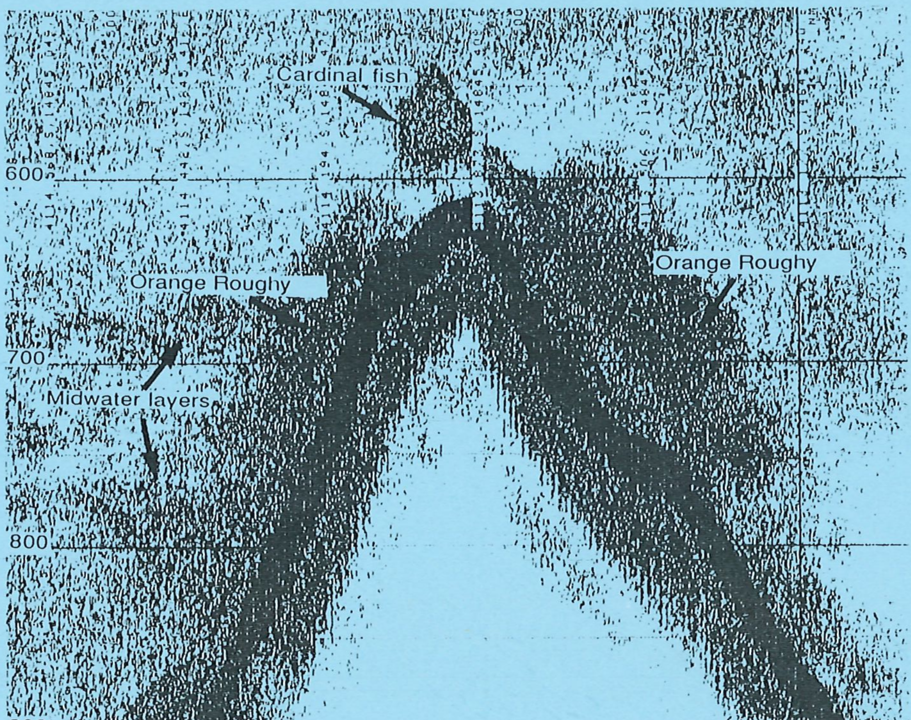
THE ABUNDANCE, DISTRIBUTION, MOVEMENTS AND POPULATION DYNAMICS OF ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*) IN SOUTH EAST AUSTRALIAN WATERS

Final Report to the Fishing Industry Research and Development Council
Project 87/129



CSIRO
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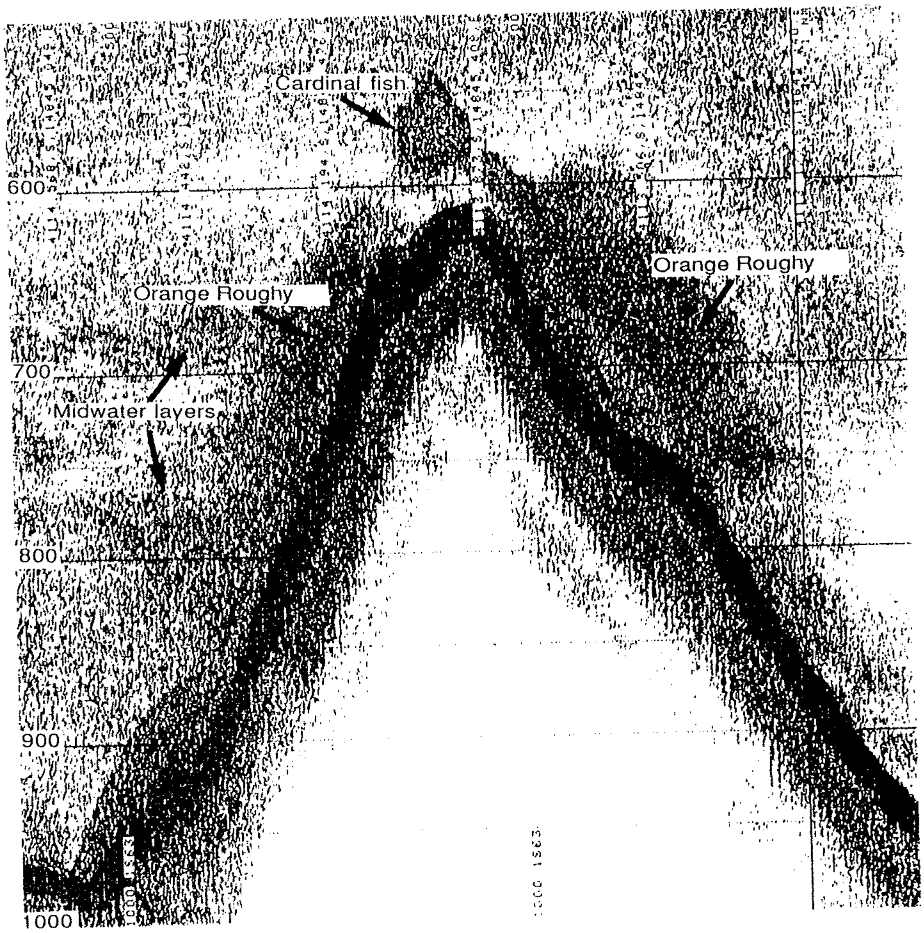

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A. INTRODUCTION

Although orange roughy was first found in Australian waters in 1981, it was not until 1986 that substantial quantities were caught in this country, following the discovery of the Sandy Cape grounds on the north west coast of Tasmania. The 1986 catch was 4,600 t, and although great expectations of high catch levels were held, the 1987 catch was only 5,700 t.

At this stage, the distribution, abundance and biology of orange roughy in Australia were unknown. Comparisons with the New Zealand fishery were of limited use. The fishery there had begun in 1978, and catches had increased from 1,500 t to a peak of 54,000 t in 1988/89. It was based mainly on 4 winter spawning aggregations, and 4 to 8 smaller non-spawning aggregations. Although work was in progress in New Zealand on the distribution, spawning period and feeding of the species, there were still many important gaps, particularly on growth rates, age structure, mortality rates, recruitment, migration patterns, and *in situ* target strength, which is required to conduct acoustic surveys. Some of the early reports on these topics were controversial and subsequently proved erroneous and led to mismanagement of the New Zealand fishery. Thus research from New Zealand could not simply be transferred to the Australian situation, and in the absence of any known winter spawning aggregation, even a rough estimate of the potential of an Australian fishery was impossible.

Against this background CSIRO was granted funds from FIRDC to commence a research program with the broad objectives of estimating the abundance of orange roughy and studying its biology and life history in southeastern Australian waters. By the time the program became operational in early 1987, the Sandy Cape grounds had ceased to be productive and the fleet had dispersed in attempts to discover other grounds. Preliminary exploratory cruises carried out in 1987 resulted in an examination of the bathymetry of the grounds at Sandy Cape and Cape Grim on the west coast and off St. Patrick's Head on the east coast, and in the collection of biological data from these areas.

In 1988 and 1989 a random trawl survey was carried out to determine orange roughy biomass in the area from Kangaroo Island in the Great Australian Bight to the east coast of Tasmania, and to obtain biological data on the species. A trawl survey was the only feasible means to survey orange roughy and examine its biology at this time, but it was recognized that other research capabilities would need to be developed over a longer time period to properly investigate the species and other deep water fishery resources in temperate Australia. Steps were therefore taken during this grant period to develop deep water acoustic and underwater stereo photographic systems. The stereo camera system was first trialled in July 1988, and during the 1989 survey, the system was mounted on the net headline in order to investigate small-scale changes in distribution patterns. To develop an acoustic system suitable for deepwater fisheries, a deepwater towed body system was designed, built and tested, and initial acoustic studies commenced in January 1989. A Simrad EK500 echo sounder was later purchased, but initial trials of this system were carried out after the expiry of this grant.

B. OBJECTIVES

1. To estimate the abundance of orange roughy in southeast Australian waters, with particular reference to the Sandy Cape, Cape Grim and St. Patrick's Head Grounds in the first instance.

2. To add to our knowledge and understanding of the life history of orange roughy.

3. To present the results in a manner which can be used by advisory and management agencies for the benefit of the fishery, and by industry to reduce the cost of capture and increase the value of the catch.

4. To apply acoustic methods of estimating fish abundance to the deep water fisheries resources - here orange roughy - in the Australian fishing zone.

C. SUMMARY

Abundance estimates

The results of the 1988 and 1989 random demersal trawl surveys are discussed in

Document 1. The biomass estimates obtained for each year were similar and ranged between about 10,000 and 20,000 tonnes for the southeast trawl region. However, shortly after the completion of the 1989 survey, a spawning aggregation was discovered on the east coast. In the first three months of fishing 17,000 tonnes were caught, considerably more than the estimates for the east coast biomass of between 1,333 and 5,000 tonnes.

Results of the random trawl survey were strongly biased downward because the orange roughy off southeast Australia occur predominantly on untrawable grounds, such as at St Helens and Maatsuyker. About one third of the area surveyed was considered untrawlable. Orange roughy also occur in the water column where they are not sampled by a demersal trawl, leading to a further downward bias. Despite these problems, random trawl surveys may still be useful as a relative measure in monitoring further biomass trends.

Two further factors which could result in a downward bias of the trawl survey were examined. **Document 2** compares the surveying ability of F.R.V. *Soela,* the CSIRO research vessel, and a commercial vessel, both of which surveyed the same area. Biomass estimates from the two vessels did not differ significantly for the four quarters when the comparison was made. Escapement of roughy through the net mesh is examined in **Document 3**. No roughy above 21cm escaped, and the total number was small. Mesh escapement results in an underestimate of biomass indices of about 1%.

A further source of downward bias may be avoidance of the trawl. Orange roughy density estimated from photographs obtained from the camera system mounted on the trawl headline where 1.7 to 2.5 times larger than estimates from the trawl (**Document 8**). However this may have also resulted from prolonged swimming in front of the net prior to capture.

Aggregation surveys

At the end of the 1989 random trawl survey, a small aggregation was located off Bicheno. on the east coast of Tasmania (**Document 11**). Several acoustic surveys were carried out, and the results compared with the known commercial catch. Assuming a fishing down operation by the commercial boats, the initial biomass was estimated to be 235 tonnes, of which 206 tonnes were removed. Acoustic biomass estimates, assuming a target strength of -39dB, decreased from 220 to 92 tonnes over the same period.

During August 1989 a preliminary acoustic survey of the spawning aggregation off St. Helens was carried out on a ship of opportunity (**Document 12**). This resulted in an estimate of 320 000t,.but due to the nature of the equipment used in the survey (in particular the uncalibrated echo sounder), the assumptions made in the calculations, and the use of a maximal density estimate of 0.5 fish/m^3, the confidence in this estimate is only to within a factor of 3-5. This is of limited use for management purposes, and indeed a more robust estimate of 110 000t was obtained on board *R.V. Southern Surveyor* after the expiry of this grant.

Life History

i) Reproductive condition

Most of the reproductive material that we obtained was shared with Dr. J. Bell, who has reported separately to FIRDC. Our investigations were restricted to obtaining data on sex, stage and gonad weight (**Document 4**). The length at maturity for both sexes ranged from 30 to 33 cm, depending on sex and location. Gonadosomatic index (GSI) values were highest in female fish caught in July off the east coast of Tasmania, where the gonads were about 5% of the body weight. Values for NSW fish were lower than elsewhere. Length at maturity analyses showed that an average of 35% of all adult female fish from the east coast of Tasmania were non-reproductive in April. These fish did not progress beyond a stage two condition, which is necessary if reproduction were to occur. These results suggest that not all fish spawn each year. This has substantial implications for future surveys of spawning areas, since estimates of spawning biomass would need to be raised by the fraction of non-spawners to assess the total stock biomass.

ii) Ichthyoplankton

Ichthyoplankton samples previously collected between 1984 and 1985 at two month intervals and at nine transect positions spaced equally around Tasmania were examined for the presence of orange roughy eggs and larvae The samples were obtained from oblique tows to a depth of 200m, and no orange roughy eggs or larvae were found, suggesting that egg density and larval behaviour may confine eggs and larvae to water deeper than 200m. Larvae of three related species were found, and their larval development was described (**Document 5**).

iii) Length frequency distributions

For non-aggregated fish length frequency distributions for major regions between the Great Australian Bight and eastern Bass Strait were similar for both 1988 and 1989 and typically exhibited a bimodal distribution with peaks at about 25 and 35cm, that is within both the juvenile and adult size ranges. East Bass Strait frequencies were dominated by the presence of juveniles (**Document 4**).

This bimodal nature of the length frequency distributions was a subject of discussion at the second orange roughy workshop in Adelaide during July 1988. The present data indicate that the phenomenon is widespread and not the result of inadequate sampling. With information available from other research groups mentioned in Document 4 on longevity (estimated to be 75-150 years) and exceptionally slow growth rate it is most likely that the biomodality is a result of a combination of a decrease in mortality and/or growth rate at maturity. The alternative explanation of recruitment failure is unlikely, since a large number of age classes would be involved.

The consistent presence of juveniles off eastern Bass Strait indicates that this area may serve as a juvenile nursery ground.

iv) Diet

About 7500 stomachs obtained during the random trawl surveys were examined for the composition, weight, and digestive stage of prey items (**Document 6**). The diet was similar to that recorded off New Zealand, with the juveniles feeding mainly on bentho- and meso-pelagic crustaceans, while mature fish predominantly consumed fish and squid. Based upon the decline in stomach fullness observed at a station sampled over an 80 hour period, gut evacuation and hence food consumption rates could be estimated.

Daily rates of food consumption were estimated as 1.47% body weight for adults and 1.16% for juveniles.These estimates were combined with data on growth and reproduction to obtain a preliminary energy budget. Metabolic rates were estimated to be similar to those of active migratory mesopelagic fish and to be substantiously higher than those of non-migratory bathypelagic fish.

v) Live holding

Questions relating to the stock structure of orange roughy off SE Australia might be examined directly if fish could be tagged. As a first step in determining if tagging is feasible, specimens were held on board to observe their survival. Selected fish did not survive at a temperature of 15^{O}C, and at temperatures of 8 to 10°C the fish survived for 5 hours, but their condition was poor (**Document 7**). The observations were made with only basic equipment (a deck tank and blocks of sea water ice), and the use of a proper refrigerated water system may increase survival rates. Survival for over 24 hours has apparently been observed in brine tanks on commercial vessels when catches have been very low. These factors indicate that the possibility of tagging orange roughy, which lack a gas-filled air bladder merits further investigation.

vi) Distribution patterns

During the 1989 random trawl survey the camera system was mounted on the trawl headline (**Document 8**). There is a relationship between roughy catch and the presence of sessile benthos indicating that roughy are more abundant in areas where organic production levels are high. There is a similar connection with the presence of motile benthos forms, after the elimination of a few samples from sites where fishing has occurred. These few samples were typified by the presence of large numbers of motile benthos forms, but low roughy catches. Motile benthos has been observed to aggregate on organic debris, which suggests that in these areas there is a large amount of such debris present after fishing operations. The low roughy catches also indicate that at least in the short term, roughy do not move in from surrounding areas.

ACOUSTICS

Towed body

When working with deep sea fish it is especially advantageous to mount the echo sounder transducer in a towed body. Three main advantages are (i) the provision of a stable platform, (ii) a detection capability which is not sensitive to sea state or vessel course, and (iii) decreased distance to the fish and hence decreased attenuation and a diminished sample volume.

A suitable size towed body was designed and manufactured in the laboratory. Due to the absence of a divisional research vessel during the period when the towed body had been built and was available for testing only two series of sea trials were performed (**Document 10**). In the first series, pitch at a depth of 200 meters and a speed of about 5 knots ranged from -1° to -7°. After some laboratory modifications these figures were reduced to the design range of from 1.6° to -1° for the second series.of trials. The next major step in improving the system was to reduce background noise levels by purchasing a suitable electromechanical cable, which was achieved after the expiration of this grant.

Mean volume backscatter strength and trawl catch

During the 1989 random trawl survey, MVBS (mean volume backscattering strength) and corresponding trawl catches were recorded (**Document 9**). Low but significant correlations were obtained between these two variables for a number of major catch components, with r^2 values ranging from 0.33 to 0.46. Using data from catches where the orange roughy component was high (95 to 96%), it is suggested that the literature mean target strength value of -36dB may be too high.

MID-SLOPE COMMUNITY

Data from the 1989 random trawl survey were combined with data from the Tasmania Department of Sea Fisheries demersal trawl surveys off Tasmania at 800-1200 m from 1987-89 to examine the biomass, diversity, and structure of the fish community in this region (**Document 13**). The mean density of demersal species was 4.82 g/m^2, which is comparable to the density of fish observed at similar depths in the temperate

North Atlantic and North Pacific. However, the density of orange roughy (*Hoplostethus atlanticus*) on rough, untrawlable ground, as estimated from acoustic surveys in 1990, was 39.0 - 67.3 g/m^2. Although 37 families and 118 species were represented in the catch, 96% of the catch was obtained from 7 dominant families: Trachichthyidae (i.e. orange roughy) (23%), Squalidae (22%), Oreosomatidae (20%), Macrouridae (13%), Synaphobranchidae (8%), Alepocephalidae (5%), and Moridae (4%). The species abundance pattern was characterized by the dominance of a few species combined with a relatively large number of rare species: 37.6% of species occurred only once or twice in the survey. Nonhierarchical cluster analysis indicated that the species could be sub-divided into assemblages by depth (shallow, intermediate and deep stations) and area (east and west Tasmania). There is a distinct break in the species composition of demersal fishes between mid-slope (800-1200 m) and upper-slope (500 m) depths off southeast Australia: only 20% of upper-slope species were found in the mid-slope region. Comparison across biogeographic provinces indicated no overlap in species composition with demersal fish communities at similar latitudes and depths in the North Pacific, but there were affinities with fish communities in the North Atlantic. This is consistent with the circulation pattern of intermediate-depth water masses: the southeast Australian mid-slope fishes reside in Antarctic Intermediate Water, the flow of which can be clearly traced into the North Atlantic but not the North Pacific.

D. PRINCIPAL RECOMMENDATIONS FOR MANAGEMENT

1) Develop non-trawl survey methodologies

The trawl survey demonstrated that orange roughy are distributed primarily on rough ground that cannot be routinely surveyed with a trawl. Random trawl surveys may provide useful relative indices of abundance for roughy and other slope fishes, but they cannot be used to set TACs at present. We therefore recommend continued support for development of acoustic and other survey methodologies (e.g. the egg survey method). Although the acoustic estimates of the small Bicheno aggregation and comparison of acoustic and trawl data represented preliminary uses of acoustic methods, these studies, combined with the successful trials of a deep towed vehicle, indicated the feasibility of the use of acoustic techniques with orange roughy in Australian waters.

2) Determine deepwater productivity

The present study indicates that the mid-slope fish community off southeast Australia is characterized by exceptionally high productivity. There are apparently extremely high densities of orange roughy in the untrawlable areas – more than an order of magnitude higher than the density of all fishes occurring on trawlable ground either in this region or in the North Pacific and Atlantic. The orange roughy also seem to be characterized by higher levels of food consumption and metabolism than bathypelagic fishes living at these depths that have been hitherto studied. Calculations indicate that the food requirements of the orange roughy cannot be met by the *in situ* productivity within the narrow mid-slope area. The sources and extent of the productivity supporting temperate Australian deepwater fisheries should be further investigated as a means to assess long-term sustainable yield.

3) Non-reproductive roughy

The relatively large proportion of mature orange roughy that do not spawn within a given year has significant implications for future assessments of spawning biomass.

Regardless of the method used to survey the spawning population, the non-reproductive portion will not be assessed, thereby leading to an underestimate of stock biomass. Further studies need to assess more precisely the extent of non-reproductive fish in major spawning aggregations, such as off St. Helens.

4) Feasibility of tagging

Although there was limited success in preliminary experiments to maintain orange roughy live, the feasibility of tagging orange roughy should be further examined. Stock structure of orange roughy, particularly the relationship between fish on adjacent fishing grounds, such as the Maatsuyker and St. Helens, Tasmania fisheries, is a major uncertainty in managing the fishery at present. Genetic methods seem unlikely to resolve stock differences over such a limited ambit. Tagging would provide a clear answer to questions of exchange between such fishing grounds.

E. DETAILS OF THIS STUDY

Documents 1 to 13.

DOCUMENT 1

CSIRO MARINE LABORATORIES REPORT

Draft
CSIRO Marine Laboratories Report No 215

Orange Roughy Surveys, 1988 & 1989: Abundance Indices

C. M. Bulman, S. E. Wayte and N. G. Elliott

CSIRO Division of Fisheries Research
Hobart

Introduction

The orange roughy fishery in Australia is relatively new and consequently it is unpredictable in both standing stock and yield estimates. Prior to the 1988 survey, no estimates based on a single vessel full sweep survey had been made, therefore there was an urgent need to obtain basic information on the abundance and distribution of this species from within the South East Trawl management area. To address these problems, and to collect other biological information of use in the management of the fishery, CSIRO's FRV *Soela*, was used to make a comprehensive survey of the area encompassed by the management scheme. The objectives of the survey were:

1. To assess the abundance and distribution of orange roughy in the south eastern waters of Australia.

2. To obtain biological information on orange roughy for use in the determination of stocks, the size (and age) composition and the reproductive strategies of the fish.

Survey design

A stratified random sampling methodology was used. Such surveys have become widely used in the assessment of distribution and abundance of fish stocks (Grosslein, 1969; Doubleday, 1981; Francis, 1984). A random sampling strategy gives a fairly even distribution of sampling locations within each stratum and should provide valid estimates of the variance of the abundance indices (Grosslein, 1969). Variance normally increases with population density so allocating more effort into high density strata will increase the precision of the estimates (Saville, 1977; Francis, 1981;1984). Prior knowledge of the catch rates likely to be encountered enables allocation of effort before the survey e.g. orange roughy survey on the Chatham Rise, N.Z. (Robertson et al., 1984) although an adaptive strategy based on results from the first part of a two-phase survey design could be employed where this knowledge is lacking (Francis, 1984).

1988 Survey

The 1988 survey in south east Australian waters (largely the South East Trawl zone), from Kangaroo Island (137° E), around Tasmania and east to Gabo Island (150° E), was designed as a depth-stratified random sample survey. The depth range surveyed was from 700 m to 1200 m in 100 m intervals in 1988. Accurate charts of depth contours were obtained from the survey conducted by the Tasmanian Department of Sea Fisheries (TDSF) (Wilson et al, 1984) and the area within each depth interval was calculated by electronically digitizing the areas over a superimposed grid. The survey area, 13 220 km^2, was divided into sub-areas of approx. 600 km^2, a total of 21 sub-areas (A to U) and 5 depth intervals giving 105 strata (Fig 1). Random positions were generated at a density of 1 station per 33 km^2 for the first cruise and 1 station per 53 km^2 for subsequent cruises, with stations within a depth stratum no less than 4 km apart. The change in density was due to time restraints for the survey, which necessitated the reduction the actual density of predetermined sampling locations on the first cruise to 1 per 57 km^2. No prior knowledge of fish densities was assumed so strata were allocated stations proportional to their individual areas.

Tows were aimed to be of 30 minutes duration (bottom time),and if tows occurred that were less than fifteen minutes, they were not included in calculations. A sampling location was abandoned if a suitable tow was not found within an hour's search around the predetermined position.

1989 Survey

The sampling methodology for the 1989 survey was similar apart from some changes to the sampling intensity and survey areas. The depths surveyed were reduced to between 800 m and 1200 m because the 1988 results suggested only a small likelihood of roughy in the 700 to 799 m zone. Although the survey was extended in the Kangaroo Island region, from 137° E to 136° E, the total ground surveyed, 7 165 km^2, was reduced because the previous survey indicated unsuitable trawl grounds in some areas. The resulting reduction in ground to be surveyed gave us the opportunity to increase the number of planned stations, so the coverage was increased from 1 station per 53 km^2 to 1 per 30 km^2. The actual density of valid tows was 1 per 46.5 km^2. All other survey conditions still applied.

A 35.5 m headline Engel High-lift bottom trawl was used throughout both surveys.

Survey results

1988

Three *Soela* cruises were made to complete the survey : SO1/88 (January - February), Kangaroo Island to Portland; SO2/88 (March-April) Portland to north-east coast Tasmania and SO3/88 (May) east coast Tasmania to Gabo Island and southern NSW. The actual number of stations completed wasabout half the number planned (Table 1). Of the area surveyed, a large portion (about 4700 km^2) was deemed to be untrawlable, either because the ground appeared rough and hard and it was considered very likely that the gear would have been severely damaged even if recovered at all, or because it was thought that the constraint of the tow having to remain within the predetermined 100 m depth range would have been violated. Tows in these areas were not attempted. Small sections of ground within most subareas were considered untrawlable but these were an insignificant part of the total area. The areas of isolated aborted shots, (i.e. shots where the gear was hooked up before the minimum requirement of 15 minutes tow or where the gear was so badly damaged that the catch was not considered to be indicative of the fish population), were not included in the calculation of "untrawlable area". Thus, only relatively large areas of ground were estimated. The largest area considered untrawlable (approx 2300 km^2) was the ground south of 43° S latitude (southern Tasmania) although a few small, isolated patches were found to be suitable for trawling (e.g. off Port Davey, the Hippolytes) and more are known. The east coast of Tasmania through to Gabo Island was also untrawlable (approx. 2400 km^2) except for the grounds off St Patricks Head (N.E. Tasmania), an area N.E. of Flinders Island (about 39° S) and very small areas around both Maria and Gabo Islands. Several exploratory tows were made off the N.S.W. coast north of the survey and S.E.T. management areas but have not been included in the estimates since they did not conform to the survey requirements.

Catch rates of orange roughy from the survey trawls were generally under 100 kg/h (Figs 3-7). Five relatively large catches were taken: three from the Beachport area, which later became a commercial site (Fig 3), one from the east coast of Tasmania (Fig 6) and one N.E. of Flinders Island (Fig 7), which consisted almost entirely of small fish, i.e.<30 cm.

1989

Another three cruises were used to complete the 1989 survey: SO1/89 (January - February), Kangaroo Island to west of Portland; SO2/89 (March), west of Portland to Low Rocky Point (W Tasmania) and SO3/89 (April - May) east coast of Tasmania and north-east of Flinders Island (E Bass Strait). The proportion of stations actually completed was similar to 1988 results (Table 2).

Catch rates were under 100 kg/h (Figs 8-11). One large catch was taken from an area east of Bicheno which was later commercially exploited. *Soela* also continued to study this area in detail by including further tows through the aggregation. However these non-random tows were not included in the analyses.

Table 1. Results of the 1988 CSIRO surveys.

Stratum	from	to	Area (km^2)	Stations planned	Stations trawled	%
A	136° 00'	137° 38'	559	14	8	57
B	>137° 38'	138° 26'	610	20	6	30
C	>138° 26'	138° 49'	570	21	17	81
D	>138° 49'	139° 09'	583	20	13	65
E	>139° 09'	139° 42'	627	20	8	40
F	>139° 42'	141° 30'	823	21	14	33
G	>141° 30'	142° 41'	675	12	8	67
H	>142° 41'	40° 12'	639	12	4	33
I	>40° 12'	40° 54'	582	12	6	50
J	>40° 54'	41° 33'	554	12	9	75
K	>41° 33'	42° 16'	555	12	11	92
L	>42° 16'	42° 57'	549	12	11	92
M	>42° 57'	145° 37'	538	12	2	17
N	>145° 37'	146° 09'	521	12	1	8
O	>146° 09'	147° 30'	590	12	0	0
P	>147° 30'	42° 24'	678	12	4	33
Q	<42° 24'	41° 31'	622	12	6	50
R	<41° 31'	41° 02'	582	12	4	33
S	<41° 02'	39° 14'	774	12	3	25
T	<39° 14'	38° 21'	749	12	4	33
U	<38° 21'	37° 40'	840	12	3	25
Total			**13 220**	**296**	**142**	**48**

Table 2. Results of the 1989 CSIRO surveys.

