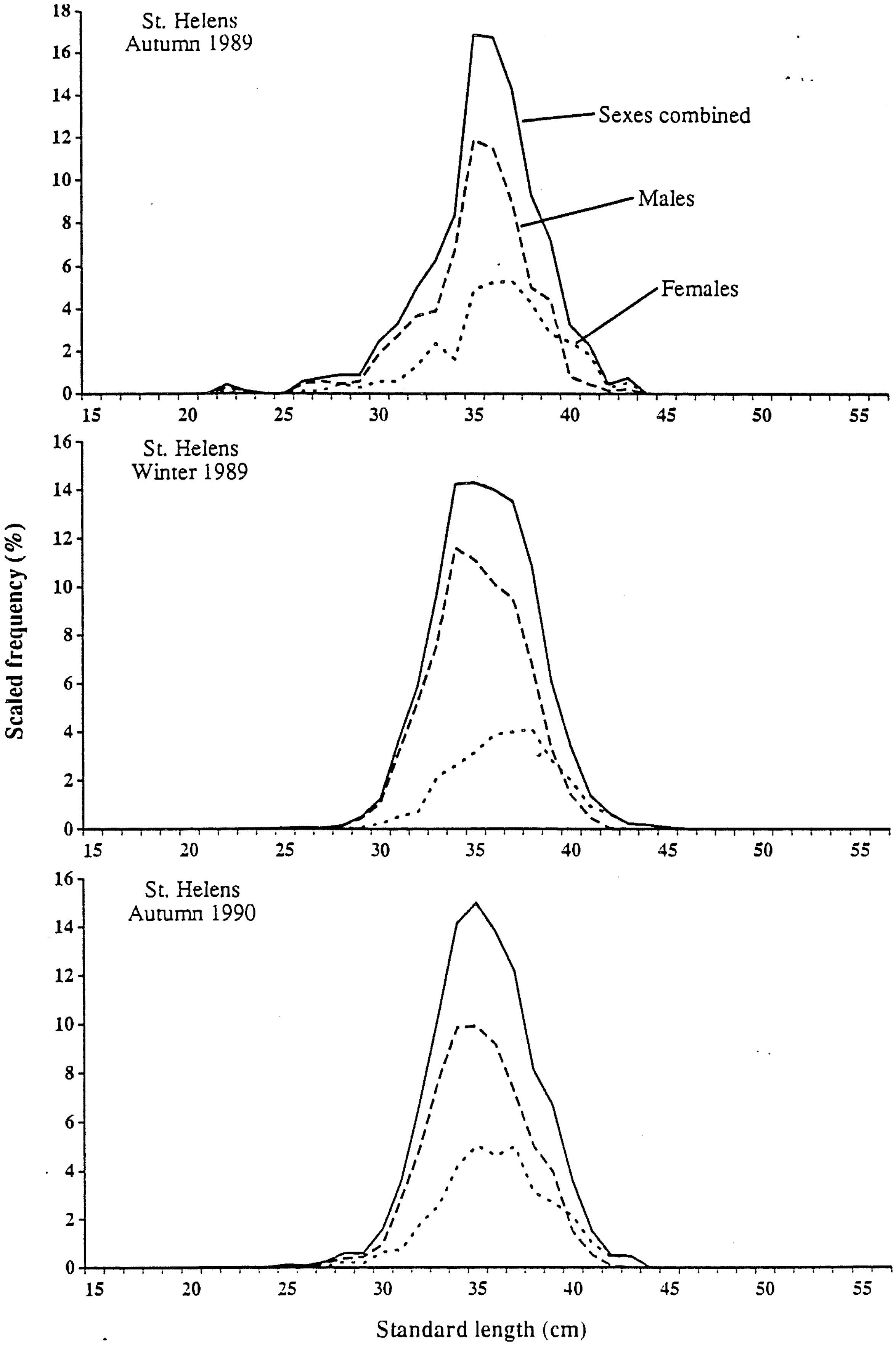
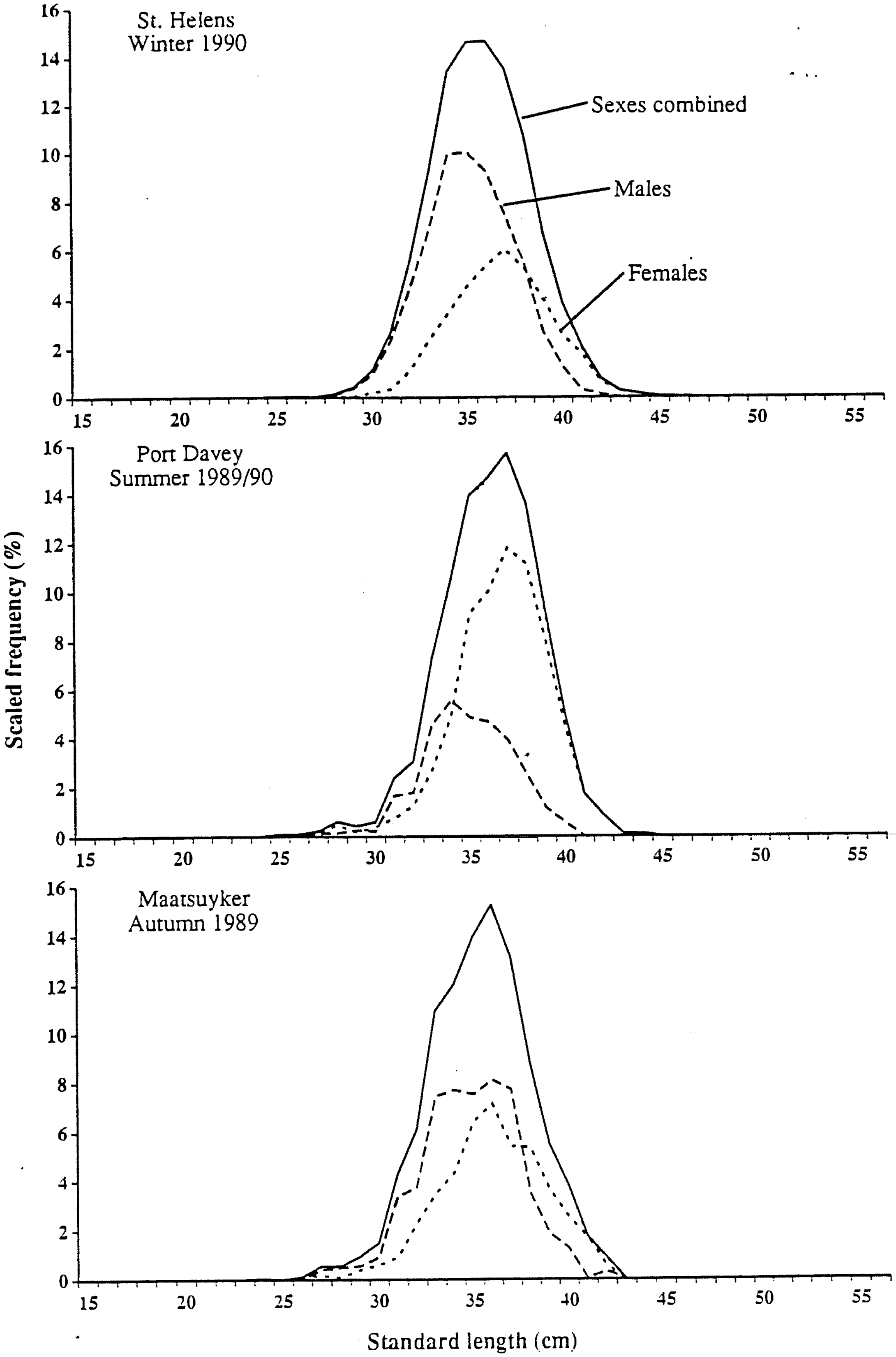


Figure 15: (cont.)



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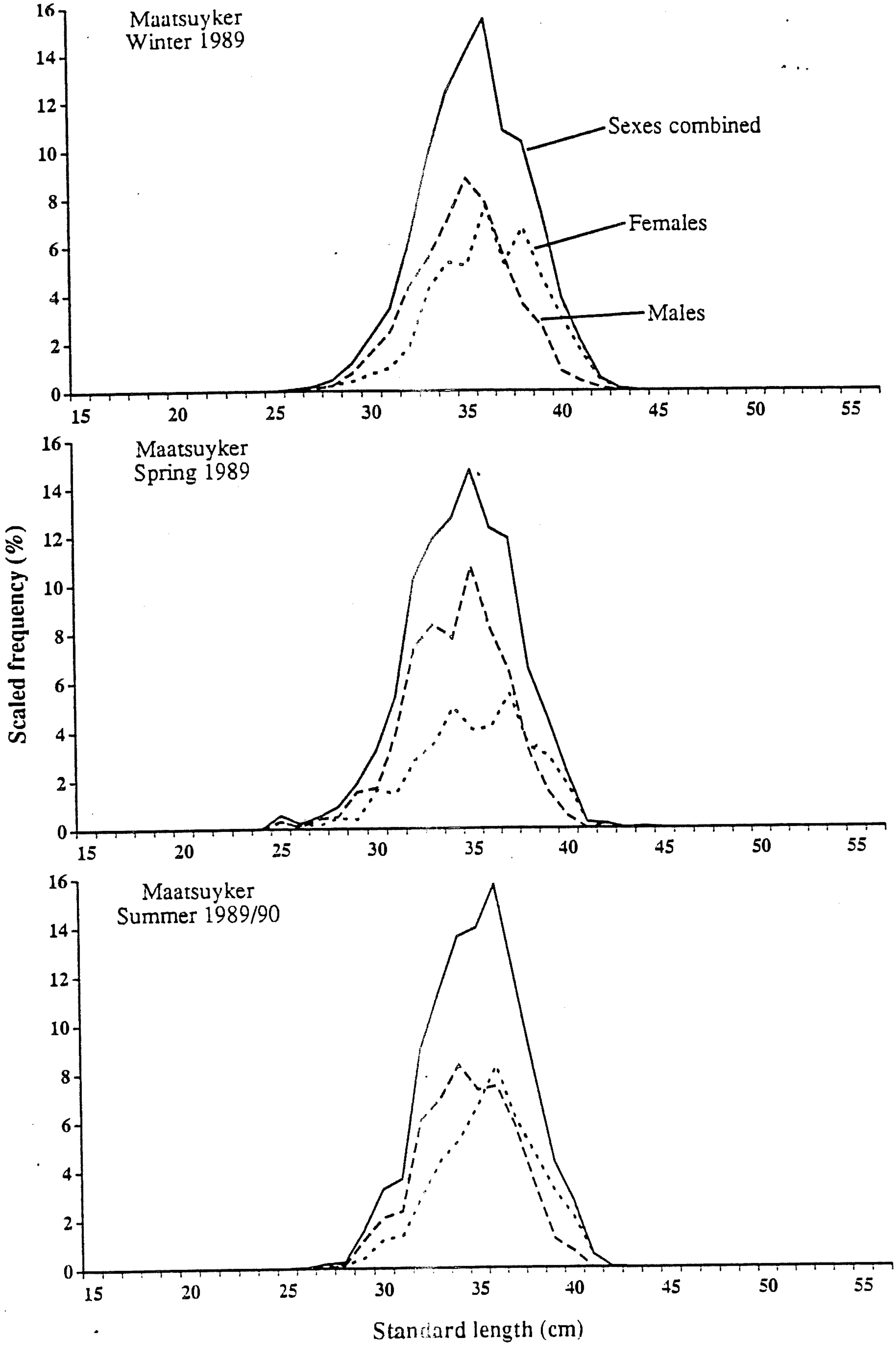

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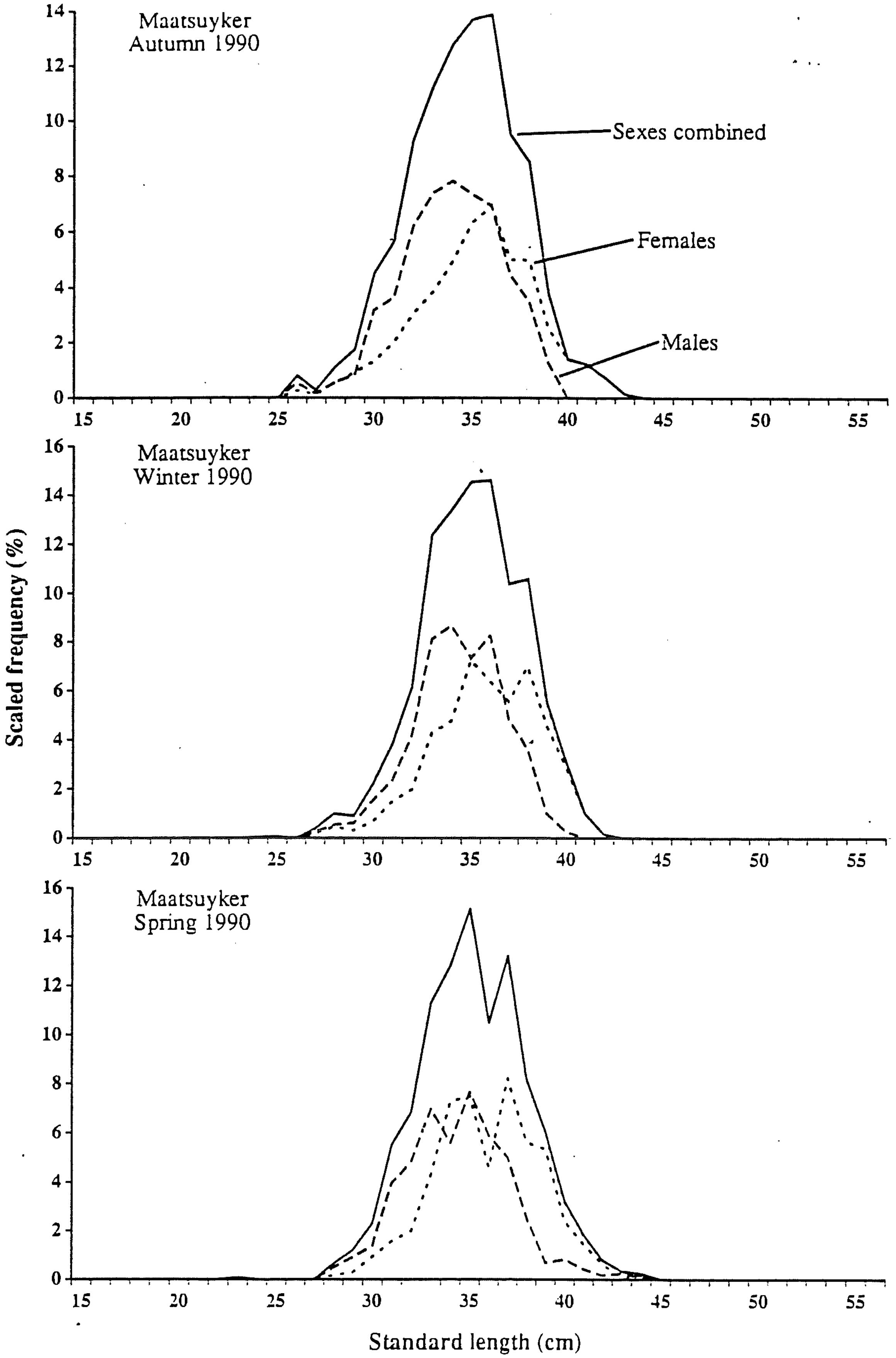

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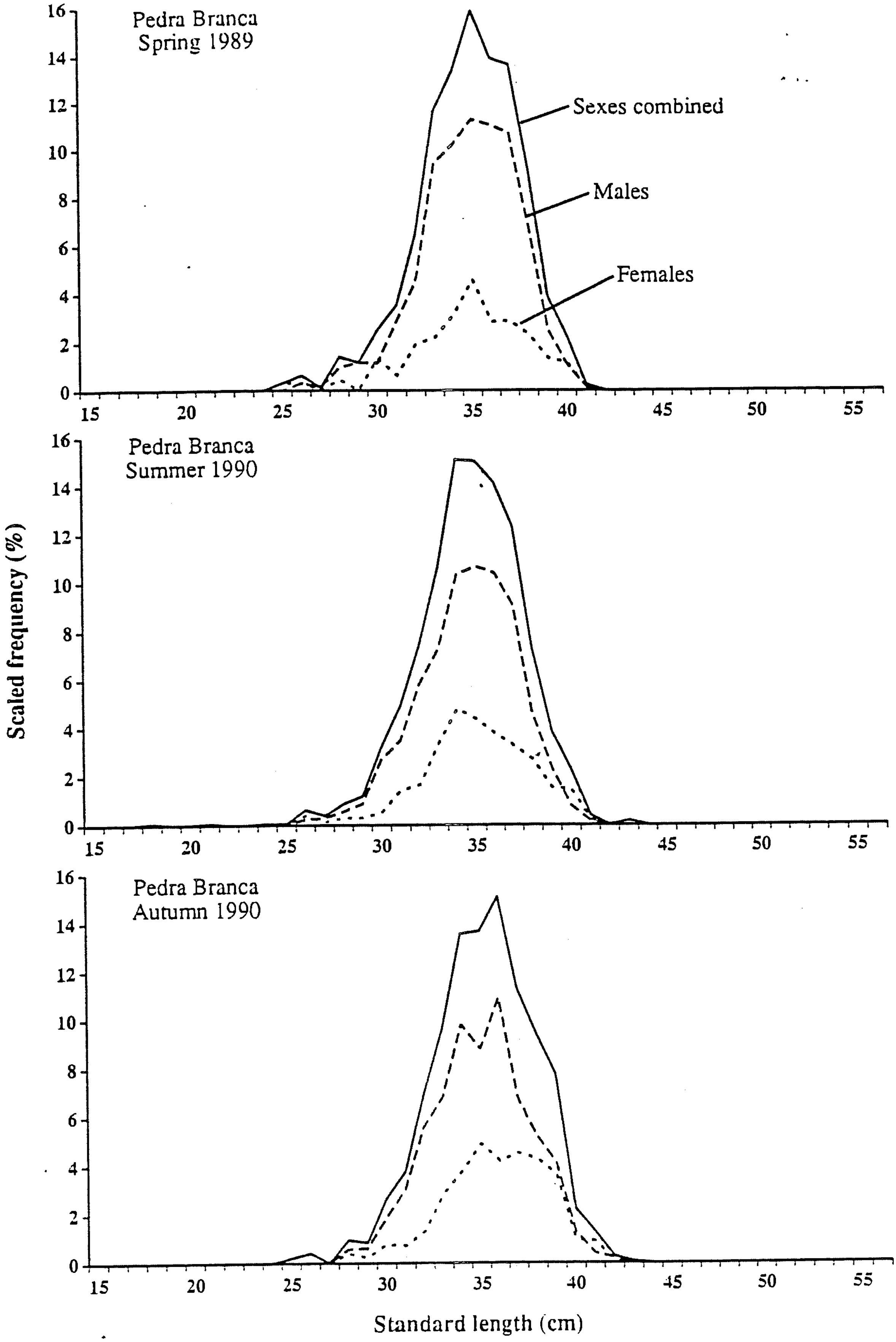

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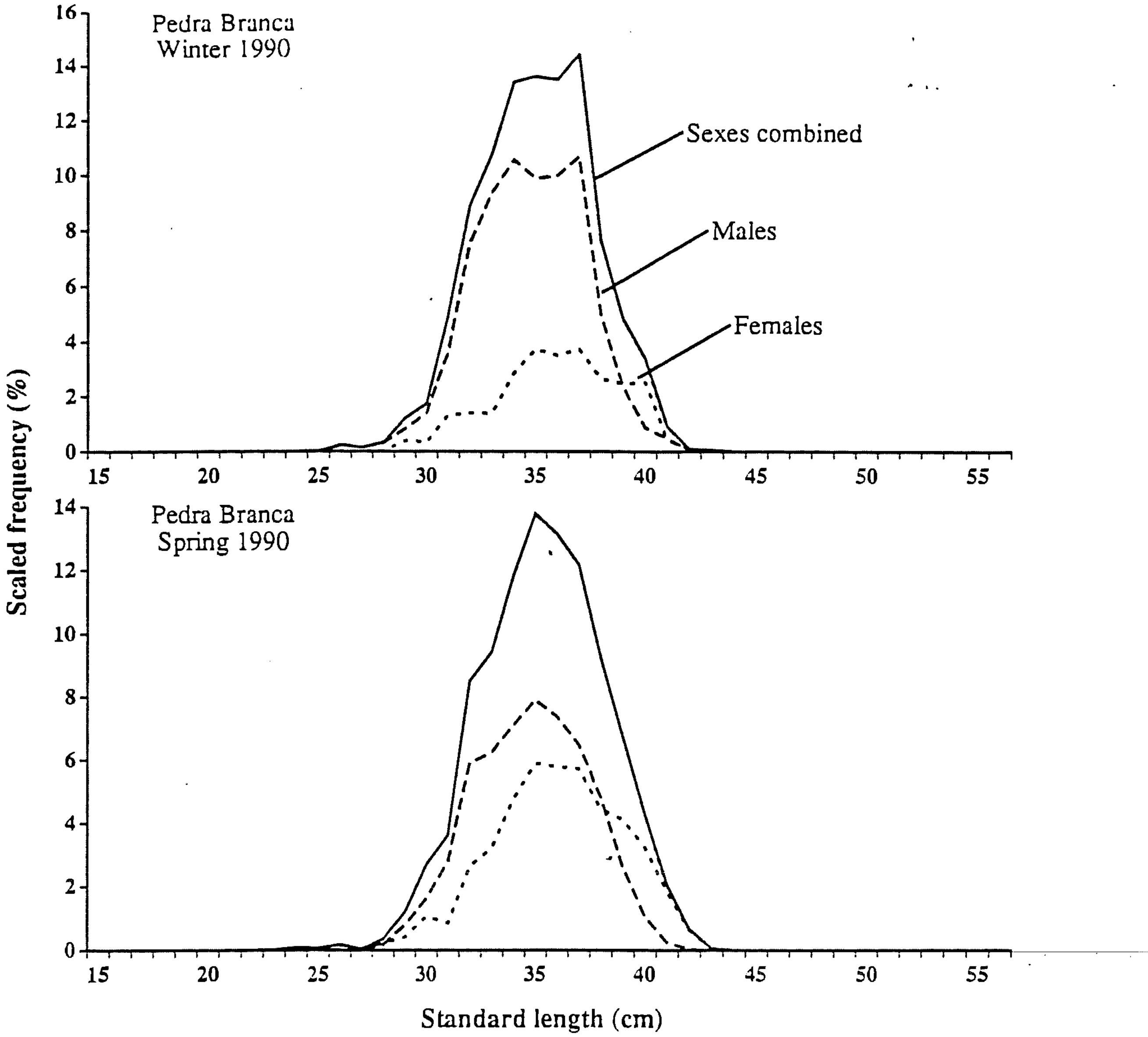


Figure 15: (cont.)

3.3 Orange Roughy Biology

3.3.1 Length-weight relationship

Plots of length on weight for orange roughy are shown in Figure 16. Length-weight relationships have been expressed by the equation $W = aL^b$, where W = body weight (g), L = standard length (cm), and a,b = constants. The regression equations by sex for fish from western Tasmania are:

Males:	$W = 2.11 \times 10^{-2} L^{3.123}$	$N = 2\,105$, $r^2 = 0.99$ ($P < 0.001$)
Females:	$W = 2.03 \times 10^{-2} L^{3.134}$	$N = 2\,324$, $r^2 = 0.99$ ($P < 0.001$)

There were no significant differences between the exponents ($F = 1.09$; d.f. 1, 4 425: $0.1<P<0.25$) or intercepts ($F = 1.09$; d.f. 1, 4 426: $0.1<P<0.25$) of the two curves and, it is therefore valid to pool the data and derive a single length-weight relationship. The relationship is:

$$W = 2.07 \times 10^{-2} L^{3.128} \qquad N = 4\,439,\ r^2 = 0.99\ (P < 0.001)$$

The regression equations by sex for north-eastern Tasmania are:

Males:	$W = 3.83 \times 10^{-2} L^{2.942}$	$N = 1\,420$, $r^2 = 0.98$ ($P < 0.001$)
Females:	$W = 3.51 \times 10^{-2} L^{2.970}$	$N = 904$, $r^2 = 0.99$ ($P < 0.001$)

Again there were no significant differences between exponents ($F = 2.84$; d.f. 1, 2 320: $0.05<P<0.10$) or intercepts ($F = 2.84$; d.f. 1, 2 321: $0.05<P<0.10$) of these curves. The length-weight relationship for north-eastern Tasmania can be described as:

$$W = 3.70 \times 10^{-2} L^{2.952} \qquad N = 2\,339,\ r^2 = 0.98\ (P < 0.001)$$

Length-weight relationships for the two areas did, however, differ significantly in their exponents ($F = 307.87$; d.f. 1, 6 774: $P<0.001$).

3.3.2 Length at maturity

Length at maturity was assessed using macroscopic gonad stages. Females that had developed to Stage 3 (exogenous vitellogenesis) or greater and males of Stage 2 or greater were considered mature. Samples for this analysis were taken from research cruises conducted between February and June in 1988 and 1989.

The smallest male and female orange roughy classified as mature were 25 and 28 cm respectively and the length at 50% maturity was 30 - 31 cm for males and 32 cm for females (Figure 17).

3.3.3 Reproductive cycle

Gonosomatic index or GSI (i.e. gonad weight as a percentage of body weight) and gonad staging data have been used to describe the reproductive cycle. Data for the west, north-east (St Helens and St Patricks Head grounds) and south coasts (Maatsuyker and Pedra Branca grounds) have been treated separately in this analysis.

Monthly changes in GSI for mature fish (based on length at 50% maturity) indicate a distinct seasonal reproductive cycle for fish from north-east Tasmania (Figure 18). Highest GSI values for females occurred during July followed by a sharp decline in August. Ovulated and spent fish were present throughout July and early August and

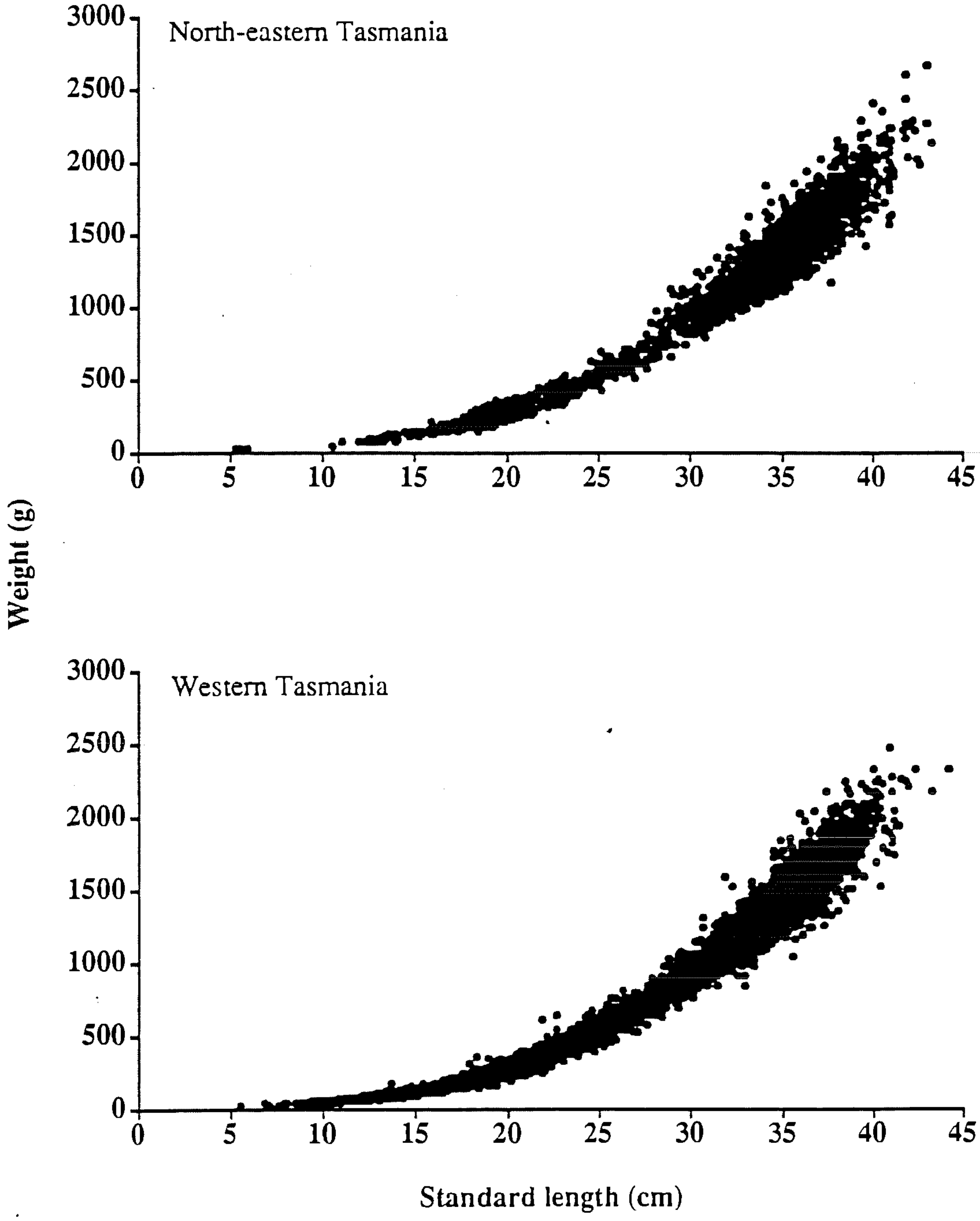


Figure 16: Length-weight relationships for orange roughy from north-eastern and western Tasmania.

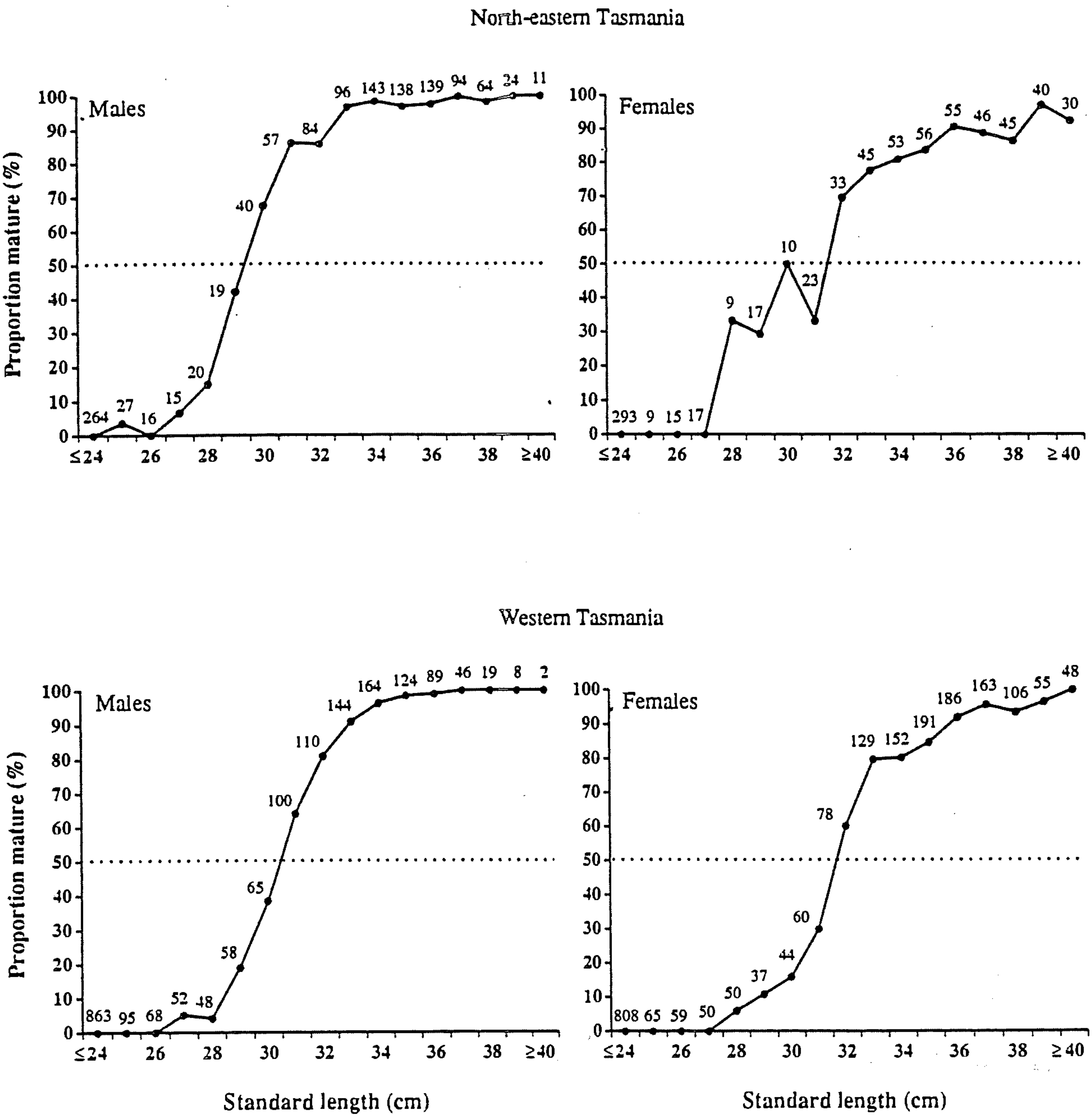


Figure 17: Proportion of mature fish in each centimetre size class of orange roughy from north-eastern and western Tasmania. (numbers are sample sizes)

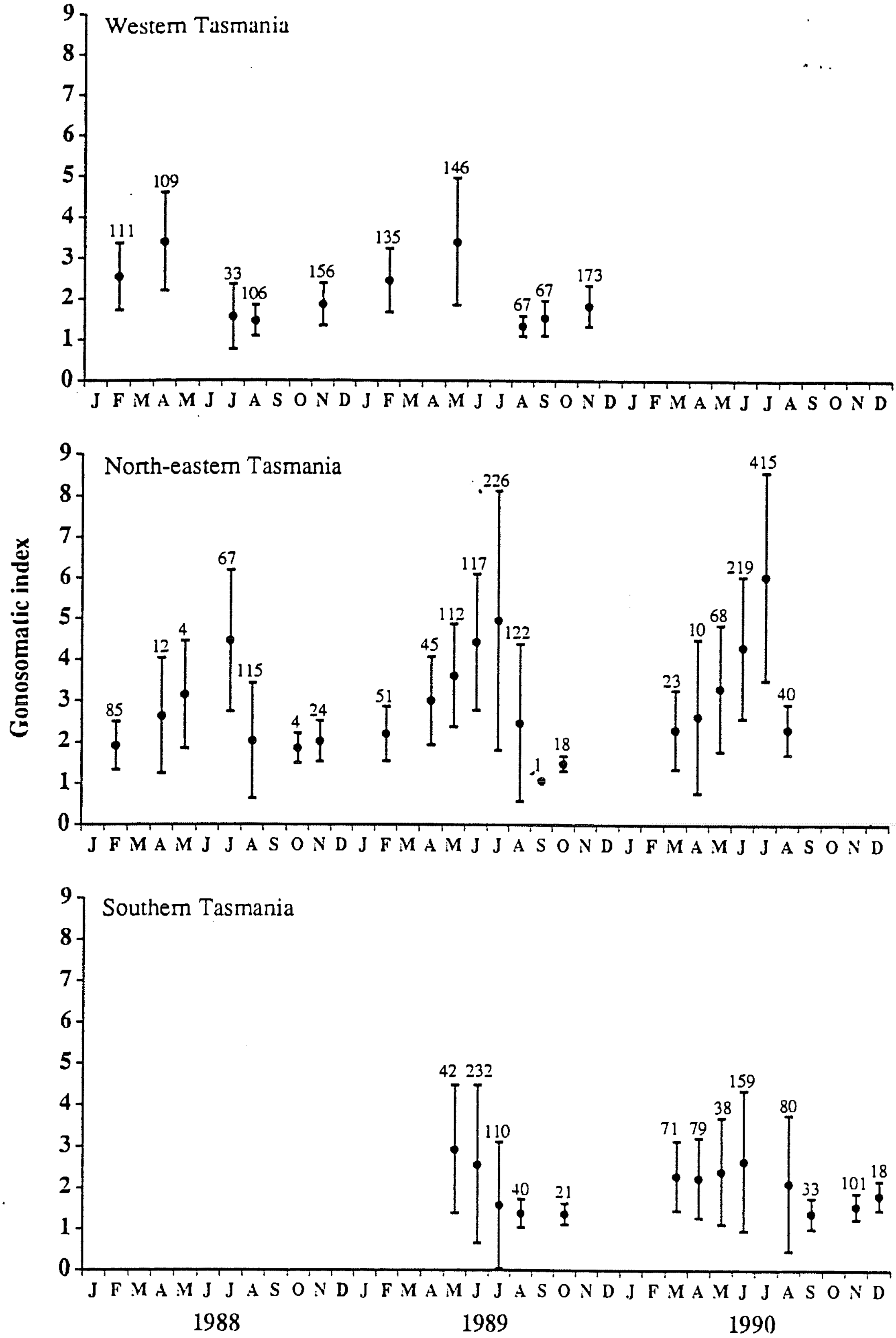


Figure 18a: Variation in mean gonosomatic index for female orange roughy ($\geq$32 cm) from three areas off Tasmania. (Error bars are standard deviations. numbers are sample sizes)

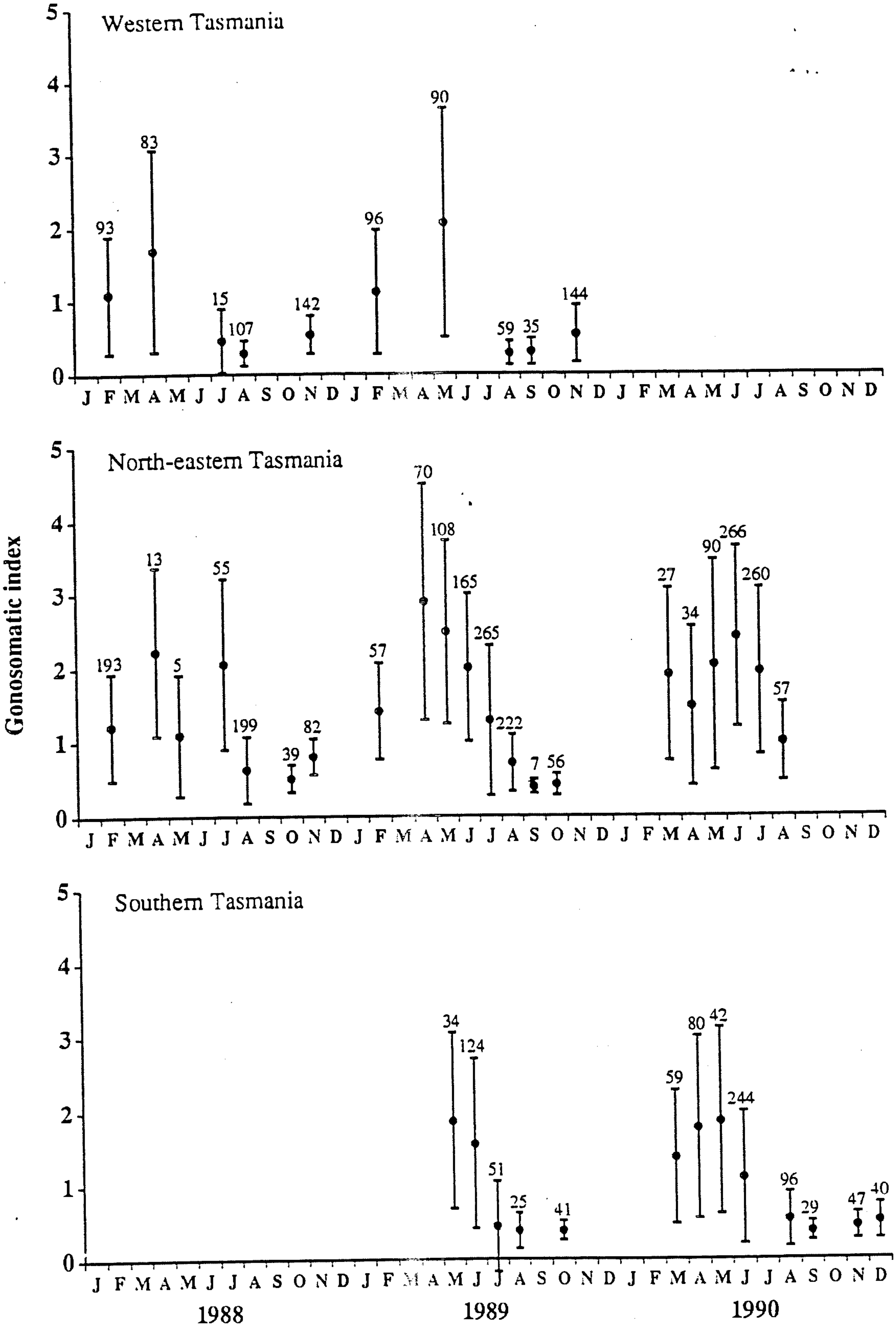


Figure 18b: Variation in mean gonosomatic index for male orange roughy (≥30 cm) from three areas off Tasmania. (Error bars are standard deviations, numbers are sample sizes)

by September most females were in a resting or recovering condition. Male GSI peaked between April and June, with spermiated and spent fish present from June to August. Maximum GSI values for males and females were 8.1 and 18.4 respectively.

The pattern of gonad development for fish from the west and south coasts showed some marked differences to that observed for north-east Tasmania, particularly for females. In June 1988 female GSI for western Tasmania was unexpectedly low and close to the August minimum. Unfortunately no estimates of GSI were available for June or July 1989. Female GSI for the southern fish peaked in May 1989 and by July had declined substantially. In 1990, GSIs showed little variation between April and August, with values for May and June substantially lower than those for north-eastern Tasmania. Male GSIs for west and south coast fish were slightly lower than those for north-eastern Tasmania between June and August, otherwise the pattern was similar for each of the three areas.

It is possible to explain these differences if changes in gonad condition are considered. During the course of this study it became apparent that not all post-mature females spawned each year. Some females showed no evidence of reproductive development in the period leading up to spawning (March - June), i.e. failed to initiate vitellogenesis, while in others there was evidence of wholesale atresia of maturing oocytes (Bell *et al.*, in press). Those fish which had not undergone vitellogenesis were easily recognised macroscopically whereas fish at early stages of arrested development proved difficult to stage visually. It is, therefore, possible that some of these individuals may have been classified as viable Stage 3.

Not all of the non-reproductive fish are distributed at the lower size limit for sexual maturity (refer to Figure 19), so lack of development cannot be attributed entirely to fish that mature later in life.

In June 1988 non-reproductive females represented 82% of the fish in the GSI sample from the west coast, while 62 and 53% of the females examined in June 1989 and 1990 respectively, from southern Tasmania were non-reproductive. The high proportion of non-reproductive fish in these samples has contributed to the low observed GSI values.

In order to investigate this phenomenon further, fish from north-eastern (predominantly St Helens spawning site) and southern Tasmania (predominantly Maatsuyker and Pedra Branca areas) were staged routinely as part of length/sex composition analysis. By recording gonad stages in this manner it has been possible to examine large numbers of fish and to supplement the biological information which is the basis of the GSI analysis.

The pattern of occurrence of non-reproductive fish appeared consistent between 1989 and 1990, though data for 1989 are more limited (Table 10 and Figure 20). In June 1989 almost 9% of the females examined from north-eastern Tasmania were judged to be non-reproductive while in early July, immediately prior to the onset of spawning, this figure had been halved. In 1990 the proportion of non-reproductive individuals decreased from about 44% in March/April to about 17% by June and to 2% by early July. By contrast, in June 1989 almost half of the females off the south coast were non-reproductive and this proportion had increased to 90% by early July. A similar pattern was observed in 1990 with just over half of the fish non-reproductive in June. No data were available for July 1990.

TABLE 10: Mean percentage (± S.D.) of non-reproductive female orange roughy (≥ 32 cm) in samples taken from north-eastern Tasmania (predominantly St Helens spawning site) and off southern Tasmania in March - July, 1989 and 1990. A sample is comprised of > 35 adult female orange roughy from either a single tow or landed catch. *N* is number of fish examined; - = no data.

Year	**1989**			**1990**		
Month	**No. samples**	***N***	**% non-repro.**	**No. samples**	***N***	**% non-repro.**
North-eastern Tasmania						
March	-			4	(160)	44.7±10.7
April	-			4	(307)	44.4±3.2
May	1	(42)	19.0	5	(486)	35.4±7.2
June	6	(464)	8.6±2.9	8	(1 164)	16.7±16.0
July*	2	(84)	4.6±2.6	19	(1 947)	2.1±1.9
Southern Tasmania						
March	-			2	(236)	34.4±21.2
April	-			3	(264)	41.7±9.4
May	1	(42)	21.4	1	(209)	49.3
June	5	(438)	49.3±26.6	5	(588)	55.3±15.7
July*	4	(228)	90.6±7.4	-		

* Pertains to samples collected prior to the date of the onset of spawning at St Helens (i.e.,13 July).

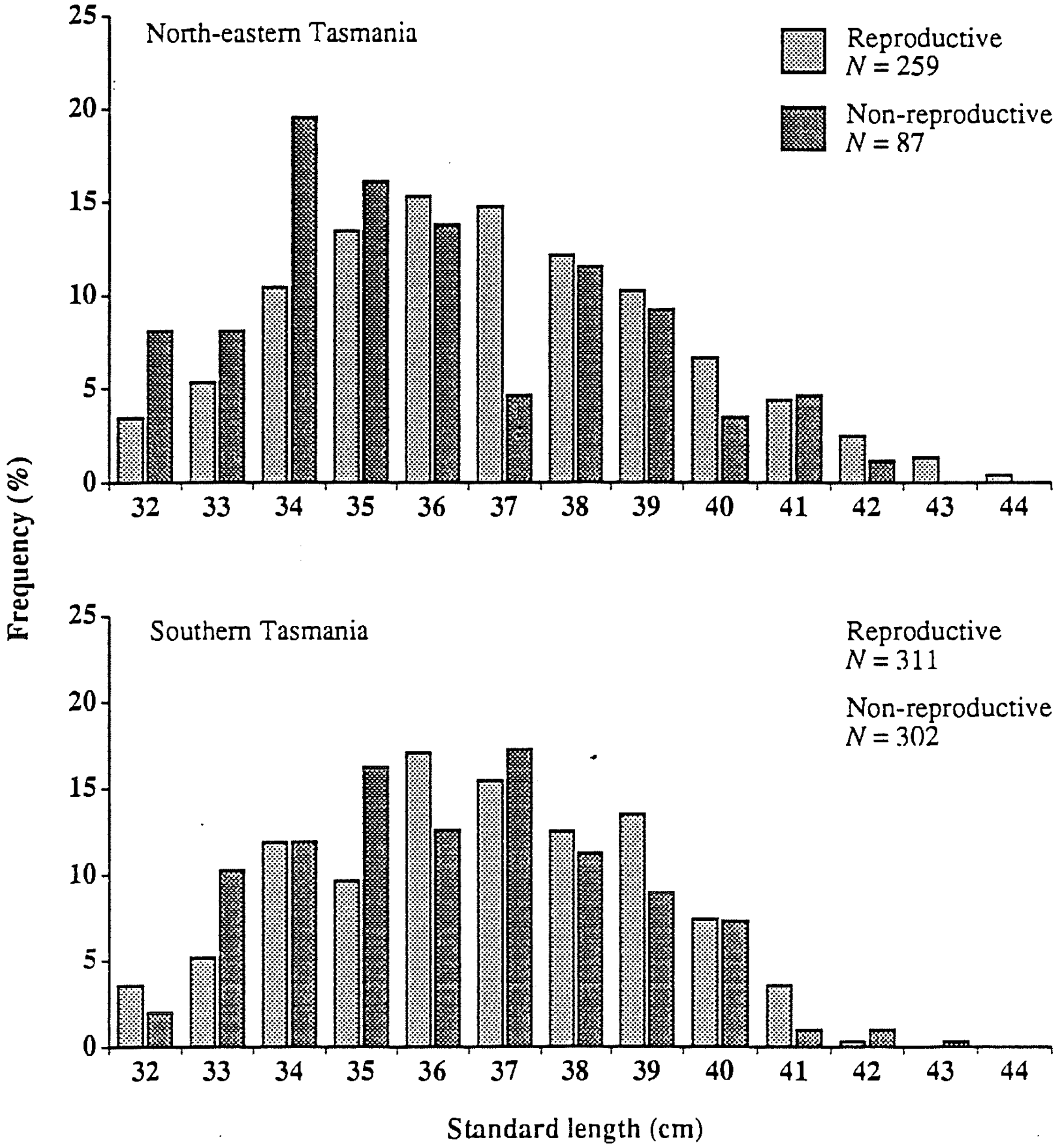


Figure 19: Length frequency distributions of random sub-samples of non-reproductive and reproductive females from north-eastern and southern Tasmania in March-June 1989 and 1990. (N = sample size)

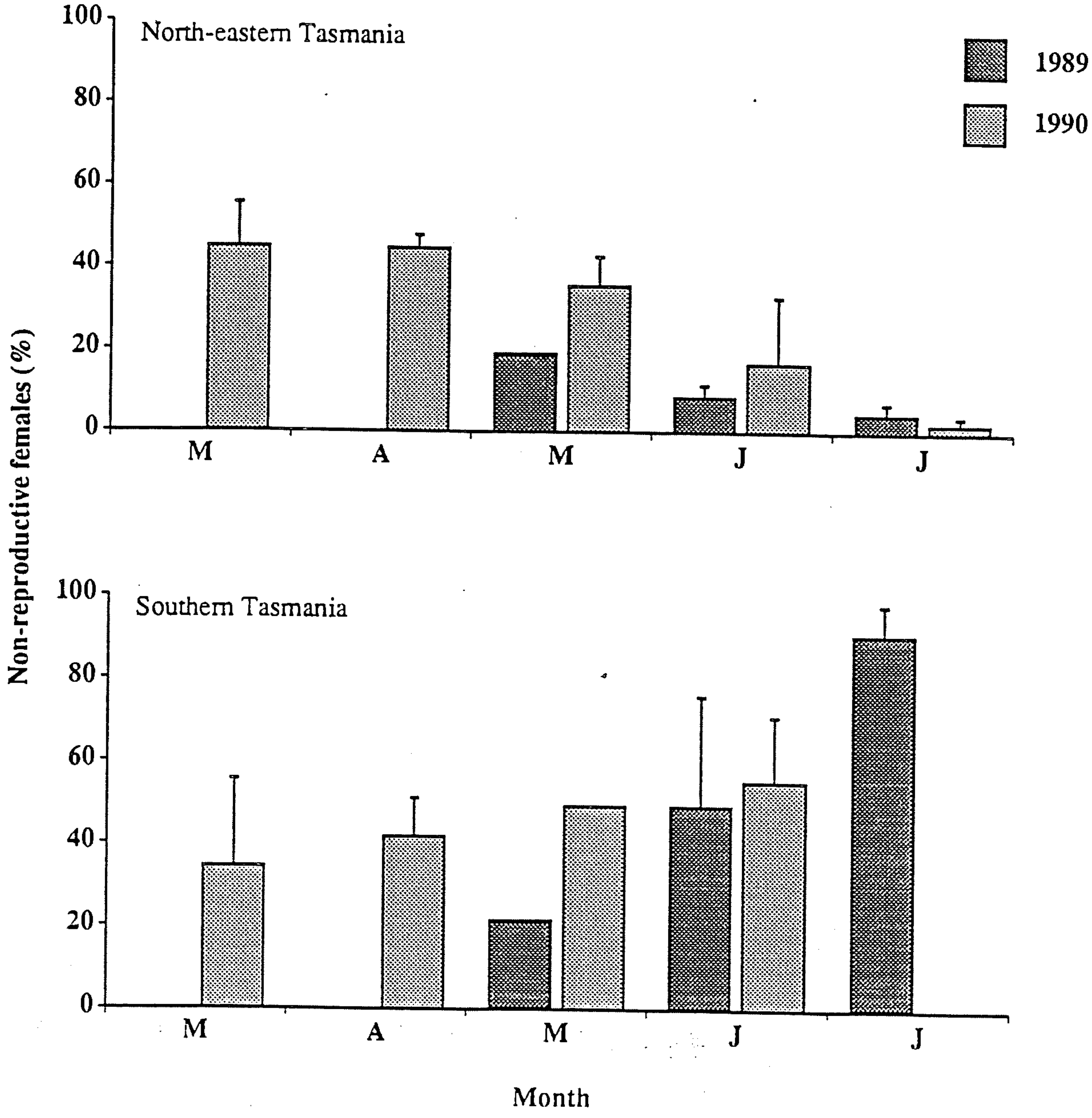


Figure 20: Mean percentage of non-reproductive females (≥32 cm) in samples of orange roughy from north-eastern and southern Tasmania in March-July 1989 and 1990. (Error bars are standard deviations)

3.3.4 Timing of spawning

The discovery of the St Helens spawning aggregation in 1989 enabled the timing of the spawning event to be defined precisely. Changes in female gonad stage between late June and early August are shown in Figure 21.

By 3 July 1989 almost 30% of the females examined were at Stage 4 (final oocyte maturation; nuclear migration and breakdown; coalescence of yolk material and oil droplet formation) though none were judged to have commenced spawning. Ten days later, over 50% of the ovaries were Stage 5 (running ripe) and 8% Stage 6 (spent). Fish with ovaries at Stage 5 continued to dominate the samples until the first week of August. By 8 August over 90% of the fish examined were spent.

A similar pattern was evident in 1990. From the beginning of July approximately 10% of the fish had Stage 5 ovaries. This proportion increased sharply on 13 July and at this time spent fish began to appear consistently. By the first week of August spawning was almost completed, with about 80% of females in a spent condition.

The collection of fertilized orange roughy eggs in the vicinity of the St Helens spawning aggregation site provided further confirmation of spawning in 1989. Between 20 July and 8 August eight plankton tows were undertaken in the immediate vicinity of the spawning site. The oblique tows were dropped to depths of between 425 and 855 m and all caught eggs (range 5 - 294 eggs). On 9 August an additional plankton tow approximately 15 nautical miles due south of the spawning site yielded six orange roughy eggs.

Plankton tows conducted off western Tasmania in mid-August 1988 yielded no orange roughy eggs. Most of the females observed at that time were either spent or in a resting state and less than 3% were still running ripe.

As noted above, a large proportion of the fish off southern Tasmania were non-reproductive. A small number of running ripe and spent females were, however, recorded, indicating limited spawning activity. The earliest recorded occurrence of an ovulated female was 11 July 1989 from the Maatsuyker 'hot spot'. In 1990, only one sample of fish was examined from southern Tasmania during July. The fish were caught from the Pedra Branca area on 27 July and in the sample of 81 females, 74% were at Stages 4 - 6.

3.3.5 Diet

The stomach contents of 4 101 orange roughy from western and 1 834 from north-eastern Tasmania were examined. The incidence of everted stomachs was vary rare (< 0.3% of the fish examined), probably because the swim bladder in orange roughy is filled with a fatty wax ester rather than gas. Fish were divided into two categories to examine dietary changes with size - < 30 cm (juveniles) and ≥ 30 cm (adults). Overall, about 50% of the stomachs contained food, the proportion being slightly lower among west coast juveniles and north-east coast adults (Table 11).

Crustaceans were the most frequently occurring prey, present in 70% of the stomachs from either coast (Table 11). Fish and cephalopods were present in approximately 35% and 10% of the stomachs, respectively. Adult orange roughy preyed more heavily on fish and cephalopods than juveniles and crustaceans were more commonly consumed by juveniles.

TABLE 11: Percentage occurrence (based on stomachs with food) of the main prey categories in the stomachs of orange roughy from western and north-eastern Tasmania.