Stratum	from	to	Area (km^2)	Stations planned	Stations trawled	%
A	136° 00'	137° 38'	474	24	9	21
B	>137° 38'	138° 26'	505	17	4	24
C	>138° 26'	138° 49'	459	15	11	73
D	>138° 49'	139° 09'	453	15	15	100
E	>139° 09'	139° 42'	561	19	14	74
F	>139° 42'	141° 30'	690	23	15	65
G	>141° 30'	142° 41'	601	20	14	70
H	>142° 41'	40° 12'	550	18	1	6
I	>40° 12'	40° 54'	480	17	14	82
J	>40° 54'	41° 33'	437	15	17	113
K	>41° 33'	42° 16'	457	15	15	100
L	>42° 16'	42° 57'	451	15	14	93
Q	<42° 24'	41° 31'	552	18	9	50
R	<41° 31'	41° 02'	494	16	2	13
Total			**7 164**	**247**	**154**	**62**

Estimation of index of abundance

To obtain enough stations in each stratum for variance estimation, several sub-areas were combined. For 1988 these were: 1 = A, B + C; 2 = D, E + F; 3 = G, H + I; 4 = J + K; 5 = L, M, N + O; 6 = P, Q, R, S, T + U. Depth strata remained the same. For 1989, areas 1 to 4 remained unchanged from 1988 but area 5 = L and area 6 = Q + R.

The average area swept by the Engel High Lift bottom trawl was estimated using an average wingtip-to-wingtip measurement of 19 m, (approximately 54% of the headline length), measured by the Scanmar net monitoring system in depths of 400-500 m at about 2.5 knots. The frequency of the equipment was not suitable for monitoring at depths greater than 600 m. The wingtip-to-wingtip measurement is used in calculations of swept areas in New Zealand stock estimates (D. Robertson personal communication). The door spread was measured at about 66 m.

For each station, a catch rate for orange roughy was calculated as weight of fish (kg) per swept area of the tow (km^2):

$$X_{ij} = \frac{W_{ij}}{a_{ij}}$$

where X_{ij} is the catch rate, W_{ij} is weight (kg) of orange roughy caught from station j in stratum i, and a_{ij} is the swept area of station j in stratum i in km^2. The swept area, a_{ij}, is calculated from:

a_{ij} = speed of tow (knots) x 1.852 (km per nm) x tow duration (bottom time) x 1/60 x 0.019 (wing spread in km).

A mean catch rate and standard error was calculated for each stratum:

$$\bar{X}_i = \frac{\sum_{j=1}^{n_i} X_{ij}}{n_i}$$

where n_i = number of stations in stratum i.

The standard error of the mean for stratum i is given by:

$$S_i = \left[\frac{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_i)^2}{n_i\,(n_i - 1)} \right]^{\frac{1}{2}} .$$

The biomass estimate for the survey area was obtained by summing the products of the mean catch rate per stratum and the area of the stratum, A, over all strata, where T is the total number of strata:

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

and standard error was:

$$S\,(B) = \left(\sum_{i=1}^{T} S_i^2 A_i^2 \right)^{\frac{1}{2}} .$$

The treatment of strata where no tows were made presented a problem. By combining strata, the occurrence of this was reduced however this situation did arise in Area 5 (800 m depth stratum). There was no reason to assume that this 800m depth stratum was different from any other 800 m stratum or from the other strata in the area apart from possibly the 700 m stratum. The mean and standard error of this stratum were estimated using the catches from stations in all the 800 m depth strata, and all stations from all depth strata in Area 5:

$$\bar{X} = \frac{\sum_{i=1}^{n} n_i \bar{X}_i}{N}$$

where n is the number of strata used in the estimation, n_i is the number of stations in stratum i, and X_i is the mean in stratum i and

$$N = \sum_{i=1}^{n} n_i \,.$$

The standard error was calculated by

$$S = \left[\frac{\sum_{i=1}^{n} n_i (n_i - 1) S_i^2}{N (N - n)} \right]^{\frac{1}{2}}$$

where S_i is the standard error of stratum i.

In Area 6 (1988), the 700 m depth stratum had only one station therefore no standard error could be calculated. The standard error was estimated using stations from the 700 m depth strata only, because the catch rates of the 700 m stations generally appeared to be different from catch rates in deeper strata. This also occured in the 1100m stratum in the 1989 survey in area 6.

Assumptions were made in the calculation of the "biomass estimate", most of which would result in a conservative (minimum) estimate:

1. The accessibility of fish to the net was 100% i.e., there were no fish above the headline and there was no significant movement of fish in or out of the survey area (either by depth or geographically, during the period of the survey).

2. The vulnerability of fish was 100%, i.e., there was no escapement or avoidance by fish and the effective path swept was equal to the measured wing spread.

Table 3. Mean catch rates of orange roughy per stratum for 1988 survey.

Stratum		Area (km^2)	No. stns	Mean (kg/km^2)	S.E.
Area 1	700	301.4	5	0	0
	800	388.4	7	46.5	22.5
	900	388.6	8	17030.8	11650.6
	1000	370.8	7	6155.5	5955.4
	1100	289.3	3	167.6	128.5
Area 2	700	328.9	6	1.6	1.6
	800	372.9	5	651.8	253.4
	900	403.4	6	993.3	116.7
	1000	447.3	9	885.7	223.8
	1100	480.6	7	317.6	125.8
Area 3	700	265.6	2	8.9	8.9
	800	308.6	3	1882.4	364.6
	900	336.4	3	3294.9	1048.4
	1000	376.8	5	578.8	67.6
	1100	609.2	4	361.0	38.1
Area 4	700	214.0	2	40.0	40.0
	800	218.8	5	884.8	299.5
	900	223.8	5	576.7	296.6
	1000	238.6	5	914.1	66.2
	1100	213.6	3	1508.2	559.9
Area 5	700	308.1	3	693.7	363.4
	800	401.4	0	867.3*	272.0*
	900	484.7	5	668.6	392.7
	1000	444.0	3	434.1	176.7
	1100	559.7	3	1293.4	427.7
Area 6	700	831.7	1	65.0	51.5*
	800	921.9	9	1566.1	1165.9
	900	823.7	3	5651.5	5189.7
	1000	781.6	4	1390.2	572.2
	1100	885.4	4	1840.7	614.1
Total		**13 219.3**	**135**		

* estimated from other stations

Table 4. Mean catch rates of orange roughy per stratum for 1989 and for the comparable area in 1988.

Stratum	Area	(km^2)	1988 No stns	1988 Mean (kg/km^2)	1988 S.E.	1989 No stns	1989 Mean (kg/km^2)	1989 S.E.
Area 1	800	388.4	7	46.5	22.5	9	96.6	61.2
	900	388.6	8	17030.8	11650.6	8	164.7	109.4
	1000	370.8	7	6155.5	5955.4	5	91	23.6
	1100	289.3	3	167.6	128.5	2	28.4	28.4
Area 2	800	372.9	5	651.8	253.4	11	557.5	139.6
	900	403.4	6	993.3	116.7	10	471.9	78.9
	1000	447.3	9	885.7	223.8	12	611.1	143.6
	1100	480.6	7	317.6	125.8	12	383.0	102.5
Area 3	800	308.6	3	1882.4	364.6	5	787.0	125.1
	900	336.4	3	3294.9	1048.4	9	818.3	164.6
	1000	376.8	5	578.8	67.6	9	3302.4	2852.8
	1100	609.2	4	361.0	38.1	6	3906.1	37559.9
Area 4	800	218.8	5	884.8	299.5	8	1110.5	400.2
	900	223.8	5	576.7	296.6	8	367.2	110.6
	1000	238.6	5	914.1	66.2	10	651.6	107.6
	1100	213.6	3	1508.2	559.9	5	676.8	170.8
Area 5	800	99.5	0	867.3*	272.0*	3	1092.2	624.8
	900	131.0	4	277.9	277.9	3	456.6	216.4
	1000	132.6	2	262.7	262.7	5	658.6	227.0
	1100	88.4	2	879.1	879.1	3	679.2	146.6
Area 6	800	257.9	4	3238.8	2539.4	3	16372.0	15500.7
	900	289.8	2	468.9	468.9	3	372.1	146.5
	1000	243.8	1	2923.1	1249.5	3	1932.0	778.9
	1100	254.7	2	2373.0	1115.8	1	1932.9	665.2
Total		**7164.8**	**102**			**154**		

* estimated from other stations

The high catch rates from three tows off Beachport (S.A.) in 1988, typically produced high mean catch rates with large variances for the corresponding strata

(Area 1, 900 m and 1000 m strata - Table 3). To reduce the size of variance, the area of high density was treated as a separate stratum, effectively reducing the area to which a high mean catch rate of fish could be attributed. The other areas were reduced accordingly. Two area sizes for the extra stratum were used, i.e., 1) an area of 60 km^2, which was defined as the immediate vicinity of the *Soela* catches, and 2) an area of 277.7 km^2 which was defined by the area of commercial exploitation during the weeks following the initial discovery by *Soela*. This approach essentially gave an upper bound (commercial area) and a lower bound (survey area) for the biomass estimate.

The mean catch rates for orange roughy for both cases were recalculated (Table 5) and overall biomass indices were calculated (Table 6). It was necessary to adjust Area 1 figures only. The results showed an improvement in standard errors and consequently the 95% confidence limits (1.96 x S.E.) of the mean catch rates for the high density area in both instances.

The 1989 mean catch rates (Table 7) produces abundance estimates similar to the previous year.

Table 5. Adjusted mean catch rates for Area 1, for alternative sizes aggregation strata a) commercial exploitation area and b)Soela survey area.

Stratum	Area (km^2)	No. stns	Mean (kg/km^2)	S.E.
a) Area 1 700	301.4	5	0	0
800	388.4	7	46.5	22.5
900	233.3	3	357.2	287.3
1000	248.4	4	43.3	30.1
1100	289.3	3	167.6	128.5
aggregation	277.7	8	22261.3	11774.2
b) Area 1 700	301.4	5	0	0
800	382.4	7	46.5	22.5
900	364.6	6	681.2	389.1
1000	346.8	5	59.0	28.1
1100	283.3	3	167.6	128.5
aggregation	60.0	4	43738.3	18414.7

Table 6. Biomass estimates of orange roughy from 1988 Soela survey of the South East Trawl management area with alternatives for the post stratification of the high density area off Beachport.

treatment of strata	mean (tonnes)	± s.e	95% confidence limit (%)
original strata	23833	6764	55.6
Soela aggregation ($60\ km^2$)	17825	4635	51.0
Commercial fishing area ($278\ km^2$)	21209	5562	51.4

Table 7. Biomass estimates from the 1989 survey compared with the recalculated 1988 estimates of the same area (7165 km^2).

treatment	mean ± S.E. (tonnes)		95 % confidence limit
1989 no stratification	11 127	4 742	83.5
1989 post-stratification	7 406	2 559	67.7
1988 no stratification	15 674	5131	64.2
1988 (upper bound)	13 049	3392	50.9
1988 (lower bound)	9 665	1 432	29.0

Discussion

The biomass indices obtained from the trawl surveys are very conservative because of the assumptions made. Little is known about the way in which a trawl net samples fish populations or about the behaviour of orange roughy apart from the fact that it sometimes aggregates. Obviously, fish can be expected to move in and out of the survey area, to be stacked above the net particularly in aggregations, or to escape or avoid the net. Measurement of these factors was beyond the scope of these surveys however some advances were made. Escapement experiments indicated little or no escapement, at least under normal abundances. A camera on the headline of the net provided us with good pictures of roughy in an aggregation but avoidance of the net by fish was difficult to ascertain. Factors relating to the performance of the net may also frustrate estimations, such as the width of the path actually swept, the time on the bottom etc., although modern net monitoring devices now provide useful data. Measurements of wing spread, door spread, bottom temperature and headline height gave us the best possible estimate about the trawl net's performance.

The confidence of the 1988 estimates at ± approximately 50% is probably good accuracy bearing in mind that the distribution of this species appears to cause a high degree of sampling variability when densely clustered aggregations are encountered. The 1989 results, on the other hand, were disappointing because the 95% confidence limits increased to 68 %.

Poor precision was a result of the variability in catch rates caused by a few large catches. In 1988, two large catches of adult fish were made, apart from the 'Beachport' catches: one from the east coast and one north east of Flinders Island (both Area 6). The two tows were widely separated and so were not considered part of the same "aggregation". Another catch comprised of small fish (<30 cm) unlike the usual size composition of the commercial aggregations (adult fish >30 cm). In 1989, two relatively large catches were made in western Bass Strait (area 3), in 1000 m and 1100 m, apart from one east of Bicheno (area 6, 800m) which was post-stratified . No information was available to enable us to estimate the area covered by these denser populations therefore the tows were retained in their original strata and not treated separately. Because of this, the mean catch rates of the corresponding strata may be overestimated, causing inflation of the biomass estimates. This situation emphasizes the degree to which small aggregations can influence variance around the estimates.

The 95% confidence intervals for the Chatham Rise (New Zealand) stock estimates derived from the 1982 orange roughy survey were as low as ±25% (Robertson et al, 1982). A recent survey of the Challenger Plateau orange roughy fishery gave estimates with coefficients of variation of between 18 and 47 % (Clark & Tracey, 1988). The 95% confidence limits of these estimates are then ±35% and ±92% respectively, and our confidence intervals fall within the range. Ninety percent confidence limits obtained from a survey, off the western United States, for rockfish, which have similar patterns of distribution as roughy, were typically between ±30 and 150% (Gunderson &

of distribution as roughy, were typically between ±30 and 150% (Gunderson & Sample, 1980).

Clark (1988) concluded that trawl surveys are not very precise, a view with which we must agree. Current New Zealand stock assessments use results from trawl surveys as relative indices of abundance rather than overall biomass estimates (Roberstson, 1989). The estimate for the Chatham Rise population is about 20% of the virgin biomass and apparently decreasing.

Our surveys do not cover the entire geographic or depth range of orange roughy in Australia and we don't consider our estimates an accurate evaluation of biomass. A major problem of our survey was in determining the validity of extrapolating abundance values from "trawlable" areas to "untrawlable" areas. The limitations assocoated with this extrapolation were highlighted by the discovery of a spawning aggregation of orange roughy off the Tasmanian east coast shortly after the conclusion of the 1989 survey. The aggregation was located about a pinnacle in an area which had been excluded due to its rough nature. The amount of roughy caught from this area was about 17 000 tonnes over three months. Our abundance index of the east coast area for 1989 was between 1300 and 5000 tonnes, indicating considerably less fish than this later commercial exploitation revealed. Since the practice of extrapolation was questionable, the "untrawlable" areas not surveyed were not included in the abundance calculations or comparisons. The large amount of commercial activity off Maatsuyker Island and Pedra Branca (southern Tasmania) since late 1989 which we were unable to survey also highlights the impossibility of using a random trawl survey to accurately assess fish populations on rough or "untrawlable" ground.

Despite the obvious inadequacies of the trawl surveys, they provided an initial of assessment of a major part of the Australian population of orange roughy. Future surveys will need to be refined and combined with other stock aseessment techniques, but annual surveys could only be regarded as a means of monitoring general trends in the population and of gathering information on stock parameters.

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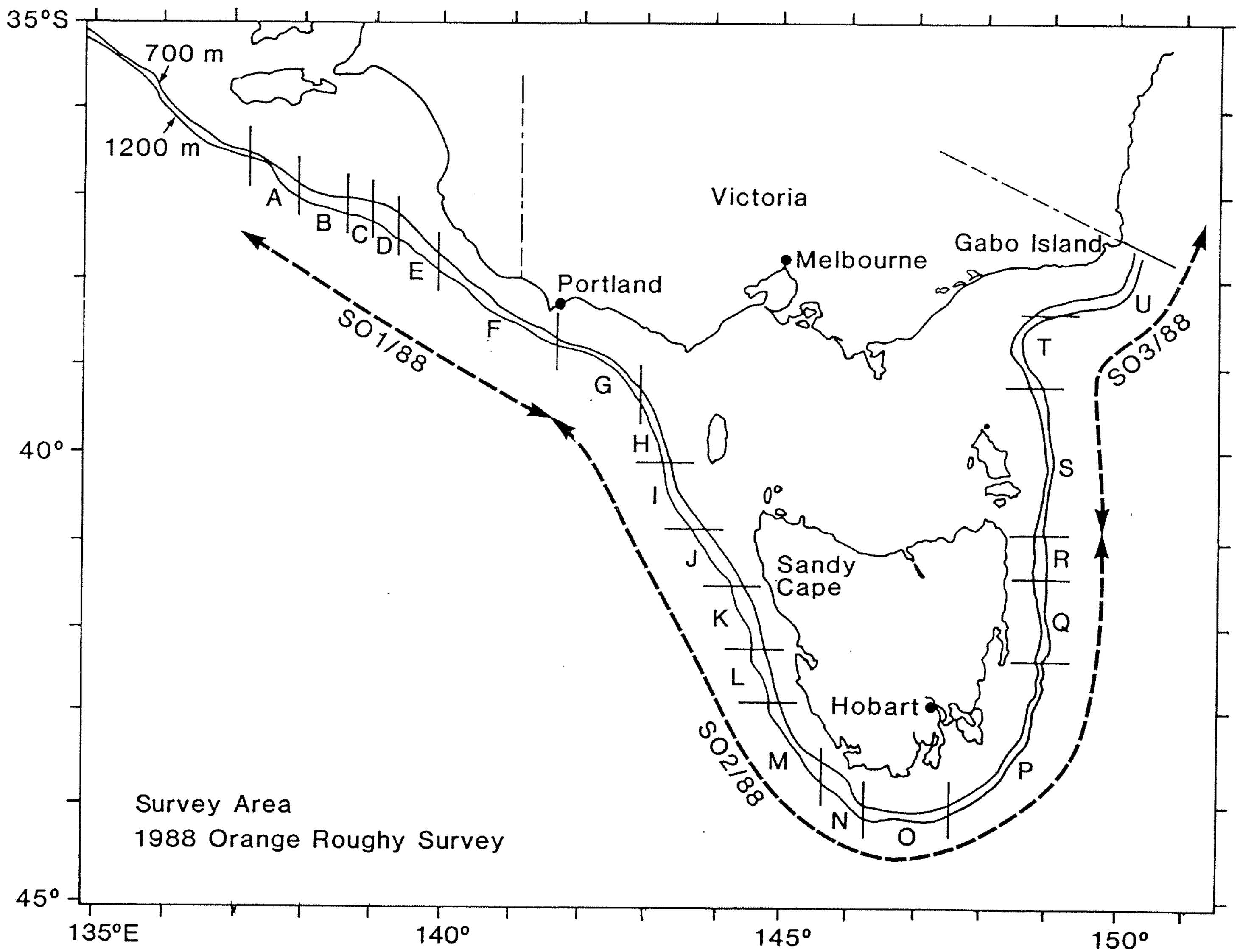


Fig 1. The South East Trawl area surveyed by the CSIRO FRV *Soela* in 1988 showing the 21 areas, each of which contained 5 depth strata from 700 m to 1200 m.

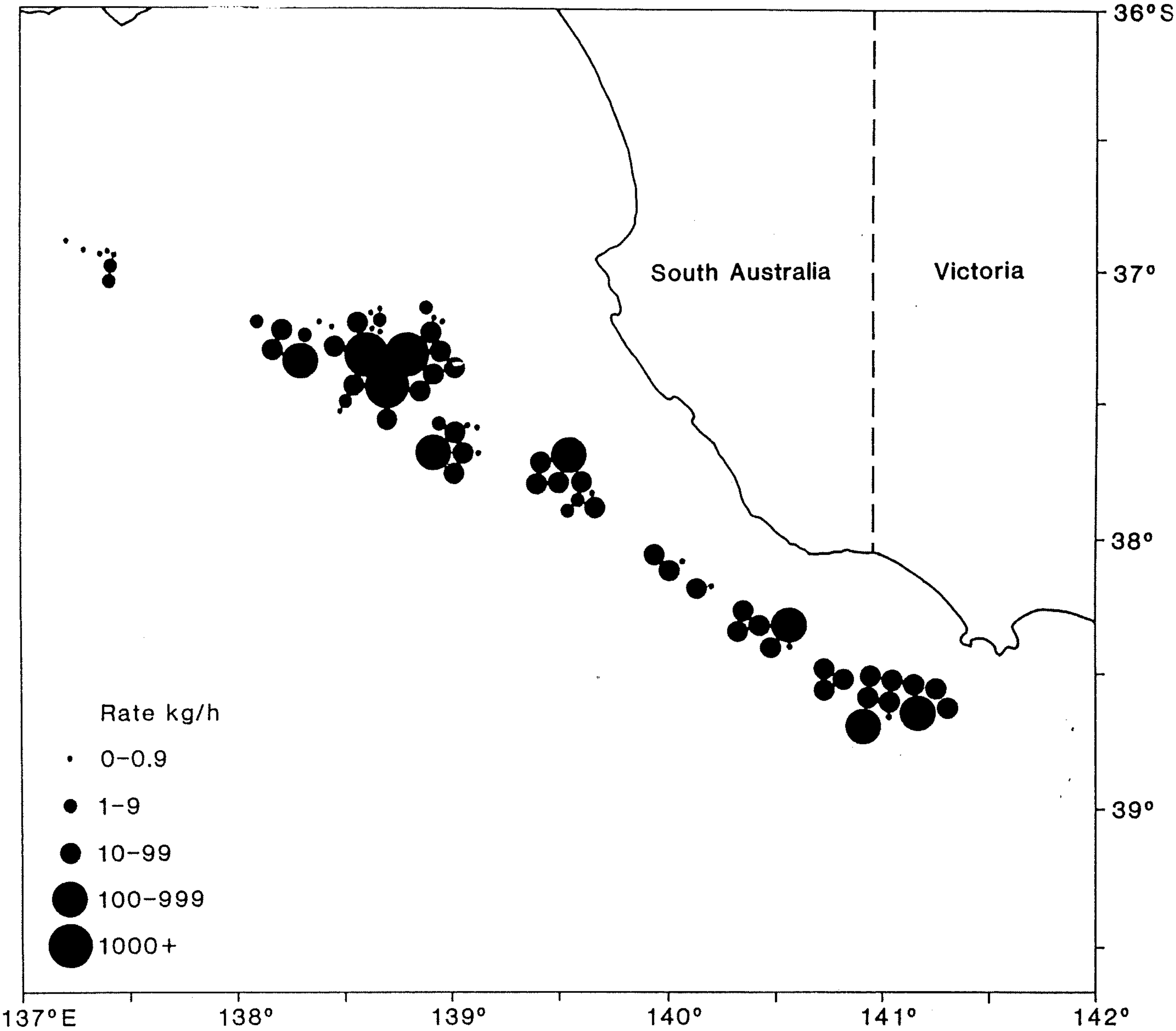


Fig 3. Catch rates of orange roughy (kg/h) including rates from depths greater than 1200 m from the Kangaroo Island to Portland area during SO1/88 (January - February) .

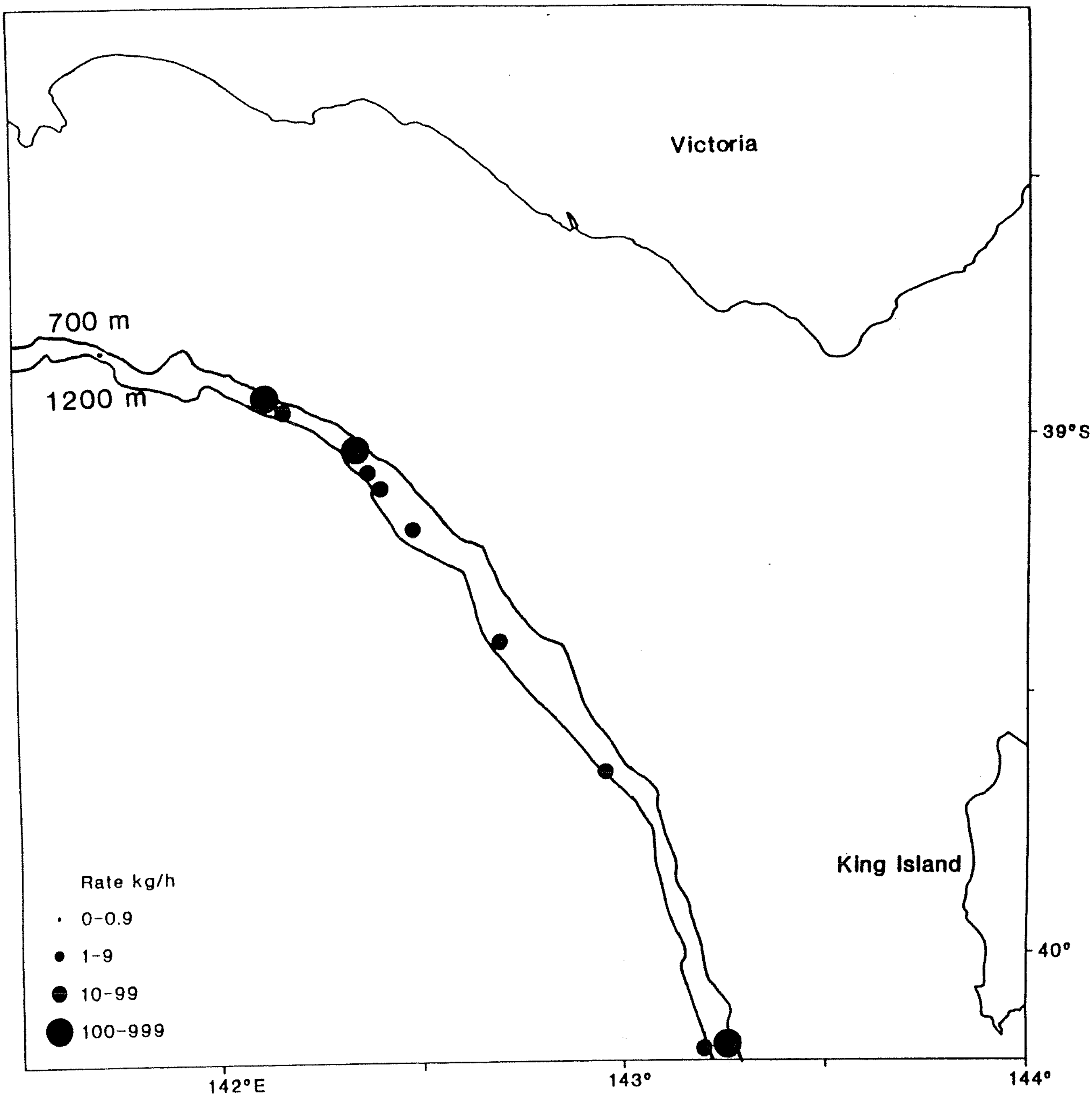


Fig 4. Catch rates of orange roughy (kg/h) from the western Bass Strait and King Island area during SO2/88 (March - April) including hauls in depths greater than 1200 m.