	Percentage occurrence					
	Western Tasmania			North-eastern Tasmania		
Prey category	Juv.	Adult	Total	Juv.	Adult	Total
Fish	23.0	49.1	36.7	15.1	48.1	35.0
Crustacea	80.0	61.0	70.0	90.7	56.4	70.0
Cephalopod	7.1	14.0	10.7	3.0	9.1	6.7
Other	0.4	0.6	0.5	0.6	1.4	1.1
No. examined	2 067	2 034	4 101	633	1 201	1 834
No. with food	990	1 094	2 084	332	507	839
% with food	47.9	53.8	50.8	52.4	42.2	45.8

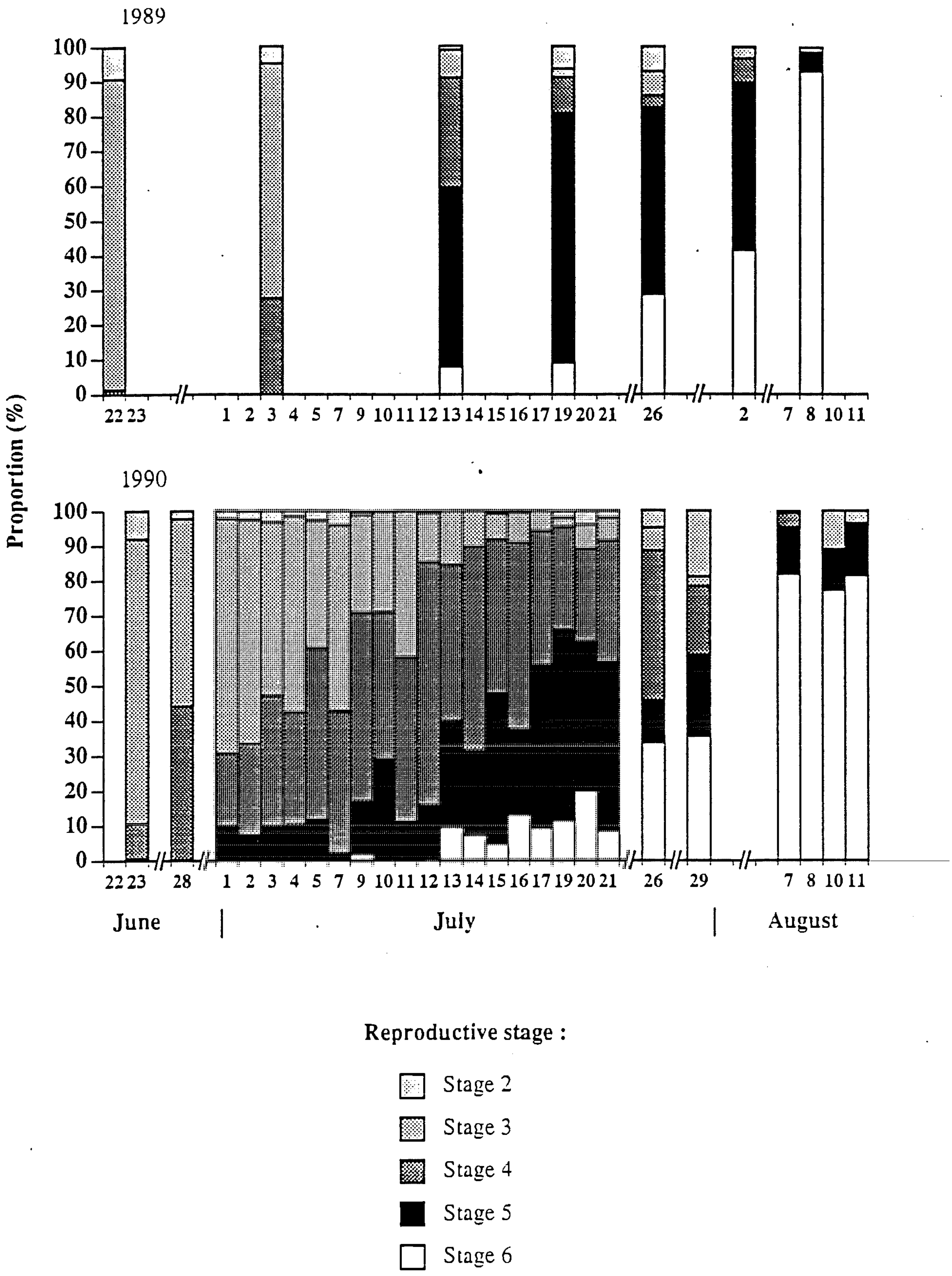


Figure 21: Change in sexual stage with date of female orange roughy (≥32 cm) captured from the St. Helens spawning aggregation in June-August 1989 and 1990.

Crustaceans were mainly represented by deep-water prawns, although amphipods (family Gammaridae) and copepods were recorded. Most of the fish encountered in the stomachs were too digested to be readily identified. However, of the recognisable fish prey, members of the families Macrouridae (whiptails), Neoscopelidae (lantern fish), Myctophidae (lantern fish), Nemichthyidae (snipe eels) and Alephocephalidae (slickheads) were the most commonly encountered. Other less frequently occurring fish families included Gonostomatidae (light fish), Paralepididae (barracudina), Bathylagidae (deep-sea smelts), Melanostomiatidae (dragon fish), Melamphaeidae (crusthead), Sternoptychidae (hatchet fish), Apogonidae (cardinal fish), Chauliodontidae (viper fish) and Idiacanthidae (dragon fish). Cephalopods were represented entirely by squid, most of which were at an advanced stage of digestion and in many instances only beaks remained. Specimens belonging to the families Chiroteuthidae and Histioteuthidae were identified. Apart from the major taxa, Gastropoda, Echinodermata, Tunicata and medusae were infrequently ingested.

Seasonally, the proportion of stomachs containing food did not differ greatly from 50% for fish from the west coast, the pattern being similar for juveniles and adults (Figure 22a). By contrast, adult fish from north-eastern Tasmania exhibited a pronounced seasonal feeding pattern, with less than 20% of the stomachs containing food during winter compared to over 45% in spring and summer (Figure 22b). The pattern was less distinct for juveniles with only slight fluctuations around the 50% level.

There was no evidence for a distinct seasonal pattern of feeding on the major prey categories, with minor variations in the occurrence of the prey over the sampling period (Figure 22).

3.4 Warty Oreo Biology

3.4.1 Length-weight relationship

Length-weight relationships for male and female warty oreo are:

Males:	$W = 1.48 \times 10^{-2} L^{3.139}$	$N = 1\,469$, $r^2 = 0.97$ ($P < 0.001$)
Females:	$W = 1.29 \times 10^{-2} L^{3.191}$	$N = 1\,708$, $r^2 = 0.98$ ($P < 0.001$)

where L is total length (cm). There was a significant difference between the exponents of the two curves ($F = 7.81$; d.f. 1, 3 173: $0.005<P<0.01$) indicating that sex influences the length-weight relationship. Plots of length against weight for male and female warty oreo are shown in Figure 23.

3.4.2 Size and sex composition

Length frequency distributions for warty oreo are based on data for both coasts combined and have been scaled up where sub-sampling occurred (Figure 24). Fish measured 10 - 39 cm total length with females attaining larger sizes than males (largest male being 37 cm).

Although not clearly defined, a bimodal size structure was apparent, with a broad mode between 17 - 25 cm and another between 29 - 34 cm. The two modes were separated by a shallow trough at 27 - 28 cm. With the exception of summer 1988/89, the mode of smaller fish dominated. The summer 1988/89 sample was influenced by two big catches of predominantly large fish.

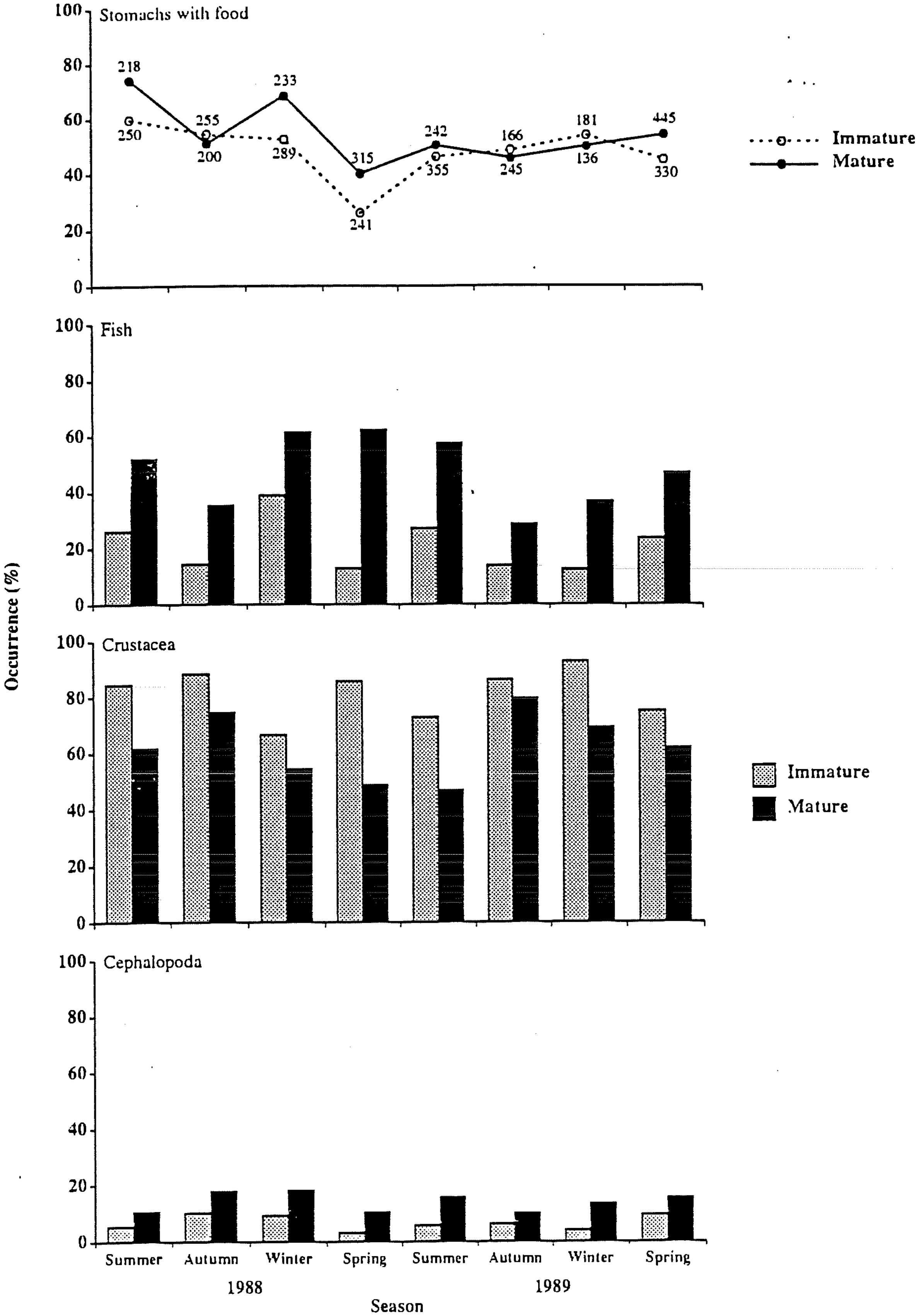


Figure 22a: Seasonal occurrence of stomachs containing food and proportion of stomachs with food that contained fish, crustacea and cephalopods for immature (<30 cm) and mature (≥30 cm) orange roughy from western Tasmania. (numbers are sample sizes)

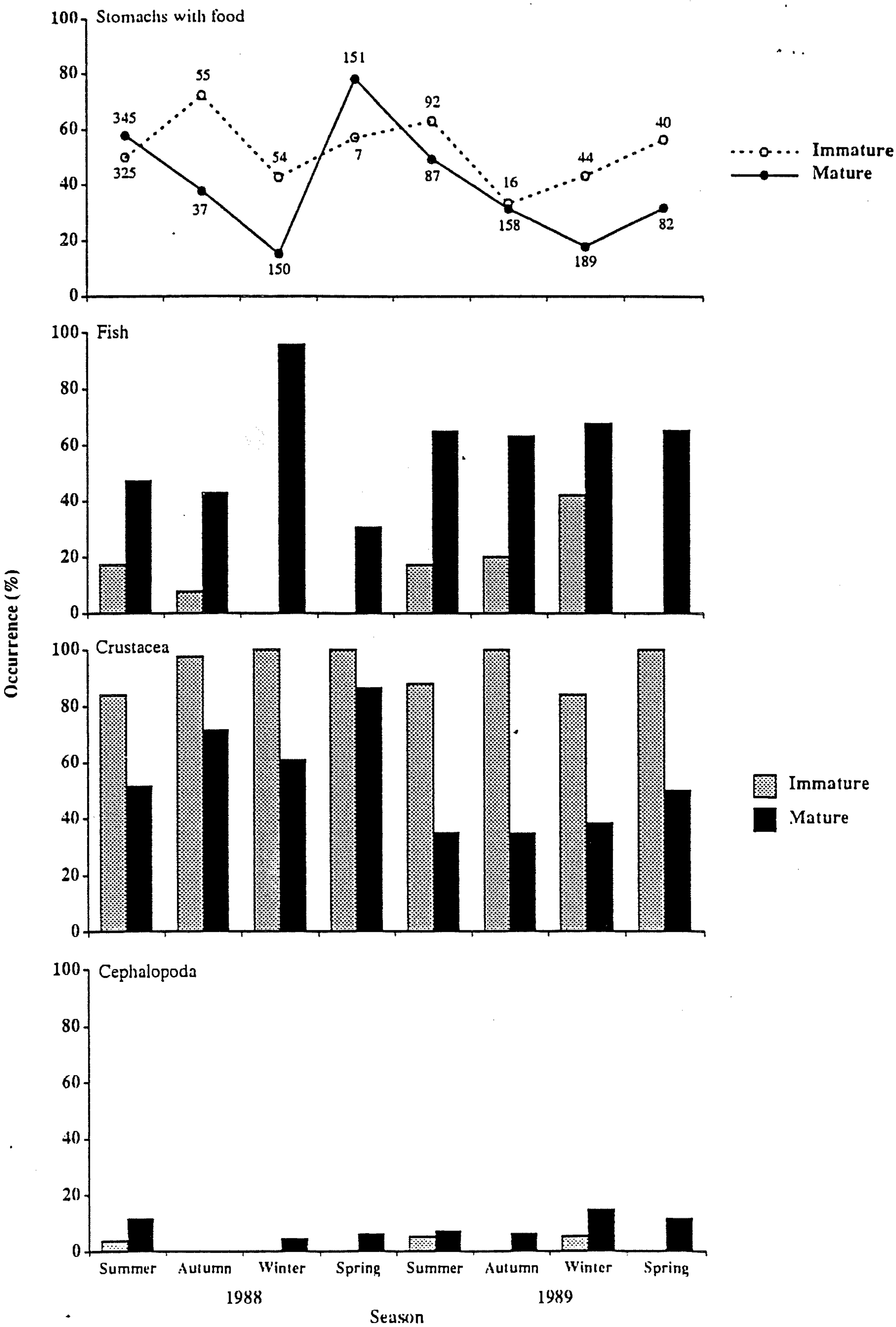


Figure 22b: Seasonal occurrence of stomachs containing food and proportion of stomachs with food that contained fish, crustacea and cephalopods for immature (<30 cm) and mature (≥30 cm) orange roughy from north-eastern Tasmania. (numbers are sample sizes)

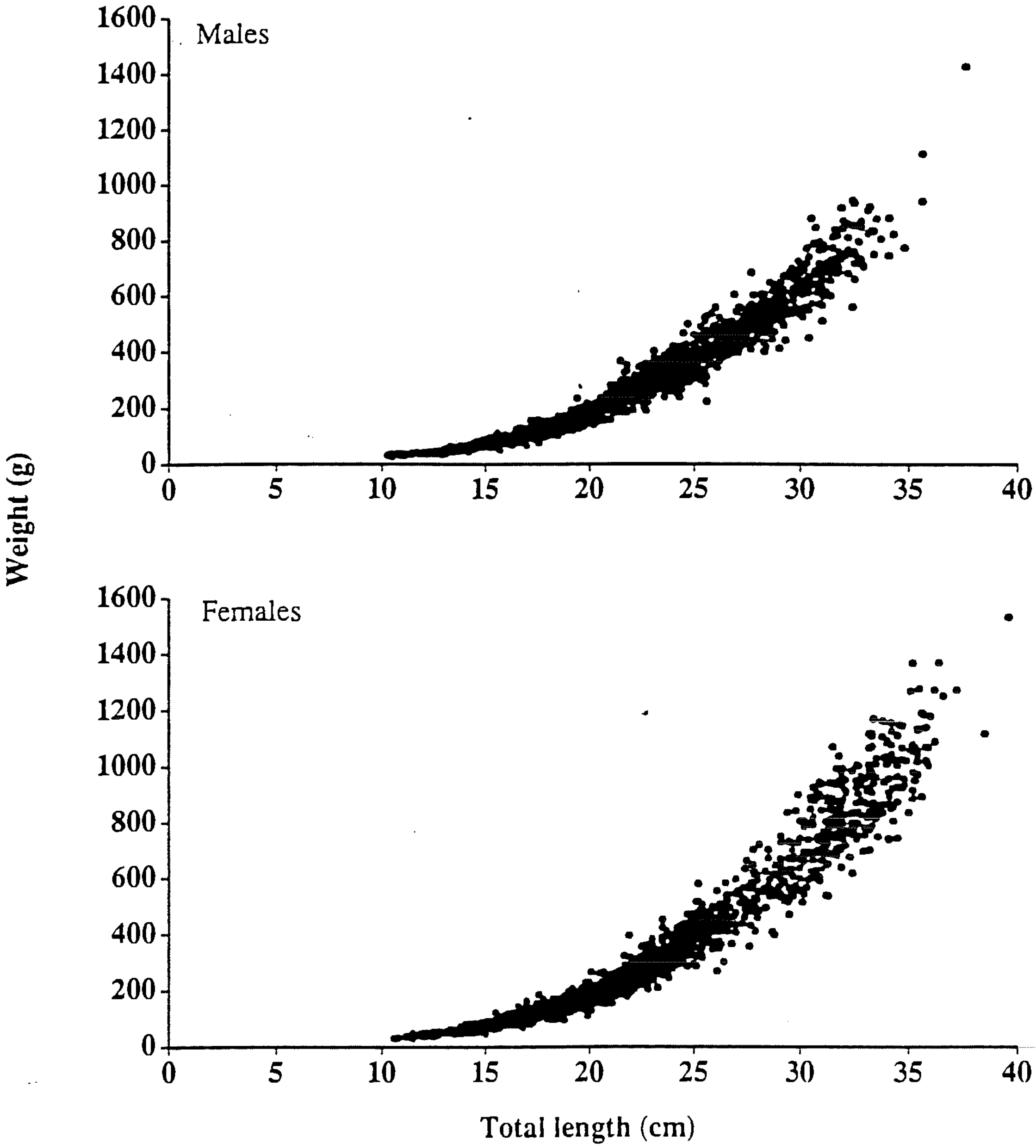


Figure 23: Length-weight relationships by sex for warty oreo.

The bimodal size distribution was more pronounced for females (Figure 24). Length frequency distributions for fish smaller than about 25 cm were very similar for both sexes. When distinct modal peaks for the larger size classes were evident, the female peak occurred at 31 or 34 cm compared to 28 - 30 cm for males.

In most seasons sex ratios did not differ greatly from 1:1, though there was a slight but significant excess of females overall (Table 12).

3.4.3 Length at maturity

By comparing the proportion of mature fish for each centimetre length class, it was evident that greater than 50% of the fish were judged mature at 24 cm in males and 28 cm in females (Figure 25). Sizes at first maturity were 18 cm for males and 23 cm for females.

3.4.4 Reproductive cycle

Monthly changes in GSI for mature females (i.e. ≥ 28 cm) suggest a distinct reproductive cycle, with the GSI peaking in April and May, and declining sharply by August (Table 13). Mean GSI values were 6.9 - 7.6 in April and May, with individual values of up to 14.6. Of the mature females examined in May 1989, 37% were Stage 4 and a single spent fish was found. No running ripe fish were recorded. Despite the absence of information for June and July, available data suggest that ovaries commence to ripen in April/May with spawning completed by August.

Monthly GSI values for mature males (i.e. ≥ 24 cm) did not show such a pronounced seasonal cycle (Table 13). Gonad staging data revealed the presence of some spent fish between August and September, which supports an early winter spawning season.

3.4.5 Diet

Out of a total 3 173 warty oreo examined for stomach contents, 55.7% were everted. Unlike orange roughy, oreos have a gas filled swim bladder and this will have contributed to the high proportion of everted stomachs. No distinct seasonal feeding cycle was apparent, with around 90% of the non-everted stomachs containing food (Figure 26).

Crustaceans were found in 71.4%, fish in 33.5% and cephalopods in 26.3% of the stomachs that contained food. Crustaceans were mainly represented by prawns, with amphipods (family Gammaridae) and copepods (mostly in small fish) also eaten. Although fish prey were usually at an advanced stage of digestion, members of the families Myctophidae, Macrouridae (*Coryphanoides* sp.), Neoscopelidae, Gonostomatidae and Nemichthyidae were identified. Cephalopods were entirely represented by squid and in many instances only beaks remained.

There was little evidence of a seasonal pattern of feeding on the main food types, with only minor variations in the percentage occurrence of the prey over the sampling period (Figure 26). The low occurrence of cephalopods during summer 1988/89 was offset by increased predation on crustaceans at that time.

TABLE 12: Number (scaled for sub-sampling) of warty oreo examined and percentage of females by season. Sex ratios differing significantly from 50% are indicated (based on Chi-square test). n.s., not significant: * $P < 0.05$; ** $P < 0.01$; N is sample size.

Year	Season	N	% female
1988	Summer	1 491	48.7 n.s.
	Autumn	2 113	51.8 n.s.
	Winter	1 027	55.6 **
	Spring	827	48.9 n.s.
1989	Summer	5 294	51.6 *
	Autumn	1 363	54.8 **
	Winter	1 030	50.5 n.s.
	Spring	1 013	47.8 n.s.
	All data	14 158	51.4 **

TABLE 13: Gonosomatic index (GSI) values for warty oreo. N is sample size; SD is standard deviation.

Month	N	Male GSI mean±SD	Range	N	Female GSI mean±SD	Range
1988						
February	76	0.75±0.39	0.04-1.90	44	5.43±2.24	0.06-8.59
April	78	0.62±0.39	0.06-1.97	52	6.93±3.53	0.30-14.35
August	67	0.60±0.35	0.06-1.40	49	3.22±1.14	0.25-5.15
November	48	0.76±1.02	0.02-5.76	21	4.12±1.82	0.16-6.18
1989						
February	55	0.69±0.44	0.03-1.68	35	5.89±2.31	0.52-9.29
May	76	0.61±0.37	0.03-1.49	62	7.56±3.86	0.02-14.64
August	50	0.80±0.40	0.12-1.68	37	3.45±0.81	1.29-4.98
September	32	0.53±0.37	0.03-1.35	21	3.58±1.40	0.28-5.84
November	56	0.68±0.43	0.05-1.57	48	4.32±1.86	0.27-8.18

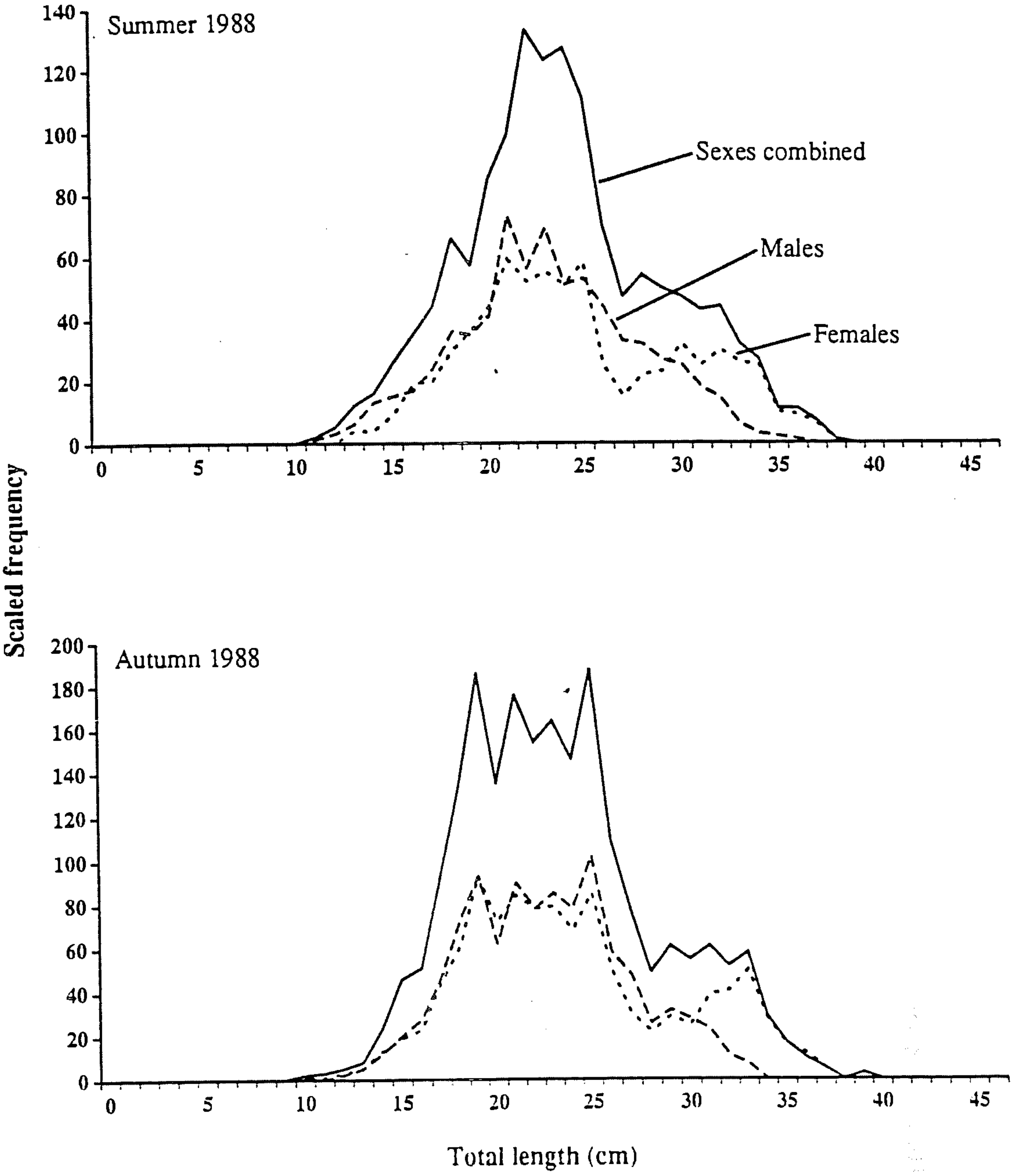


Figure 24: Scaled (by percentage sampled) length frequency distributions of warty oreo by season.

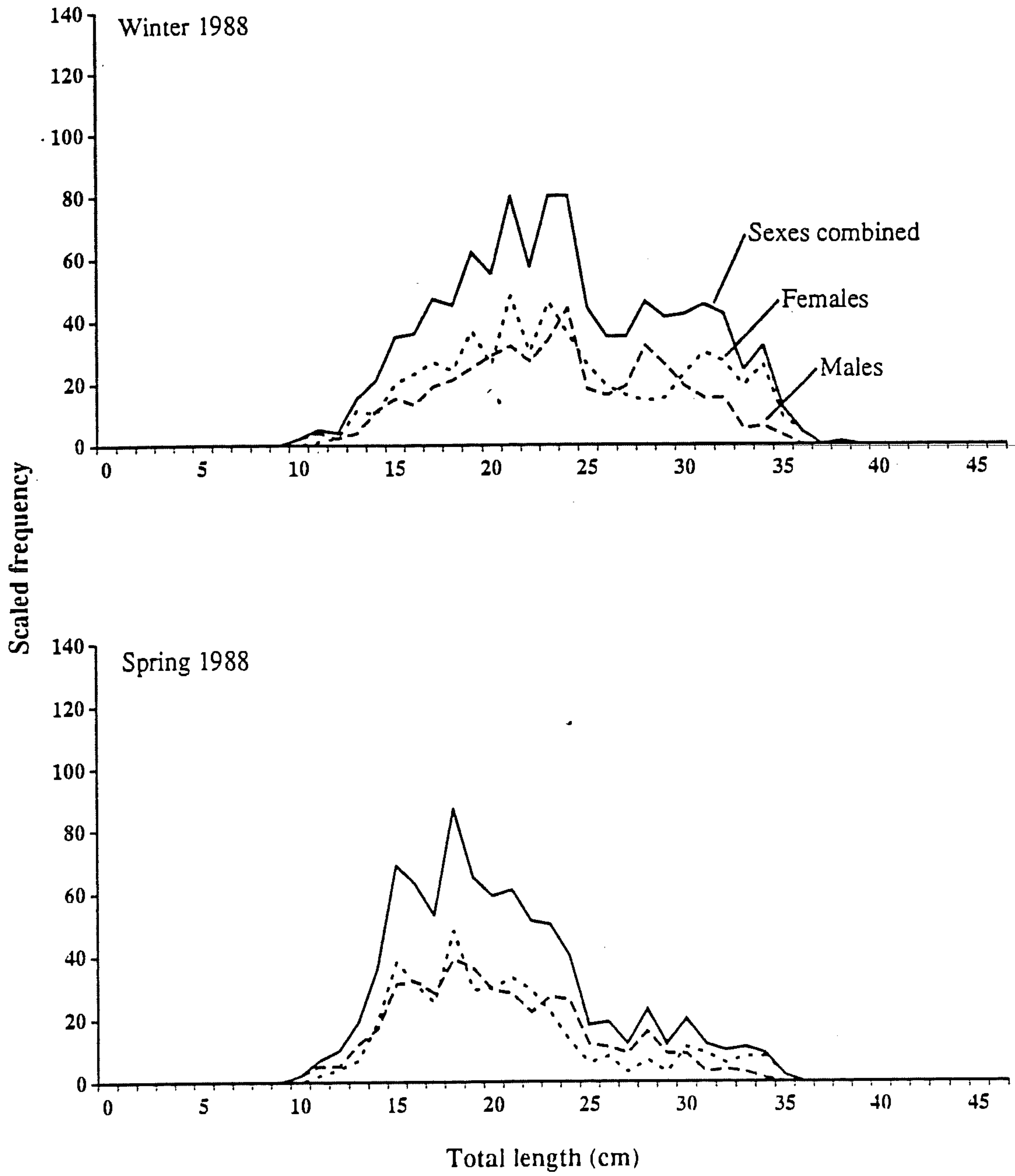
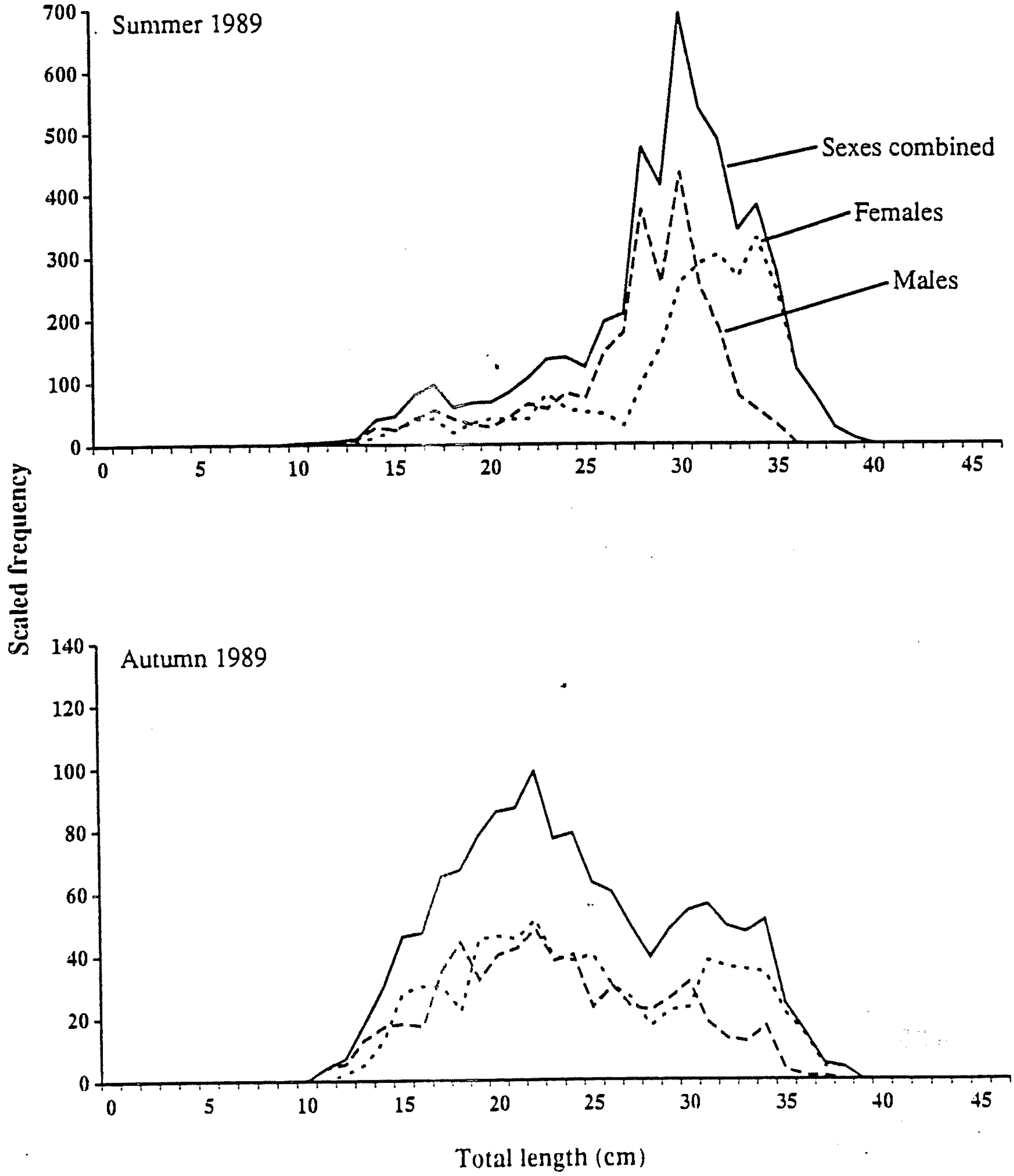


Figure 24: (cont.)



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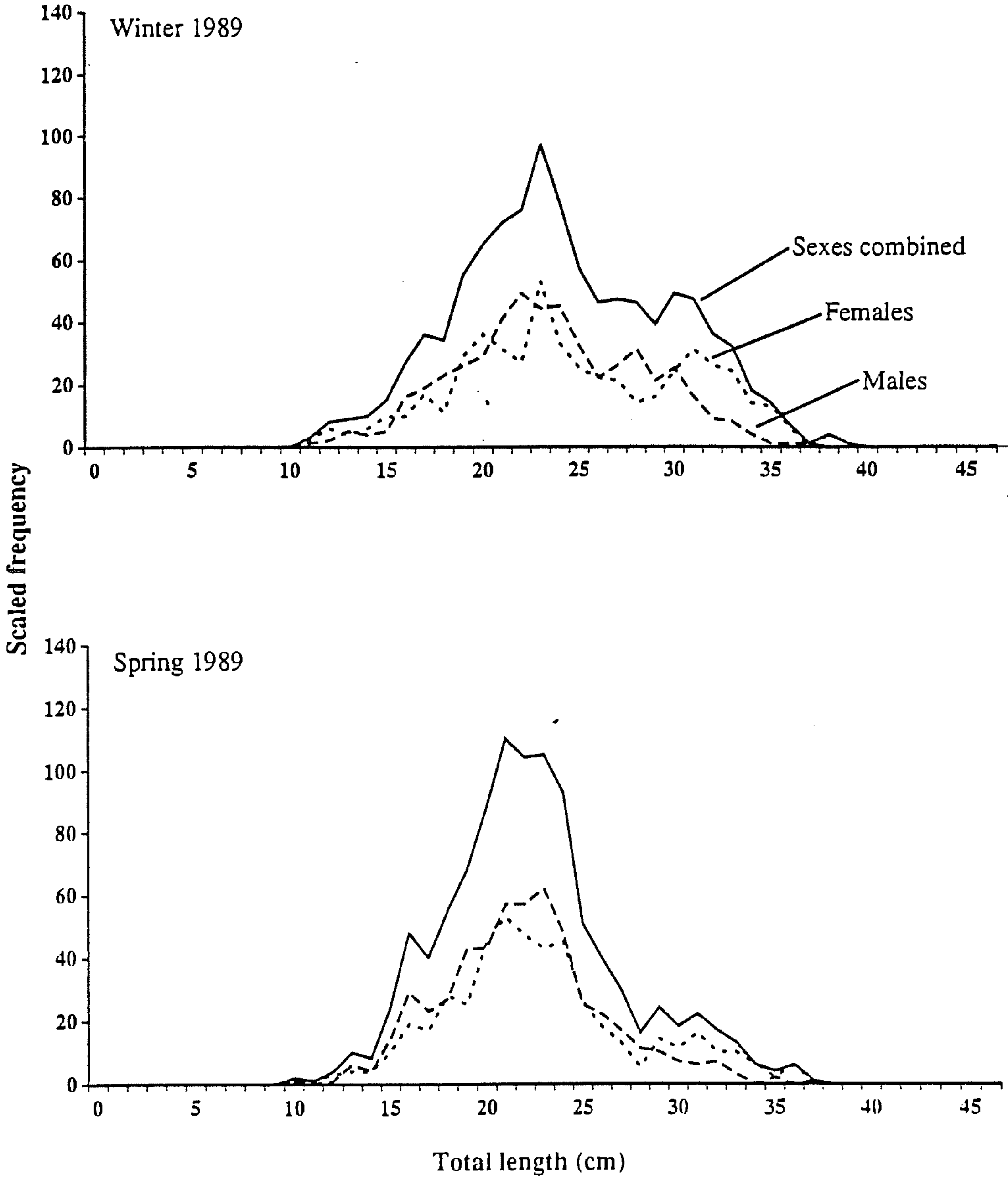

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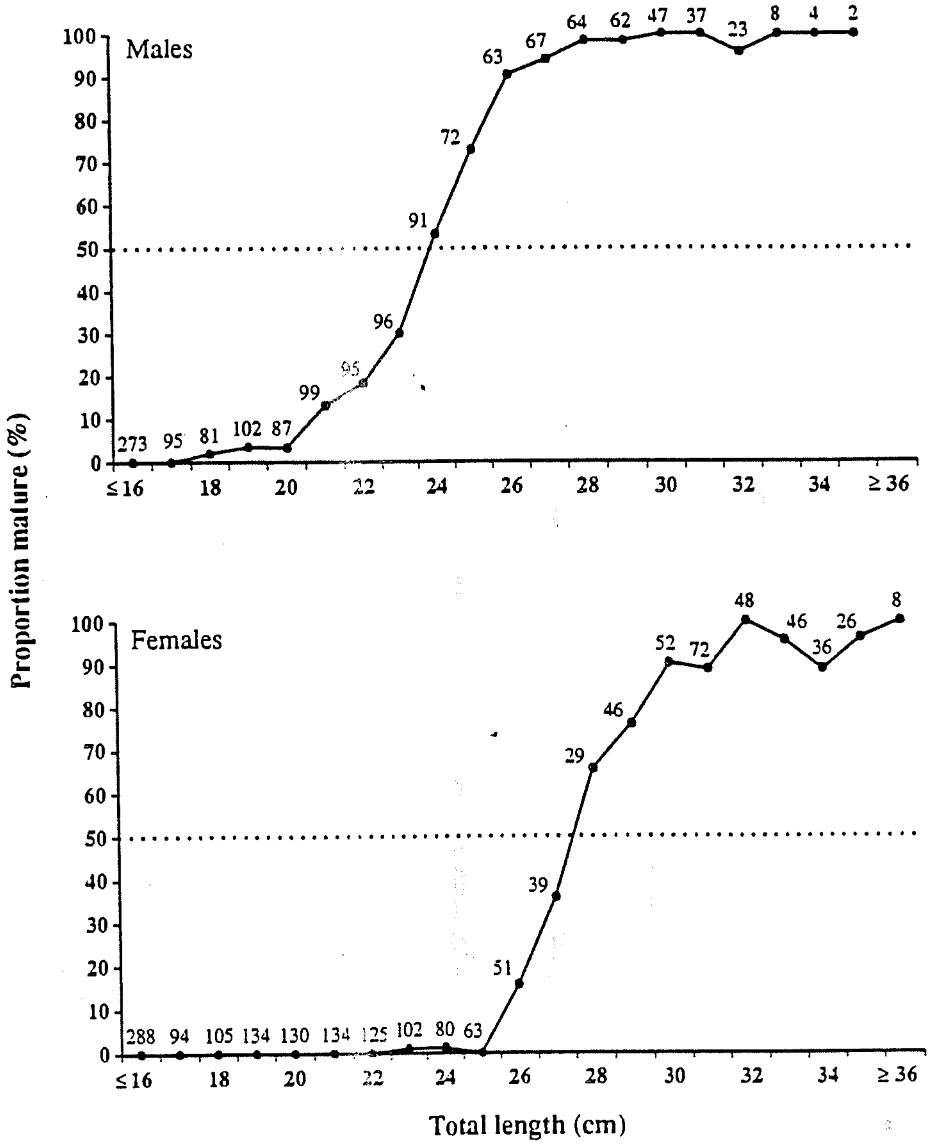


Figure 25: Proportion of mature fish in each centimetre size class of warty oreo. (numbers are sample sizes)

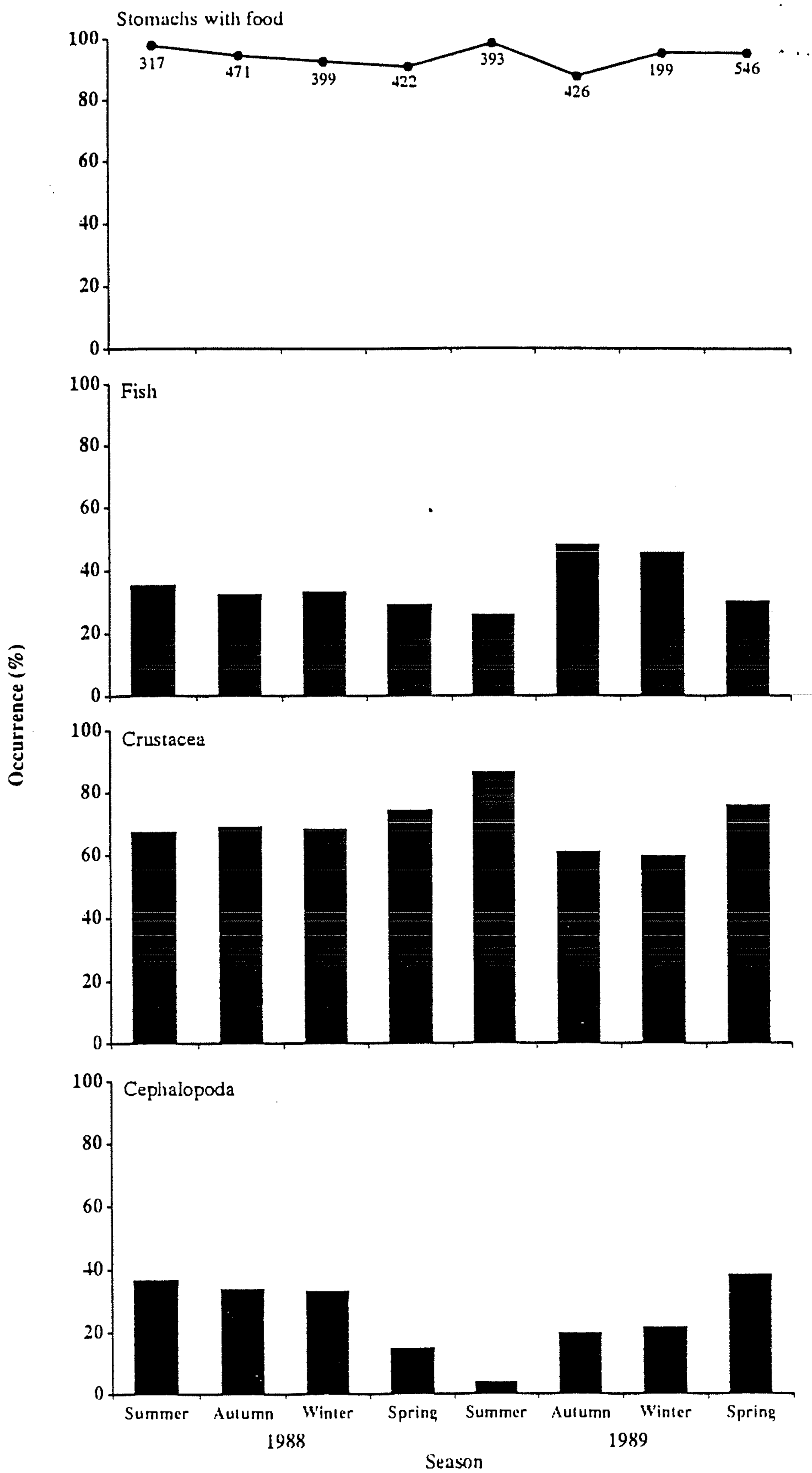


Figure 26: Seasonal occurrence of stomachs containing food (excluding everted stomachs) and proportion of stomachs with food that contained fish, crustacea and cephalopods for warty oreos. (numbers are sample sizes)

3.5 Spiky Oreo Biology

3.5.1 Length-weight relationship

Length-weight relationships by sex for spiky oreo are:

Males:	$W = 2.52 \times 10^{-2} L^{2.946}$	$N = 622$, $r^2 = 0.99$ ($P < 0.001$)
Females:	$W = 2.29 \times 10^{-2} L^{2.980}$	$N = 798$, $r^2 = 0.99$ ($P < 0.001$)

where L = total length (cm). There was a significant difference between the exponents of the two curves ($F = 4.12$; d.f. 1, 1 416: $0.025 < P < 0.05$) indicating that sex influences the length-weight relationship. Plots of length on weight by sex are shown in Figure 27.

3.5.2 Size and sex composition

Length frequency distributions for spiky oreo, based upon data for both coasts combined, are shown in Figure 28. Spiky oreos ranged from 8 - 44 cm, the largest male and female individuals being 43 cm and 44 cm, respectively. Although sample sizes were comparatively small, several modes were apparent in most samples. Modes were consistently present at 10 - 12 cm, 14 - 15 cm, 20 - 22 cm, 32 - 34 cm and 35 - 37 cm.

There were significantly more females in the samples, representing 56% of the total numbers, and this trend was evident in most seasons (Table 14).

3.5.3 Length at maturity

By comparing the proportions of mature to immature fish for each centimetre length class, it was evident that the size at 50% maturity occurs at about 29 cm in males and 34 cm in females, with sizes at first maturity of 28 cm and 29 cm, respectively (Figure 29).

3.5.4 Reproductive cycle

Monthly changes in GSI values for mature females (i.e. ≥ 34 cm) suggest a regular cycle in reproductive activity, with GSI peaking in August and September, then declining sharply by November (Table 15). Mean GSI values were between 3.1 - 4.6 between August and September, with individual values of up to 8.2. Of the mature females examined in August 1988, 42% of the ovaries were at Stage 4 and a further 14% were Stages 5 and 6. In August/September 1989, just under 10% of the fish were at Stages 4 - 6. Spent fish accounted for 15 and 45% of the November 1988 and 1989 samples, respectively. The remaining mature fish were either recovering or in a resting condition at this time.

Although monthly GSI values for mature males (i.e. ≥ 29 cm) do not show a clear trend, analysis of reproductive condition indicated the first occurrence of spent males in August and by November 1989, over two-thirds of mature males were spent. These data suggest that spiky oreos spawn in late winter to early spring, with spawning completed by November.

3.5.5 Diet

Detailed dietary analysis for spiky oreo could not be undertaken since 93.8% of the 1 427 stomachs examined were everted. Of the 55 stomachs that contained food, fish and crustaceans were each present in 23.6%, cephalopods were found in 18.2% and other prey taxa (almost exclusively salps) occurred in 49.0% of the stomachs.

TABLE 14: Number of spiky oreo examined and percentage of females by season. Sex ratios differing significantly from 50% are indicated (based on Chi-square test). n.s., not significant; * $P < 0.05$; ** $P < 0.01$; N is sample size.

Year	Season	N	% female
1988	Summer	351	56.5 *
	Autumn	246	59.4 **
	Winter	204	55.2 n.s.
	Spring	263	50.4 n.s.
1989	Summer	530	51.7 n.s.
	Autumn	302	59.5 **
	Winter	126	61.2 *
	Spring	156	60.7 **
	All data	2 178	55.8 **

TABLE 15: Gonosomatic index (GSI) values for spiky oreo. N is sample size; SD is standard deviation.

Month	N	Male GSI mean±SD	Range	N	Female GSI mean±SD	Range
1988						
February	68	0.36±0.25	0.02-1.23	72	1.57±0.65	0.45-3.90
April	37	0.41±0.22	0.06-0.97	46	2.80±1.12	0.44-5.72
August	30	0.26±0.13	0.05-0.50	43	3.06±1.53	0.57-5.79
November	57	0.29±0.18	0.03-0.80	55	1.41±0.84	0.01-5.84
1989						
February	93	0.38±0.22	0.06-0.84	90	1.73±0.83	0.06-3.90
May	28	0.40±0.28	0.03-1.13	37	2.22±1.37	0.41-4.92
August	16	0.34±0.21	0.05-0.91	16	4.32±2.58	0.34-8.16
September	9	0.38±0.16	0.17-0.72	15	4.62±1.84	0.42-6.87
November	40	0.39±0.21	0.07-1.07	42	1.51±0.57	0.40-2.82

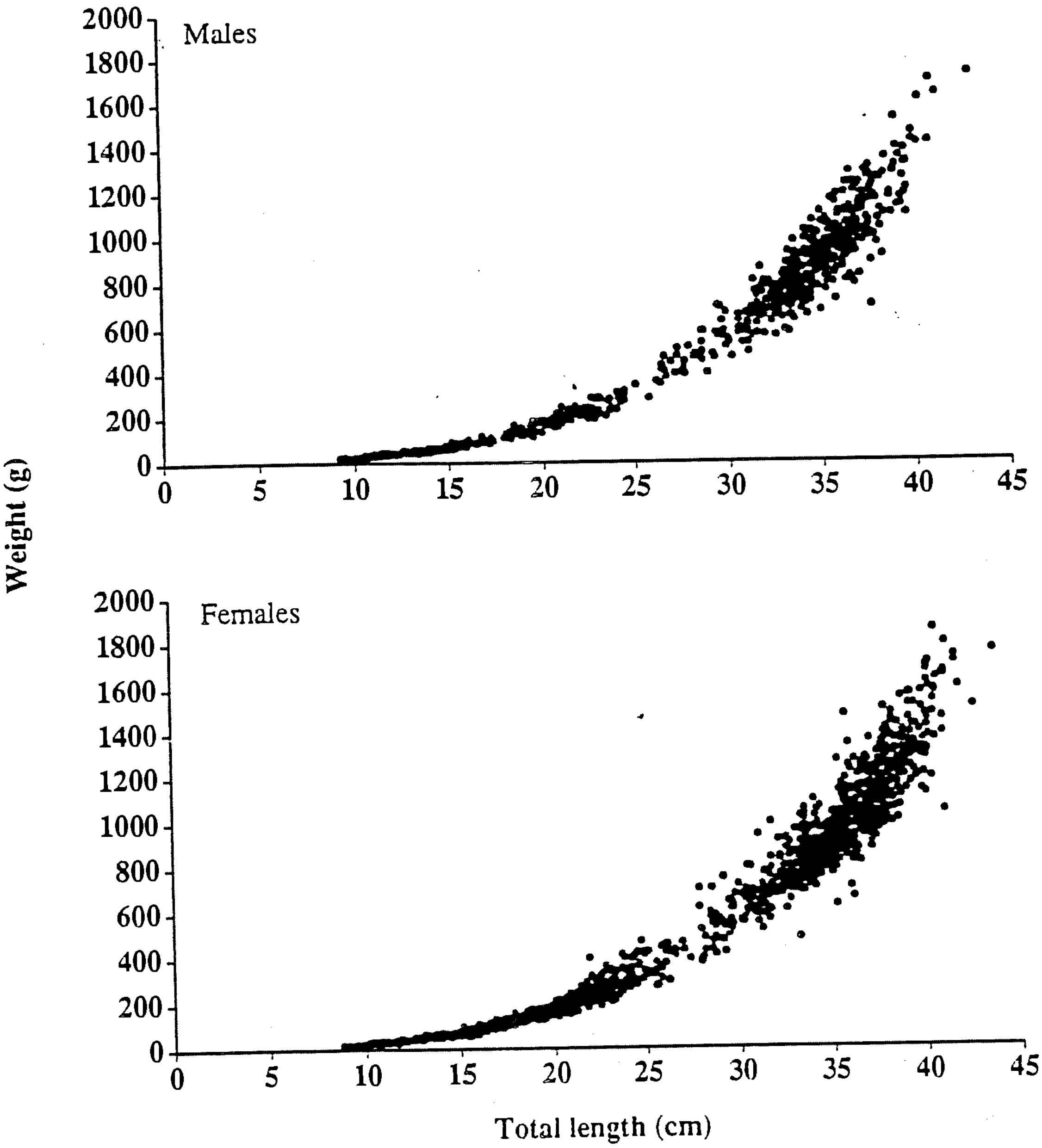


Figure 27: Length-weight relationships by sex for spiky oreo.

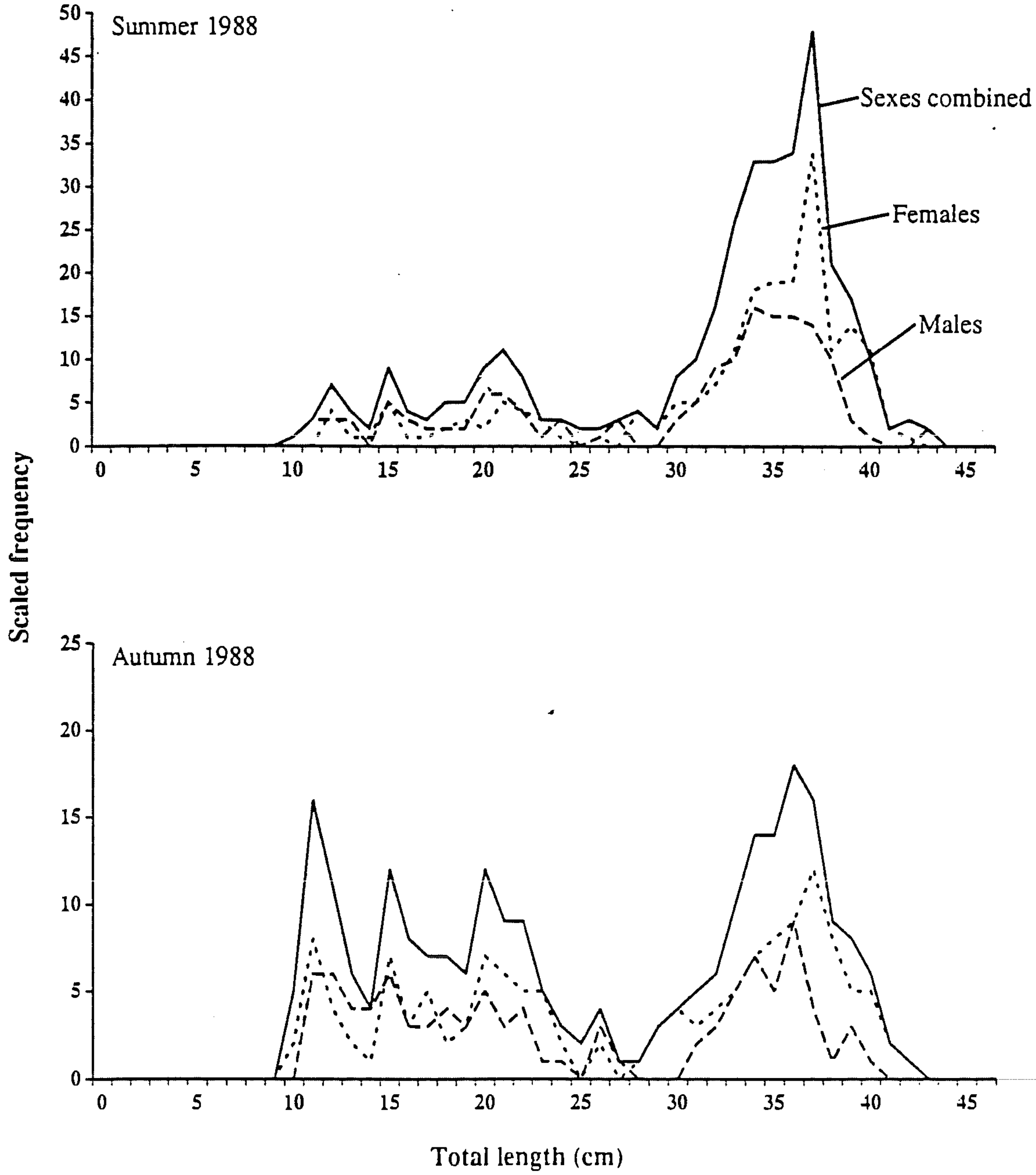


Figure 28: Scaled (by percentage sampled) length frequency distributions of spiky oreo by season.