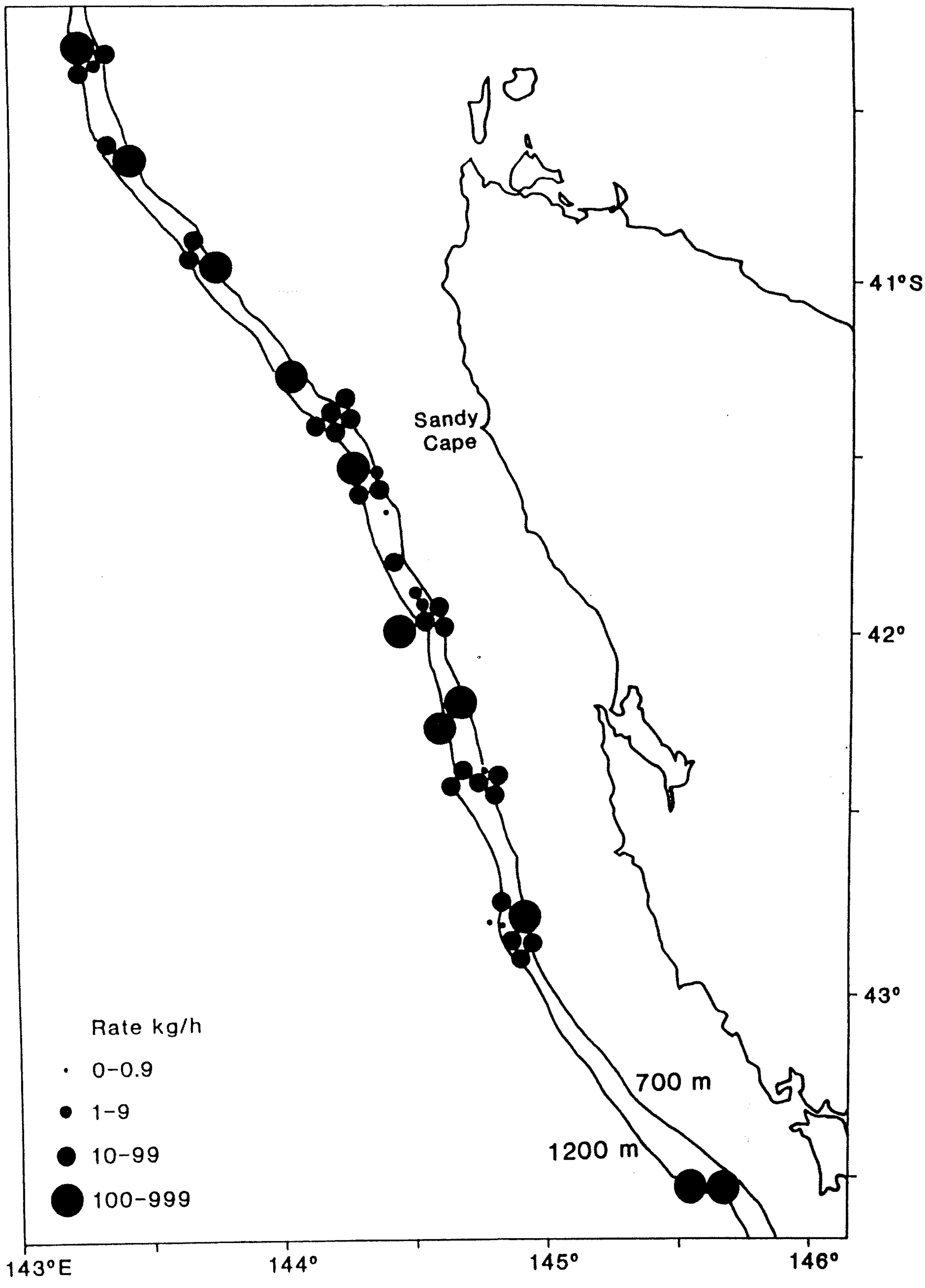


Fig 5. Catch rates of orange roughy (kg/h) from the west coast of Tasmania during SO2/88 (March - April) including hauls in depths greater than 1200 m.

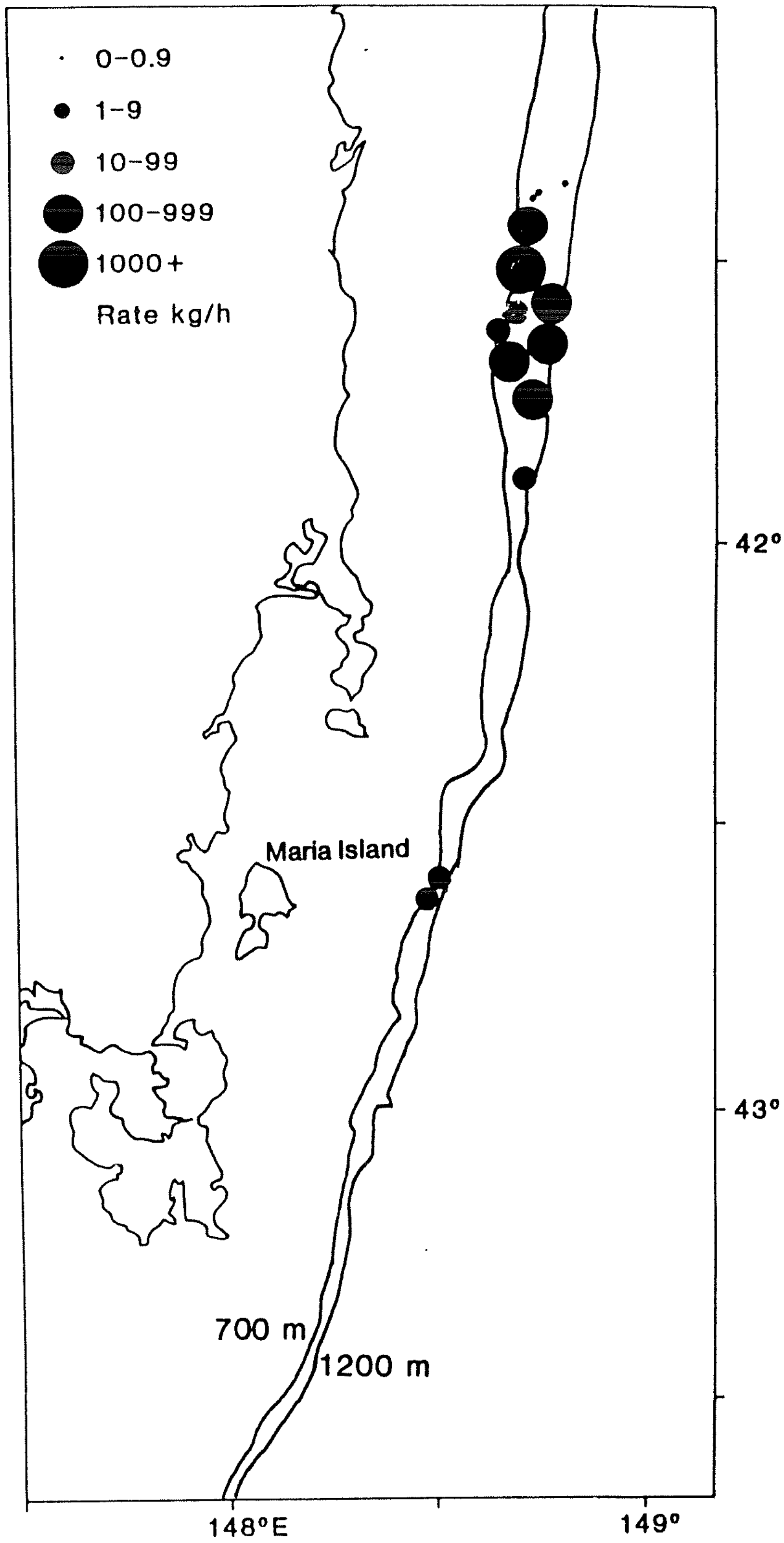


Fig 6. Catch rates of orange roughy (kg/h) from the east coast of Tasmania during SO2/88 (March - April) including hauls in depths greater than 1200 m.

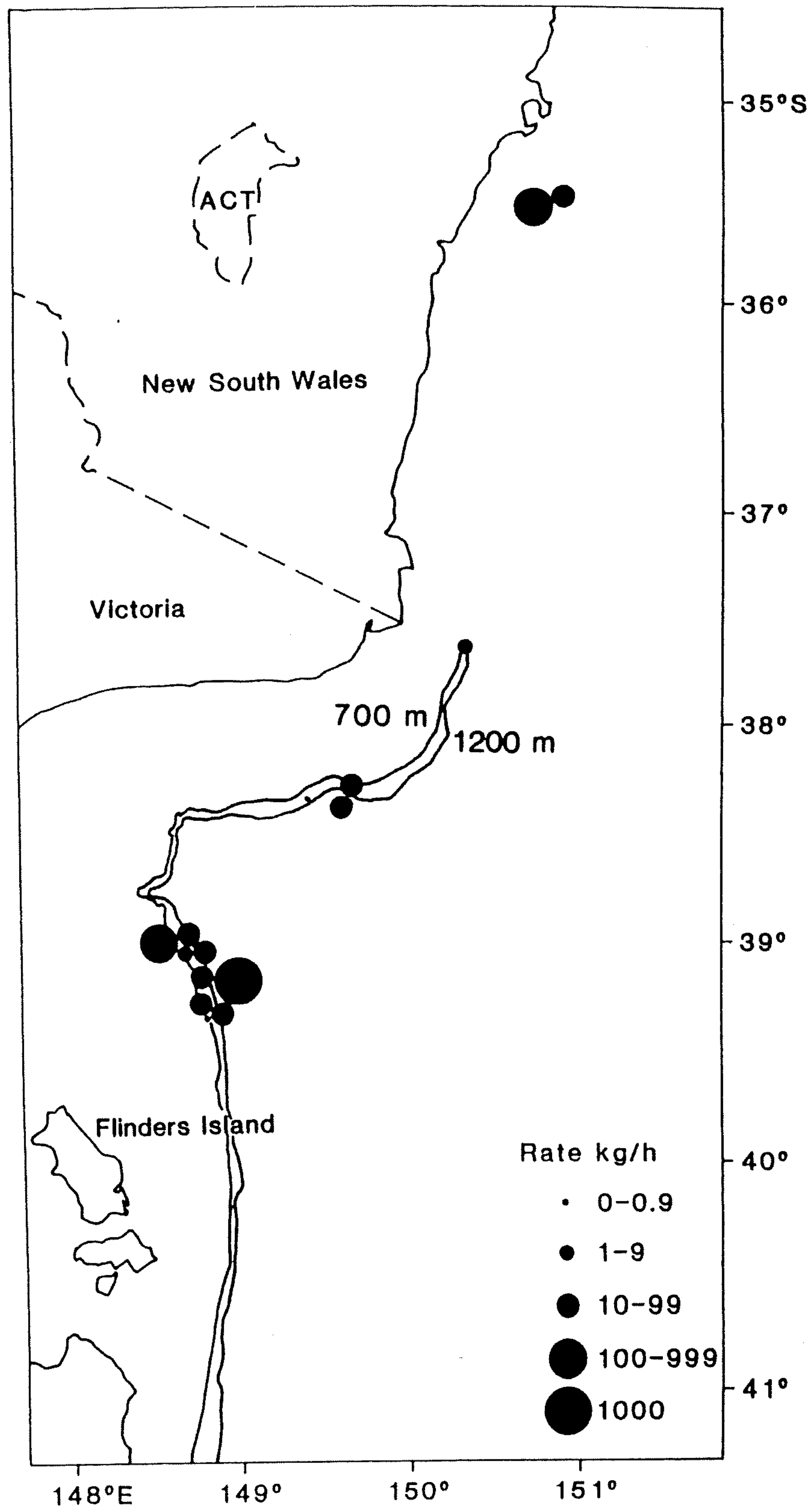


Fig 7. Catch rates of orange roughy (kg/h) from eastern Bass Strait and N.S.W. during SO3/88 (May) including hauls in greater than 1200 m.

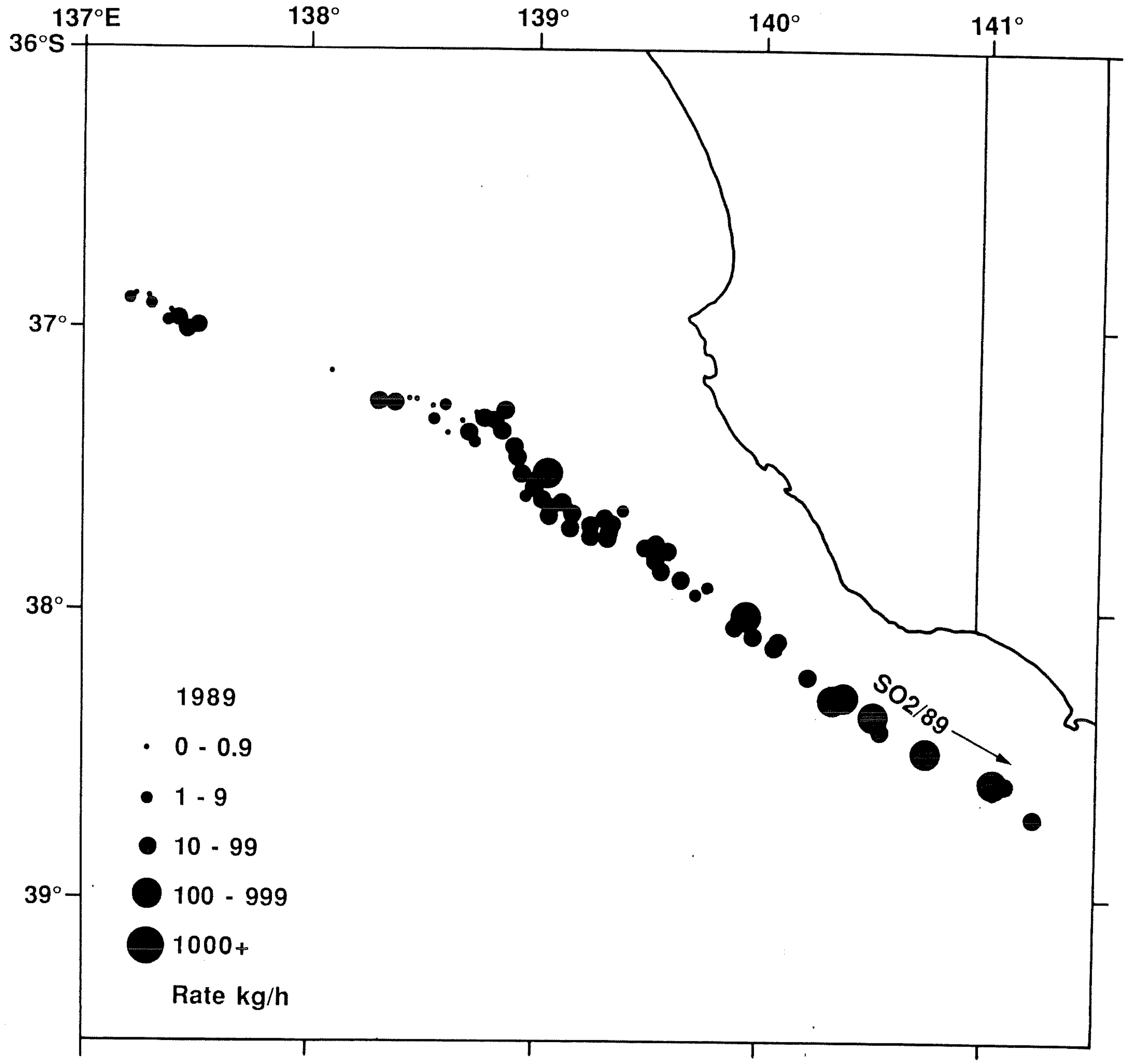


Fig 8. Catch rates of orange roughy (kg/h) from Kangaroo Island to Portland area during SO1/ & SO2/89 (January - March).

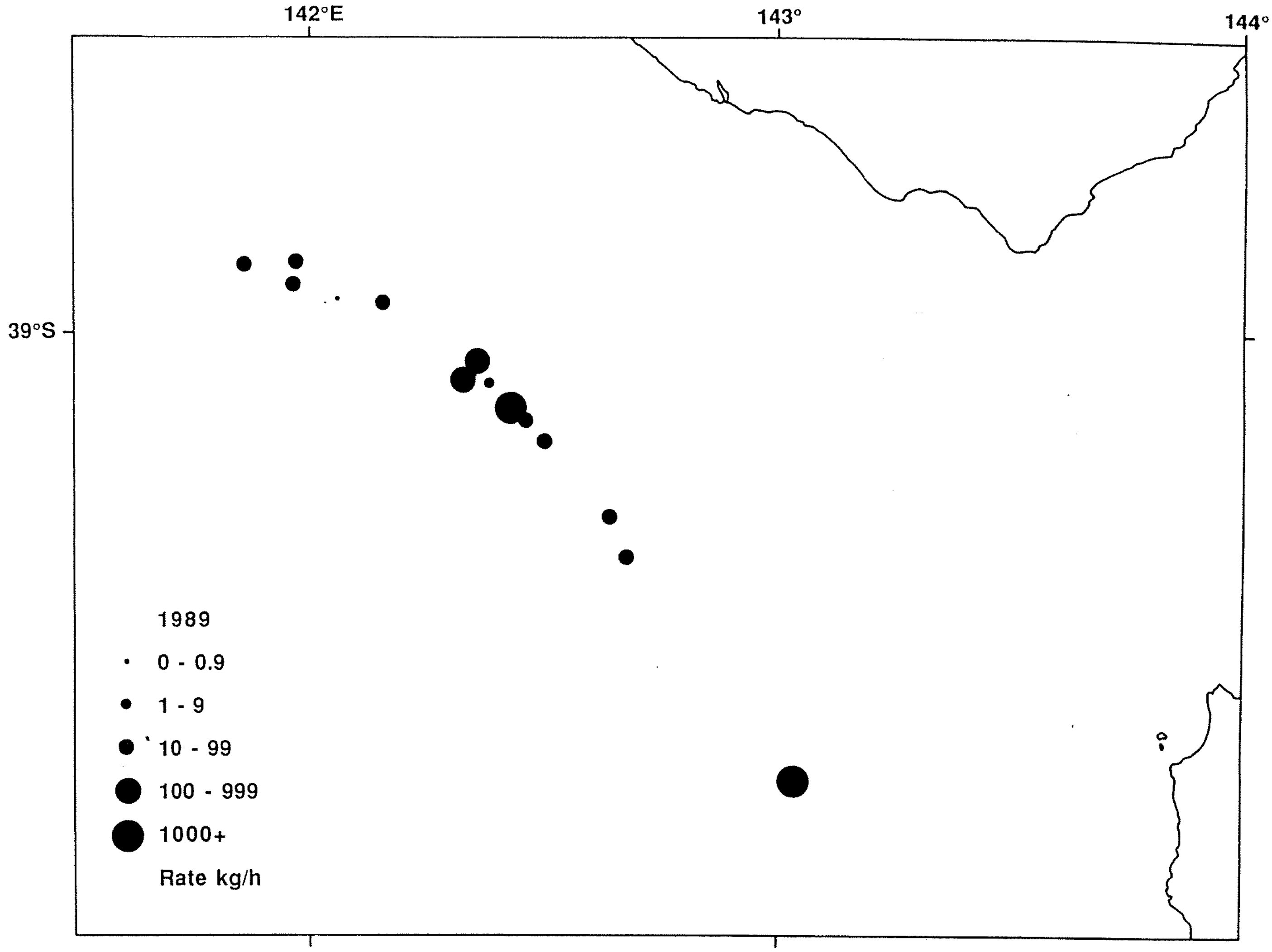


Fig. 9. Catch rates of orange roughy (kg/h) from Portland to King Island during SO2/89 (March).

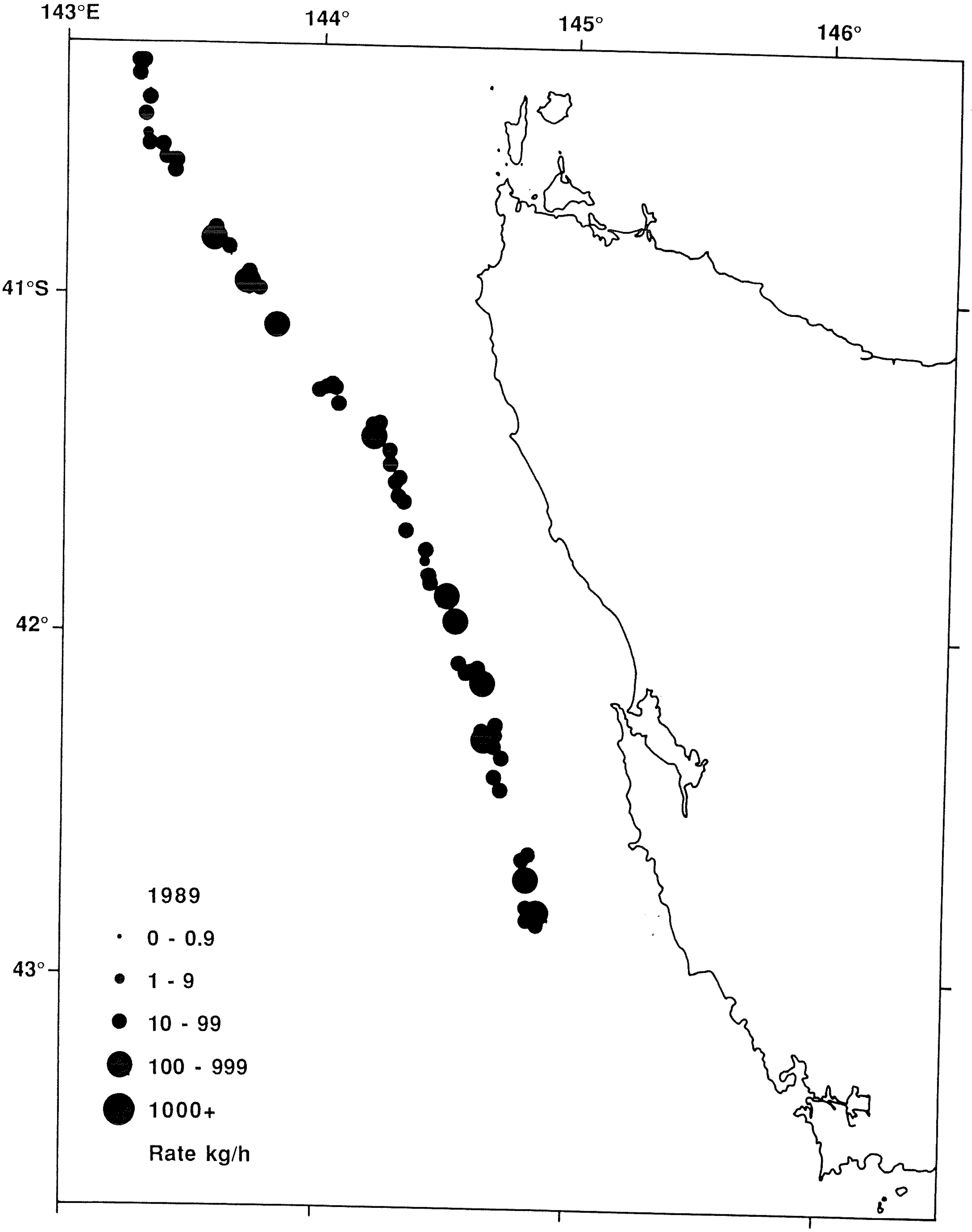


Fig. 10. Catch rates of orange roughy (kg/h) from King Island to Low Rocky Point during SO2/89 (March).

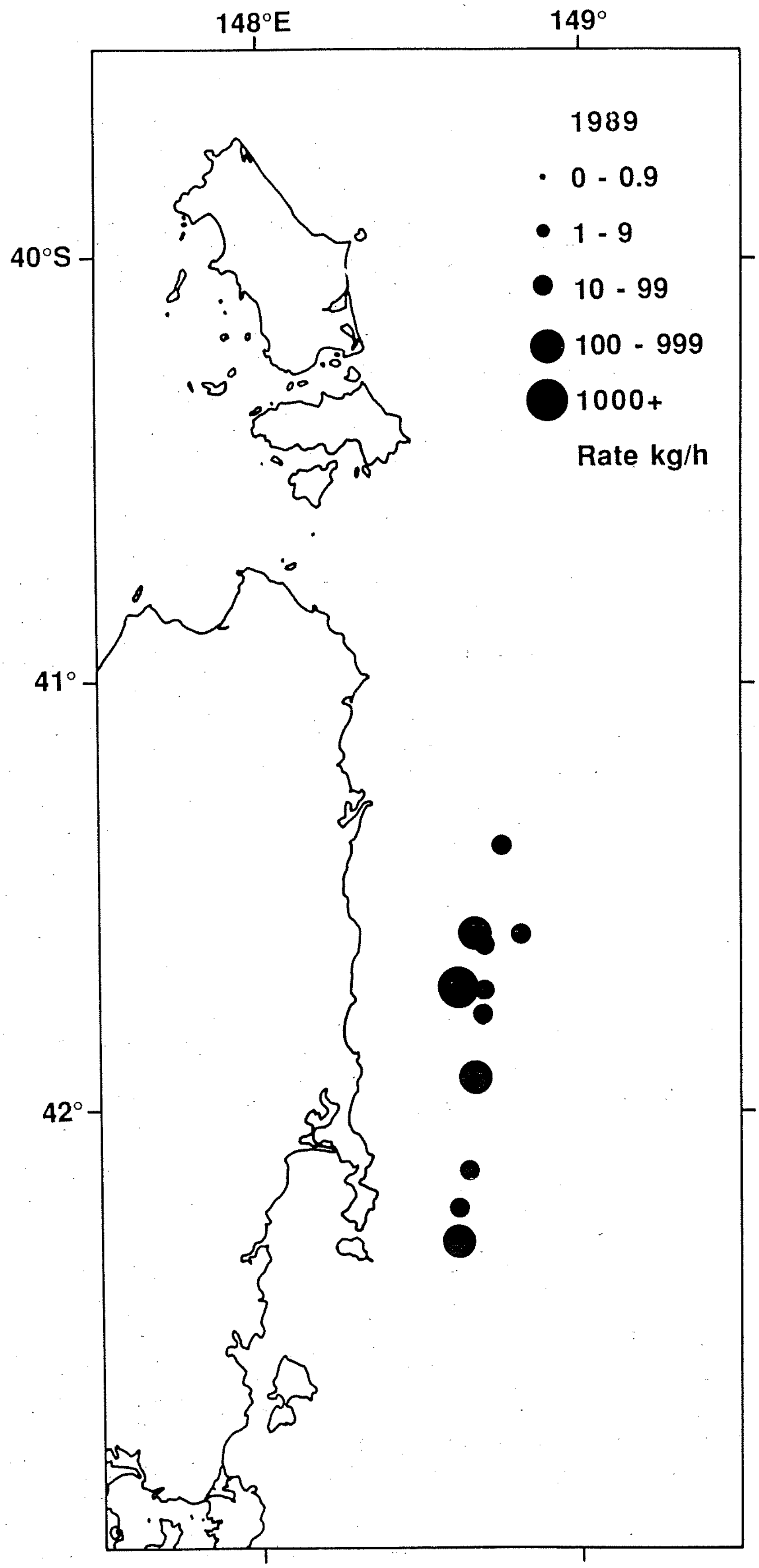


Fig. 11. Catch rates of orange roughy (kg/h) from the east coast of Tasmania during SO3/89 (April - May).

DOCUMENT 2

INTERNAL REPORT

A comparison between estimates of the biomass of orange roughy (*Hoplostethus atlanticus*) derived from surveys carried out by F.R.V. Soela and a commercial vessel.

Sally Wayte
Division of Fisheries
CSIRO Marine Laboratories, Hobart

In 1988 the Tasmanian Department of Sea Fisheries (TDSF) conducted 4 trawl surveys for orange roughy in a sub-section of the area covered by F.R.V.Soela during the FIRTA funded 1988 orange roughy survey. The TDSF surveys on the west coast used a 24 m commercial vessel, the F.V.Petuna Endeavour, owned by Petuna Seafoods Ltd. The fishing gear of the 2 vessels is described in Table 1.

The area of the survey is off the west coast of Tasmania between 41° S and 42° 30'S. TDSF surveys took place in summer (15 trawls), autumn (17 trawls), winter (16 trawls) and spring (21 trawls). F.R.V.Soela surveyed this area with 18 trawls during cruise SO2/88 in autumn (see Fig.1). The F.R.V.Soela trawls in the 700 m depth stratum are excluded from this analysis, as the F.V. Petuna Endeavour did not fish at this depth. For the purpose of comparison, estimated biomass has been calculated from each vessel's survey using the method described in Bulman et. al. (1988). Catch rates are also compared between depth strata and cruises using an analysis of variance. An area on the east coast also surveyed by CSIRO and TDSF did not contain enough trawls for a meaningful comparison to be made.

The biomass estimates are shown in Table 2. The analysis of variance in Table 3 was performed (via regression) on the natural logarithm of catch-rates expressed as kg/km^2. It shows that there are no significant differences in catch rates between cruises or depth strata. The back-transformed means of the catch-rates with 95 % confidence limits are shown for each cruise in figure 2.