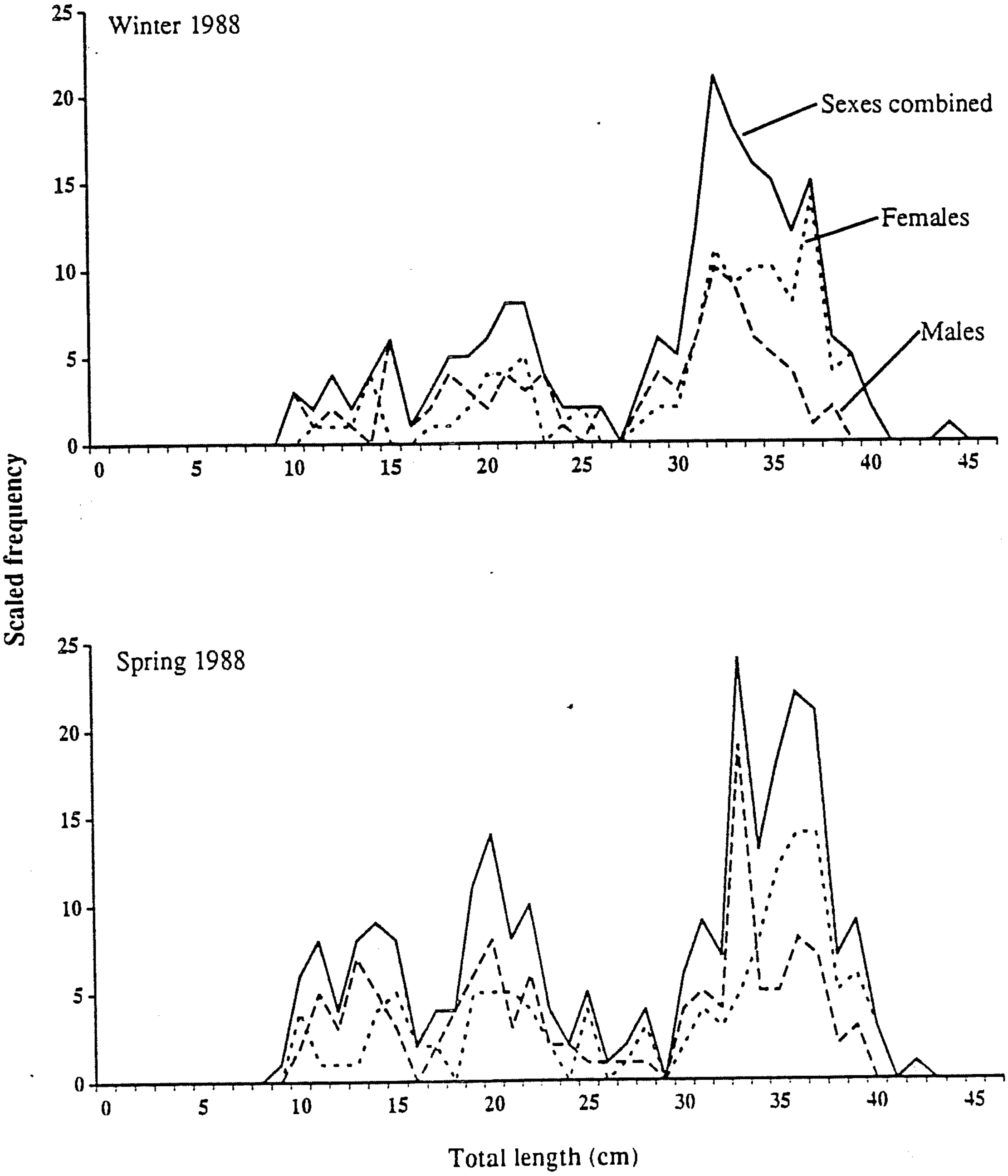
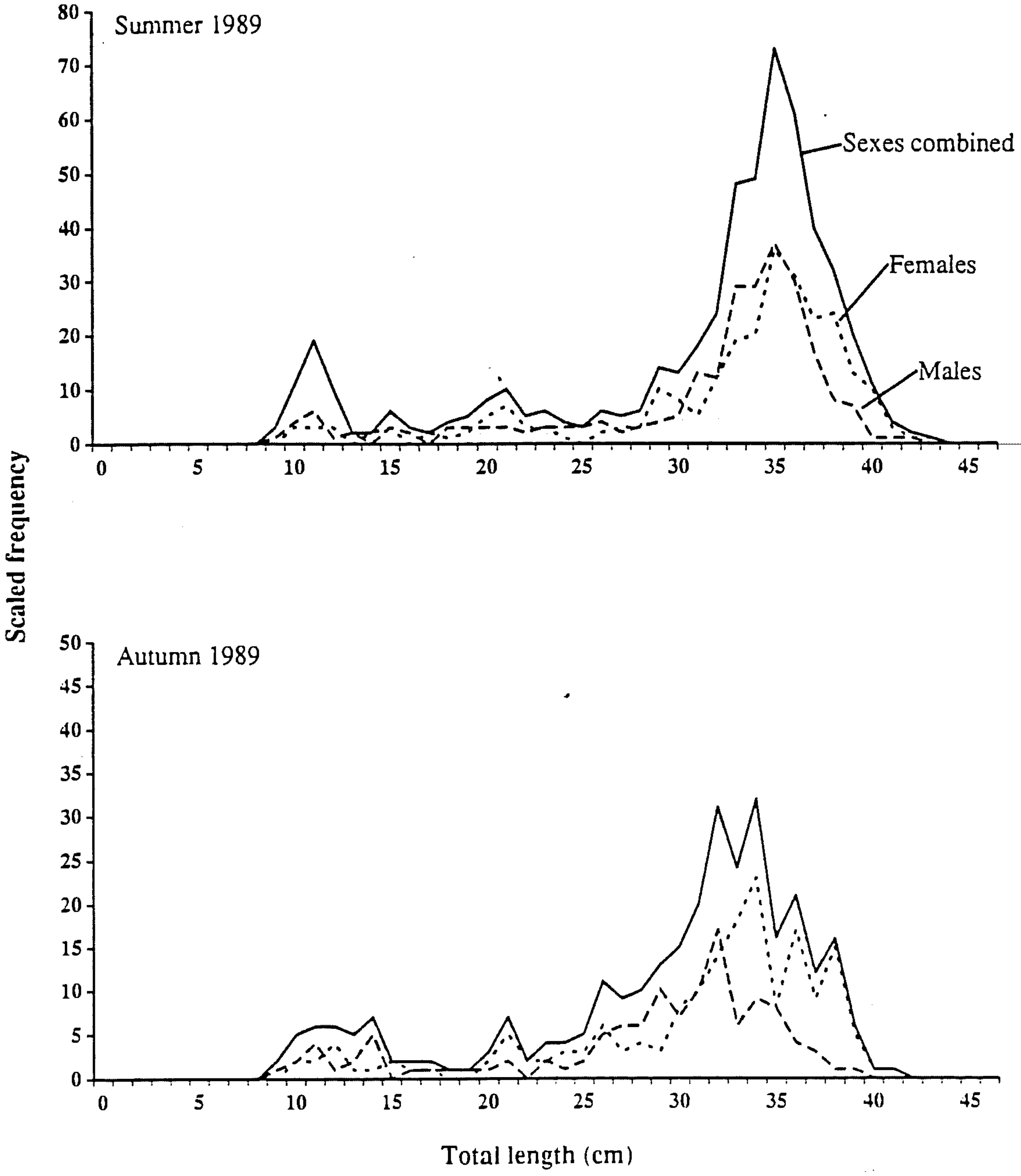


Figure 28: (cont.)



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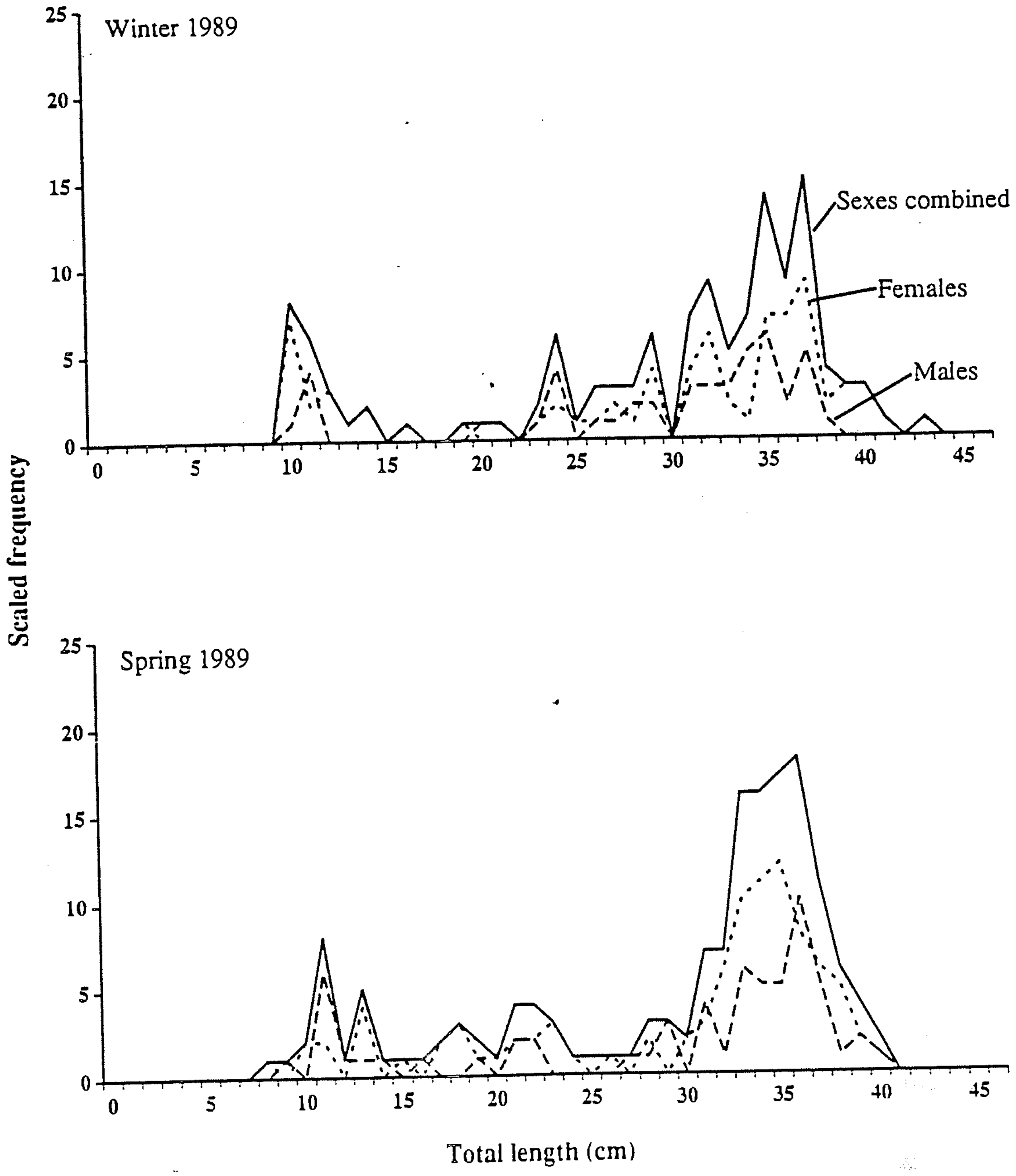

Figure 28: (cont.)

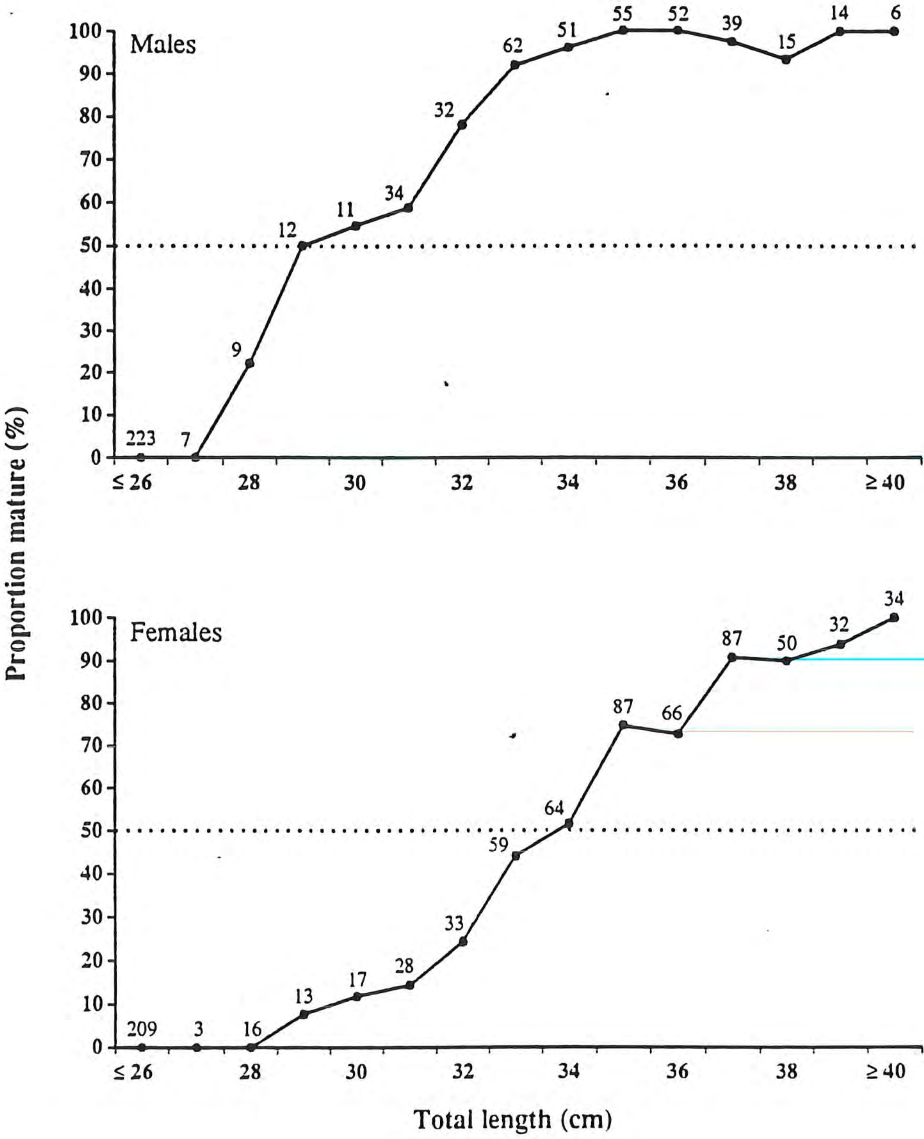

Figure 29: Proportion of mature fish in each centimetre size class of spiky oreo. (numbers are sample sizes)

4. DISCUSSION

4.1 Biomass

Extensive areas of rough ground exist off southern, south-eastern and north-eastern Tasmania, accounting for almost two-thirds of the mid-slope region. Because of the risk of damage to fishing gear in such areas, survey coverage was restricted to areas of relatively smooth and readily trawlable bottom.

The estimated biomass of orange roughy in the NW Tas and NE Tas areas was of a low order, generally below 1 500 tonnes in each area, and there was little evidence of seasonal or interannual variability. Coefficients of variation on the estimates for NW Tas were comparatively low and comparable with those achieved in New Zealand trawl surveys (Robertson *et al.*, 1984; Tracey *et al.*, 1990). Coefficients of variation were somewhat higher for NE Tas and have resulted from low sampling density combined with the patchy distribution of the fish.

Extrapolation to include unsampled areas produced biomass indices of 4 000 - 11 500 tonnes for the entire Tasmanian region, though little confidence can be attributed to these estimates.

Other trawl surveys of the mid-slope waters off south-eastern Australia have also produced low estimates of orange roughy biomass. In 1988, CSIRO undertook a stratified random trawl survey between Kangaroo Island (137° E), around Tasmania and east to Gabo Island (150° E) (a total area of 13 220 km^2). The biomass of orange roughy in this area was estimated as 23 800 tonnes (c.v. of 28%). In a subsequent survey conducted in 1989 but based on a reduced survey area (7 165 km^2), the calculated biomass was 11 100 tonnes (c.v. of 43%) (Bulman *et al.*, 1991). The biomass of orange roughy derived from trawl surveys off NSW, between 31° 45' and 36° 00'S (a total area of 3 960 km^2), was estimated to be 670 tonnes (Graham, 1990).

Recent exploitation of large concentrations of fish off southern and north-eastern Tasmania has occurred in areas of rough ground that were excluded from the trawl surveys. Total catches for 1989 and 1990 combined are approximately 34 500 tonnes from north-eastern Tasmania and 30 000 tonnes from southern Tasmania. Given the magnitude of these catches it is evident that that the trawl surveys have substantially under-estimated biomass and that orange roughy are not evenly distributed between areas of smooth and rough bottom.

In view of this discrepancy there is a need to re-appraise the suitability of assessment techniques such as trawl surveys for estimating orange roughy biomass. Stratified random trawl surveys have been used successfully in New Zealand in areas of relatively smooth bottom, for example the North Chatham Rise (Robertson *et al.*, 1984) and Challenger Plateau (Tracey *et al.*, 1990). However, where fish are highly aggregated and largely distributed over rough ground it becomes increasingly difficult to sample the stocks in an unbiased and representative manner. In such circumstances acoustic techniques may show promise while egg production surveys seem to offer good prospects for assessment of spawning biomass (Smith and Koslow, 1990). Not withstanding the problems associated with trawl surveys, their value in the longer term may be in detecting relative changes in absolute biomass for the whole stock.

Of the other potentially commercial species, the combined biomass of warty and spiky oreos was generally below 460 tonnes for NW Tas. The especially high summer 1988/89 biomass for warty oreos (nearly 1 500 tonnes) was heavily influenced by two large catches and there were particularly wide confidence limits associated with this estimate (c.v. of 61%). Both species of oreo are known to occur over a wider depth range than that sampled in this study so estimates will be conservative; spiky oreos are most common between 600 - 900 m while warty oreos are common below 800 m and extend deeper than 1 200 m (James *et al.*, 1988). Graham (1990) estimated warty oreo biomass off NSW to be 220 tonnes.

During the past two years there has been growing interest in the commercial potential of smooth and black (*Allocyttus niger*) oreos, with some large catches recorded off southern Tasmania. Reported landings of oreos in 1989 and 1990 were 529 and 1 036 tonnes, respectively (SET logbook data). Actual catches are likely to be significantly greater because discarding is known to occur. Smooth and black oreos were rarely caught in our surveys and most individuals were juvenile. The trawl surveys suggest that these species are present in low densities over smooth bottom while commercial catches indicate that they form dense aggregations in areas of rough ground.

4.2 Population Structure

Robertson *et al.* (1984) found some evidence for a size depth relationship for orange roughy off the North Chatham Rise, with smaller fish tending to predominate at the shallower depths. A similar pattern of size stratification by depth was apparent off the west coast in this and earlier studies (Lyle *et al.*, 1989a). There was no clear evidence of size depth relationships for north-eastern Tasmania, though these observations were based on limited sample sizes.

The bimodal length frequency distributions of orange roughy that were typical of the trawl surveys have been noted previously from Australia (Lyle *et al.* 1989a, Williams 1989) and New Zealand (Robertson *et al.*, 1984). In attempting to explain the significance of the observed size structure in terms of population dynamics, the question of how representative the distributions are arises. It is possible that fish in the middle size classes (25 - 32 cm) are less vulnerable to trawl gear, perhaps by favouring untrawlable ground or being dispersed in the water column. Alternatively, the modes could represent pulses of good recruitment separated by a period of poor recruitment. While it has not been possible to resolve these issues in this study, recent ageing work by Mace *et al.* (1990) and Fenton *et al.* (1991) and attempts to develop size structured models to explain the distributions (K. Sainsbury, pers. comm.) suggest that orange roughy are extremely slow growing and long-lived. It seems probable, therefore, that the mode of adult fish represents the accumulation of a very large number of age classes.

Unlike the surveys, commercial catches are almost exclusively comprised of mature fish, size compositions lack the mode of the juvenile fish seen in the survey data. Since the codend mesh size used in the surveys is the same as that used by the commercial fleet, these differences can not be attributed to mesh selectivity. Adult orange roughy clearly form large aggregations which are targeted by the commercial fleet. There are anecdotal reports of large catches comprised almost exclusively of juvenile fish, suggesting that in certain circumstances juveniles may also aggregate.

The size composition of commercial catches taken from the major fishing areas around Tasmania showed only minor differences. There are, however, marked differences between size distributions of fish from Tasmania and the Cascade Plateau (Lyle *et al.*, 1991) and New South Wales (authors' unpubl. data). The Cascade Plateau size distribution is highly distinctive, being comprised of fish that are substantially larger (modal peak at 41 cm and maximum size of 56 cm) than those that have been reported from elsewhere in Australia and New Zealand. Recent (December 1990 and March 1991) commercial catches from east of Sydney were comprised of smaller fish than are usually found off Tasmania, with a modal peak at 31 - 33 cm which compares with 35 - 37 cm for Tasmania. Trawl surveys off New South Wales confirm the predominance of smaller fish in that area (Graham and Gorman, 1988; Graham, 1990).

Lester *et al.* (1988) compared the the parasite fauna in orange roughy from several localities off southern Australia and were able to discriminate five Australian stocks. They are: (1) Great Australian Bight, (2) South Australia/west Victoria/west Tasmania, (3) north-east Tasmania, (4) New South Wales and (5) Cascade Plateau/ Tasman Rise. The differences in size structure between areas support the existence of separate Cascade Plateau and New South Wales stocks of orange roughy. The similarity in the size composition of fish from the various areas around Tasmania provide no clear indications of possible stock structure.

Sex ratios did vary between fishing areas with almost two-thirds of the fish from north-eastern Tasmania and Pedra Branca being male. The sex ratio was more even in the Maatsuyker area. While these data provide some evidence of structuring within the population(s), the implications and significance remain unclear.

4.3 Biology

Orange roughy are group synchronous spawners which form large winter spawning aggregations. In New Zealand the timing of spawning is consistent between years and aggregations re-occur within the same general area each year (Pankhurst, 1988). The only major spawning site known in Australian waters is located east of St Helens. Available data suggest that the spawning aggregation is associated with a single pinnacle (41° 14'S, 148° 45'E) and that the timing of spawning is consistent between years. Spawning occurs between mid-July and early August, a period of just over three weeks.

Spawning and spent fish have also been found off southern Tasmania in July, Newcastle (between 32 and 33°S) from late May to mid June (Graham and Bell, 1989) and south west of Port Lincoln (35° 36'S, 133° 46'E) in early August (Newton *et al.*, 1990). Although only small quantities of fish have been caught at each of these sites, the finds do suggest that other spawning populations may exist off eastern and southern Australia.

Photoperiod (day length) may play a role in regulating the acute timing of spawning. There is a difference of about three weeks in the onset of spawning between the northern and southern limits of the New Zealand fishery. By making correction of day length for latitude, Pankhurst (1988) noted that the day length at the time spawning commenced was essentially the same at each of three spawning sites, i.e ~ 9 h 30 min. Spawning at St Helens commences during the second week of July when the day length is ~ 9 h 30 min.

Aspects of the spawning dynamics of orange roughy in New Zealand have been investigated by Pankhurst (1988). Males appear to arrive on the grounds first and, while spawning is in progress, they are present at lower depths than females. Schooling by sex in the spawning season has also been noted by Robertson *et al.* (1984). The highly variable sex ratios of individual samples suggests some localised segregation of the sexes within the St Helens spawning aggregation. It is not clear, though, whether the sexes are distributed in a consistent manner in relation to factors such as depth or position on the pinnacle.

Pankhurst (1988) concluded that individual males probably spawn over a 1 - 2 week period whereas females complete spawning within 1 - 7 days. Aggregations disperse 3 - 4 weeks after spawning has finished (Pankhurst, 1988; Lyle *et al.*, 1990). Robertson *et al.* (1984) cited evidence for dispersal into deeper water following spawning. Survey catch rates were highest in the 1 100 m stratum off NE Tas in the winter surveys (mostly conducted after the peak spawning period) and good catches of post-spawning fish were taken by the commercial fleet taken in deep water off St Patricks Head in August and September 1988. This suggests a similar pattern of dispersal into deep water after spawning.

Little is known about the early life history of orange roughy. Orange roughy eggs are large (2.0 - 2.5 mm diameter) and have a distinctive orange oil globule present. Fertilised eggs are positively buoyant and rise to at least 400 m. It is not known whether they rise above the thermocline (which occurred at 200 - 300 m off the east coast of Tasmania). Although very few larvae have been captured, there are indications that hatching occurs 10 - 20 days after fertilization (C. M. Bulman, pers. comm.) and that the larval/post larval phase may last at least 7 - 10 months (Mace *et al.*, 1990).

An important finding of this study has been that a significant proportion of post-mature females do not spawn each year, some individuals either fail to initiate or maintain vitellogenesis. Bell *et al.* (in press) found that of the two types of non-reproductive fish, fish with arrested development accounted for 27% of the non-reproductive individuals they examined histologically. The occurrence of large numbers of non-spawners has not been reported from New Zealand and this may be related to the fact that reproductive studies in that country have been centred around known spawning aggregations (Pankhurst *et al.*, 1987). Limited food availability may be a contributing factor to the occurrence of non-reproductive females since indicators of condition (eviscerated weight - length and hepatic weight - length relationships) show that non-reproductive fish tend to be in poorer condition than reproductive fish (Bell *et al.*, in press, authors' unpubl. data). There are indications that not all adult males reproduce each year but this has yet to be confirmed histologically (authors' unpubl. data).

The proportion of non-reproductive females varied spatially and temporally. At the St Helens spawning site, the proportion of non-reproductive females decreased from about 45% in March and April 1990 to about 2% immediately prior to the onset of spawning, presumably reflecting the movement of spawners into the area. A similar pattern was observed in 1989. By contrast, the high proportion (>50%) of non-reproductive females in aggregations off southern Tasmanian immediately prior to and during the spawning season suggests that there may be some movement of spawners away from these sites. This was particularly pronounced in 1989 when approximately 90% of the females in early July were judged to be non-reproductive.

These observations have particular relevance to understanding possible migration patterns and stock structure. Experience from New Zealand suggests that orange roughy undertake limited spawning migrations, travelling up to at least 100 nautical miles to join spawning aggregations (D.A. Robertson, pers. comm.). The obvious questions that arise from our data are where do the spawning fish off southern Tasmania go and over what area are the fish that spawn at St Helens drawn? At the present time the southern fish are being managed as a separate 'stock' from the east coast fish. Stock discrimination studies have produced equivocal results and it may take the discovery (or non-discovery) of a spawning aggregation to resolve this situation.

Another implication of this phenomenon for management is that biomass assessment based on spawning biomass will underestimate current biomass if the portion of the population not undertaking the spawning migration is not considered. Achieving representative samples may prove difficult since the proportion of non-reproductive fish varies spatially and temporally. It is clear, however, that sampling should be conducted early in the year (say March/April) before the fish commence their spawning migration and that spatial coverage should be as wide as is feasible.

Orange roughy feed opportunistically on benthopelagic and mesopelagic organisms. Crustaceans (mostly prawns) were the most commonly eaten prey, with fish and cephalopods (squid) of secondary importance. These findings are consistent with the diets of orange roughy reported from other geographical localities (Kotlyar and Lipskaya, 1981; Mauchline and Gordon, 1984; Robertson *et al.*, 1984; Rosecchi *et al.*, 1988). Orange roughy from the Challenger Plateau have been shown to undergo a transition from prawns, mysids and fish, to prawns, fish and squid as they grow in size (Rosecchi *et al.*, 1988). In accordance with these observations, juvenile orange roughy from Tasmania fed most heavily on crustaceans and to a lesser extent fish, while the diet of adults was comprised of crustaceans, fish and squid. Rosecchi *et al.* (1988) also reported that while most of the food organisms undergo vertical migrations there was no evidence that orange roughy moved into the water column in search of their prey.

The proportion of empty stomachs in orange roughy from north-eastern Tasmania had a seasonal peak in the winter, which was more pronounced among adult fish. Most of these fish were either in spawning or post-spawning condition, suggesting that orange roughy do not feed heavily during the spawning season. Spawning fish from New Zealand also show a high incidence of empty stomachs (Robertson *et al.*, 1984; Rosecchi *et al.*, 1988).

4.4 Oreo Biology

There is little published life history information available for warty and spiky oreos. Warty oreo length frequencies were bimodal whereas spiky oreo size distributions reveal several distinct modes. In the absence of validated ageing data for either species, the significance of these modes is unknown.

As for orange roughy, male oreos mature at smaller sizes than females and females attain greater lengths. Our data suggest that warty oreos spawn during early winter whereas spiky oreos spawn in early spring. Although no running ripe female warty oreos were observed, ovaries had begun to ripen in April/May, and by August a high proportion of the fish had spawned. The first running ripe spiky oreo females were encountered in August and by November there were numerous spent fish in the samples. Macroscopic staging of the gonads suggests synchronous ovarian development in the two species. The onset and duration of the spawning event for both species could not be determined and it is not known whether they aggregate to spawn.

The closely related smooth and black oreos spawn in November/December in New Zealand waters (Pankhurst *et al.*, 1987) and off southern Tasmania (authors' unpubl. data). Smooth and black oreos exhibit synchronous ovarian development and spawning is a discrete event, the timing of which is consistent between years in New Zealand (Pankhurst *et al.*, 1987).

Mel'nikov (1980) studied the food and feeding habits of warty oreo from South African waters. He found that they fed principally on prawns as well as fish and cephalopods, which is consistent with our findings. Mel'nikov (1980) also reported that fish and cephalopods became more important in the diet as the fish grew in size and that warty oreo do not carry out vertical migrations. Due to the high incidence of everted stomachs data are limited for spiky oreo though results suggest that salps are the main food, with fish, crustaceans and cephalopods of lesser importance.

Results of studies of the diets of other species of oreo are consistent with those presented here. Clark *et al.* (1989) noted that black oreo feed on amphipods, salps and prawns while smooth oreo feed on salps and amphipods. They concluded that while many of the prey species undertake vertical migrations, the oreos do not appear to move substantial distances in the water column.

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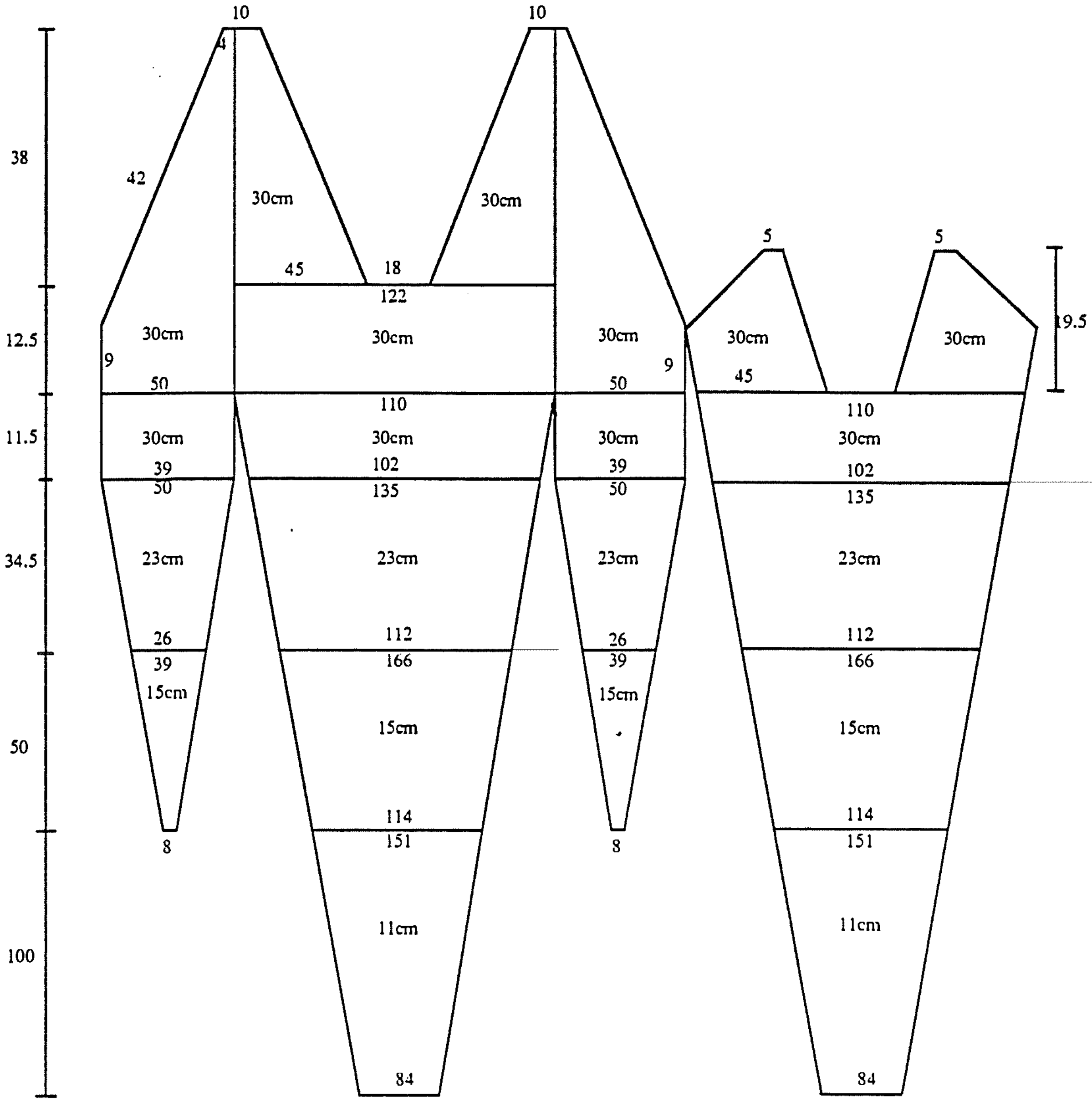
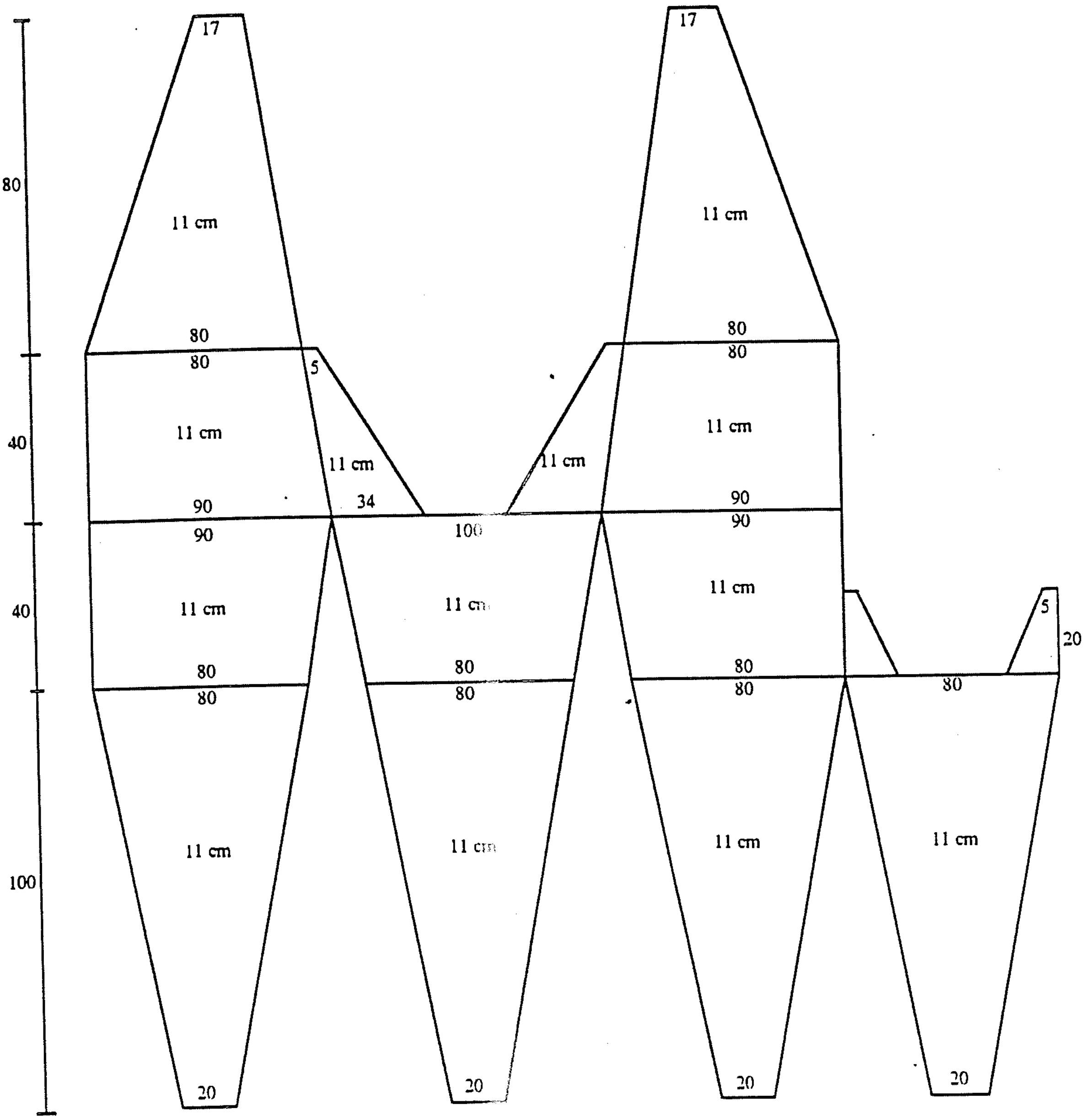
APPENDIX I: Trawl net plans and characteristics.

FV *Petuna Endeavour* - Milligan Orange Roughy trawl net.



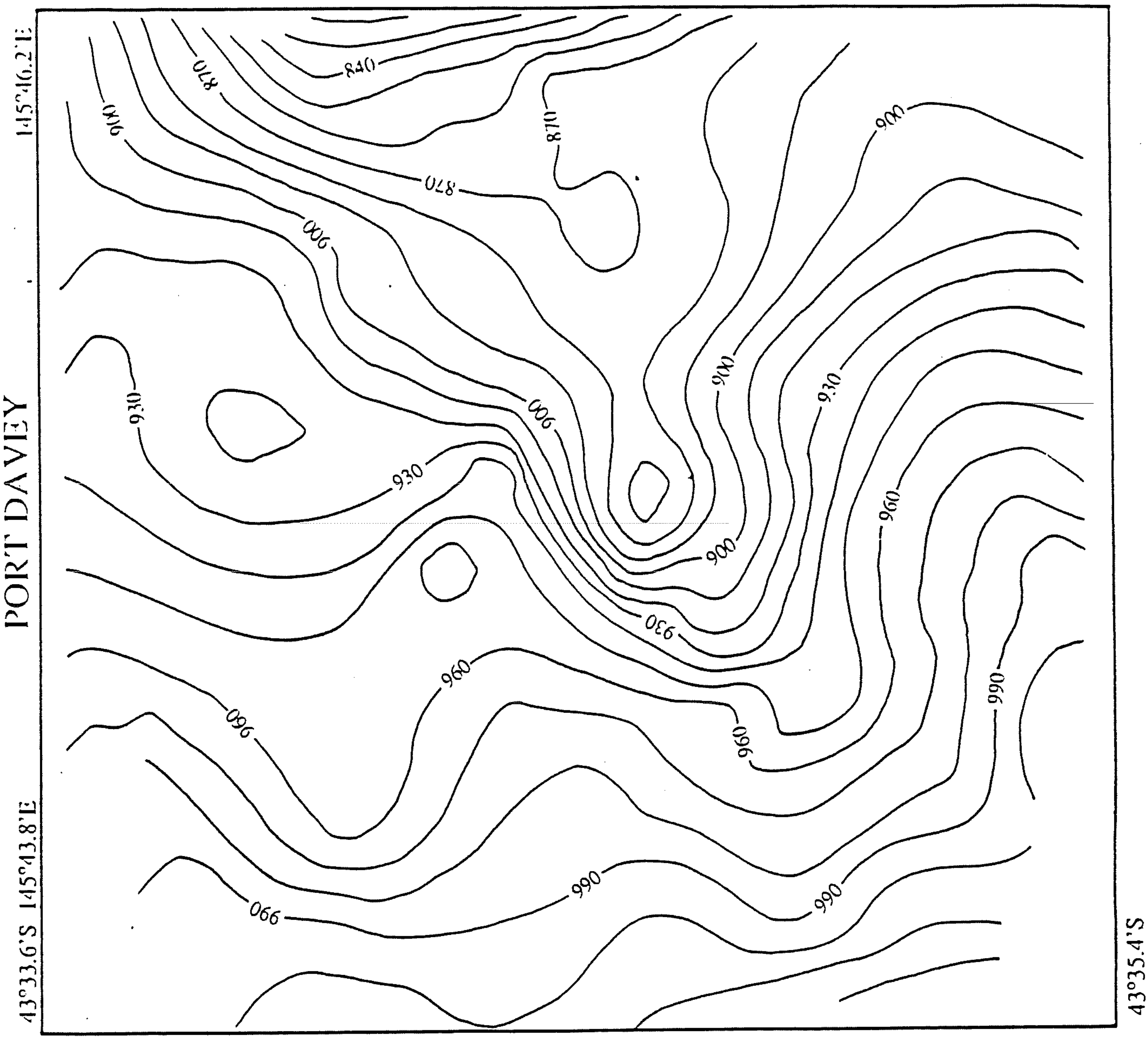
Headline	36.6 m
Footrope bosom	18.3 m
Wings	rigged flying, mesh only attached to ground rope in bosom
Rigged	9.4 m chain on each wing, bosom with rubber bobbins
Bridles	41.3 m
Sweeps	36.6 or 79.4 m
Mesh size	30 to 11 cm (12" to 4.5")
Codend mesh	11 cm
Net height	4.8 to 6.6 m
Trawl doors	Super-V

RV *Challenger* - Modified Atlantic Western Trawl net.

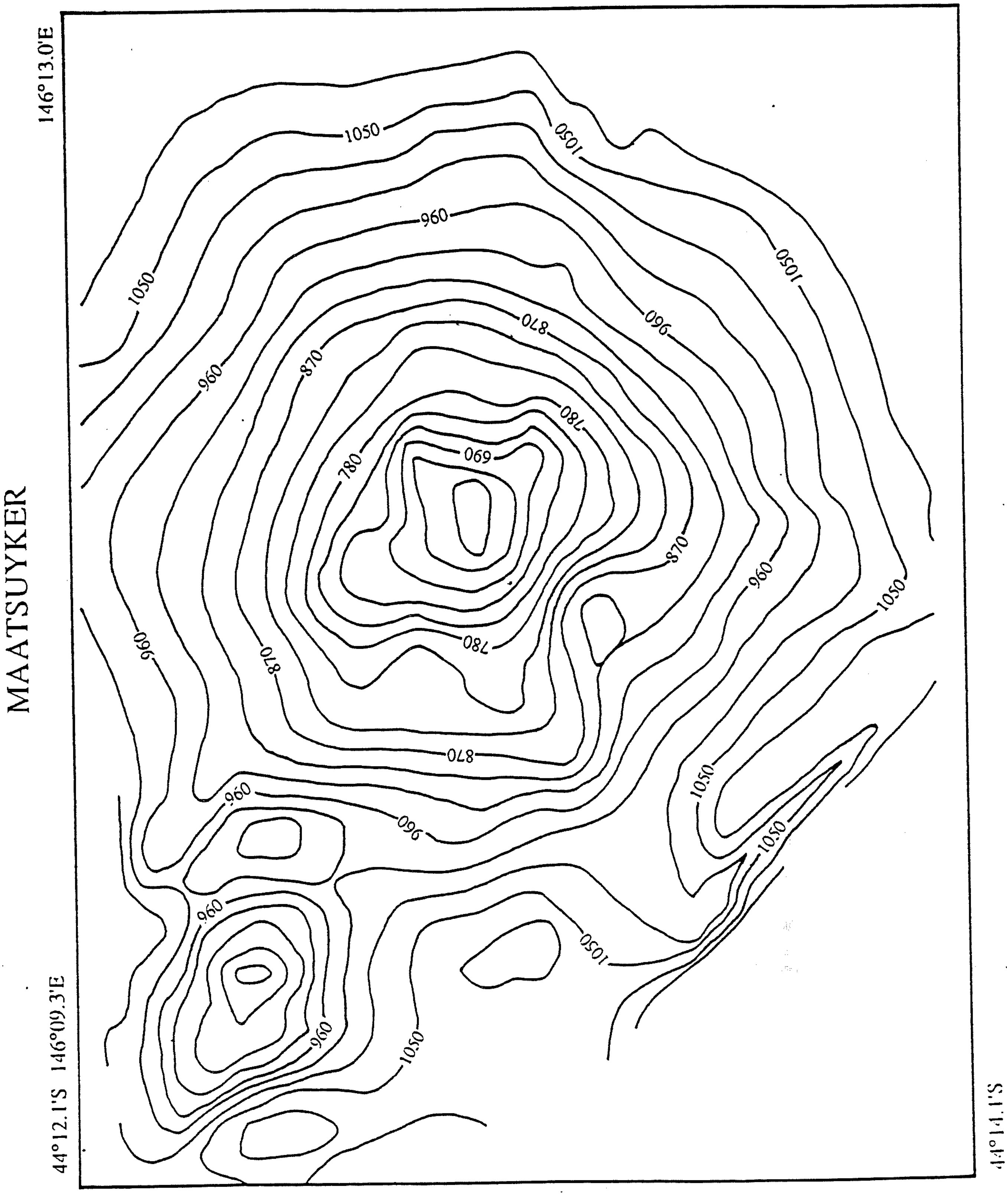


Headline	34.9 m
Footrope bosom	20.0 m
Wings	rigged flying, mesh only attached to ground rope in bosom
Rigged	11.3 m chain on each wing, bosom with rubber bobbins
Bridles	25.0 m
Sweeps	38 m
Mesh size	11 cm (4.5" throughout)
Codend mesh	11 cm
Net height	3.0 to 3.7 m
Trawl doors	Polyvalent

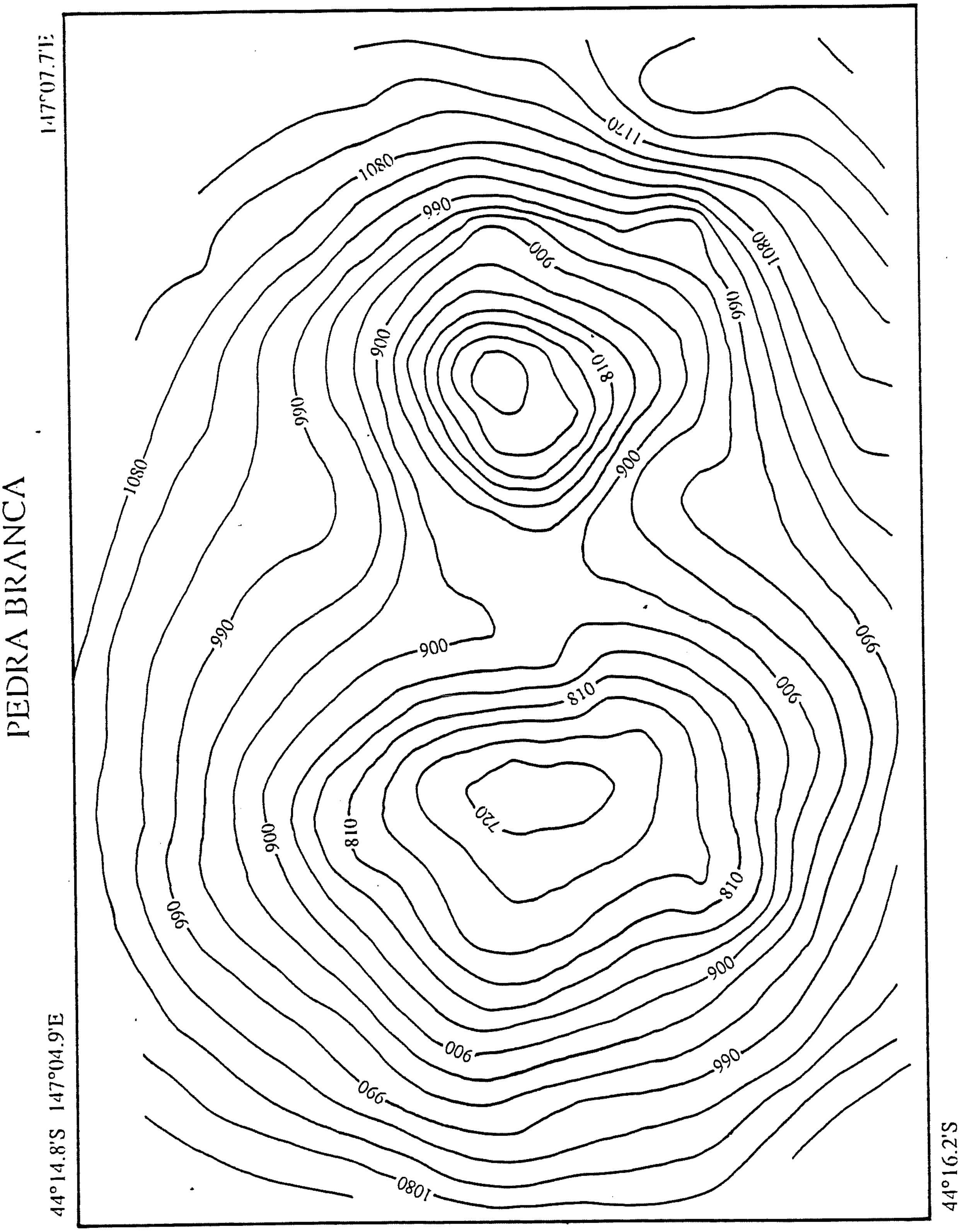
APPENDIX II: **Bottom bathymetry of the Port Davey aggregation site.**



APPENDIX II: **Bottom bathymetry of the main Maatsuyker aggregation site.**



APPENDIX II: **Bottom bathymetry of the main Pedra Branca aggregation site.**



APPENDIX III: **Summary of research trawl data.**

Cruise	Date	Shot No.	POSITION Start Lat.	Start Long.	Finish Lat.	Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Temp(°C) Bot	Depth (m) Min	Depth (m) Max	Headline ht. (m)	CATCH WEIGHTS (kg) Orange roughy	Smooth oreo	Spiky oreo	Warty oreo
North-eastern Tasmania																		
CR152	01/12/87	0001	41.38	148.42	41.40	148.39	1200	60	2.5	16.2	4.5	790	950		126	0	6	0
CR156	02/02/88	0001	41.33	148.42	41.32	148.44	1125	50	2.5	18.6	4,5	921	1015		77	0	16	0
CR156	02/02/88	0002	41.34	148.40	41.37	148.43	1425	50	2.5	18.5		991	1050		384	0	17	0
CR156	03/02/88	0003	41.38	148.40	41.36	148.41	0915	60	2.5	18.3		888	962		27	0	14	0
CR156	03/02/88	0004	41.41	148.38	41.42	148.40	1220	60	2.5	18.2		931	1058		590	0	6	0
CR156	03/02/88	0005	41.43	148.39	41.44	148.37	1705	35	2.5	18.1		862	897		576	1	4	0
CR157	13/02/88	0002	41.40	148.40	41.37	148.41	1215	60	2.5	18.2		851	915		17	0	0	0
CR157	13/02/88	0003	41.38	148.43	41.39	148.40	1545	60	2.5	18.5		930	989		74	0	1	0
CR157	14/02/88	0004	41.40	148.40	41.39	148.41	1030	30	2.5	18.6		919	960		75	0	0	0
CR157	14/02/88	0005	41.39	148.42	41.41	148.41	1245	60	2.5	19.3		1025	1074		115	0	0	1
CR157	14/02/88	0006	41.43	148.40	41.47	148.38	1545	60	2.5	19.6	4.8	914	996		1 306	0	2	0
CR164	19/04/88	0001	41.47	148.43	41.45	148.43	1245	60	2.5	18.9	4.0	1131	1171	3.7	29	0	0	1
CR164	20/04/88	0002	41.22	148.44	41.20	148.44	1055	60	2.5	18.6	6.0	840	860	3.7	38	0	11	0
CR165	27/04/88	0001	41.40	148.42	41.43	148.40	1155	60	2.5	18.1	4.7	944	1155	3.7	209	0	3	0
CR166	03/05/88	0001	41.36	148.44			1410	25	2.5	5.0		1058	1082		56	0	1	6
CR168*	20/07/88	0001	41.44	148.39	41.46	148.38	1230	45	2.5	15.5		860	941		6	0	0	0
CR169	10/08/88	0002	41.42	148.40	41.39	148.40	1250	60	2.5	14.5	5.5	927	949		195	3	1	0
CR169	11/08/88	0003	41.37	148.42	41.39	148.42	1040	20	2.5	14.5	4.0	1017	1030		27	0	0	0
CR169	12/08/88	0004	41.40	148.42	41.43	148.42	1035	60	2.5	14.6	4.5	1048	1102		68	0	0	1
CR169	12/08/88	0005	41.41	148.44	41.39	148.44	1355	60	2.5	14.7	4.0	1137	1176		429	0	0	2
CR169	12/08/88	0006	41.43	148.44	41.46	148.44	1640	60	2.5	14.5	4.0	1174	1214		2 421	0	0	1
CR170	24/08/88	0001	41.38	148.40	41.38	148.40	1155	20	2.5	14.0	6.0	850	892		9	0	0	0
CR170	24/08/88	0002	41.34	148.42	41.33	148.44	1340	35	2.5	13.8	8.0	817	830		0	0	13	0
CR170*	24/08/88	0003	41.35	148.45	41.35	148.45	1650	1	2.0	13.9	5.0	1070	1070		0	0	0	0
CR174	11/10/88	0001	41.42	148.44	41.37	148.45	1140	45	2.5	13.4	4.0	1155	1238		61	0	0	1
CR174	13/10/88	0002	41.39	148.44	41.37	148.45	1115	60	2.5	13.5		1097	1111		5	1	0	1
CR178	29/11/88	0001	41.48	148.41	41.44	148.39	1015	60	2.5	15.3	4.5	1022	1076		433	0	0	0
CR191	08/02/89	0001	41.38	148.41	41.35	148.42	1140	60	2.5	20.5	4.5	876	906	3.0	20	0	9	0
CR191	08/02/89	0002	41.35	148.42	41.32	148.45	1640	60	2.5	20.8	4.5	928	983	3.0	473	0	18	0
CR192	23/02/89	0001	41.38	148.42	41.42	148.42	1225	60	2.5	22.0		1050	1121	3.0	30	0	0	0