Reference

Bulman C.M., S.E. Wayte and N.G. Elliot (1988). 1988 Orange Roughy Survey. *CSIRO Division of Fisheries, unpublished report*

Table 1. Details of the fishing gear of F.R.V. Soela and F.V. Petuna Endeavour

	F.R.V. Soela	**F.V. Petuna Endeavour**
Net type	Engel high lift bottom trawl	N.Z. orange roughy net
Headline	35.5 m	36.6 m
Footrope bosom	18 m	18.3 m
Wings	rigged flying ; mesh only attached to the ground rope in the bosom	mesh only attached to the ground rope in the bosom
Rigged	16 m chain on each wing, bosom with rubber bobbins	?
Bridles/sweeps	upper and lower 50 m no sweeps	82.3 m or 36.6 m (depending on ground)
Mesh size	180 mm to 100 mm	?
Codend mesh size	90 mm with 40 mm liner of knotted 400/60 twine in final 2 m	90 mm
Wing spread	19 m (measured by Scanmar)	20 m (55% of headline length)
Net height	3 — 4 m	5 — 7 m
Trawl doors	Polyvalent, 1000 kg	Super-V
Door spread	66 m	?

Table 2. Biomass estimates from the 5 cruises

		F.R.V. Soela				F.V. Petuna Endeavour					
		autumn		summer		autumn		winter		spring	
depth	area (km^2)	n	mean (se) (kg/km^2)	n	mean (se) (kg/km^2)	n	mean (se) (kg/km^2)	n	mean (se) (kg/km^2)	n	mean (se) (kg/km^2)
800	243.0	4	659.1 (254.2)	2	3019.4 (2707.4)	3	1575.8 (549.7)	4	1769.5 (898.7)	4	2385.3 (472.5)
900	273.1	8	473.3 (185.5)	6	576.3 (136.1)	4	364.6 (75.0)	5	1811.3 (1010.8)	6	870.2 (284.4)
1000	270.7	4	915.2 (85.4)	3	572.5 (280.0)	6	687.9 (221.6)	5	1169.0 (443.5)	6	508.2 (239.5)
1100	239.1	2	1928.7 (640.4)	4	834.6 (246.9)	4	1463.8 (572.3)	3	971.1 (655.7)	5	2021.8 (545.2)
Biomass (tonnes)			998.3		1245.6		1018.7		1473.3		1438.2
Standard error			(174.2)		(665.9)		(201.5)		(403.6)		(201.0)

Fig.1 F.R.V.Soela trawls in the 800, 900, 1000 and 1100 m depth strata during cruise SO2/88

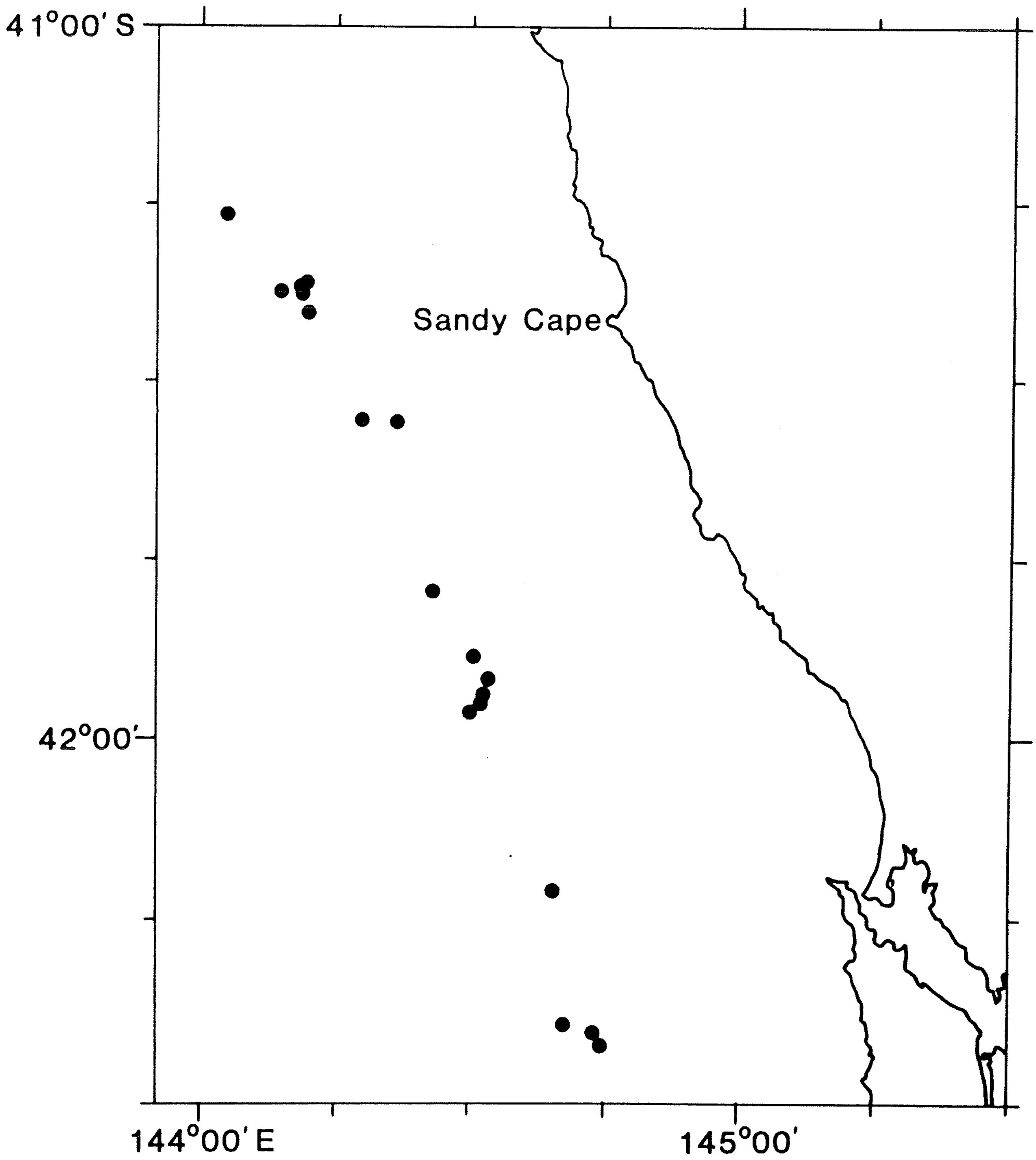
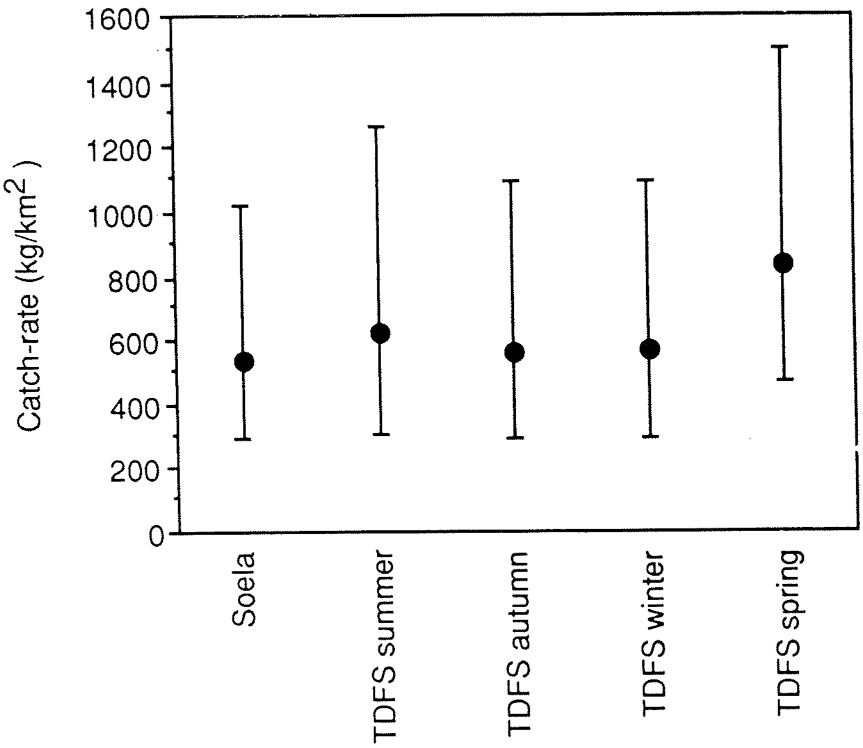


Table 3. Analysis of variance of the natural logarithm of catch-rate (catch per area swept)

Source of variation	df	ss	ms	vr	
cruise (elim. depth)	4	2.4	0.6	0.36	n.s.
depth (ignoring cruise)	3	10.1	3.37	1.99	n.s.
cruise X depth	12	25.0	2.08	1.23	n.s.
residual	68	114.8	1.69		
total	87	152.3			

Fig. 2 Back-transformed Means and 95% confidence limits of catch-rates



DOCUMENT 3

INTERNAL REPORT

Retention in the Engel high lift bottom trawl with special reference to orange roughy (Hoplostethus atlanticus)

C.A.Stanley

Division of Fisheries

CSIRO Marine Laboratories, Hobart

Abstract

For most species escapement through the meshes of the Engel high lift bottom trawl is through the bottom panels. Exceptions are those species which normally occur higher in the water column such as viper and lantern fish. For orange roughy escapment is restricted to fish below 21cm and is minimal, with a loss of approximately 1% of the weight of the fish which enter the net.

Introduction

To estimate biomass from the random trawl survey (Document 1), it is necessary to estimate the retention of fish in the net. During the 1989 trawl survey this was investigated by determining escapement through the net mesh.

Methods

During *Soela* cruise SO289 18 bags (mesh size 10mm) were attached to 10 x 10 squares of net mesh on the Engel net, the sites being selected to completely cover the upper and lower panels (Fig. 1). Once fitted, a constant check was maintained on the condition of the bags. The number of instances when a bag was found to be unusable was only 1% (Table 1), and most of these were caused by cod end knots coming undone.

All fish retained in the bags were removed, counted and identified to species level (sometimes not all Macrourids were identified).Orange roughy were also measured.

Results

The retention of fish by shot and bag number are listed in Table 1. Fish were never found in bags 2,4,8,10, and 16 to 18, and are not listed in any of the table summaries. Bags 12 and 13 on the lower wings were the only ones to consistently retain fish, and bag 14, posterior to these, also retained fish in many shots. Fish were found in all other bags on only a few occasions.

21 species of fish were recorded (Table 2), with Macrourids (whiptails) and Synaphorbranchids (eels) being the most common groups. For all species bags attached to the underside of the net retained by far the most individuals, with possible exceptions being *Avocettina* sp (snipe eels), *Photichthys argenteus* (a light fish), *Chauliodus sloani* (a viper fish), and *Macruronus novaezelandiae* (blue grenadier). For these latter species over 75% were retained in bags attached to the upper panels, but the total numbers retained were very low.

A total of 11 orange roughy, ranging in length from 5 to 21cm (TL) were retained, all either in bags 12 and 13 (Table 3). After calculating the ratio between the area covered by each bag in relation to the total area covered by the corresponding net panel, total escapement through the entire net can be calculated, and the resulting length frequency distribution is superimposed in Fig. 2 on corresponding data for fish retained in the net. The equivalent weight loss of roughy through the meshes for this set of shots is 19.11 kg, using an appropriate weight length relationship formula of :

$$W = 0.0504\ L^{2.88}$$

where W is the weight in grams and L is the length in centimeters

This represents 1.22% of the 1564 kg of orange roughy caught for the shot series. With only 11 roughy escaping through the meshes in this series of shots, any factors to correct length frequency data are necessarily of a preliminary nature. A roughly smoothed set is listed in Table 4 for future reference.

Table 1

Bags in which fish were retained (√). 'x' indicates an unusable bag. Total and orange roughy (O.R.) catches are also listed for each net shot

Shot	Bag number											Catch (kg)	
number	1	3	5	6	7	9	11	12	13	14	15	O.R.	Total
45	-	-	-	-	-	-	x	-	-	-	-	37	283
46	-	-	-	-	-	-	x	√	√	√	-	28	365
47	-	-	-	-	-	-	x	√	√	-	-	57	450
48	-	-	-	-	-	-	-	√	√	-	-	61	227
49	-	-	-	-	-	√	-	√	√	√	-	18	147
50	-	-	-	-	-	-	-	√	√	-	-	10	77
51	-	-	-	-	-	-	√	√	√	-	-	12	158
52	-	-	-	√	-	-	-	√	-	-	-	12	165
53	-	-	-	-	-	-	-	√	-	-	-	13	106
54	-	-	-	-	-	√	-	√	√	√	√	39	249
56	-	-	-	-	-	√	-	√	-	-	-	47	185
57	-	-	-	√	-	-	√	√	-	-	√	21	168
58	√	-	-	-	-	-	-	√	-	√	-	10	79
59	-	-	-	-	-	-	-	√	√	√	-	43	349
60	-	-	-	-	-	-	-	-	-	√	-	30	205
61	-	-	-	-	-	-	-	√	√	-	-	35	216
62	-	-	-	-	-	-	√	√	√	-	-	44	234
63	-	-	-	-	-	-	-	√	-	-	-	14	134
64	-	-	-	-	-	-	-	√	√	-	-	10	133
65	-	-	-	-	-	-	-	-	√	-	-	0	4
66	-	-	-	-	-	-	-	-	-	-	-	12	68
67	-	-	x	-	-	-	-	-	√	-	-	3	104
68	-	√	-	√	-	-	√	√	√	-	-	22	565
69	-	-	-	-	-	√	-	√	√	-	-	9	83
70	-	-	-	√	-	-	-	-	√	√	-	45	270
72	-	-	-	-	-	-	-	x	x	-	-	85	409
73	-	-	-	-	-	√	-	√	√	-	-	55	475
74	-	-	-	-	-	-	√	√	√	√	-	23	276
75	-	-	-	-	-	-	-	√	√	-	-	22	368
76	-	-	-	√	-	-	-	√	√	√	√	31	326

Table 1 continued

Shot number	Bag number 1	3	5	6	7	9	11	12	13	14	15	Catch (kg) O.R.	Total
77	-	√	-	-	-	-	-	√	√	-	-	25	240
78	-	-	-	-	-	√	-	√	√	√	-	175	530
79	-	-	-	-	-	-	-	√	√	-	-	25	389
80	-	-	-	-	-	-	-	√	-	√	-	61	366
81	-	-	-	-	√	-	-	-	x	-	-	58	395
82	-	-	-	-	-	-	-	√	√	-	-	8	123
83	-	-	-	-	-	-	-	√	-	-	√	17	195
84	-	-	-	-	-	-	-	-	-	-	-	32	432
85	-	-	-	-	-	-	-	√	√	-	-	14	211
87	-	-	-	-	-	-	√	√	√	-	-	10	185
88	-	-	-	-	-	-	-	√	-	-	-	57	202
89	-	-	-	-	-	-	-	-	-	-	-	16	202
90	-	-	-	-	-	-	-	-	-	-	-	20	363
91	-	-	√	-	-	-	√	-	-	√	√	111	334
93	-	-	-	-	-	-	-	x	-	-	√	36	315
94	-	-	√	-	-	-	-	x	x	-	√	11	193
95	-	-	-	-	-	-	-	-	√	-	-	40	283

Table 2

Total numbers of species, summed over all shots, retained in bags.

Species	Bag number										
	1	3	5	6	7	9	11	12	13	14	15
SQUALIDAE											
Centroscymus crepidater	-	-	-	1	-	-	1	3	3	-	-
Etmopterus baxteri	-	-	-	-	-	-	-	1	1	-	-
Deania calcea	-	-		-	-	-	-	1	-	-	-
NEMICHTHYIDAE											
Avocettina sp	1	1	-	-	1	-	-	1	-	-	-
SYNAPHORBRANCHIDAE											
Diastobranchus sp	-	-	-	1	-	2	-	25	26	2	3
NOTOCANTHIDAE											
Notocanthus sexspinis	-	-	-	-	-	-	-	2	4	1	-
ALEPOCEPHALIDAE											
Total	-	-	-	1	-	1	-	1	-	-	1
Alepocephalus sp 1	-	-	-	-	-	1	-	-	-	-	1
GONOSTOMATIDAE											
Photichthys argenteus	-	-	-	-	-	-	2	-	-	-	-
CHAULIODONTIDAE											
Chauliodus sloani	-	1	-	-	-	-	-	-	-	-	-
MORIDAE											
Halargyreus johnsonii	-	-	1	-	-	1	1	3	-	1	-
MERLUCCIIDAE											
Macruronus novaezelandiae	-	-	-	1	-	-	-	-	-	-	-
MACROURIDAE											
Total	-	-	-	23	-	3	11	291	135	23	16
Coelorinchus innotabilis	-	-	-	-	-	-	-	2	-	1	1
Coelorinchus matamua	-	-	-	-	-	-	-	1	-	-	-
Coryphaenoides serrulatus	-	-	-	-	-	-	-	13	1	-	-
Coryphaenoides subserrulatus		-	-	-	-	1	-	44	7	5	2
Lepidorhynchus denticulatus	-	-	-	-	-	-	-	2	-	-	-
Macrourid sp K	-	-	-	-	-	-	-	1	2	-	-
TRACHICHTHYIDAE											
Hoplostethus atlanticus	-	-	-	-	-	-	-	5	6	-	-
OREOSOMATIDAE											
Allocyttus verrucosus	-	-	-	-	-	-	-	2	3	-	-
Pseudocyttus maculatus	-	-	-	-	-	-	2	-	1	-	1
APOGONIDAE											
Epigonus robustus	-	-	-	1	-	-	-	3	2	2	2

Table 3

Lengths (cm TL) of orange roughy retained in bags.

Shot number	Bag number	
	12	13
47	10	5
57	18	-
64	14	19
68	7	-
70	-	21
73	-	11
74	-	16
75	-	8
80	21	-

Table 4

Preliminary raising factors to adjust orange roughy length frequency data from net catches to allow for escapment through the mesh.

Length (cm)	Raising factor
5	14.0
6	14.0
7	14.0
8	14.0
9	8.9
10	3.2
11	2.4
12	2.0
13	2.0
14	1.5
15	1.3
16	1.2
17	1.2
18	1.2
19	1.2
20	1.2
21	1.2

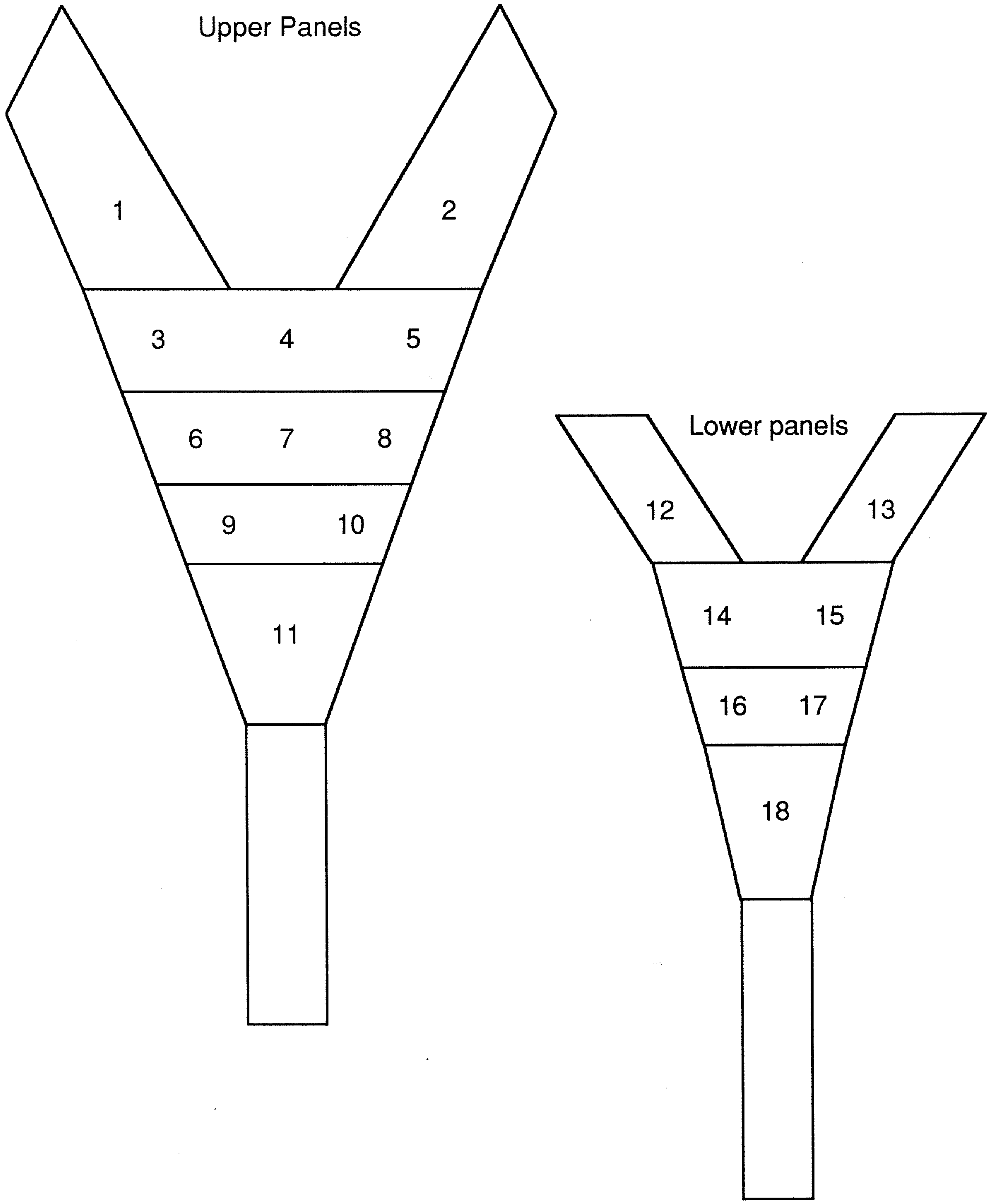


Fig. 1 Attachment sites of bags to be upper and lower panels of the Engel net

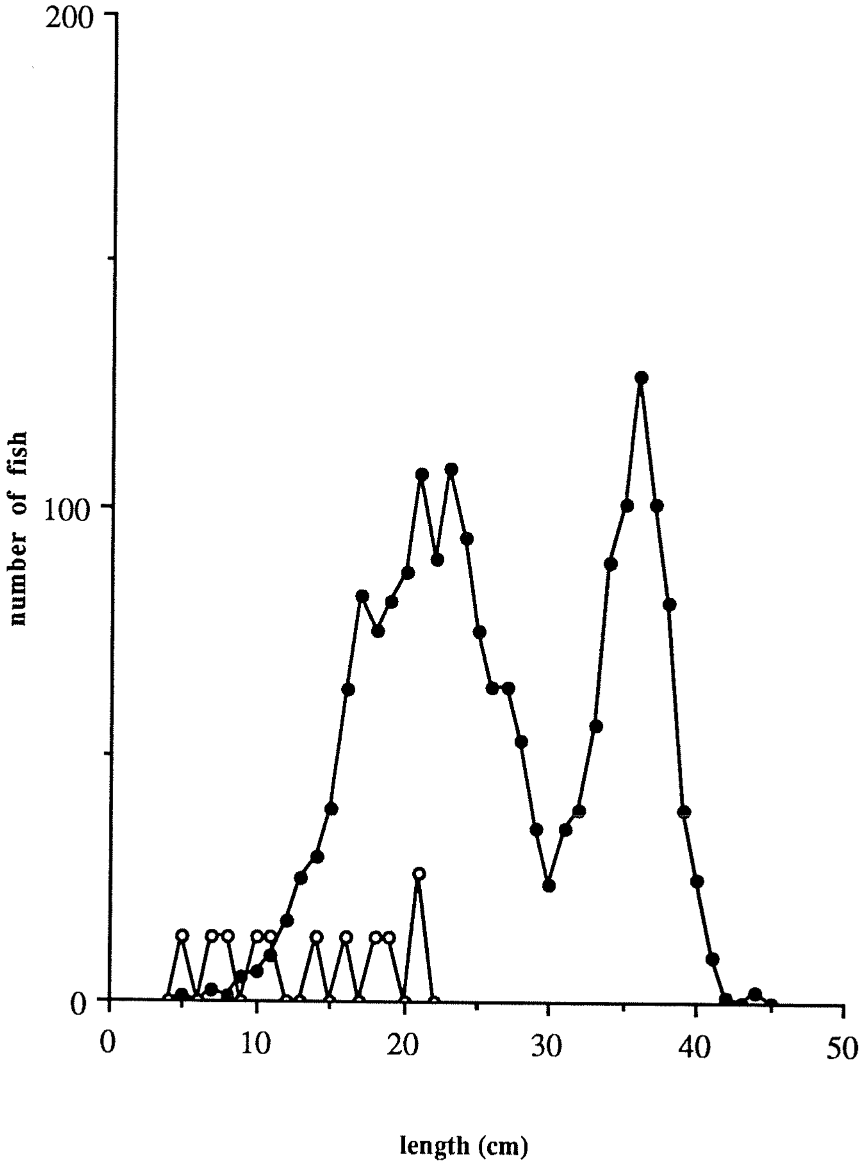


Fig. 2. Length frequency distributions of orange roughy retained in the net (solid circles) and escaping through the net mesh (open circles).

DOCUMENT 4

CSIRO MARINE LABORATORIES REPORT

CSIRO Marine Laboratories Report
Draft

Orange Roughy Survey, 1988 and 1989; Biological Data

C. M. Bulman and N. G. Elliott
CSIRO Division of Fisheries
Hobart, Tasmania

Abstract

The continental slope of southeastern Australia was surveyed in 1988 and 1989 to determine the distribution and abundance of orange roughy *Hoplostethus atlanticus,* and to obtain biological information on the species. The survey area covered the eastern region of the Great Australian Bight, western Bass Strait, west Tasmania, east Tasmania, eastern Bass Strait and, in 1988, southern New South Wales. A total of seven cruises during 1988 and 1989 were made to complete the surveys. Standard measurements of length, weight and maturity were made, and stomach contents, gonad material and otoliths were also collected for other studies. On the east coast of Tasmania, gonadal development wa observed in fish from March and July 1988 and April 1989. Also on the east coast, the female:male ratio of 1:1.5 was different from other regions which were almost equal. Length at maturity was at 32 cm for females and 30 cm for males. An average of 35% of adult females (≥32 cm) were described as non-reproductive. The proportion is important to biomass surveys of the spawning aggregation, since non-reproductive individuals do not migrate to the spawning grounds. The bimodal length frequency distribution, typical of a long-lived fish which has a slower growth rate and/or lower mortality at maturity, was found for roughy from all areas except New South Wales and east Bass Strait.

Introduction

The orange roughy (*Hoplostethus atlanticus* Collett 1889) fishery in Australia is relatively new. The first major aggregation was fished commercially in 1986 off west Tasmania and the first major spawning aggregation was discovered in 1989 off east Tasmania. Prior to 1988, there were no estimates of stock size based on a single vessel full sweep survey. There was, therefore, an urgent need to obtain basic information on the abundance, distribution and biology of this species from within the South East Trawl management area. On FRV *Soela*, we conducted a comprehensive survey of the area with the following objectives:

1. to assess the abundance and distribution of orange roughy in the south eastern waters of Australia, and

2. to obtain biological information on orange roughy for use in the determination of stocks, their size (and age) composition and reproductive strategies.

This report summarizes the biological data obtained during the surveys in 1988 and 1989. Details of the survey design and the abundance indices are described in Bulman et al (submitted).

Methods

Survey design

The survey was of a random depth-stratified design (Bulman et al., submitted). The 1988 survey covered south east Australian waters (largely within the South East Trawl Management Zone), from Kangaroo Island (137° E), around Tasmania and east to Gabo Island (150° E) in the depth range from 700 m to 1199 m in 100 m intervals (Fig 1). No prior knowledge of fish densities was assumed so strata were allocated stations proportional to their individual areas.

In 1989, the depths surveyed were reduced to between 800 m and 1199 m because the 1988 survey found negligible quantities of roughy in the 700 to 799 m zone. Although the survey was extended in the Kangaroo Island region from 137° E to 136° E, the total ground surveyed was further reduced by excluding unsuitable trawl grounds encountered off southern and southeastern Tasmania and northeastern Bass Strait during the 1988 survey.

The entire area was divided into broad geographical areas: Great Australian Bight & western Bass Strait (GAB), western Tasmania (WTas), eastern Tasmania to Flinders Island (ETas), eastern Bass Strait to Gabo Island (EBass) and southern NSW to Brush Island (NSW) (Fig 1).

Standard survey tows were of 30 minutes duration (bottom time). This time could not always be achieved and only tows greater than 15 minutes were used in calculations for abundance. However, biological data were obtained from all trawl catches. A sampling location was abandoned if a suitable tow was not found within an hour's search around the predetermined position.

Biological assessment

Biological data were obtained from a maximum of 40 orange roughy (randomly selected) per trawl catch in 1988 and 20 per catch in 1989. Standard measurements were taken from the fish examined i.e. standard length (SL cm), weight (kg), sex, maturity stage (Pankhurst et al., 1987) and gonad weight (g) (except for very small fish). Length frequencies were taken from a maximum of 200 fish per catch. In cases where catches were subsampled, length frequencies were adjusted to represent the whole catch. Length frequencies from individual stations in each of the broad regions i.e. the Great Australian Bight and west Bass Strait, West Tasmania, East Tasmania, and New South Wales and east Bass Strait, were combined by sex and year. Gonosomatic indices (GSI) were calculated as the ratio of gonad weight to total weight of the fish. Stomach contents were examined and otoliths were collected from most specimens. Females ≥ 32 cm and males ≥ 30 cm were selected as mature, based on the 1987 length at maturity data (Bulman and Elliott, submitted). Length at maturity, i.e.length at which 50% of fish are maturing (females ≥ stage 3 (exogenous vitellogenesis); males ≥

stage 2 (spermatozoa present)), was determined for fish from the west coast and east coast since these populations were sampled closer to spawning. The selection of the female maturity stage criterion was chosen to be consistent with the study by Bell et al. (submitted) for which gonads were collected and preserved for histological examination and verification of our macroscopic staging. Detailed reproductive biology and dietary analyses are reported separately (Bell et al., submitted; Bulman and Koslow, submitted).

Survey

The 1988 survey consisted of three FRV *Soela* cruises: SO1/88 (January-–February), Kangaroo Island (SA) to Portland (Vic); SO2/88 (March–April) Portland to north–east coast Tasmania and SO3/88 (May) east coast Tasmania to Gabo Island (NSW) and southern NSW. Data from 162 tows were used. An additional cruise in July (SO4/88) added another 98 adult fish from the east Tasmanian coast to the data set. Another three cruises comprised the 1989 survey: SO1/89 (January–February), Kangaroo Island to west of Portland; SO2/89 (March), west of Portland to Low Rocky Point (W Tasmania) and SO3/89 (April–May) east coast of Tasmania and north-east of Flinders Island. Data from 167 tows were used. The survey results and abundance estimates are reported elsewhere (Bulman et al., submitted).

Results

6964 fish were examined over both years, 4462 from 1988 and 2502 from 1989.

Reproductive biology

The sex ratio in most areas was equal however on the east coast males outnumbered females by about 1.5 times (Table 1).

Table 1. Female:male ratios in the major regions.

Year	GAB & WBass	WTas	ETas	NSW & EBass
1988	1: 0.92 (n=1714)	1: 0.88 (n=1060)	1: 1.47 (n=385)	1: 0.95 (n=1303)
1989	1: 0.97 (n=1296)	1: 0.86 (n=764)	1: 1.60 (n=382)	1: 1.50 (n=60)

The length at maturity data were combined over the two years. In the Bight and west Bass Strait area advanced gonadal development was not widespread at the time of sampling. The west Tasmanian fish were sampled in March and were showing signs of maturity at about 33 cm for females (Fig 2a) and 31 cm for males (Fig 2b). Later (in April), the eastern Tasmanian fish showed definite signs of gonadal development indicating they were to spawn that year. The females showed maturity at 32 cm (Fig 3a) and the males 30 cm (Fig 3b), as in 1987. Sample sizes in the east Bass Strait and New South Wales areas were too small to calculate reliable estimates.

GSI against length is plotted for individual males and females for both years in Appendix 1. All fish, including juveniles, are included in the plots. The numbers represent the individual's gonad stage. Juveniles with gonads which were less than we could weigh were attributed an arbitrary weight of 0.5 g. In the smaller fish, this causes the GSIs to apparently increase as the fish decrease in size and therefore should be disregarded.

Mean gonosomatic indices (GSI) were calculated for mature males and females in each area for both years (Table 2). Gonad development, as measured by an increase in mean GSI, was seen in both females and males throughout the surveys in both years and was particularly evident on the east coast of Tasmania between April and July 1988 (Table 2 & Appendix 1). July is the major spawning period for orange roughy in Australia and New Zealand (Anon., 1982; Evans & Wilson, 1987; Bell et al., submitted; Pankhurst et al., 1987). The GSIs for NSW and east Bass Strait fish were low even though they were obtained closer to spawning than the other areas (see also Appendix 1) but numbers of adults were low.

Table 2. Mean gonosomatic indices for mature orange roughy in 1988 and 1989.

	Female (≥32 cm)			Male (≥30 cm)		
Cruise (date)	Mean	±SD	n	Mean	±SD	n
Great Australian Bight & west Bass Strait						
0188 (23/1-10/2/88)	2.12	0.89	188	1.48	1.40	199
0189 (22/1-8/2/89)	2.34	1.09	88	1.56	1.28	27
0288 (15/3-18/3/88)	2.16	1.10	30	0.49	0.82	23
0289 (2-5/3/89)	2.19	0.96	61	0.74	0.96	18
West Tasmania						
0288 (18-27/3/88)	2.86	1.04	404	1.65	1.31	313
0289 (5-20/3/89)	2.94	0.96	253	1.78	1.13	178
East Tasmania						
0288 (28/3-7/4/88)	2.32	0.90	80	2.19	1.54	149
0389 (14-30/4/89)	3.13	1.01	69	3.26	1.86	151
0488 (15-17/7/88)	5.07	2.28	34	1.82	0.82	64
East Bass Strait and NSW						
0388 (May 88)	1.58	0.75	45	0.21	0.27	36

GSIs for males were lower than those for females except on the east coast in April 1989, when the highest male GSI was recorded. The highest female GSI mean of about 5% (range 2-11.4%) was recorded in July 1988 at peak spawning time.

The proportion of maturing adult females (≥ 32 cm and ≥ stage 3) in the Great Australian Bight and western Bass Strait region, early in either year (January and March), was 55.3% in 1988 and 51.3% in 1989 (Table 3). The proportion from western Tasmania was 88.4% in 1988 (sampling midpoint 22/3/88) and 67.3% in 1989 at a slightly earlier date (midpoint 12/3/89). From eastern Tasmania, the proportion was higher in 1988 at an earlier date (73.8%; midpoint 2/4/88) than in 1989 (57.9%; midpoint 22/4/89) but sample sizes were small. From 15-17 July 1988 sample, nearly 21% of females were at stage 3 and 68% were at stage 4 but no running ripe (stage 5) females were found (the spawning aggregation off St Helens was undiscovered at that time). Only 26.7% of NSW and eastern Bass Strait females in May 1988 were at stage 3.

Table 3. Proportions of gonad maturity stages from female orange roughy.

			Stage				
Area	Year	n	1	2	3	4	5
GAB	88	221	3.6	41.2	54.8	-	0.5
	89	150	1.3	47.3	51.3	-	-
WTas	88	405	1.5	10.1	88.4	-	-
	89	254	0.8	31.9	67.3	-	-
ETas	88	80	1.3	25.0	73.8	-	-

July	88	34	2.9	8.8	20.6	67.6	-
	89	69	-	42.0	56.5	1.4	-
NSW	88	45	4.4	68.9	26.7	-	-
	89	1	-	-	100	-	-

The proportion of maturing adult males (≥ 30 cm and ≥ stage 2) from the Bight and western Bass Strait was about 58% in 1988 and 46% in 1989 (Table 4). A large proportion of males from west Tasmania were at stage 2 in both years (88.6% and 89.4%). A slightly greater proportion of males from east Tasmania in 1988 were at a similar development stages but in 1989, 1.3% were found to have progressed to stage 3. In July 1988, 90% of males were at stage 3 and 2% were running ripe (stage 4) . Over 60% of the adult NSW and east Bass Strait males were immature (stage 1) in May 1988.

Table 4.Proportions of gonad maturity stages from male orange roughy.

			Stage			
Area	Year	n	1	2	3	4
GAB	88	228	42.1	47.4	10.5	-
	89	102	53.9	46.1	-	-
WTas	88	316	11.4	88.6	-	-
	89	207	10.6	89.4	-	-
ETas	88	149	8.7	91.3	-	-
July	88	64	-	6.8	92.2	1.6

	89	153	4.6	94.1	1.3	-
NSW	88	43	62.8	37.2	-	-
	89	1	-	100	-	-

Length frequency

The regional length frequencies were very similar between years for each area. They were also similar between sexes. The GAB-west Bass Strait length frequency data were dominated by juveniles in both years with only a weak mode in the adult sizes (Fig. 4). The west Tasmanian population was strongly bimodal, with a broader but slightly lower peak in the juvenile range than in the adult range (Fig. 5). The NSW/East Bass Strait frequencies were dominated by juveniles. However the sample sizes in 1989 were less than 10% of the 1988 sample sizes and did not include fish from New South Wales (Fig. 6). In contrast, the adult population of east Tasmania was predominantly male whereas the sex ratio of the juvenile population was equal as in other regions (Fig. 7).

Discussion

An interesting feature of the reproductive data was the proportion of adult females that did not progress beyond stage 2, (stage 3 being the level of development at which maturation is presumed to continue until spawning). About 30% of adult females from the east coast in

April 1988 and over 40% in April 1989 were at stage 2 whilst the majority were more advanced. The length at maturity analysis shows clearly that an average of about 35% of all adult female fish off east Tasmania, even those greater than the mode at 37-38 cm, were non-reproductive in April whilst the large majority of males did show gonadal development.

The high proportion of non-reproductive females may be due to underepresentation of the reproductive females in the sampling. For example, if a large proportion of the reproductive females had aggregated on the St Helens Hill prior to spawning, or over rough ground not included in our survey, we would have been unable to sample them. However, the Tasmanian Department of Sea Fisheries (TDSF) found that fish were not highly aggregated on the Hill during March and May 1990 and, of the females examined from the Hill, 40-46% showed no evidence of gonadal development. In July the proportion of non-reproductive fish had dropped to 5% as a consequence of an influx of spawning females into the area (Lyle et al., 1990). Assuming that our sample was indeed representative of the population, our results support the suggestion that not all fish reproduce every year. Histological examination of gonad material collected from "non-reproductive" fish confirm that a proportion of females do not reproduce every year (Lyle et al., 1990; Bell et al., submitted). Our data indicates that this proportion may vary from year to year (26% in 1988 to 42% in 1989), perhaps depending on food availability.

On the east Tasmanian coast, the male to female ratio for adults was about 2:1 and the ratio for juveniles was about equal. In contrast, other areas showed little difference in length distribution between males and females and the sex ratio was about equal. Surveys on the St Helens Hill conducted in March and May 1990 by TDSF also found that males outnumbered females (Lyle at al., 1990). As with the proportion of non-reproductive females, this inequality in sex ratios may also be a result of the unavailability of mature females during our sampling period.

Orange roughy exhibited a bimodal length frequency distribution in all areas except the New South Wales and east Bass Strait area. The Great Australian Bight length frequencies were dominated by juvenile fish whereas the proportion of juveniles to adults in the west Tasmanian distributions were nearly equal. The east Tasmanian distributions were bimodal but with the greatest proportion being adult males. Since seasonal data for each area were not obtained, we could not determine the extent to which regional differences were influenced by seasonal movements of fish stocks for spawning or feeding purposes. Bimodal distribution could result from a decrease in mortality at maturity (at about 30-32 cm), or from a reduction in growth rate at maturity, or perhaps both, where length (age) classes greater than about 30 cm are compressed. Current evidence suggests exceptionally slow growth in this species (Mace et al., 1990) and that fish may live in excess of 50-70 years (Mace et al., 1990; Fenton et al., submitted), thus implying low natural mortality and low productivity (Mace et al., 1990).

Variability in the reproductive potential of females may result in significant annual variation in the biomass of the spawning aggregation. Biomass estimation based on acoustic and the egg production methods require an estimate of the proportion of non-reproductive fish, which would not be included in surveys of the spawning aggregation. This proportion must therefore be determined annually along with sex ratio and fecundity to account for this variation (Bell et al., submitted). The extent to which the males are non-reproductive each year is also in need of further investigation. Given the sex ratio and proportion of non-reproductive fish, the spawning biomass estimate can be extrapolated to give a total stock biomass, but the geographical area over which this stock is distributed is still unknown. Until we are certain of the geographical boundaries of the stock which spawn on the east coast, management will need to be conservative to prevent overfishing.

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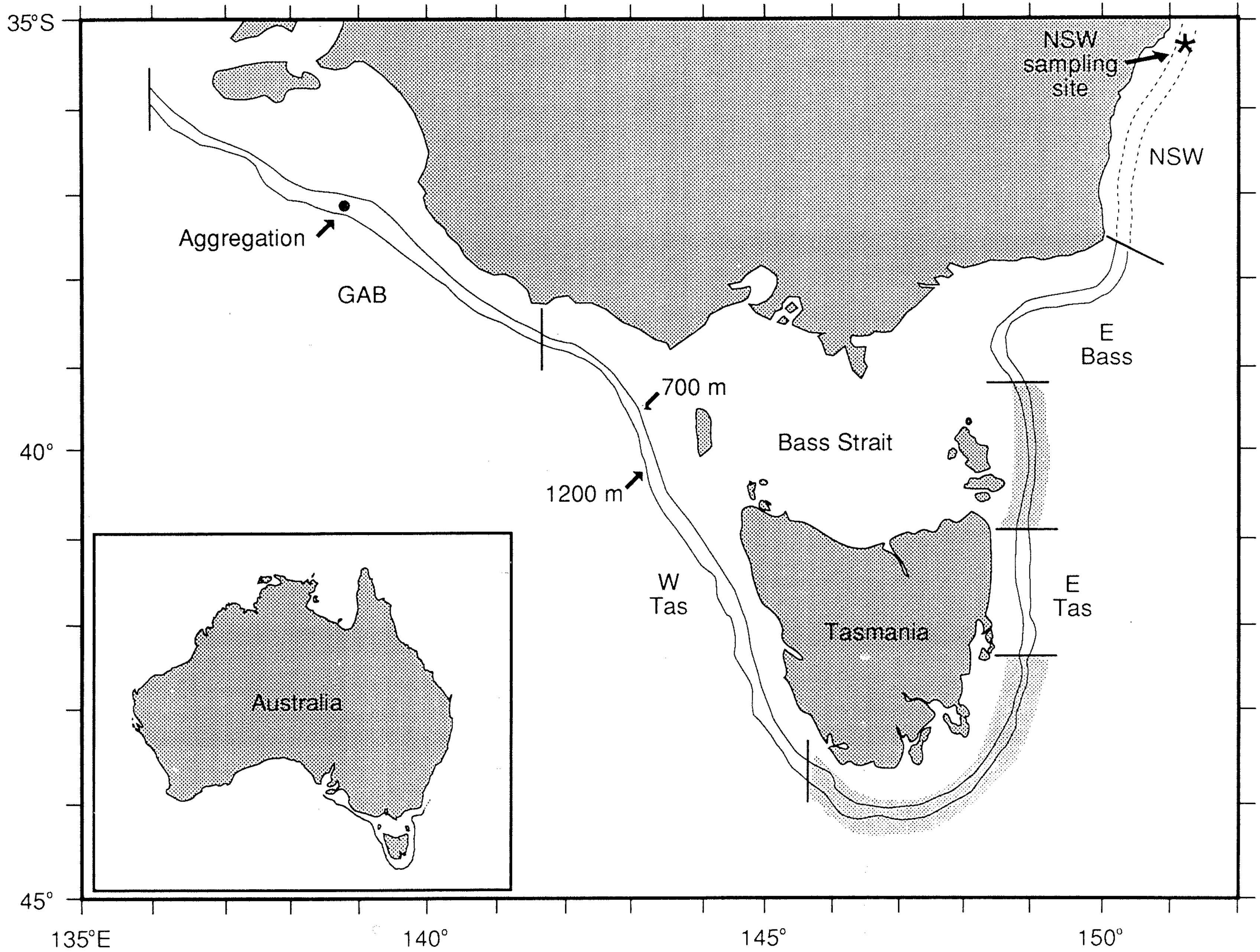


Fig. 1. Survey area.

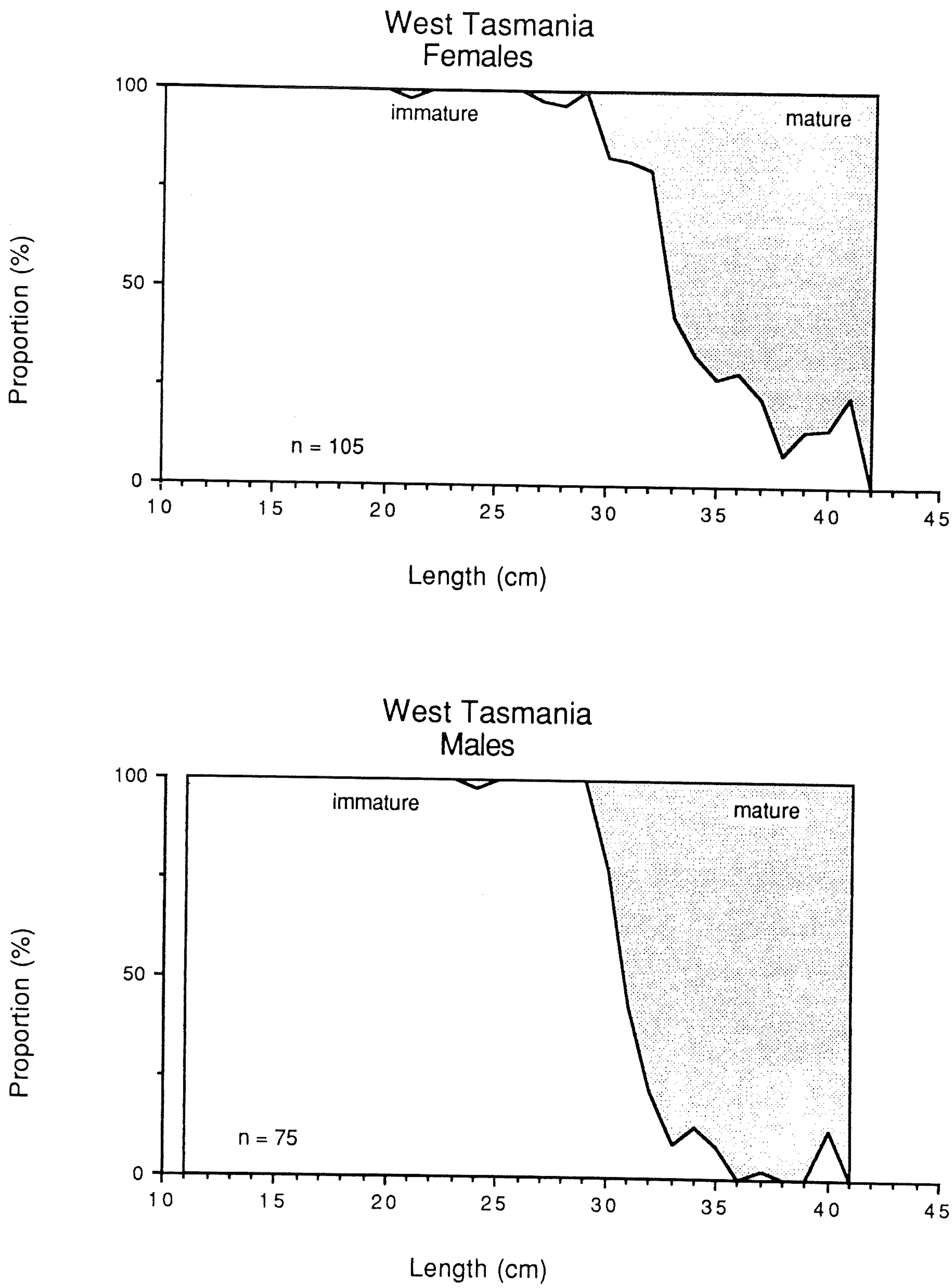
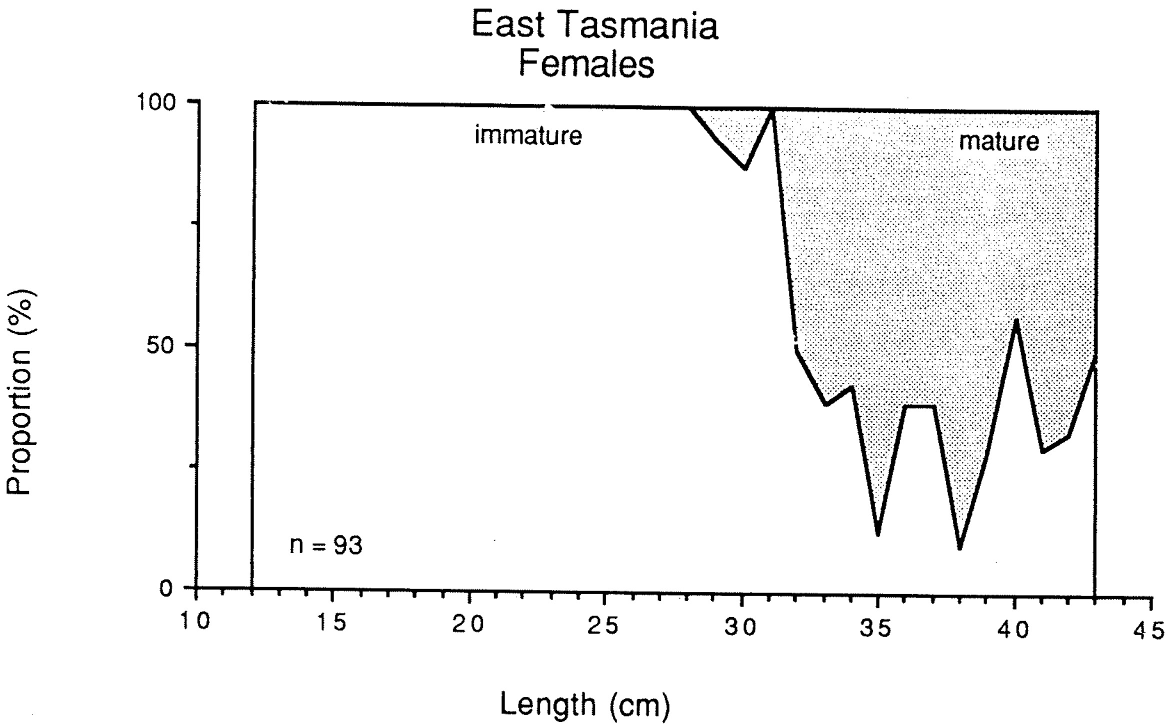


Fig. 2. Proportion of mature vs. immature fish for (a) female and (b) male orange roughy from west Tasmania over 1988 and 1989.



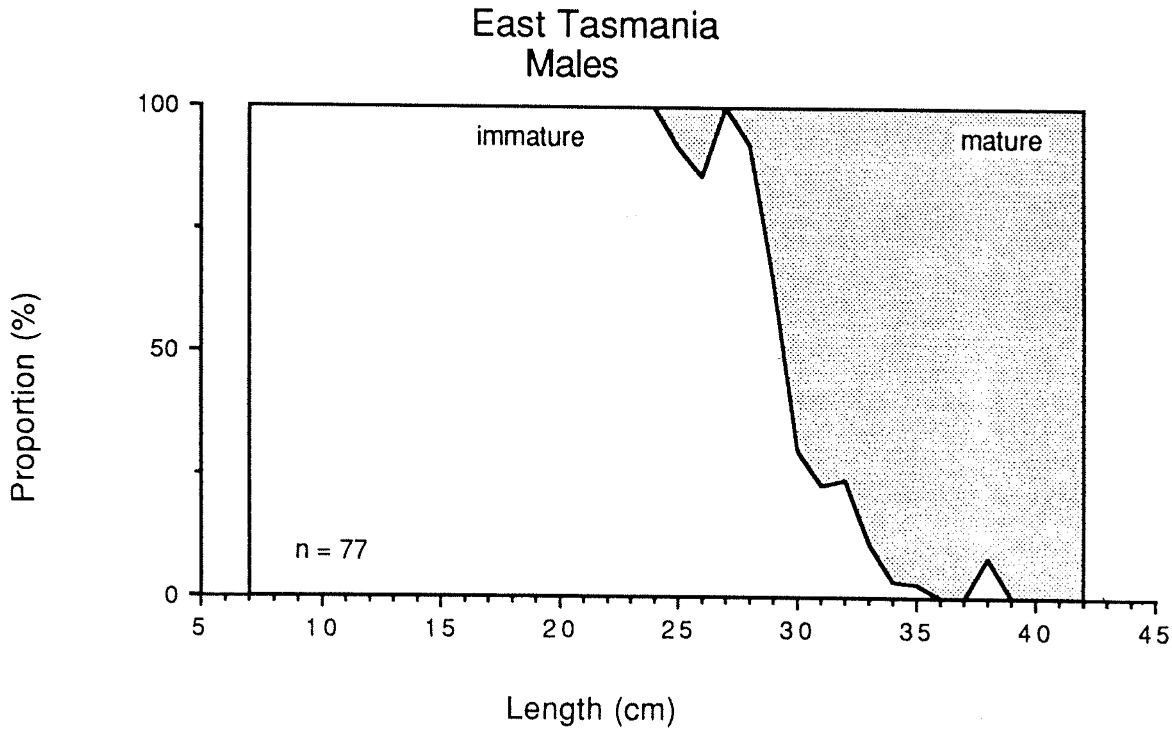


Fig. 3. Proportion of mature vs. immature fish for (a) female and (b) male orange roughy from east Tasmania over 1988 and 1989.