			POSITION											Headline	CATCH WEIGHTS (kg)			
		Shot	Start		Finish		Start	Durn	Speed	Temp(°C)		Depth (m)		ht.	Orange	Smooth	Spiky	Warty
Cruise	Date	No.	Lat.	Long.	Lat.	Long.	(h)	(min)	(kts)	Sur	Bot	Min	Max	(m)	roughy	oreo	oreo	oreo
CR192*	23/02/89	0002	41.42	148.39	41.42	148.39	1550	1	2.5	22.4		989	989	3.0	0	0	0	0
CR192*	23/02/89	0003	41.43	148.39	41.43	148.39	1750	5	2.5	22.4		926	926	3.0	31	0	0	0
PE105	14/05/89	0021	41.43	148.39	41.40	148.39	1002	60	2.4	15.7		822	860	5.5	95	0	7	0
PE105	14/05/89	0022	41.40	148.41	41.43	148.40	1235	60	2.6	15.8	5.5	924	984	6.0	145	0	0	0
PE105	14/05/89	0023	41.44	148.42	41.42	148.43	1541	60	2.6	15.5	4.0	1063	1113	6.0	142	0	3	1
PE105	14/05/89	0024	41.41	148.43	41.43	148.43	1855	60	2.3	15.4	3.5	1129	1179	6.2	101	2	0	0
PE105*	15/05/89	0025	41.23	148.43	41.23	148.43	0708	3	2.5	16.3	4.0	838	844		22	0	0	0
PE105	15/05/89	0026	41.33	148.44	41.34	148.44	1150	30	1.7	15.9		950	988		50	0	0	0
PE105	15/05/89	0027	41.44	148.41	41.46	148.41	1505	60	2.3	15.0		1023	1083		154	0	0	0
PE105+	15/05/89	0028	42.06	148.39	42.07	148.39	2045	30	2.2	14.4		962	1014		44	0	0	0
CR203	18/07/89	0001	41.42	148.43	41.38	148.43	0930	60	2.5	15.1	5.0	1045	1079	3.0	812	0	0	0
CR203*	19/07/89	0002	41.28	148.44	41.28	148.44	1715	4	2.5	15.3	4.0	911	911		34	0	1	0
CR204	26/07/89	0001	41.44	148.40	41.43	148.40	0830	30	2.5	15.0	5.5	916	930		13	0	0	0
CR205	09/08/89	0001	41.37	148.41	41.38	148.40	1140	20	2.5	15.3	6.0	944	988	3.3	192	0	0	0
CR205	09/08/89	0002	41.41	148.39	41.43	148.38	1330	45	2.5	14.7	7.0	850	900		33	0	0	0
CR205	09/08/89	0003	41.46	148.43	41.48	148.43	1615	60	2.5	14.4	4.5	1158	1158		660	0	0	0
CR212	27/09/89	0001	41.39	148.43	41.38	148.43	1010	20	2.5	15.5	4.5	1116	1120		18	0	0	0
CR213	04/10/89	0001	41.42	148.40	41.40	148.39	0925	30	2.5	14.1	5.5	875	903		25	0	0	0
CR213	04/10/89	0002	41.39	148.43	41.40	148.43	1210	60	2.5	14.6		1031	1067		33	0	1	0
CR213	04/10/89	0003	41.40	148.44	41.44	148.42	1530	90	2.5	14.8	4.5	1103	1165		61	0	0	2
Western Tasmania																		
PE100	17/02/88	0001	41.01	143.47	41.04	143.50	1110	65	3.0	16.5	5.5	822	880		38	0	22	0
PE100	17/02/88	0002	41.04	143.49	41.06	143.52	1435	65	2.8	16.9	5.0	910	990		36	0	11	29
PE100*	17/02/88	0003	41.07	143.50	41.08	143.54	1745	70	2.8	17.3	4.0	1135	1290		73	0	0	44
PE100	18/02/88	0004	41.17	144.00	41.14	143.59	0806	60	2.8	19.5	3.8	1024	1060		21	0	0	43
PE100*	18/02/88	0005	41.13	143.59			1130	1		16.7		931	931		0	0	0	0
PE100	18/02/88	0006	41.13	143.59	41.16	144.01	1613	70	3.0	16.8	4.6	880	960		95	0	8	1
PE100	18/02/88	0007	41.19	144.02	41.17	143.60	2010	60	2.4	16.8	4.0	1042	1188		33	1	0	20
PE100	26/02/88	0008	41.20	144.08	41.21	144.11	1130	60	2.4	16.2	5.0	880	920		74	0	43	1
PE100	26/02/88	0009	41.25	144.12	41.26	144.15	1420	60	2.4	16.5	3.0	1109	1170		133	0	0	149
PE100	26/02/88	0010	41.29	144.17	41.32	144.19	1730	60	2.4	16.3	3.6	1010	1090	6.0	100	0	0	55
PE100	27/02/88	0011	41.40	144.22	41.43	144.24	0730	60	2.5	16.2	4.0	941	969	6.0	19	0	4	0
PE100	27/02/88	0012	41.46	144.22	41.48	144.24	1035	60	2.5	15.8	3.0	1140	1170	6.0	88	0	0	54
PE100	27/02/88	0013	41.48	144.27	41.51	144.27	1312	60	2.8	16.5	4.6	900	934	6.0	108	0	3	1
PE100	27/02/88	0014	41.56	144.30	41.59	144.31	1720	60	2.6	16.2	3.5	1036	1000	6.0	38	0	0	7

Cruise	Date	Shot No.	POSITION Start Lat.	Start Long.	Finish Lat.	Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Temp(°C) Bot	Depth (m) Min	Depth (m) Max	Headline ht. (m)	CATCH WEIGHTS (kg) Orange roughy	Smooth oreo	Spiky oreo	Warty oreo
PE100	28/02/88	0015	42.04	144.34	42.07	144.36	0848	60	2.7	15.7	3.0	1100	1164	6.0	55	0	0	49
PE100	28/02/88	0016	42.07	144.39	42.11	144.40	1140	60	2.8	16.0	5.5	823	877	6.0	598	0	58	0
PE100	28/02/88	0017	42.14	144.41	42.17	144.42	1450	60	2.8	16.1	4.5	905	965	6.0	36	0	70	55
PE100*	28/02/88	0018	42.19	144.41	42.21	144.42	1740	1		16.1	3.6	1011	1011		0	0	0	0
PE100+	29/02/88	0019	43.29	145.33	43.28	144.31	1159	45	2.6	15.0	4.9	969	987		33	0	0	50
PE100+	29/02/88	0020	43.32	145.35	43.33	145.32	1515	60	2.7	14.8	4.0	1033	1095		23	0	0	44
PE100*+	29/02/88	0021	43.31	145.40	43.30	145.38	1900	1			4.5	850	850		0	0	0	0
PE101*	17/04/88	0001	41.02	143.45			0945	1				1180	1180		0	0	0	0
PE101	17/04/88	0002	41.00	143.45	41.03	143.47	1340	60	2.9	15.8	4.5	1055	1075	5.4	128	0	0	46
PE101	17/04/88	0003	41.04	143.45	41.06	143.49	1655	60	2.9	15.8	4.0	1116	1161	6.0	255	0	0	48
PE101	18/04/88	0004	41.13	144.00	41.15	144.01	0630	60	2.5	15.7	7.0	801	889	5.1	112	0	15	1
PE101	18/04/88	0005	41.20	144.06	41.23	144.10	1020	60	2.8	15.6	5.0	940	1000	6.0	30	0	13	10
PE101	18/04/88	0006	41.21	144.06	41.22	144.08	1423	60	2.0	15.8	5.0	1121	1169	6.6	2	0	0	2
PE101	18/04/88	0007	41.23	144.12	41.25	144.16	1754	60	2.8	15.6	5.7	932	969	6.0	47	0	20	94
PE101	19/04/88	0008	41.29	144.19	41.25	144.16	0620	60	3.0	15.7	7.5	822	865	6.0	297	0	12	10
PE101	19/04/88	0009	41.25	144.12	41.28	144.17	1015	60	2.9	15.7	4.8	993	1124	6.0	154	0	0	180
PE101	19/04/88	0010	41.29	144.19	41.27	144.18	1433	60	2.9	15.7	6.0	820	860	5.2	94	0	14	9
PE101	19/04/88	0011	41.24	144.12	41.22	144.08	1727	60	2.8	15.7	5.0	1000	1042	5.2	81	0	1	60
PE101	20/04/88	0012	41.30	144.17	41.33	144.17	0625	60	2.8	15.6	4.0	1100	1150	5.8	251	0	0	33
PE101*	20/04/88	0013	41.45	144.23				1				1090	1090		0	0	0	0
PE101	20/04/88	0014	41.45	144.23	41.48	144.25	1233	60	2.8	15.4	4.8	1050	1086	6.0	53	1	1	72
PE101	20/04/88	0015	41.52	144.27	41.55	144.30	1525	60	2.8	15.4	5.5	914	1010	6.0	55	0	14	35
PE101	21/04/88	0016	41.54	144.28	41.58	144.30	0630	60	2.7	15.2	4.0	1115	1161	5.3	108	1	0	22
PE101	21/04/88	0017	41.58	144.32	42.01	144.35	1016	60	2.7	15.2	5.5	956	1000	5.8	20	1	16	3
PE101	21/04/88	0018	42.11	144.37	42.13	144.39	1403	60	2.7	15.6	4.8	1042	1080	5.8	13	0	0	41
PE101	21/04/88	0019	42.14	144.39	42.16	144.40	1710	60	2.7	15.5	4.8	1051	1069	6.0	11	0	0	27
PE101+	22/04/88	0020	43.30	145.33	43.28	145.31	1500	50	2.7	15.3	4.8	1024	1069	6.0	99	3	0	32
PE101+	23/04/88	0021	43.28	145.34	43.30	145.38	0900	60	2.7	14.7	6.0	896	929	5.4	295	1	15	31
PE101+	23/04/88	0022	43.34	145.36	43.32	145.33	1355	60	2.6	14.7	5.0	1124	1198	6.8	93	3	0	17
PE102	16/08/88	0001	41.02	143.46	41.05	143.49	0915	60	3.1	12.3	4.5	1012	1052	5.2	59	0	2	18
PE102	16/08/88	0002	41.05	143.52	41.05	143.52	1233	60	2.6	12.4	6.3	787	902	5.2	427	0	40	0
PE102	16/08/88	0003	41.07	143.49	41.04	143.47	1618	70	2.7	12.5	3.8	1046	1168		261	0	1	19
PE102	16/08/88	0004	41.07	143.52	41.05	143.46	2028	60	3.0	12.3	3.8	979	1095	5.5	302	0	4	113
PE102	17/08/88	0005	41.15	143.58	41.12	143.59	1042	27	2.3	13.3	4.5	962	1006	6.0	2	0	1	6
PE102	17/08/88	0006	41.26	144.16	41.29	144.19	1746	60	2.5	13.1	6.2	827	875	5.0	94	0	13	0
PE102	17/08/88	0007	41.32	144.21	41.37	144.22	2046	60	2.9	13.1	6.2	849	900	6.0	137	0	12	0

Cruise	Date	Shot No.	POSITION Start Lat.	Start Long.	Finish Lat.	Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Bot	Depth (m) Min	Max	Headline ht. (m)	CATCH WEIGHTS (kg) Orange roughy	Smooth oreo	Spiky oreo	Warty oreo
PE102	18/08/88	0008	41.43	144.24	41.41	144.23	0846	60	2.5	12.7	5.5	935	974	5.5	4	2	2	0
PE102	18/08/88	0009	41.35	144.20	41.33	144.17	1152	60	2.7	12.8	4.5	1120	1160	5.5	0	0	0	6
PE102	18/08/88	0010	41.34	144.19	41.37	144.21	1441	60	2.6	12.9	4.5	1019	1094	5.5	22	0	0	14
PE102	18/08/88	0011	41.37	144.23	41.43	144.25	1755	60	3.1	12.9	6.0	780	935	5.0	45	3	18	0
PE102	19/08/88	0012	41.53	144.29	41.56	144.30	0607	60	2.4	13.7	6.0	883	1003	5.0	499	0	1	4
PE102	19/08/88	0013	42.02	144.35	42.04	144.35	0917	60	1.8	13.6	5.8	893	960	5.5	114	0	9	1
PE102	19/08/88	0014	42.06	144.36	42.03	144.35	1157	60	2.4	13.3	4.5	1037	1092	5.5	140	1	0	66
PE102	19/08/88	0015	42.07	144.37	42.10	144.37	1447	76	3.2	13.3	4.5	1002	1054	5.5	128	2	0	57
PE102	19/08/88	0016	42.16	144.40	42.18	144.42	1757	60	2.8	13.6	5.5	939	1001	5.0	176	0	5	9
PE102	20/08/88	0017	42.22	144.41	42.26	144.41	0708	60	2.0	13.4	4.0	1129	1158	6.0	52	0	0	19
PE102*+	20/08/88	0018	43.22	145.26	43.22	145.25	1700	11	2.8	12.1	5.5	946	1017	6.0	18	0	0	2
PE102+	21/08/88	0019	43.28	145.34	43.28	145.34	0659	17	2.5	11.7	6.0	898	939	5.0	49	0	3	0
PE102+	21/08/88	0020	43.31	145.36	43.34	145.54	1058	60	2.4	11.9	5.0	1030	1204	5.5	322	0	0	21
PE102+	21/08/88	0021	43.47	145.51	43.50	145.52	1649	60	1.7	11.8	4.5	1085	1131	5.0	242	1	0	23
PE103+	16/11/88	0001	43.33	145.34	43.32	145.31	0620	60	2.7	11.1	3.5	1140	1165	5.2	277	0	0	0
PE103+	16/11/88	0002	43.32	145.36	43.31	145.33	1038	60	2.4	11.2	4.3	1028	1052	5.2	254	1	0	5
PE103+	16/11/88	0003	43.18	145.21	43.19	145.22	1654	24	1.9	11.3	5.0	915	940	5.5	168	0	3	0
PE103+	17/11/88	0004	42.37	144.50	42.35	144.49	0525	60	2.6	10.9	5.2	928	957	5.0	915	2	25	6
PE103+	17/11/88	0005	42.34	144.48	42.35	144.49	0822	41	1.9	11.1	6.0	867	911	5.8	573	0	14	0
PE103	17/11/88	0006	42.26	144.41	42.24	144.40	1345	60	2.5	10.9	3.8	1167	1189	5.3	83	0	0	7
PE103	17/11/88	0007	42.25	144.44	42.23	144.43	1737	60	2.5	11.0	4.8	955	994	5.0	68	0	14	30
PE103	17/11/88	0008	42.20	144.42	42.17	144.43	2022	60	2.5	11.0	5.0	913	969	5.0	23	1	8	6
PE103	18/11/88	0009	42.21	144.41	42.19	144.41	1411	60	2.2	9.9	4.2	1036	1047	5.0	9	0	1	0
PE103	18/11/88	0010	42.18	144.44	42.16	144.43	1715	60	2.4	10.1	6.0	781	849	5.0	125	0	24	0
PE103	18/11/88	0011	42.15	144.40	42.13	144.38	2017	60	2.8	10.2	4.2	1027	1054	5.0	33	0	0	2
PE103	19/11/88	0012	42.16	144.39	42.13	144.38	0617	60	2.2	9.1	3.8	1113	1129	5.3	253	1	0	10
PE103	19/11/88	0013	42.12	144.40	42.10	144.39	0908	60	2.2	9.4	5.0	930	959	5.0	170	0	9	1
PE103	19/11/88	0014	42.02	144.35	41.60	144.32	1219	60	2.7	7.4	4.5	984	1057	5.2	161	0	2	20
PE103	19/11/88	0015	41.48	144.34	41.56	144.32	1532	60	2.6	9.1	5.2	823	915	5.2	356	0	18	0
PE103	19/11/88	0016	41.50	144.27	41.47	144.26	1849	60	2.8	7.6	4.5	960	984	5.0	57	0	5	2
PE103	20/11/88	0017	41.47	144.25	41.45	144.24	0729	60	2.0	6.2	3.8	1089	1144	4.8	206	0	1	27
PE103	20/11/88	0018	41.45	144.26	41.47	144.27	1054	60	2.3	6.9	5.8	865	897	5.2	186	1	8	1
PE103	20/11/88	0019	41.44	144.24	41.41	144.23	1409	60	2.8	4.5		963	995	5.0	135	1	3	11
PE103	20/11/88	0020	41.40	144.22	41.38	144.21	1713	60	2.4	4.0		1034	1056	5.0	13	0	0	14
PE103	21/11/88	0021	41.30	144.19	41.27	144.17	0848	60	2.6	7.9	5.2	842	911	5.0	224	1	6	0
PE103	21/11/88	0022	41.21	144.04	41.23	144.07	1335	60	2.3	8.6	3.8	1131	1153	5.8	246	0	8	18

			POSITION												Headline	CATCH WEIGHTS (kg)			
Cruise	Date	Shot No.	Start Lat.	Start Long.	Finish Lat.	Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Temp(°C) Bot	Depth (m) Min	Depth (m) Max	ht. (m)	Orange roughy	Smooth oreo	Spiky oreo	Warty oreo
PE103	21/11/88	0023	41.18	144.02	41.16	144.00	1949	60	2.9	4.8		946	990	5.0	35	0	2	3
PE103	22/11/88	0024	41.19	144.01	41.17	143.60	0850	60	2.3	4.2		1061	1092	5.0	64	0	2	33
PE103	22/11/88	0025	41.05	143.48	41.02	143.45	1405	56	2.5	4.0		1105	1180	5.0	44	0	0	4
PE103	22/11/88	0026	41.02	143.46	41.01	143.45	1735	30	2.8	4.5		1058	1114	5.3	6	0	0	2
PE104+	14/02/89	0001	43.32	145.38	43.30	145.35	1110	60	2.4	16.0	4.5	961	992	5.2	8	3	1	4
PE104*+	14/02/89	0002	43.31	145.32	43.31	145.32	1424	2	2.2	16.2	3.7	1120	1122	5.0	0	0	0	1
PE104+	14/02/89	0003	43.34	145.35	43.33	145.34	1949	60	1.8	16.2	3.8	1142	1171	5.2	30	0	0	26
PE104+	15/02/89	0004	42.34	144.48	42.37	144.50	0915	60	3.0	16.8	5.2	942	983	4.8	34	1	64	0
PE104	15/02/89	0005	42.27	144.46	42.24	144.45	1316	60	2.7	17.2	6.0	846	886	4.9	230	0	50	0
PE104	15/02/89	0006	42.21	144.40	42.18	144.40	1620	60	2.5	17.1	4.5	1133	1173	5.5	37	0	0	8
PE104	15/02/89	0007	42.13	144.40	42.11	144.40	1907	60	2.4	17.1	5.3	924	963	5.0	51	0	28	2
PE104	16/02/89	0008	41.55	144.32	41.53	144.30	0715	60	2.3	16.9	6.0	844	895	4.8	218	0	50	0
PE104	16/02/89	0009	41.52	144.28	41.49	144.26	1040	60	2.7	16.8	5.0	911	982	4.8	75	0	7	0
PE104	16/02/89	0010	41.46	144.24	41.43	144.23	1323	60	2.5	17.1	3.8	1049	1089	5.2	11	1	0	7
PE104	16/02/89	0011	41.43	144.24	41.45	144.25	1611	60	2.3	17.2	5.0	911	964	5.0	32	0	1	0
PE104	16/02/89	0012	41.40	144.21	41.38	144.21	2005	60	2.8	17.2	4.0	1041	1114	4.9	10	0	0	5
PE104	17/02/89	0013	41.41	144.20	41.39	144.20	0721	60	3.0	17.2	3.3	1142	1162	5.5	23	0	0	32
PE104	17/02/89	0014	41.32	144.17	41.29	144.16	1016	60	2.5	17.3	3.5	1085	1158	5.0	175	0	0	34
PE104	17/02/89	0015	41.25	144.13	41.24	144.10	1341	60	2.6	17.5	3.5	1107	1160	5.5	32	0	0	23
PE104	17/02/89	0016	41.24	144.12	41.25	144.15	1703	58	2.5	18.2	4.3	957	1012	5.0	5	0	6	3
PE104	17/02/89	0017	41.15	143.58	41.18	144.01	2203	60	2.8	16.6	3.5	1021	1105	4.8	61	0	0	1 984
PE104	18/02/89	0018	41.15	143.58	41.15	144.02	1900	60	2.4	16.7	5.5	791	899	4.8	22	0	40	0
PE104	18/02/89	0019	41.15	143.58	41.16	144.01	2232	60	2.1	16.7	4.0	959	1021	5.0	46	0	6	11
PE104	19/02/89	0020	41.06	143.51	41.05	143.48	0648	60	2.7	16.4	3.8	1021	1085	4.9	198	0	0	1 238
PE104	19/02/89	0021	41.02	143.47	41.04	143.49	0954	60	2.7	16.4	4.5	920	1012	5.0	14	0	30	0
PE104	19/02/89	0022	41.01	143.45	41.00	143.44	1329	22	2.5	16.5	3.5	1052	1096	6.0	19	0	2	3
PE104	19/02/89	0023	40.59	143.46	41.02	143.47	1535	60	2.5	16.4	5.2	860	911	4.9	60	0	22	0
PE104	19/02/89	0024	41.05	143.50	41.02	143.49	1940	60	2.4	16.7	5.0	866	930	5.0	52	0	59	0
PE104	20/02/89	0025	41.01	143.44	41.03	143.46	0755	60	2.6	16.4	4.0	1103	1180	5.0	131	0	0	18
PE104	20/02/89	0026	41.08	143.54	41.09	143.55	1153	31	2.9	16.7	4.5	1038	1056	6.0	27	0	0	14
PE105	07/05/89	0001	41.02	143.46	41.04	143.47	0638	57	1.8	16.1	4.0	1080	1158	6.0	236	2	0	0
PE105	07/05/89	0002	41.07	143.51	41.05	143.49	0945	60	2.4	16.1	4.2	1041	1094	5.8	948	0	0	109
PE105	07/05/89	0003	41.13	144.00	41.16	144.01	1349	60	2.3	16.2	6.5	770	882	5.5	1 267	0	124	3
PE105	07/05/89	0004	41.19	144.04	41.17	144.02	1642	60	2.4	15.8	5.0	955	1032	6.0	29	0	3	74
PE105	07/05/89	0005	41.16	143.59	41.18	144.01	1953	60	2.5	15.7	4.2	1069	1094	5.8	118	0	0	60
PE105	08/05/89	0006	41.21	144.04	41.19	144.01	0727	60	2.2	15.6	3.8	1122	1193	5.5	96	0	0	23

Cruise	Date	Shot No.	POSITION Start Lat.	POSITION Start Long.	POSITION Finish Lat.	POSITION Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Temp(°C) Bot	Depth (m) Min	Depth (m) Max	Headline ht. (m)	CATCH WEIGHTS (kg) Orange roughy	CATCH WEIGHTS (kg) Smooth oreo	CATCH WEIGHTS (kg) Spiky oreo	CATCH WEIGHTS (kg) Warty oreo
PE105	08/05/89	0007	41.22	144.05	41.23	144.06	1052	33	2.9	15.5	3.5	1138	1199	5.8	30	0	0	6
PE105	08/05/89	0008	41.29	144.18	41.32	144.20	1432	60	3.2	16.1	5.0	898	950	5.5	34	1	3	10
PE105	08/05/89	0009	41.35	144.20	41.36	144.20	1704	60	2.7	15.7	4.0	1012	1109	6.0	71	0	1	20
PE105	08/05/89	0010	41.25	144.15	41.24	144.11	2133	60	2.4	16.0	4.0	1032	1076	5.8	124	0	0	71
PE105	09/05/89	0011	41.26	144.15	41.24	144.11	0052	60	2.9	16.0	3.8	1093	1157	6.0	95	0	0	9
PE105	09/05/89	0012	41.35	144.21	41.38	144.21	1224	60	2.8	16.0	5.5	930	981	5.2	41	0	2	3
PE105	09/05/89	0013	41.46	144.26	41.49	144.27	1545	60	2.6	16.1	6.5	855	902	5.5	672	0	8	8
PE105	09/05/89	0014	41.53	144.30	41.55	144.31	1811	60	2.5	15.9	7.0	776	891	5.2	119	0	8	7
PE105	10/05/89	0015	42.01	144.35	41.59	144.33	0641	60	2.5	15.5	4.5	911	1014	6.0	50	0	22	16
PE105	10/05/89	0016	41.57	144.30	41.59	144.32	0937	60	2.4	15.9	4.2	1023	1069	6.0	69	0	1	47
PE105	10/05/89	0017	42.10	144.39	42.12	144.40	1422	60	2.2	15.6	5.0	920	977	6.0	20	0	4	4
PE105	10/05/89	0018	42.16	144.42	42.18	144.43	1656	60	2.1	15.6	6.5	851	889	5.8	207	0	5	32
PE105	11/05/89	0019	42.21	144.41	42.24	144.42	0746	60	2.8	15.6	3.8	1045	1105	6.0	39	0	0	31
PE105*	11/05/89	0020	42.25	144.43	42.25	144.43	1050	5	2.5	15.6		997	1001	5.5	5	0	0	0
PE106*	28/08/89	0001	41.01	143.46	41.01	143.46		1	2.5						0	0	0	0
PE106	28/08/89	0002	41.02	143.46	41.00	143.45	0802	60	2.2	12.5	5.5	922	972	5.0	51	3	6	1
PE106	29/08/89	0003	41.01	143.47	41.03	143.49	2006	60	2.4	12.3	6.5	845	893	4.5	84	0	10	0
PE106	29/08/89	0004	41.04	143.46	41.02	143.45	2315	60	2.1	12.4	3.3	1149	1197	4.5	26	0	0	6
PE106	30/08/89	0005	41.02	143.46	41.04	143.48	0157	60	2.5	12.3	3.9	1028	1085	4.2	90	0	0	28
PE106	30/08/89	0006	41.13	144.00	41.15	144.01	0739	60	4.8	12.9	7.5	778	878	2.1	303	2	28	0
PE106	30/08/89	0007	41.16	144.00	41.18	144.01	1050	60	2.3	12.9	4.0	1050	1076	4.8	63	0	0	29
PE106	30/08/89	0008	41.19	144.02	41.21	144.04	1355	60	2.5	12.9	3.5	1098	1160	5.0	12	0	0	91
PE106	30/08/89	0009	41.22	144.10	41.20	144.07	1718	60	2.6	13.3	5.2	922	985	4.8	64	0	6	2
PE106	30/08/89	0010	41.19	144.07	41.21	144.09	2016	60	2.0	13.0	6.2	840	909	4.8	79	3	0	0
PE106	30/08/89	0011	41.25	144.11	41.26	144.14	2332	60	2.4	12.9	3.2	1127	1186	5.0	37	0	0	55
PE106	31/08/89	0012	41.27	144.14	41.24	144.12	0226	60	2.1	12.9	4.2	1019	1072	4.8	58	0	0	25
PE106	31/08/89	0013	41.30	144.19	41.28	144.17	1653	60	2.5	12.8	5.3	893	946	5.0	93	0	4	1
PE106	31/08/89	0014	41.46	144.24	41.48	144.25	2149	60	2.5	12.8	4.3	1025	1056	4.8	27	0	0	13
PE106	01/09/89	0015	42.08	144.39	42.12	144.41	0700	60	2.4	12.3	6.3	864	895	5.0	483	0	6	1
PE106*	01/09/89	0016	42.19	144.40	42.21	144.40	0959	60	1.9	12.7	3.8	1129	1138	4.8	0	0	0	0
PE106	01/09/89	0017	42.21	144.41	42.18	144.40	1240	60	2.5	12.6	4.0	1045	1072	4.8	154	0	0	41
PE106	01/09/89	0018	42.19	144.42	42.22	144.43	1529	60	2.7	12.8	4.8	940	972	4.8	170	0	9	3
PE106	02/09/89	0019	42.27	144.41	42.24	144.41	0620	60	2.5	12.4	3.5	1129	1166	5.0	19	0	1	33
PE106	02/09/89	0020	42.26	144.45	42.27	144.45	0914	32	2.6	12.6	5.8	878	890	4.8	168	0	4	0
PE106	02/09/89	0021	42.29	144.46	42.33	144.47	1141	60	2.7	12.6	4.5	928	977	5.0	168	0	7	7
PE106+	02/09/89	0022	43.30	145.34	43.32	145.36	2150	60	2.3	12.0	4.8	977	1019	5.0	428	0	0	39