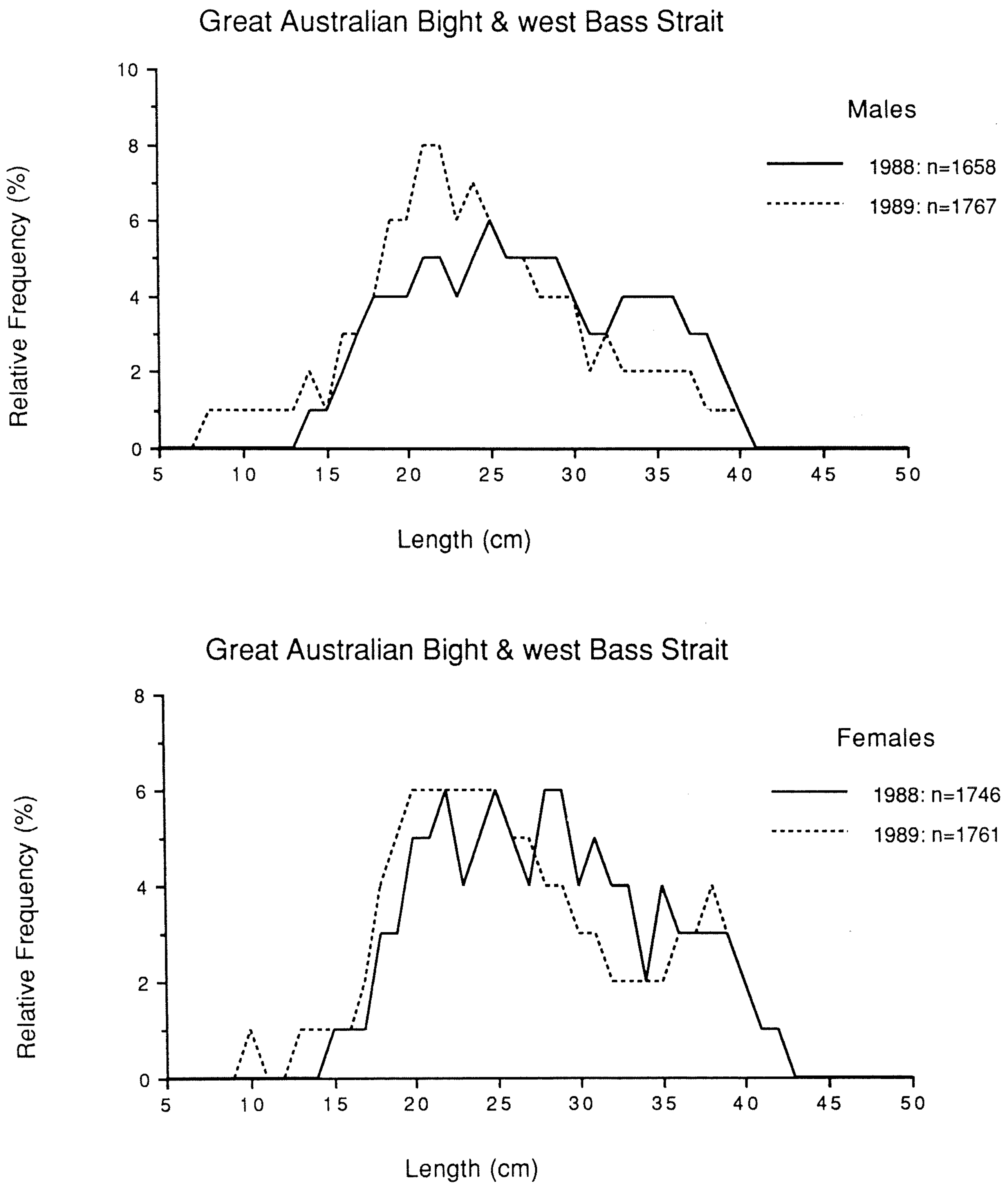
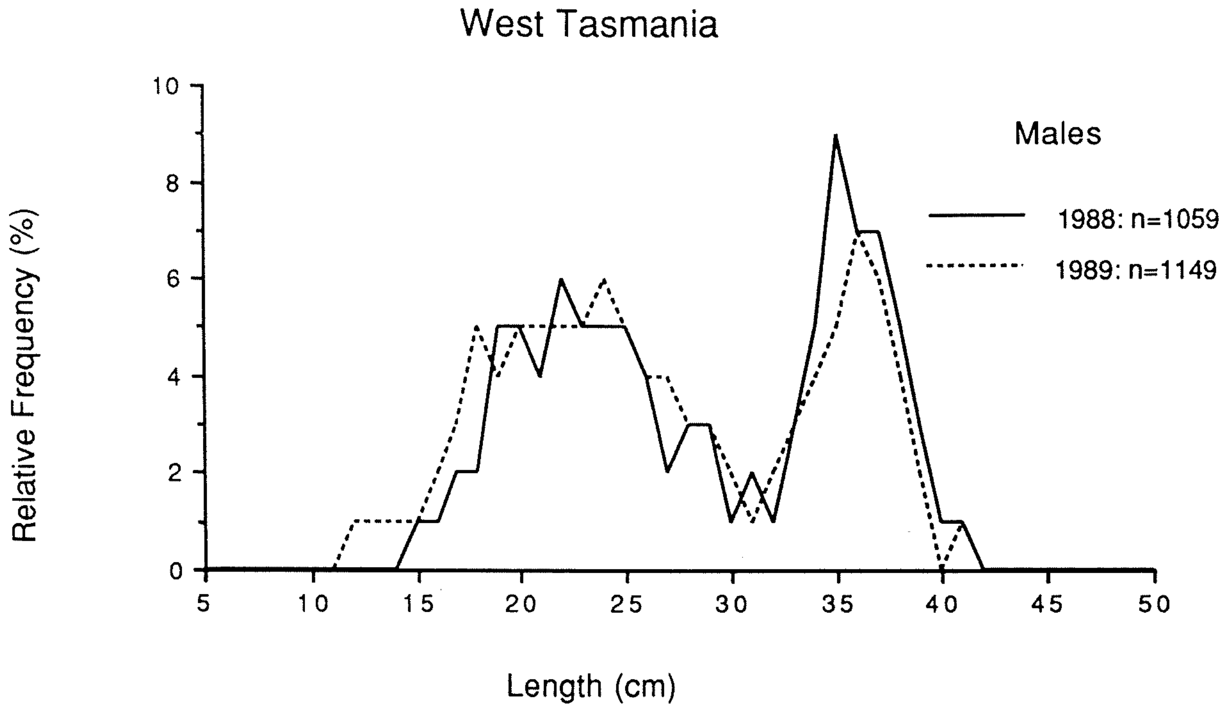


Fig. 4. Length frequency distribution of (a) male and (b) female orange roughy from the Great Australian Bight and west Bass Strait during 1988 and 1989.



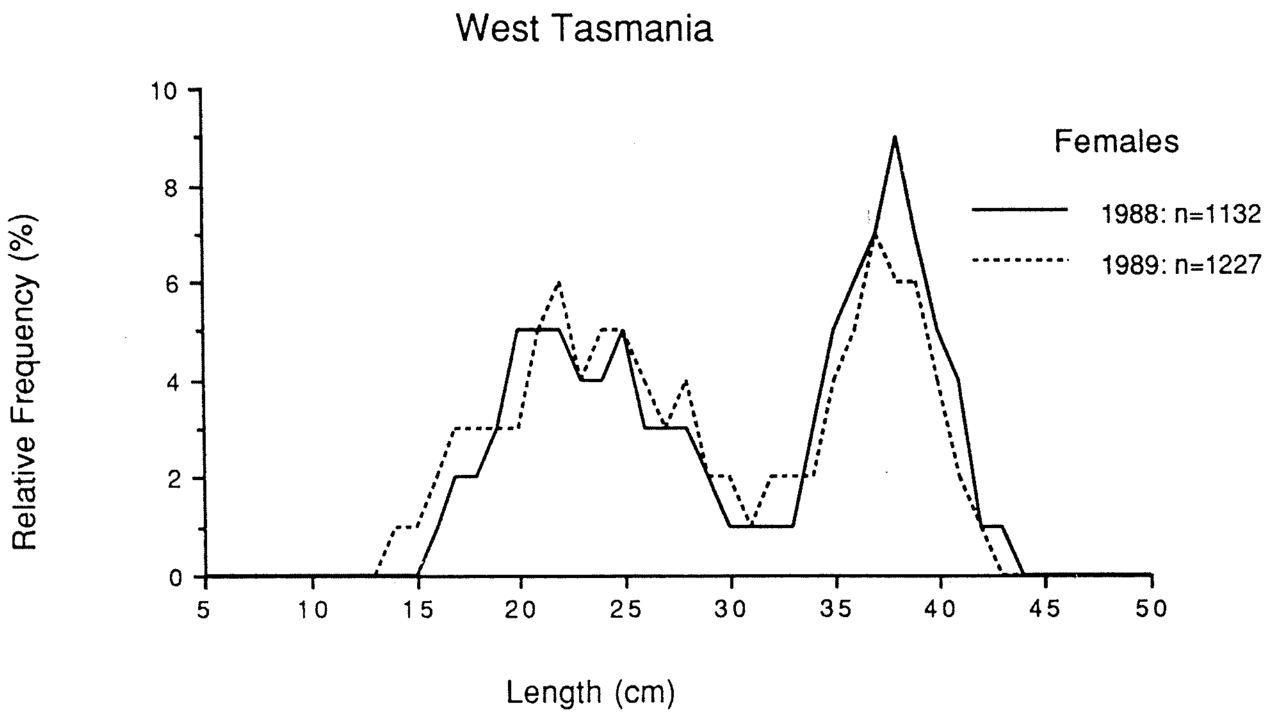
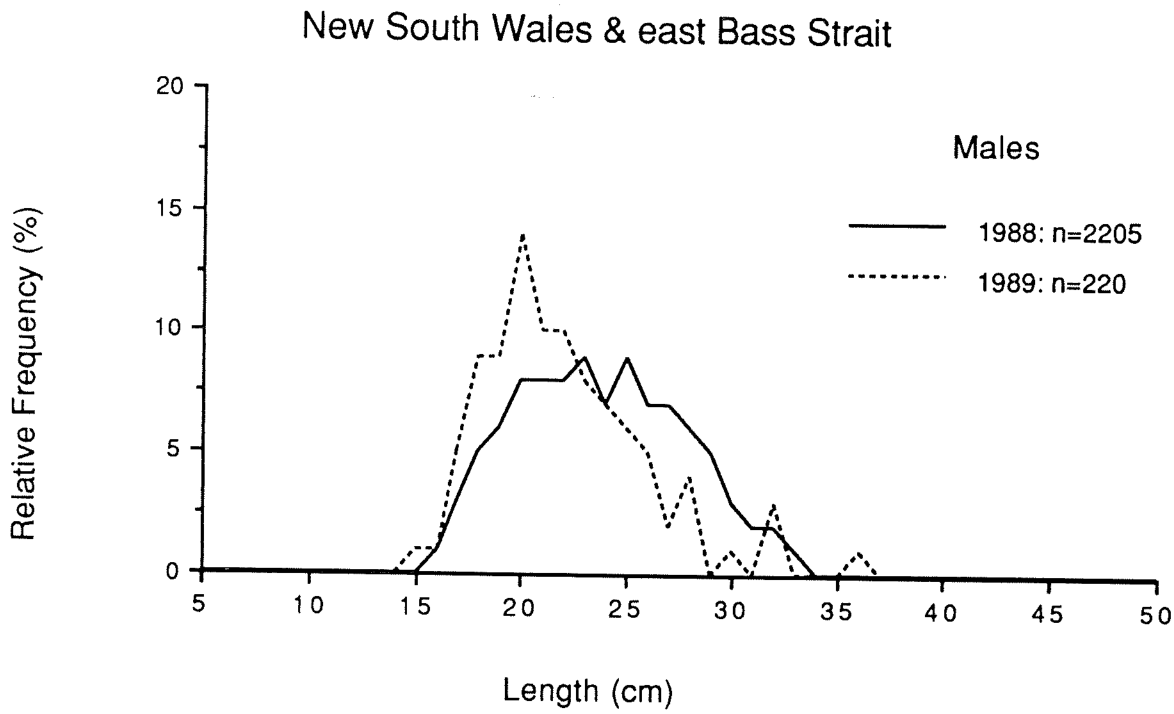


Fig. 5. Length frequency distribution of (a) male and (b) female orange roughy from the west Tasmania during 1988 and 1989.



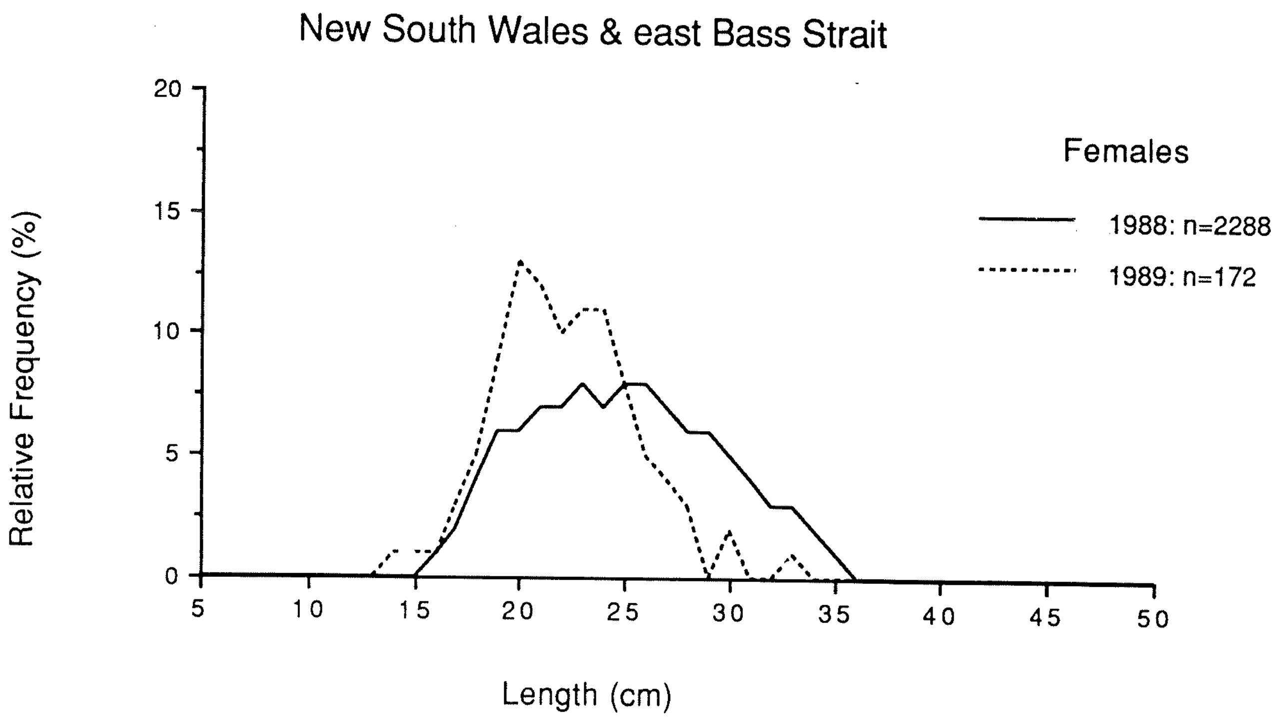
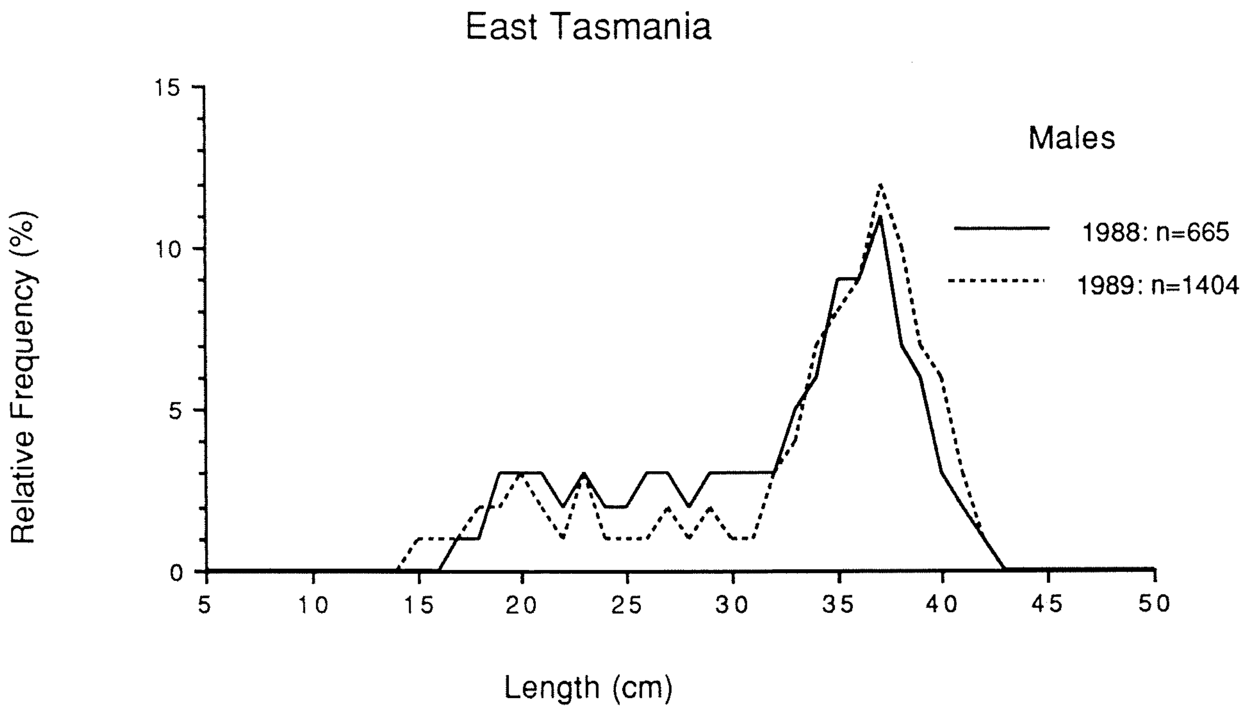


Fig. 6. Length frequency distribution of (a) male and (b) female orange roughy from the New South Wales and east Bass Strait during 1988 and 1989.



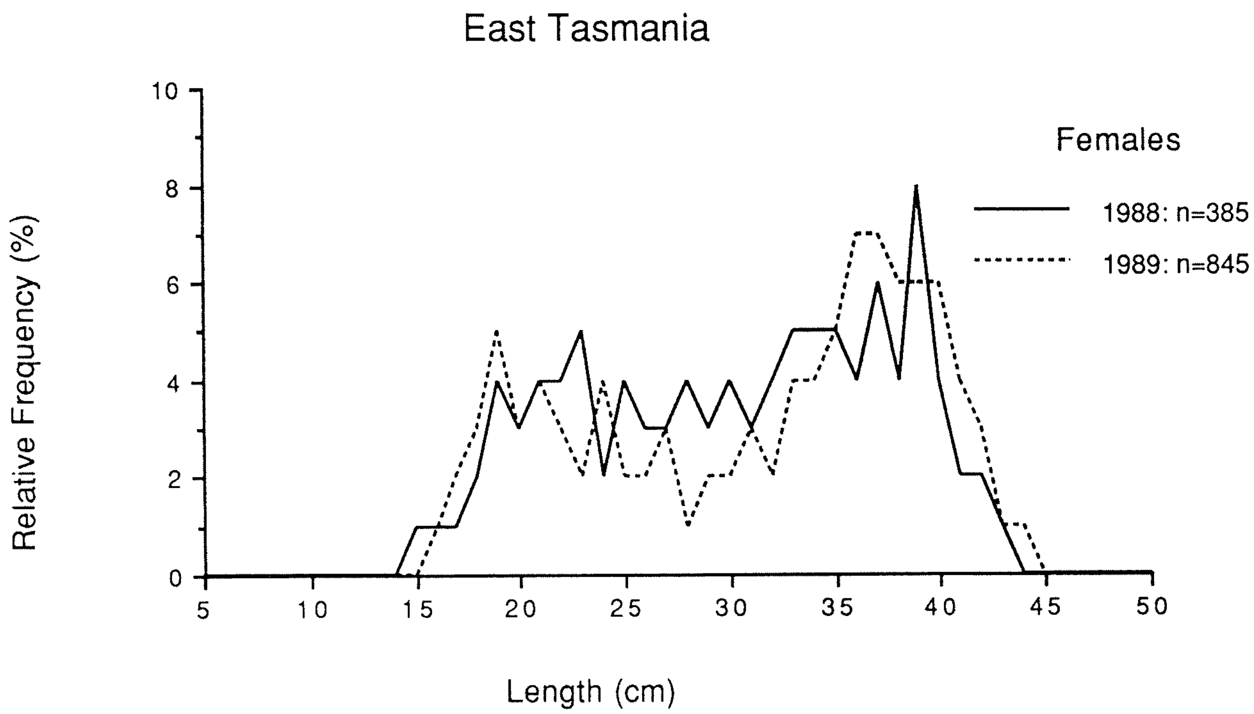
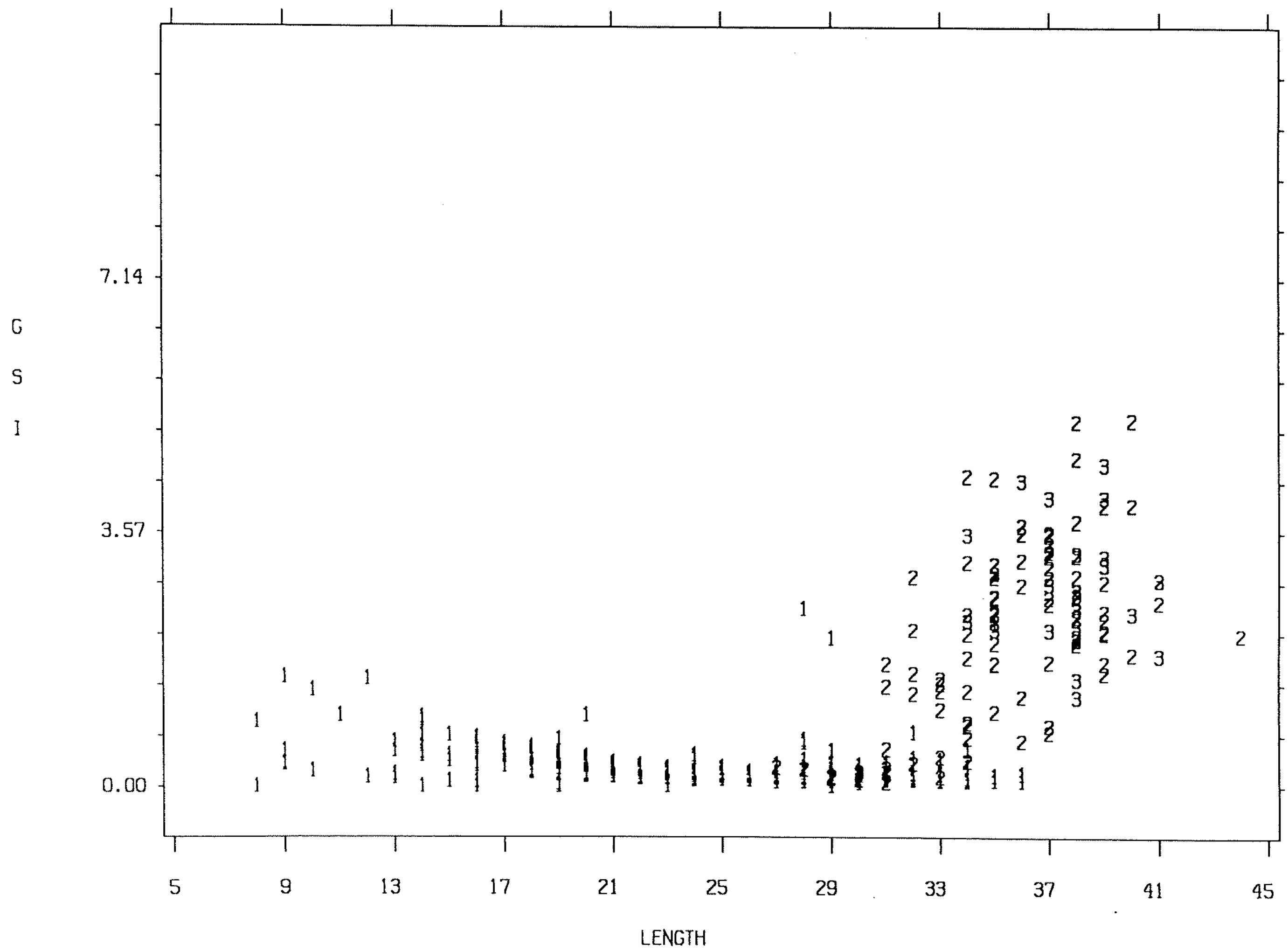


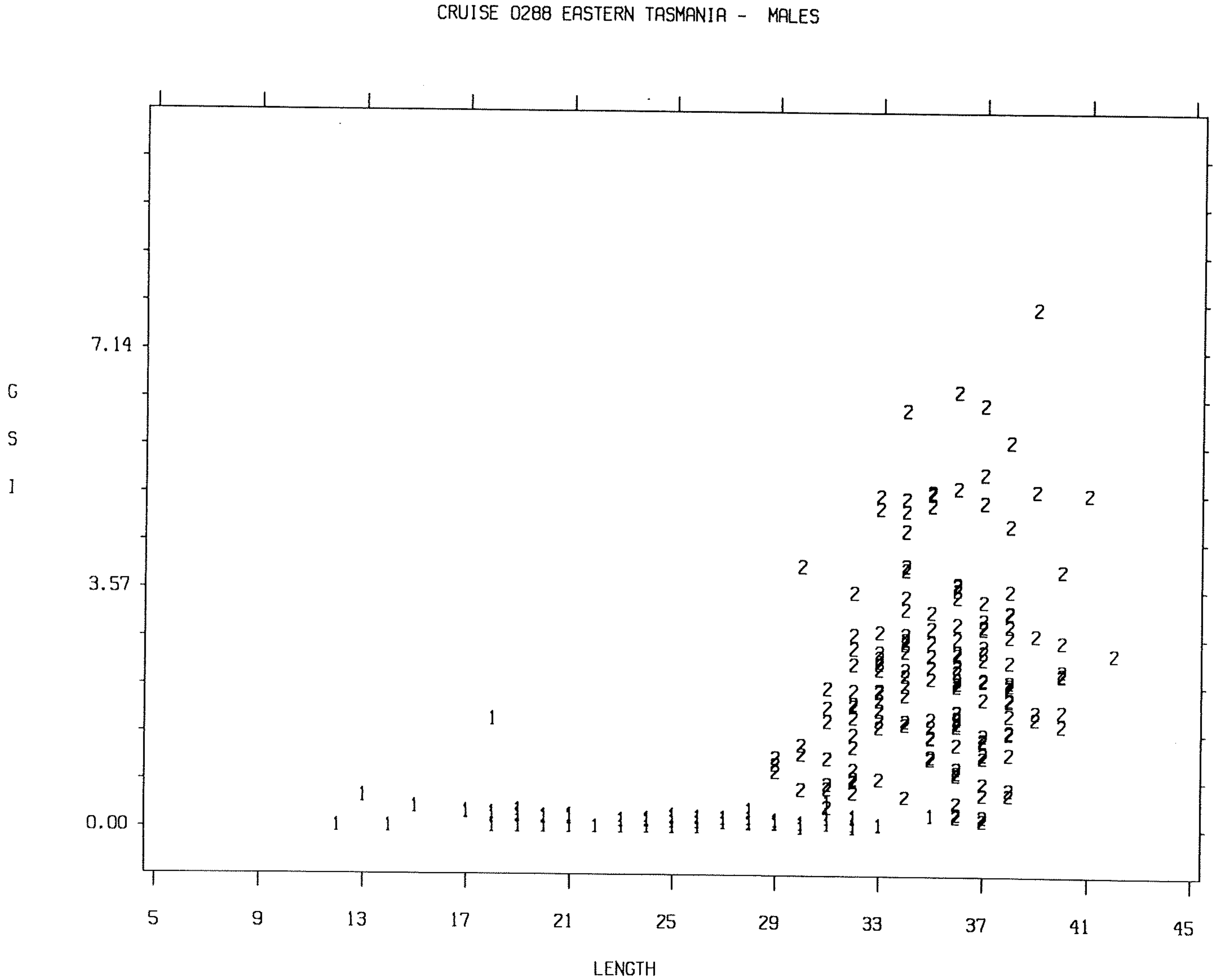
Fig. 7. Length frequency distribution of (a) male and (b) female orange roughy from the east Tasmania during 1988 and 1989.

APPENDIX

GSI indices by sex and area for 1988 and 1989 cruises

CRUISE 0188 MALES




CRUISE 0288 EASTERN TASMANIA - MALES
7.14
3.57
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G
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29
33
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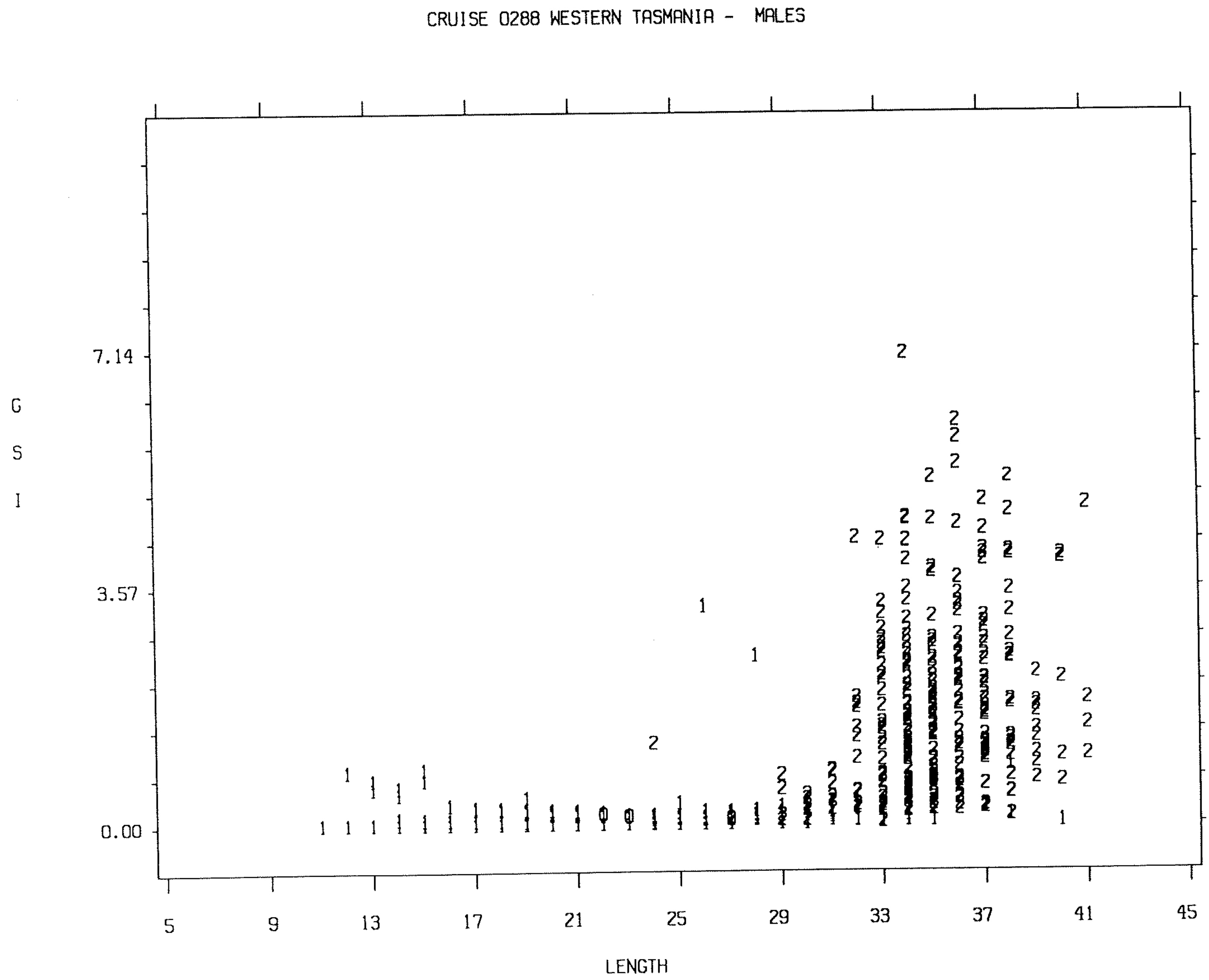
41
45
LENGTH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0.00
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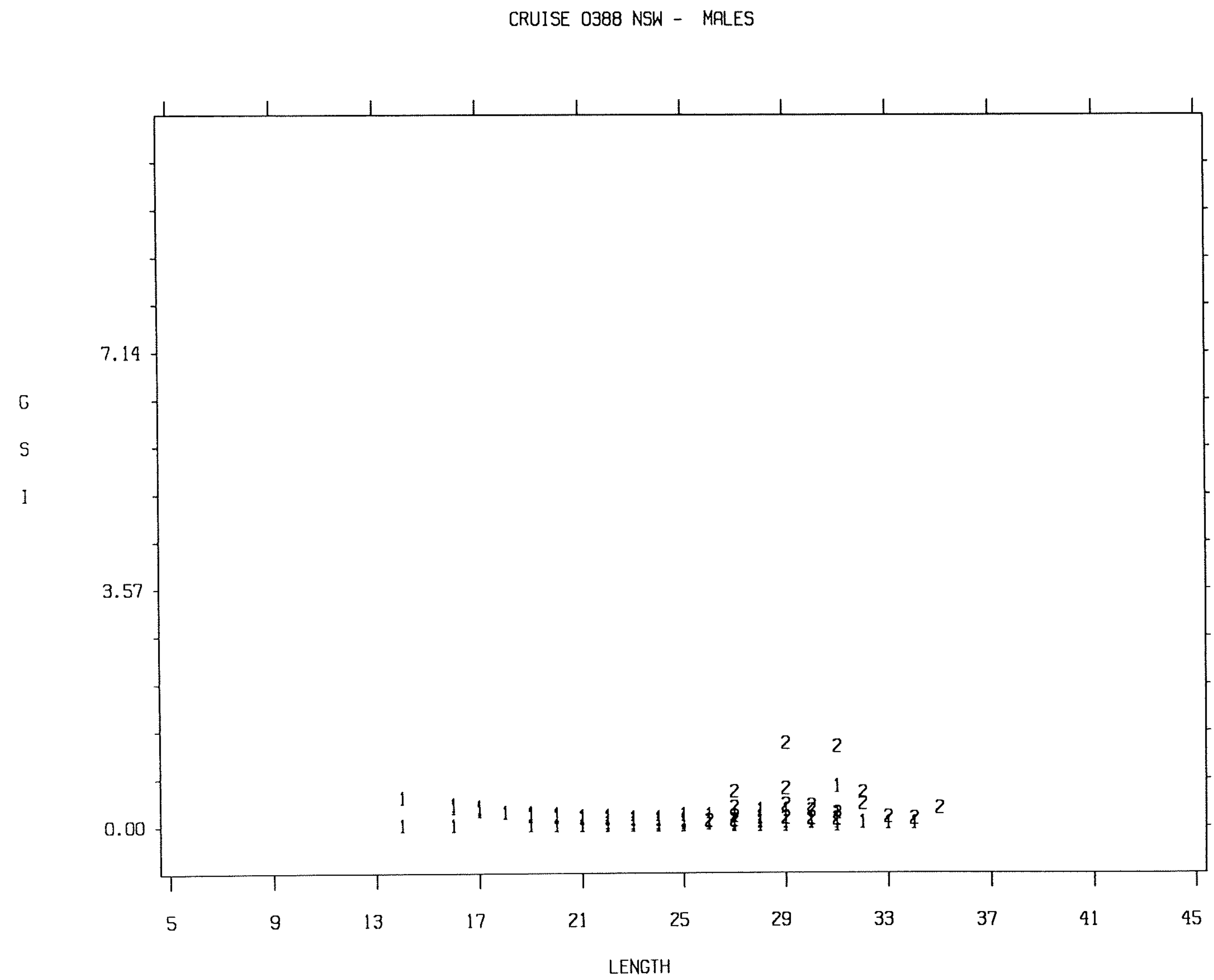
LENGTH


CRUISE 0388 NSW - MALES
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3.57
0.00
G
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13
17
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25
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33
37
41
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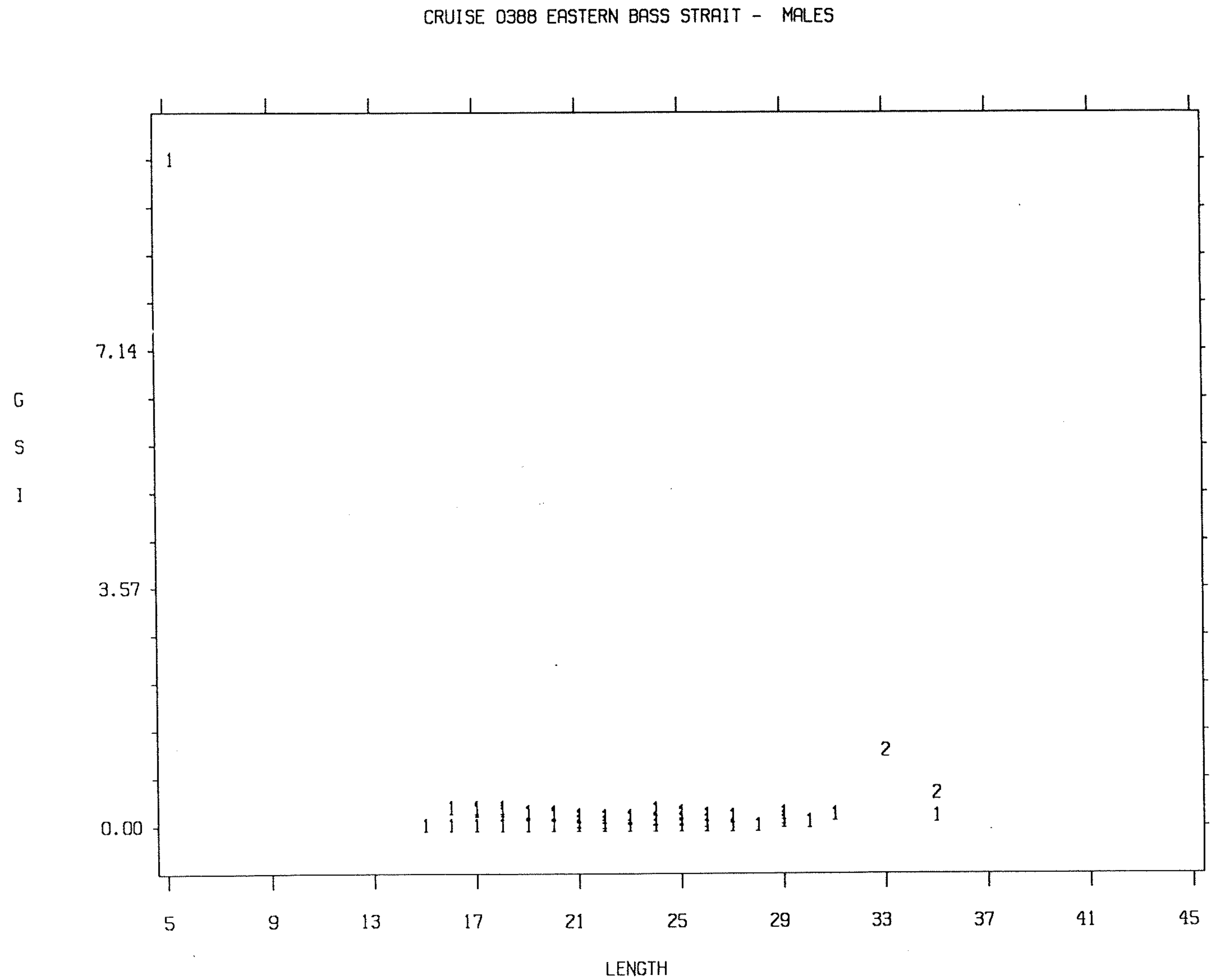
LENGTH



CRUISE 0388 EASTERN BASS STRAIT - MALES
G
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7.14
3.57
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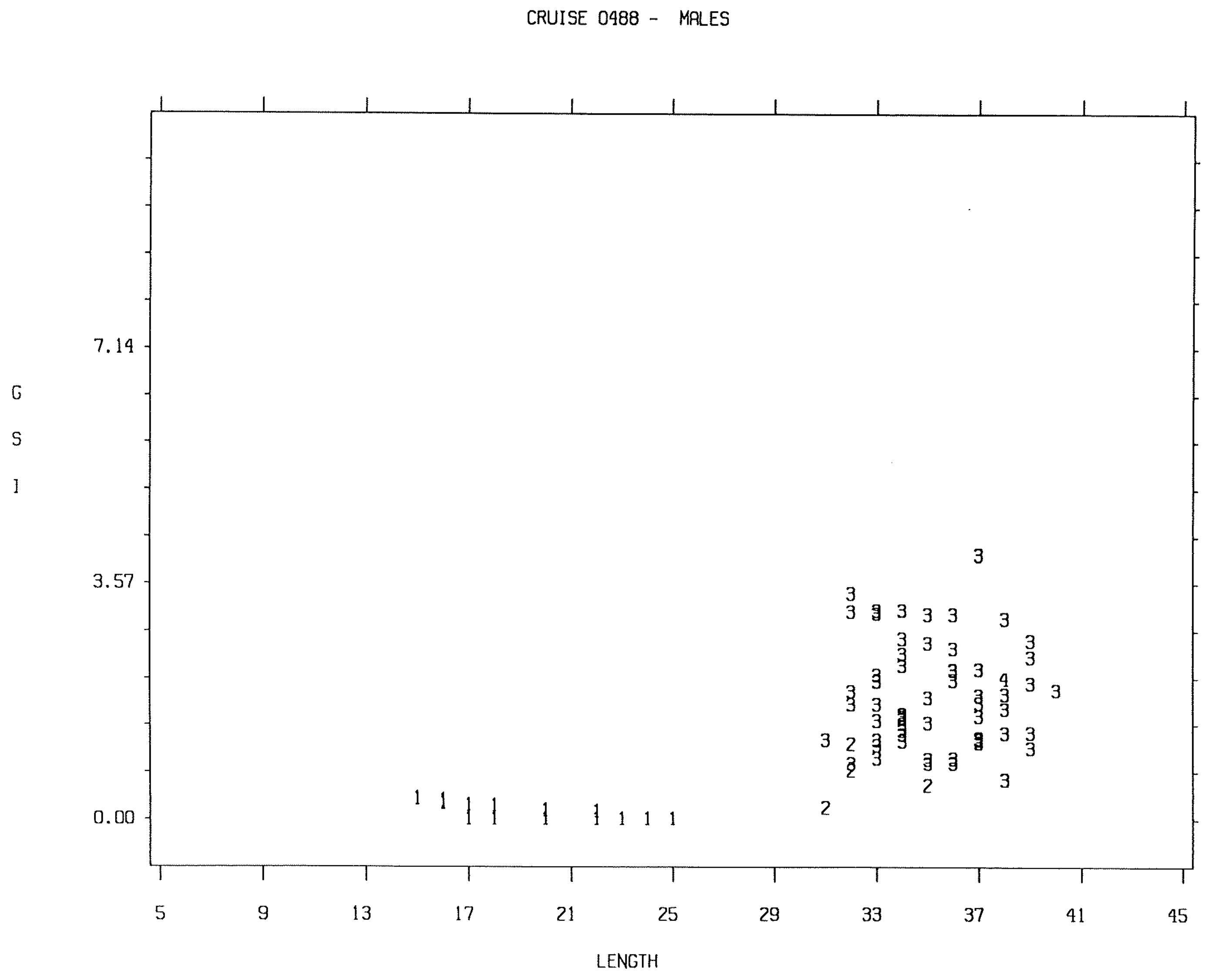
LENGTH


CRUISE 0488 - MALES
7.14
3.57
0.00
G
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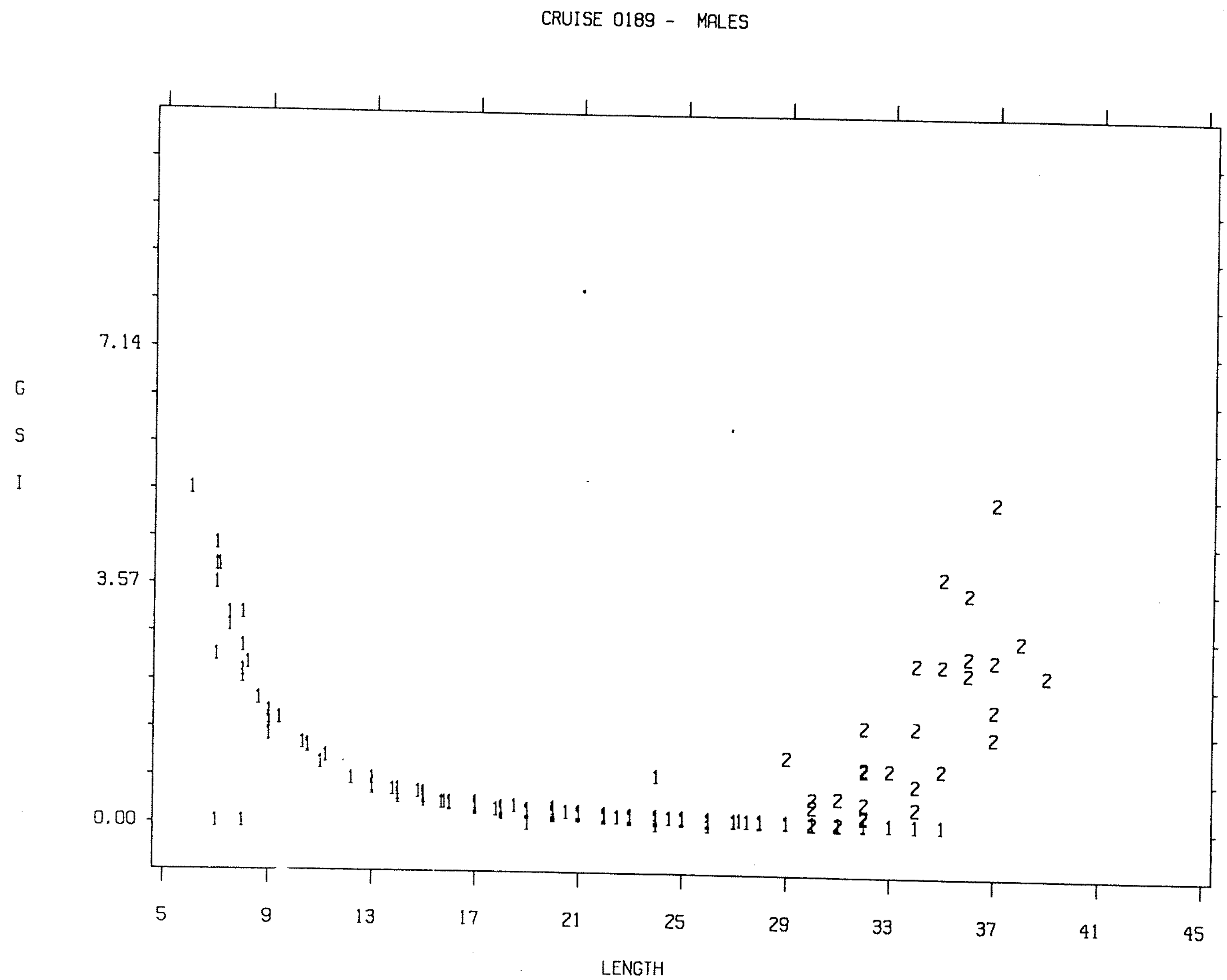
45
LENGTH


CRUISE 0189 - MALES
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3.57
0.00
GSI
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9
13
17
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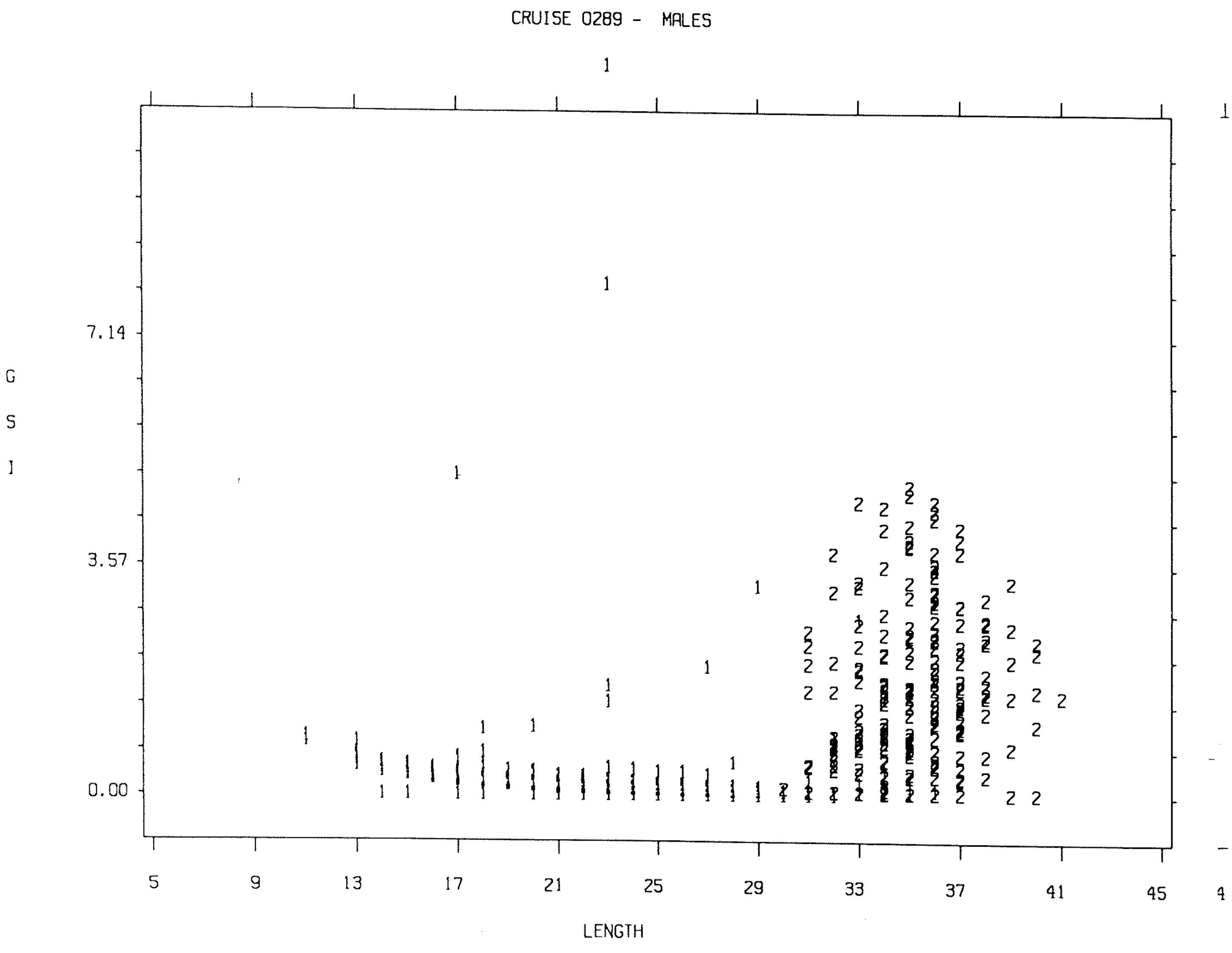
LENGTH


CRUISE 0289 - MALES
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0.00
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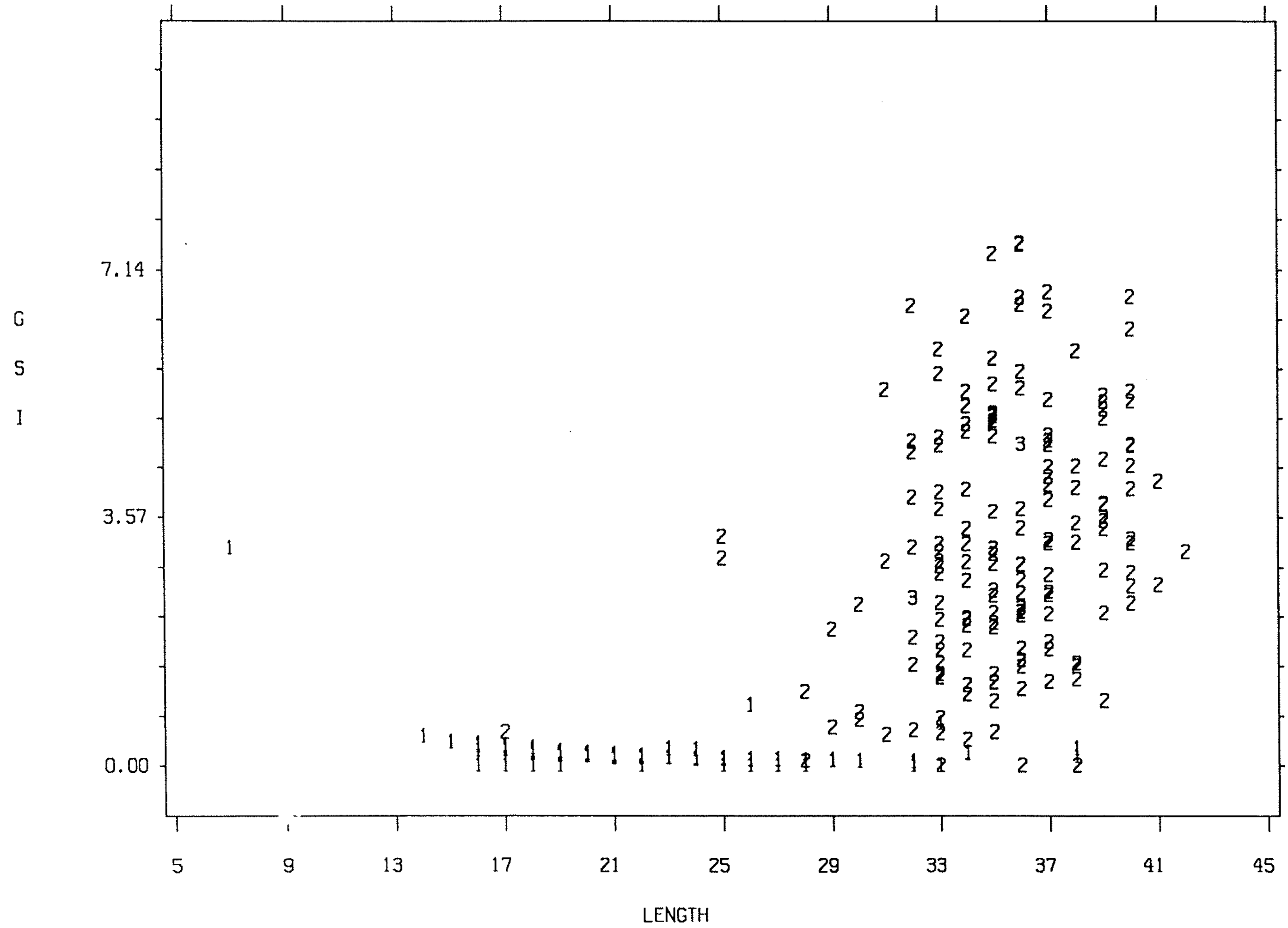
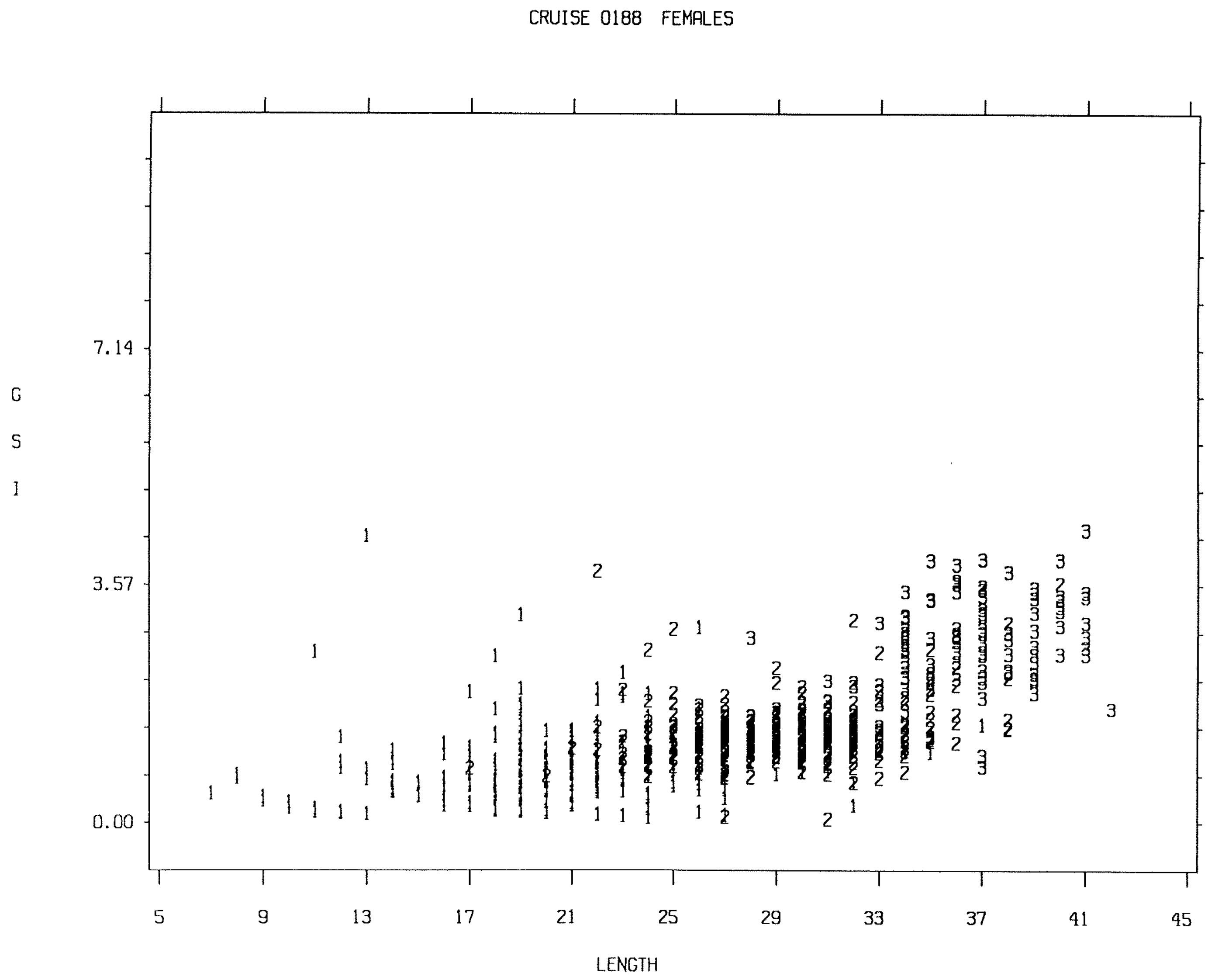
LENGTH