Cruise	Date	Shot No.	POSITION Start Lat.	Start Long.	Finish Lat.	Finish Long.	Start (h)	Durn (min)	Speed (kts)	Temp(°C) Sur	Temp(°C) Bot	Depth (m) Min	Depth (m) Max	Headline ht. (m)	CATCH WEIGHTS (kg) Orange roughy	Smooth oreo	Spiky oreo	Warty oreo
PE106+	03/09/89	0023	43.32	145.36	43.30	145.33	0140	60	2.6	12.1	4.2	1061	1089	5.2	310	0	0	27
PE106+	03/09/89	0024	43.31	145.29	43.33	145.31	0436	60	2.1	11.3	3.5	1146	1217	5.2	59	0	0	7
PE107	23/11/89	0001	41.04	143.49	41.06	143.52	0940	57	2.8	14.1	4.6	919	1040	5.5	18	0	8	1
PE107	23/11/89	0002	41.11	143.59	41.12	144.00	1313	39	2.2	13.9	4.4	946	992	5.5	22	0	2	2
PE107	23/11/89	0003	41.08	143.55	41.08	143.54	1543	28	2.4	13.9	4.2	1014	1050	6.0	42	0	1	4
PE107	23/11/89	0004	41.17	144.04	41.19	144.05	1908	26	2.3	14.5	6.3	800	909	5.5	0	0	2	0
PE107	24/11/89	0005	41.17	144.01	41.18	144.03	0613	60	2.3	14.3	4.5	946	977	5.5	31	0	4	0
PE107	24/11/89	0006	41.17	144.01	41.20	144.03	0911	55	2.8	14.4	3.6	1036	1145	4.5	16	0	0	1
PE107	24/11/89	0007	41.23	144.13	41.24	144.15	1227	60	2.1	14.5	5.5	847	920	6.0	85	0	18	0
PE107	24/11/89	0008	41.25	144.13	41.24	144.11	1522	60	2.2	14.7	4.0	1056	1112	5.5	76	0	1	4
PE107	24/11/89	0009	41.29	144.15	41.31	144.17	1848	60	2.2	14.8	3.4	1136	1226	5.0	204	0	0	53
PE107	25/11/89	0010	41.36	144.22	41.39	144.22	0525	60	2.5	14.5	5.2	844	941	5.5	63	0	2	1
PE107	25/11/89	0011	41.41	144.21	41.44	144.22	0810	60	2.7	14.3	3.5	1111	1166	5.5	176	0	0	23
PE107	25/11/89	0012	41.50	144.27	41.52	144.30	1107	60	2.9	14.8	6.0	871	899	5.5	322	0	4	0
PE107	25/11/89	0013	41.54	144.30	41.57	144.32	1339	60	2.5	15.0	4.8	908	942	5.5	111	0	12	0
PE107	26/11/89	0014	42.02	144.33	42.04	144.35	1136	60	2.1	14.9	3.2	1112	1185	5.5	209	0	2	16
PE107	26/11/89	0015	42.10	144.39	42.13	144.39	1441	60	2.4	15.0	4.5	960	984	5.5	104	0	12	0
PE107	26/11/89	0016	42.14	144.39	42.16	144.39	1732	60	2.3	14.9	3.8	1034	1098	5.5	214	0	0	38
PE107	26/11/89	0017	42.18	144.43	42.21	144.43	2021	60	2.4	14.8	5.5	867	922	5.5	51	0	17	0
PE107	27/11/89	0018	42.23	144.41	42.20	144.41	0758	60	2.5	14.4	4.0	1021	1061	5.5	148	0	1	28
PE107	27/11/89	0019	42.21	144.40	42.24	144.40	1054	60	3.0	14.7	3.5	1096	1149	5.0	254	0	0	40
PE107	27/11/89	0020	42.26	144.44	42.23	144.43	1358	60	2.3	15.6	4.5	955	994	5.5	177	0	14	37
PE107	27/11/89	0021	42.27	144.42	42.29	144.43	1648	60	2.4	15.3	3.5	1111	1162	5.5	238	0	0	24
PE107+	28/11/89	0022	43.31	145.31	43.33	145.33	0422	60	2.4	13.4	3.5	1140	1182	5.5	68	0	0	7
PE107+	28/11/89	0023	43.32	145.35	43.30	145.33	0734	60	2.0	13.6	4.2	1021	1050	5.5	27	3	0	12
PE107+	28/11/89	0024	43.28	145.34	43.30	145.36	1017	60	2.1	14.1	4.8	911	960	5.5	128	1	1	11
PE107#	28/11/89	0025	43.33	145.40	43.33	145.40	1407	9	2.5	13.9	4.5	876	933	5.5	15	0	0	0
PE107#	28/11/89	0026	43.35	145.40	43.35	145.40	2131	6	2.5	14.1	4.5	882	930	5.0	393	0	0	0
PE107*#	29/11/89	0027	44.12	146.13	44.12	146.13	0730	0	2.5	13.0	5.0	780	900	5.5	0	0	0	0
PE107*#	29/11/89	0028	44.16	147.05	44.16	147.05	1800	0	2.5			720	725	5.5	0	0	0	0

* invalid shot; + 'non-random' shot; # targeted shot

APPENDIX IV: **List of fish species caught during the trawl surveys. Relâtive abundance, assessed as frequency of occurrence, is indicated.**

Key to relative abundance
C: Common (species caught in > 50% of trawls)
F: Frequent (species caught in 10 - 50% of trawls)
R: Rare (species caught in < 10% of trawls)
- : Not recorded

Family	Species	Common Name	Rel. abundance W Tas	NE Tas
Scyliorhinidae				
	Apristius sp.1	Deep-sea Catshark	R	R
	Apristius sp.2	Long-Snouted Catshark	F	F
Hexanchidae				
	Hexanchus griseus	Six Gilled Shark	-	R
Dalatiidae				
	Dalatius licha	Black Shark	F	F
Squalidae				
	Deania calcea	Brier Shark	C	C
	Centrophoros squamosus	Nilson's Deep-sea Dogfish	R	R
	Centroscymnus crepidater	Golden Dogfish	C	C
	Centroscymnus owstoni	Owston's Dogfish	C	C
	Centroscymnus coelolepis	Large- Scaled Dogfish	R	R
	Scymnodon plunketi	Lord Plunket's Shark	R	F
	Etmopterus pusillus	Black Shark	R	R
	Etmopterus baxteri	Rough Deep-şea Shark	F	C
	Oxynotus bruniensis	Prickly Dogfish	R	-
	Squalus megalops	Spiked Dogfish	-	R
	Etmopterus lucifer	Moller's Deep-sea Shark	R	-
Rajidae				
	Raja nasuta	Long- Nosed Skate	R	-
	Raja gudgeri	Bight Skate	-	R
	Raja sp. 1	Green Bight Skate	R	R
	Raja sp. 2	Grey Skate	R	-
	Pavoraja sp.	Blue Skate	R	-
	Raja sp.	Deep-sea Skate	R	-
	Bathyraja sp. 1	Purple Skate	R	R
	Unidentified species		R	-
Chimaeridae				
	Hydrolagus sp.	Deep-water Ghost Shark	F	F
Rhinochimaeridae				
	Harriotta raleighana	Spookfish	R	R
	Rhinochimaera pacifica	Sawtail Spookfish	C	F
Congridae				
	Bathyuroconger sp.	Deep-sea Conger Eel	-	R
	Bassanago bulbiceps	Swollen-Headed Congor Eel	R	-
Nettastomatidae				
	Nettastoma sp.	Witch Eel	-	R
Synaphobranchidae				
	Diastobranchus capensis	Basketwork Eel	C	C
Serrivomeridae				
	Serrivomer sp.	Sawtooth Eel	R	-
Nemichthyidae				
	Nemichthys sp.	Snipe Eel	F	F
	Unidentified species		R	-
Eurypharyngidae				
	Eurypharynx pelecanoides	Pelican Eel	R	-

Family	Species	Common Name	Rel. abundance W Tas	NE Tas
Trachichthyidae				
	Hoplostethus atlanticus	Orange Roughy	C	C
Zeidae				
	Cyttus traversi	King Dory	R	-
Oreosomatidae				
	Allocyttus verrucosus	Warty Oreo	C	F
	Neocyttus rhomboidalis	Spiky Oreo	C	F
	Oreosoma atlanticum	Ox-Eye Oreo	F	-
	Pseudocyttus maculatus	Spotted Oreo	C	F
	Allocyttus niger	Black Oreo	R	-
Trachiptereidae				
	Trachipterus arawatae	Deal fish	R	-
Platytroctidae				
	Normanichthys sp.		R	-
Scorpaenidae				
	Neosebastes scorpaenoides	Common Gurnard Perch	-	R
	Trachyscorpia capensis	Deep-water Gurnard Perch	R	F
Platycephalidae				
	Hoplichthys haswelli	Spiny Flathead	R	-
Psychrolutidae				
	Neophrynichthys marcidus	Australian Sculpin	R	-
	Zebinania sp.	Deep-water Sculpin	F	R
Scombridae				
	Gasterochisma melampus	Butterfly Mackerel	-	R
Serranidae				
	Unidentified species		R	-
Liparididae				
	Paraliparis sp.	Snailfish	R	-
Caristiidae				
	Unidentified species	Manefish	R	-
Apogonidae				
	Epigonus sp.	Cardinalfish	C	F
	Unidentified species		R	-
Gempylidae				
	Paradiplospinnus gracilis		R	-
	Ruvettus tydemani	Oilfish	R	R
Trichiuridae				
	Benthodesmus elongatus	Slender Frost Fish	R	-
	Benthodesmus sp.		R	-
	Lepidopus caudatus	Southern Frost Fish	R	-

5 COMMUNICATION OF RESULTS

Reporting of Results to Industry

Industry magazine articles

Kitchener, J. (1990). Fishery news - Orange roughy. Open season - first week. *Fishing Today* **3** (3):
33.

Lyle, J. (1988). The orange roughy fishery. p 7 *In* Research Report, Fisheries Division, Department of Sea Fisheries. Supplement to Fishing Today Publication No TBG1074

Lyle, J. (1989). Fishery news - Orange roughy. A biological comment. *Fishing Today* **2** (4): 29.

Lyle, J. (1990). Fishery news - Orange roughy. The scientist. *Fishing Today* **3** (1): 31.

Lyle, J. (1990). Fishery news - Orange roughy. Roughy research. *Fishing Today* **3** (4): 31.

Lyle, J., Kitchener, J. and Riley, S. (1989). Orange roughy bonanza off Tasmania. *Aust.Fish.* **48**(12): 20-24.

Lyle, J., Kitchener, J. and Riley, S. (1990). St Helens roughy site - 1990 season. *Aust. Fish.* **49**(10):27-29.

Lyle, J., Baron, M. and Cropp, R. (1991). Developmental trawling suggests potential for Remote Zone. *Aust. Fish.* **50**(2):10-12.

Industry seminars

December 1990. Orange roughy research ~~seminar for the fishing industry.~~ Held at CSIRO Division of Fisheries, Hobart.

Industry liaison groups

Regular reports of research findings have been provided to the Government/Industry Technical Liaison Committee, a sub-committee of the South East Trawl Management Advisory Committee

Progress Reports

Lyle, J.M. (1988). An assessment of the orange roughy resource off Tasmania: Progress report. Report to DPFRG 26.

Lyle, J.M., Kitchener, J.A. and Riley, S.P. (1989). An assessment of the orange roughy resource off Tasmania: Progress report 1989. Report to DPFRG 28.

Scientific Publications

Bell, J. D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (in press). Spatial variation in reproduction, and occurrence of non-reproductive adults, of orange roughy, *Hoplostethus atlanticus* (Trachichthyidae), from south-eastern Australia. *J. Fish Biol.*

Koslow, J. A., Bulman, C.M. and Lyle, J.M. (in prep). The mid-slope demersal fish community of south-eastern Australia.

Further papers on orange roughy reproductive biology and oreo biology are planned.

6 ORIGINAL GRANT APPLICATION

FISHING INDUSTRY RESEARCH TRUST ACCOUNT
APPLICATION FOR NEW GRANT
1987/88

1. Title of Proposal:

An Assessment of the Orange Roughy Resource off the Coast around Tasmania.

2. Name of Applicant:

Department of Sea Fisheries, Tasmania.

3. Division, Department or Section:

Resource Assessment Section, Research Division.

4. Proposal:

To assess the orange roughy (*Hoplostethus atlanticus*) resource size and potential sustainable yield in the area off the coast around Tasmania. The proposal aims to both complement and supplement the deepwater aspect of the *Western Bass Strait Trawl Fishery Assessment Programme* (FIRTA 86/39) being undertaken by the Department of Conservation and Lands, Victoria. This information will be used to formulate management proposals to optimise the exploitation of the orange roughy resource.

Funds are being sought from FIRTA to charter a commercial orange roughy vessel to undertake systematic fishing and echo sounding surveys of the study area, and to cover the salaries and associated field costs of two research staff to be employed as part of an orange roughy research group.

5. Name of Person Responsible for Programme:

M. A. Wilson, Director,
Department of Sea Fisheries,
G.P.O. Box 619F, HOBART 7001.

Telephone: 002-306545
Telex: TASFA AA58352

6. Qualifications of Staff to be Employed on the Programme:

	% of time on this project
K. Evans, B.Sc. (Hons.) - Research Officer in Charge.	(90)
M. Noack, Biol. Lab. Tech. Cert. - Technical Officer, Fish Ageing.	(100)
I. Gibson, B.Sc. - Technical Officer.	(100)
I. Larner, B.Sc. (Hons.) - Computer Systems Officer	(10)
1 x Research Officer - minimum qualification of B.Sc. (Hons.) degree in Biological Sciences.	(100)
1 x Technical Officer - minimum qualification of 5 years secondary schooling.	(100)

7. Objectives:

1. To determine the size of the orange roughy resource on the continental slope (between 800 and 1 200m depths) off the coast around Tasmania.

2. To refine estimates and to gain a better understanding of the basic orange roughy population parameters (age, growth, survival, reproductive strategies and biology).

3. To estimate the potential sustainable yield for orange roughy on the continental slope around Tasmanian coast.

4. To further investigate the spatial and temporal distribution and relative abundance patterns of orange roughy in the study area (i.e. the occurrence, size and distribution of spawning and non-spawning aggregations of the species).

5. To investigate factors (both biotic and abiotic) which affect the distributional and abundance patterns of orange roughy.

6. To determine the distribution, resource sizes and potential yields of other potentially commercial species occurring between 800 and 1 200m depths off the Tasmanian Coast.

8. Justification, Including Practical Application:

During the past 12 months, commercial exploitation of orange roughy on the mid-continental slope off Tasmania's coast has accelerated exponentially. Landings of this species in 1986 will exceed 4 000 tonnes (value in excess of $8.0m), making it already the most valuable finfish species in the S.E. trawl fishery. Prior to mid-1986, the fishery was exploited by only a handful of specialised larger vessels, equipped with the sophisticated fishing and electronic equipment required to operate in the deep waters inhabited by orange roughy (800 - 1 200m). However, following a recent discovery of large aggregations of orange roughy off Tasmania's west coast, this number has already increased to in excess of twenty five vessels. In addition, South-western quota units are being purchased by large Australian and New Zealand corporations. Several large trawlers are currently being built or refitted to operate in the orange roughy fishery, and hence the expansion is certain to continue.

The redirection of fishing effort to the deepwater orange roughy grounds off Tasmania has resulted in a change away from the traditional multi-species harvesting strategies employed in the S.E. trawl fishery. The trend in this rapidly developing fishery is towards single-species target fishing, with 80 tonne shots in less than ten minutes fishing not uncommon. It requires larger vessels fitted with specialised trawling gear and sophisticated deepwater fish finding equipment.

Of principal concern to the fishery at present is the lack of detailed knowledge of the resource size and its potential sustainable yield. In light of the rate at which the fishery is currently developing and the massive economic investments being made into the fishery, this information is of urgent and fundamental importance to ensure the development of appropriate and controlled management regimes to avoid overfishing and a potential economic disaster.

The Tasmanian Department of Sea Fisheries has a history of involvement in the development of this fishery following the discovery of orange roughy by DSF's F.R.V. *Challenger* off the west coast of Tasmania in December, 1981. Subsequent exploratory fishing surveys, funded jointly by the State and Commonwealth, focussed on assessing the commercial potential of the resource and identifying suitable trawl grounds (ref. A ground survey of the upper and mid-continental slope of southern Australia. *Tas. Fish. Dev. Auth.*, 276 pp.) and provided the impetus for the present development. Orange roughy stock structuring and age and growth studies are being undertaken at present (FIRTA 84/27 and FIRTA 84/51) and these will provide important information on the population structure and parameters of the species.

A preliminary assessment of the resource size and likely yields of the commercial trawl fish species (including orange roughy) in South-western sector was provided by the Department in 1984 (ref. An assessment of the lightly exploited trawl resources of the developing zone. In: *DPFRG Trawl Fish Workshop*, Sydney, 1984). Dr J.L. McKoy, in his report on S.E. trawl research to FIRC last year, highlighted the importance of DSF assessment as a preliminary guide to the approximate size and possible yields from particular stocks. At present, a modelling project is being completed to refine these estimates for most species (FIRTA 86/45). It must be emphasised however, that the orange roughy assessment was based entirely on exploratory survey fishing and takes no account of the massive aggregations of fish discovered since the development of the commercial fishery. The fishing methods currently employed can be more closely allied to those of purse seine fisheries. While the preliminary orange roughy estimates provided a useful guide in the initial development planning, they are now totally inapplicable.

A systematic survey of the mid-continental slope (800 - 1 200 m) is urgently required to provide a detailed assessment of the orange roughy resources in the South-western sector. The proposed survey off the Tasmanian coast is designed to provide information which is of fundamental importance in formulating a management plan for the unique orange roughy fishery. The survey technique to be employed in this study has proven successful in New Zealand and is recommended by Dr J.L. McKoy.

The project will be complemented by the *Western Bass Strait Trawl Fish Assessment* programme being undertaken by Department of Conservation, Forests and Lands, Victoria and close cooperation and collaboration between the two Departments will be will be maintained to provide directly comparable results from the two adjacent study sites.

The DSF has had a continued commitment to the development of this fishery since its discovery in Australian waters and is clearly the most experienced research agency to undertake this project. This commitment has involved the expenditure of several hundred thousand dollars.

9. Location of Operation:

The base of operation will be at Taroona, where the Marine Laboratories of the Department of Sea Fisheries are located.

The area to be included in the study is the continental slope region off Tasmania, between 800 and 1 200 m depths, south of latitude 40°00'S (that is, the waters south of Flinders Island on the east coast and south of S.W. King Island on the west coast).

10. Proposal in Detail, Including Procedures:

(a) Plan of Operation.

(i) Method of procedure.

In order to achieve the stated objectives of the project, two field sampling programmes, to be conducted simultaneously, will be established. The first will be based on systematic, survey fishing using a chartered commercial vessel and the Department's research vessel F.R.V. *Challenger* to achieve an unbiased, independent estimate of the orange roughy resource size. Surveys will be replicated seasonally over a two year period to enable the assessment of temporal variations in resource size, distribution and relative abundance. Secondly, a commercial catch sampling and monitoring programme will be implemented. Biological information will be collected routinely, both on board commercial vessels and in ports of landing to complement the survey data.

Details of the two sampling programmes are provided below.

Survey fishing programme.

Orange roughy survey work is to be undertaken using methodologies developed jointly with the Department of Conservation, Forests and Lands, Victoria. DSF personnel will participate in the initial *Western Bass Strait Trawl Fishery Assessment* (FIRTA 86/39) survey cruises (the first in January, 1987), in order that uniform fishing and sampling techniques and strategies are developed. This close co-operation will ensure that comparable results are obtained from both the proposed study and the Victorian study. Thus a complete assessment of the orange roughy resource size will be provided from the entire South-western sector of the S.E. trawl fishery.

The orange roughy fishery is unique in that large, dense aggregations of fish (both spawning and non-spawning) occur at various times of the year. These variations in spatial and temporal distribution and abundance restrict the application of more conventional surveying techniques (e.g. random sampling). In New Zealand, stratified random sampling surveys are employed to assess orange roughy stocks. Similar techniques will be developed for this study to overcome these variations and thus give more precise estimates of the orange roughy resource size.

The study area will be divided into homogenous geographical and depth strata, each of which will be treated independently. The position of sampling stations within each strata will be drawn at random. Strata boundaries and relative sampling intensities will be determined through a combination of plotting past commercial trawl positions and CPUE data from the S.E. trawl logbook data (where lat./long. positions are provided), an analysis of DSF exploratory survey data, observer records obtained on board commercial vessels (see Commercial catch sampling and monitoring programme) and by consultation with industry.

Fishing surveys will be conducted seasonally (every 3 months) over two years, that is eight cruises in all. The charter trawler will survey the west and south coasts off Tasmania, while DSF's F.R.V.*Challenger* will complete the surveys on the east and south-east coasts. Approximately 70 trawl shots will be required seasonally to achieve the *average* station density (approximately 1 shot per 80 km^2) needed to provide sufficiently precise results for management purposes. It is estimated that 8 fishing days during each survey will be required by each vessel to complete this task.

Data on the the species composition of each sampling station will be collected routinely, along with length frequency distributions for orange roughy and all other potentially commercial species (e.g. oreo dories *Allocyttus verrucosus*, *Neocyttus rhomboidalis*). Samples of the important species will be collected from each shot, and returned to the Taroona research laboratories where they will be processed for more detailed biological information (length, sex, weight, gonad weight and condition, age).

A preliminary investigation of a number of factors which may affect the distributional and abundance patterns of orange roughy (that is, the occurrence of large aggregations of orange roughy) will be undertaken. In New Zealand, it has been observed that large aggregations of orange roughy show a preference for 4 - 5°C water temperature. The relationship between water temperature and orange roughy distribution and abundance will be investigated in this study. The Department has purchased a number of data loggers which measure temperature/salinity profiles of the water column to depths in excess of 2 000m. These will be used to measure water temperatures and salinities within each strata. A study of the effects of biotic factors (feeding and reproduction) on the occurrence of aggregations will also be included. Stomach samples will be routinely collected from each study site for detailed examination in the laboratory.

Commercial catch sampling and monitoring programme.

This programme will involve regular catch sampling on board commercial orange roughy vessels. Research staff will participate in at least one commercial trip per month, although this will be intensified during the initial stages of the project whilst the survey design is being developed. Important information which cannot be collected through the S.E. trawl logbook will be carefully monitored during these trips. Ancillary information on fishing strategies, targetting and target searching will be included. Observer data sheets to record details of these operations and the occurrence, strength and size of echo sounding targets will be employed. These results will be used to assess the viability and validity of incorporating acoustic surveying techniques in the fishing survey to enhance assessments, and to assist in defining survey strata. Randomly selected samples will be made from each catch and kept separate from the remainder of the catch for biological processing. While basic length frequency data will be collected at sea, the remainder of the biological information will be obtained on return to port. Factory facilities are to made available to the Department personnel to conduct this work in Devonport (the major port of landing in Tasmania). The Department's market measuring programme will be utilised to collect additional landed catch data and biological information.

The commercial sampling programme will be maintained for the entire three years of the project to monitor the impact of exploitation on the resource during the initial years of development.

Ageing

The Department is presently undertaking an ageing study of orange roughy (FIRTA 84/51) and although reproducible techniques are currently being developed, age validation is proving a major obstacle. Dr J.L. McKoy, in his report on to FIRC on S.E. trawl fishery research last year, highlighted the importance of age validation when conducting stock assessments in general. This area will be given more consideration in this study. Research into the structure and physiology of otolith deposition is currently being undertaken at the University of Tasmania. These results, as well as the considerable body of fish ageing expertise already employed within the Department will be fully utilised in solving problems in validation.

Data Handling and Analysis

An integrated catch and biological data base and appropriate software for analysis is already in existence on the Department's in-house computing system (ref. FIRTA 86/45 Progress Report and, "Collection and storage of data in the trawl, purse seine and drop-line fisheries." *Dept. Sea Fish. Tas. Tech. Rep.* **8**). This system will be utilised for the proposed study. Detailed analysis and documentation of results and most laboratory based work will be undertaken in the third year of the study.

(ii) Facilities available

Laboratory facilities including a dedicated fish ageing facility, freezers and fish handling area, workshop back-up and computing systems will be provided at the DSF Marine Laboratories at Crayfish Point. All administrative support will be provided by the Department.

The Department's F.R.V. *Challenger*, a fully equipped 21.0 m stern trawler, will be available to undertake the survey work off the east coast of Tasmania. The vessel is manned by three crew, all of whom have had extensive experienced in deepwater trawling for orange roughy.

(b) Supporting Data.

(i) Previous work in this or related field.

DSF has been responsible for the discovery and exploration of the orange roughy resource in southern Australia through a series of jointly funded State/ Commonwealth mid-slope exploratory surveys. These have led to the delineation of present trawl grounds, have identified spawning sites and have determined the distribution of orange roughy. More recently studies on orange roughy stock structuring (FIRTA 84/27) and age and growth (FIRTA 84/51) have been undertaken. It should be noted that these project are currently being completed and will terminate at the time that the proposed study will commence.

11. Proposed Commencement Date and Anticipated Completion Date:

Proposed commencement date:	July 1987.
Completion of survey field studies:	June 1989.
Completion date for analysis and report documentation:	June 1990.

12. Funds Requested: Details provided in Appendix 1.

	1987/88 $	1988/89 $	1989/90 $
(a) Salaries and Wages	44 574	44 574	44 574
(b) Total Operating Expenses	101 900	101 900	5 900
(c) Total Travel Expenses	17 130	17 130	6 673
(d) Capital Items	5 500	0	0
GROSS TOTAL COSTS	**169 104**	**163 604**	**57 147**
Estimated Income *	96 000	96 000	0

* The estimated income from the project is expected to be generated from the sale of orange roughy caught by the chartered survey vessel. It is proposed that in light of lucrative nature of the orange roughy fishery at present, the conditions of charter are modified to allow the owner of the charter vessel to be reimbursed for the sale of fish exceeding the cost of the charter.

13. Funds to be Provided by the Applicant or Sought from Other Source(s): details provided in Appendix 2.

	1987/88 $	1988/89 $	1989/90 $
(a) Salaries and Wages	71 614	71 614	71 614
(b) Total Operating Expenses	151 400	151 400	76 400
(c) Total Travel Expenses	15 500	15 500	3 400
(d) Capital Items	10 500	0	0
GROSS TOTAL COSTS	**248 816**	**238 316**	**151 414**

14. Co-operating Agencies and Their Function:

Marine Resources Management Branch,
Department of Conservation, Forests and Lands, Victoria.

Close co-operation will be maintained to avoid duplication of effort, to ensure that uniform surveying and sampling techniques are employed in order that results from the two adjacent studies are directly comparable, and to foster collaboration in sampling (See Section 15).

15. Is Similar Work Being Undertaken in Australia:

The Victorian Department of Conservation, Forests and Lands is currently conducting a three year study which aims to assess the trawl fish resources in western Bass Strait (FIRTA 86/. This programme is not directed specifically at orange roughy but includes all commercial finfish species on the continental slope between 200 and 1 000 m depth.

The proposed study will complement the deepwater aspect of the Victorian study so that results will provide a complete assessment of the orange roughy stocks in the whole South-western sector of the S.E. trawl fishery. Supplementary orange roughy surveying may need to be provided in the Victorian study area to increase the sampling density in the deeper waters.

16. Plans for Reporting or Publishing Results:

Progress reports will be supplied to FIRTA, with a detailed final report being submitted at the completion of the project. In addition, results will be published in the appropriate industry and scientific publications as well as the Department's Technical Report series.

Appendix 1. Detailed Statement of Funds Requested from FIRTA:

	1987/88 $	1988/89 $	1989/90 $
(a) Salaries and Wages			
1 Research Officer	21 300	21 300	21 300
1 Technical Officer	17 800	17 800	17 800
Payroll tax, Workers compensation	5 474	5 474	5 474
Total Salaries and Wages	44 574	44 574	44 574
(b) Operating Expenses			
Vessel charter - 4 x 8 fishing days at $3 000/day	96 000	96 000	0
Sampling gear and equipment	3 400	3 400	3 400
Printing	800	800	800
Computing	1 000	1 000	1 000
Car Hire	700	700	700
Total Operating Expenses	101 900	101 900	5 900
(c) Travel Expenses			
Travelling expenses (airfares to Victoria - 2 x 4 trips).	2 400	2 400	0
Interstate travel allowance.	1 376	1376	0
Sea going travel allowance	13 350	13 350	6 670
Other travel costs	1 200	1 200	0
Total Travel Expenses	18 326	18 326	6 670
(d) Capital Items			
Data mass storage device	2 800	0	0
High speed winch for temp./salinity data logger.	3 000	0	0
Total Capital Items	5 800	0	0
GROSS TOTAL COSTS	**170 600**	**164 800**	**57 144**

Appendix 2. Detailed Statement of Funds Provided by the Applicant:

	1987/88 $	1988/89 $	1989/90 $
(a) Salaries and Wages			
Salaries	62 820	62 820	62 820
Payroll tax, Workers compensation	8 794	8 794	8 794
Total Salaries and Wages	71 614	71 614	71 614
(b) Operating Expenses			
F.R.V. Challenger running costs	75 000	75 000	0
Overheads	76 400	76 400	76 400
Total Operating Expenses	151 400	151 400	76 400
(c) Travel Expenses			
Sea going travel allowance	14 300	14 300	3 400
Other travel costs	1 200	1 200	0
Total Travel Expenses	15 500	15 500	3 400
(d) Capital Items			
Temp./salinity data loggers	10 500	0	0
Total Capital Items	10 500	0	0
GROSS TOTAL COSTS	**248 816**	**238 316**	**151 414**