CRUISE 0389 - MALES




CRUISE 0188 FEMALES
G
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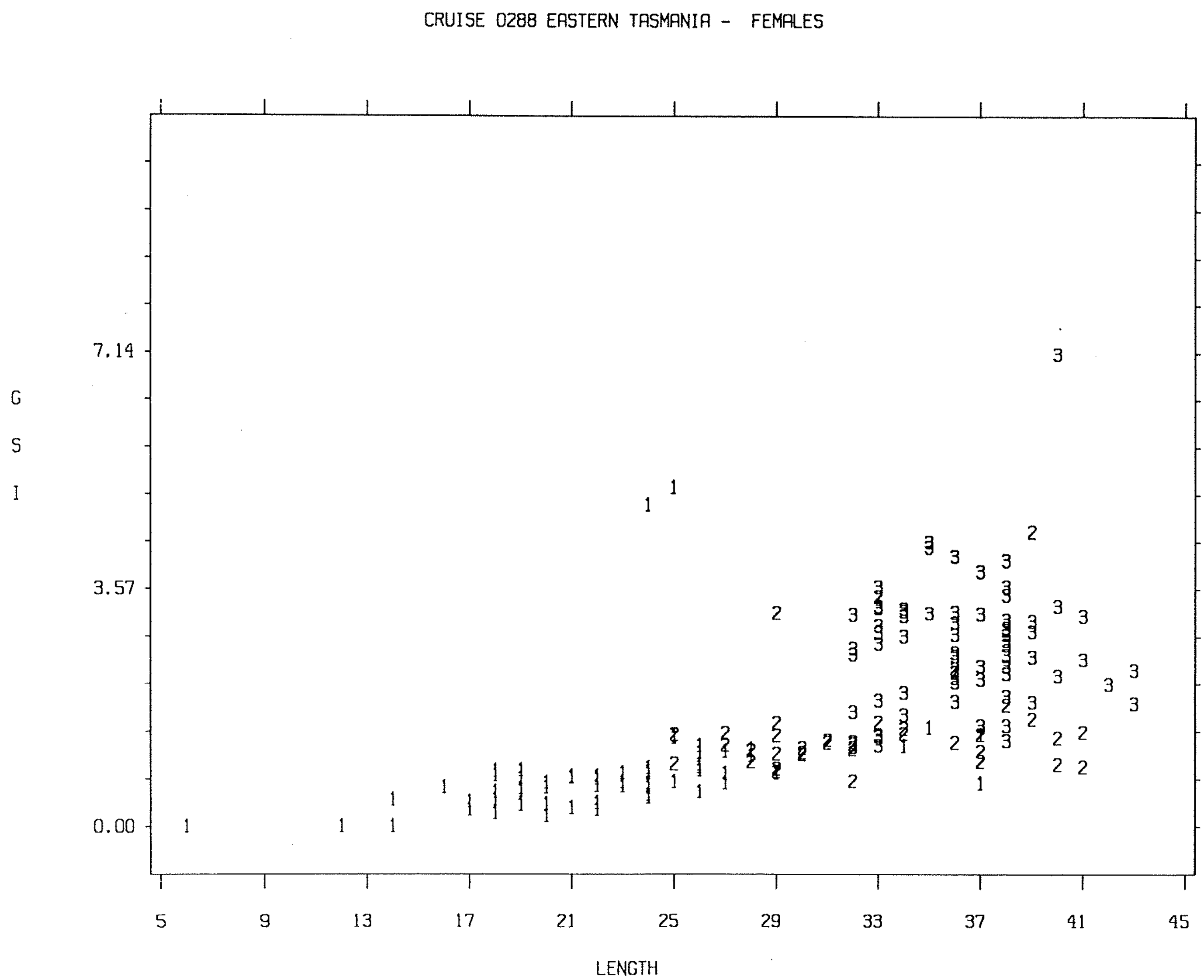
LENGTH


CRUISE 0288 EASTERN TASMANIA - FEMALES
G
S
I
7.14
3.57
0.00
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13
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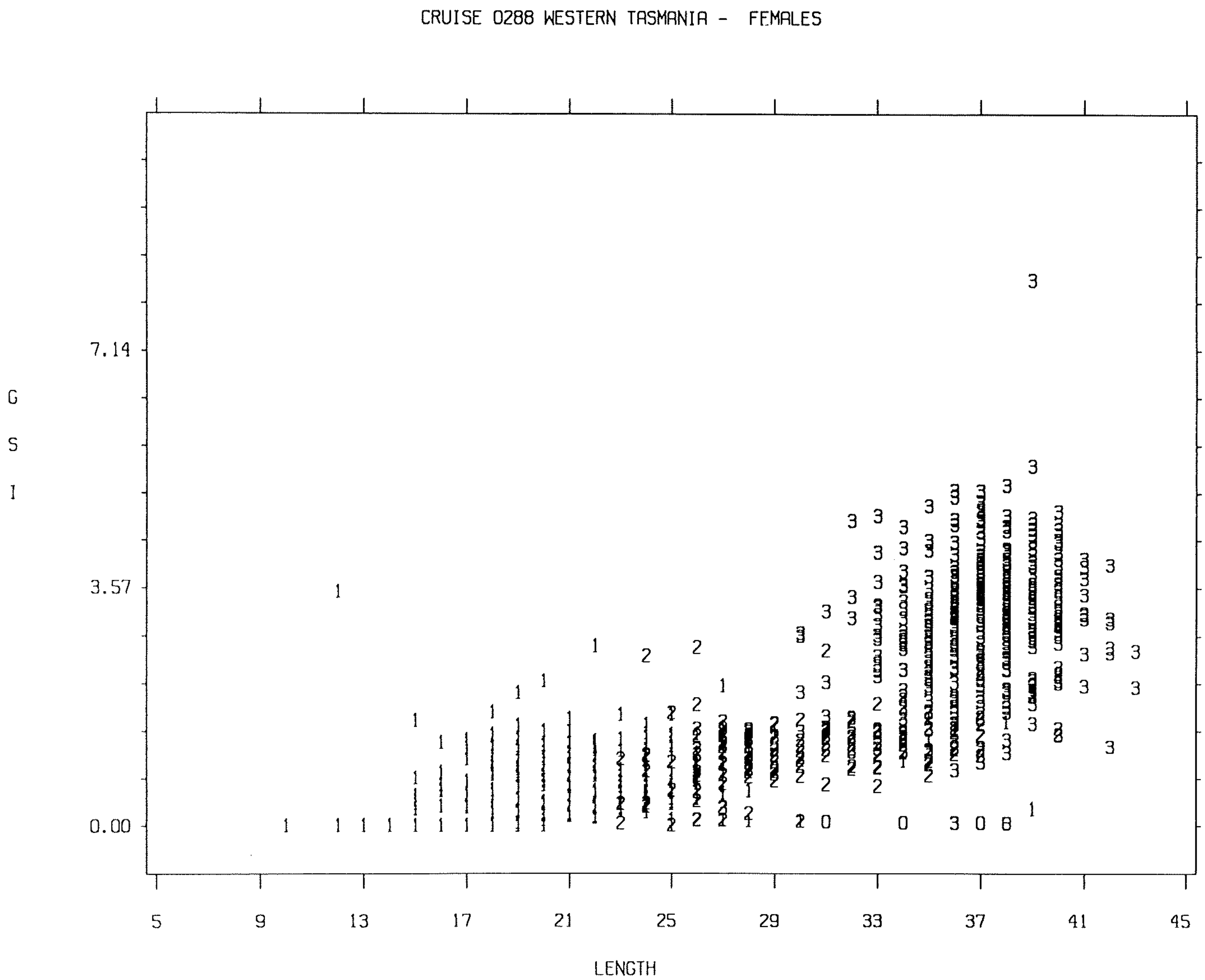
LENGTH



CRUISE 0288 WESTERN TASMANIA - FEMALES
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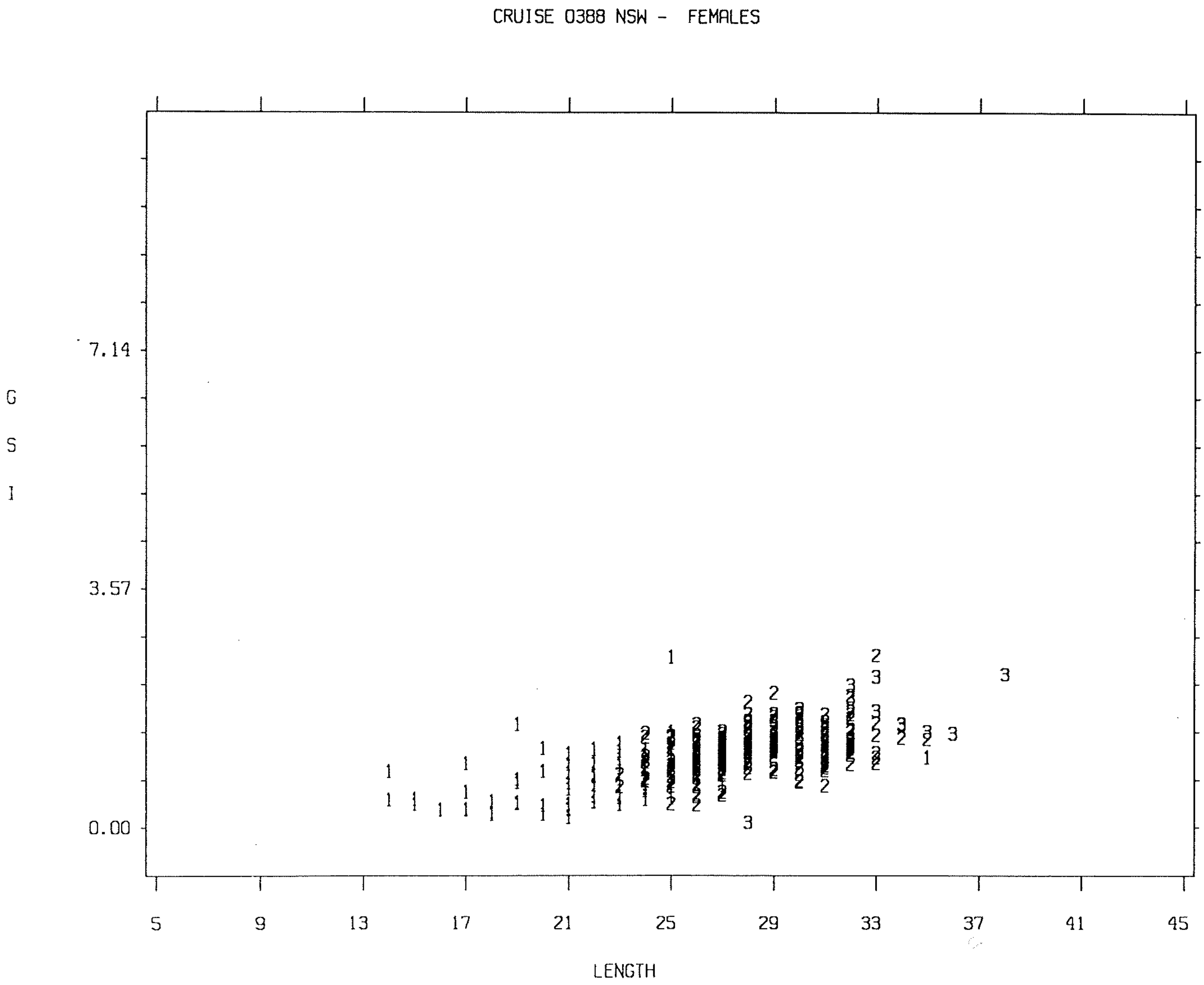
LENGTH


CRUISE 0388 NSW - FEMALES
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3.57
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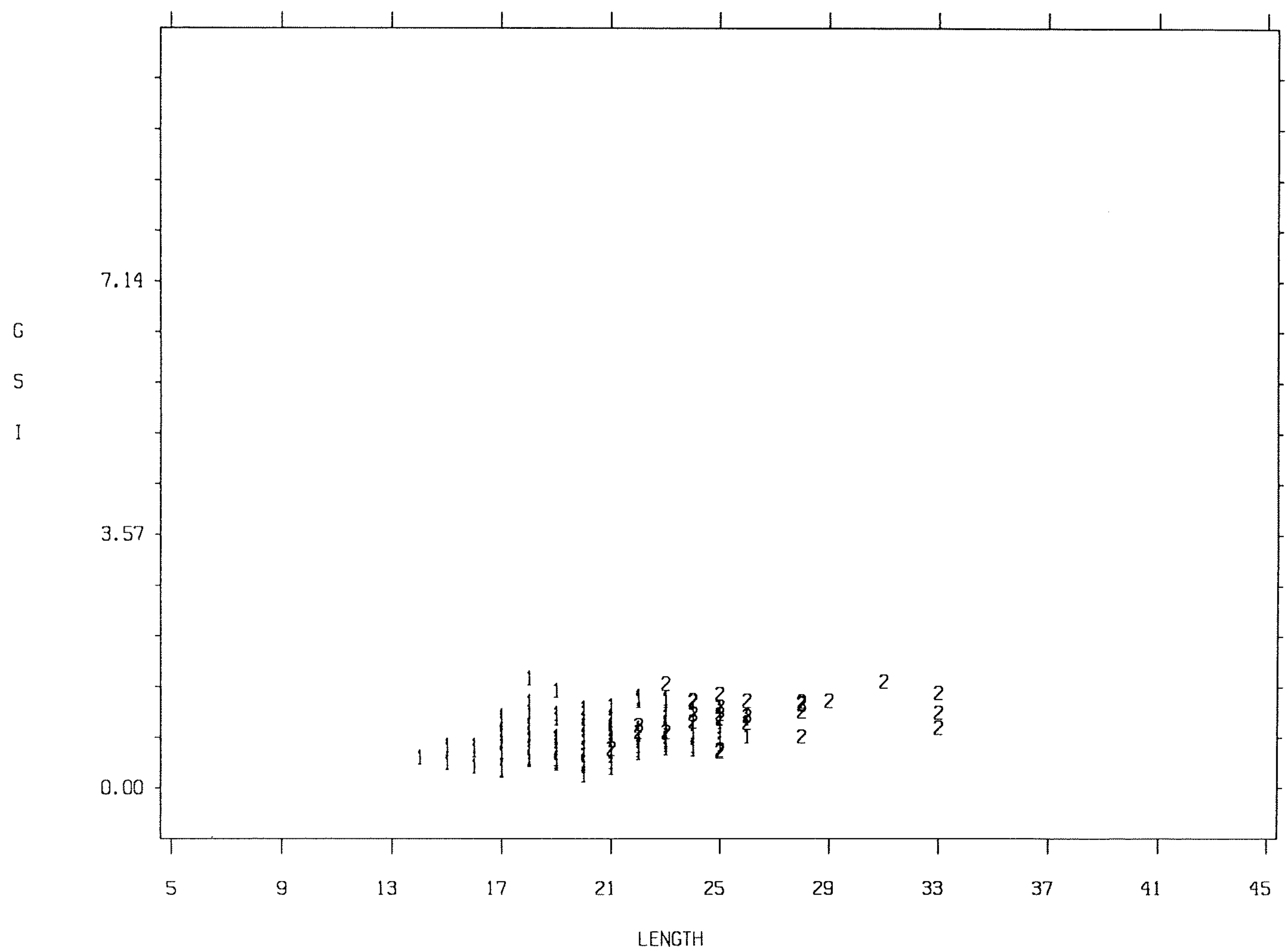
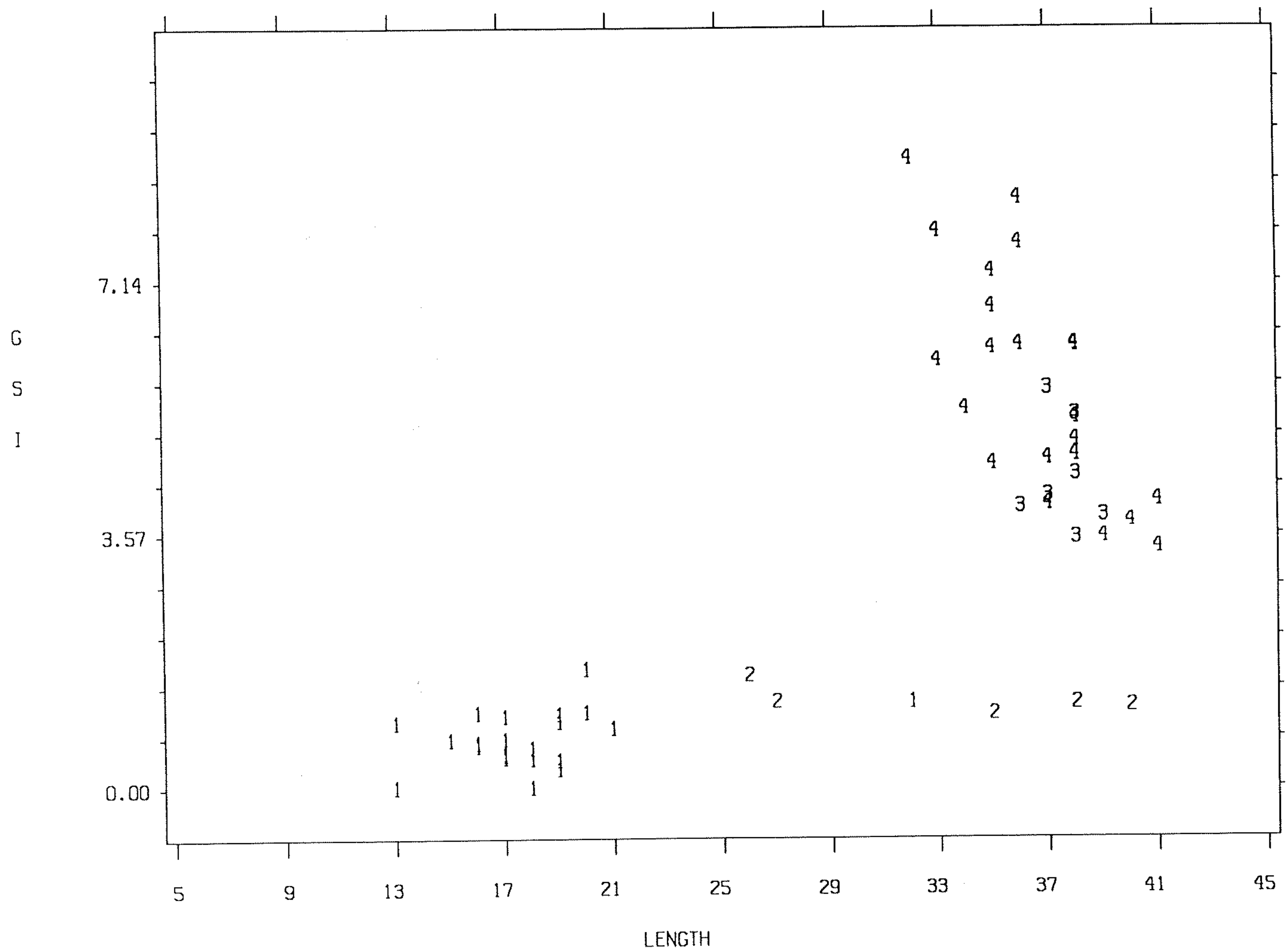
LENGTH

CRUISE 0388 EASTERN BASS STRAIT - FEMALES



CRUISE 0488 - FEMALES



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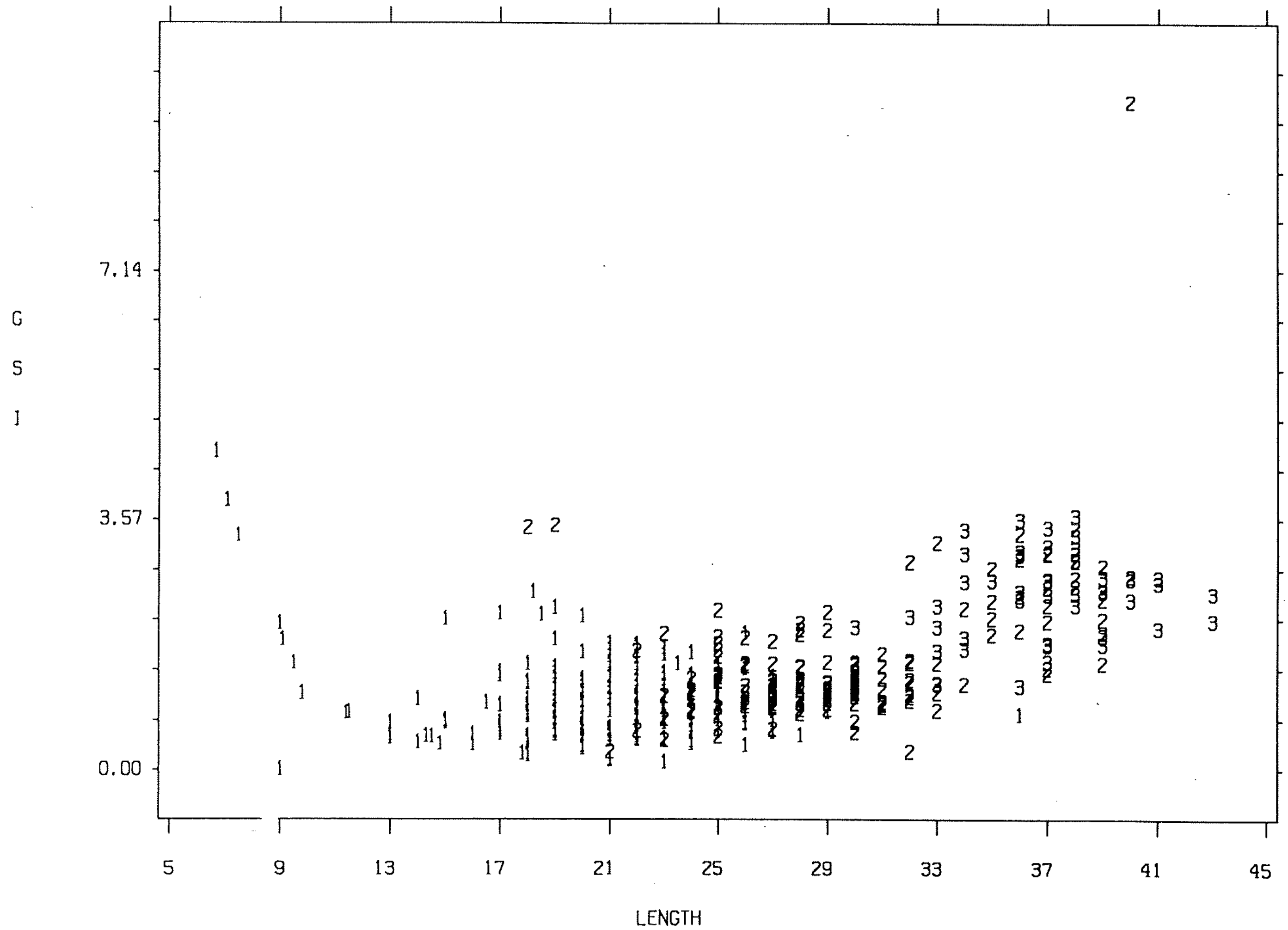

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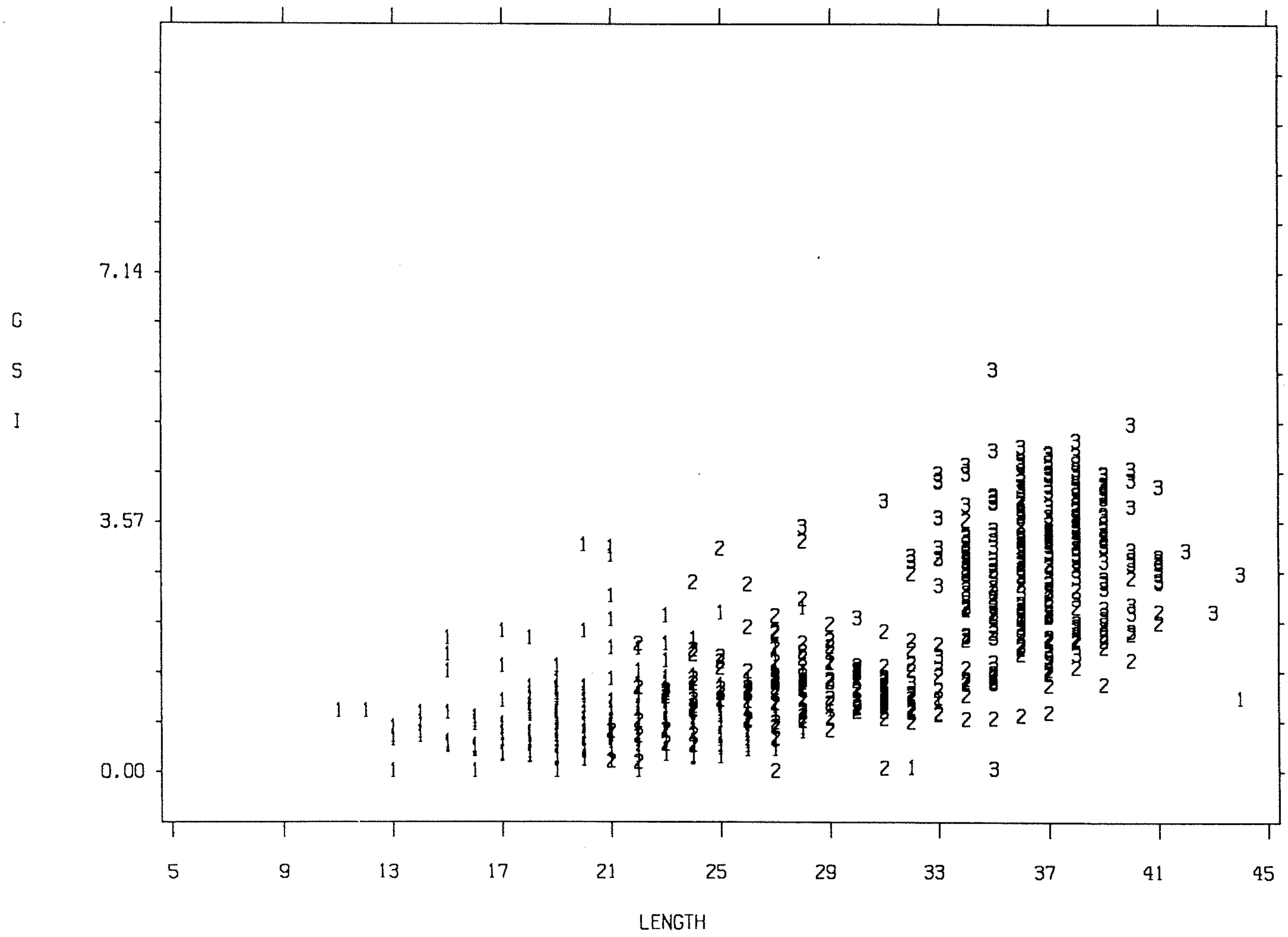

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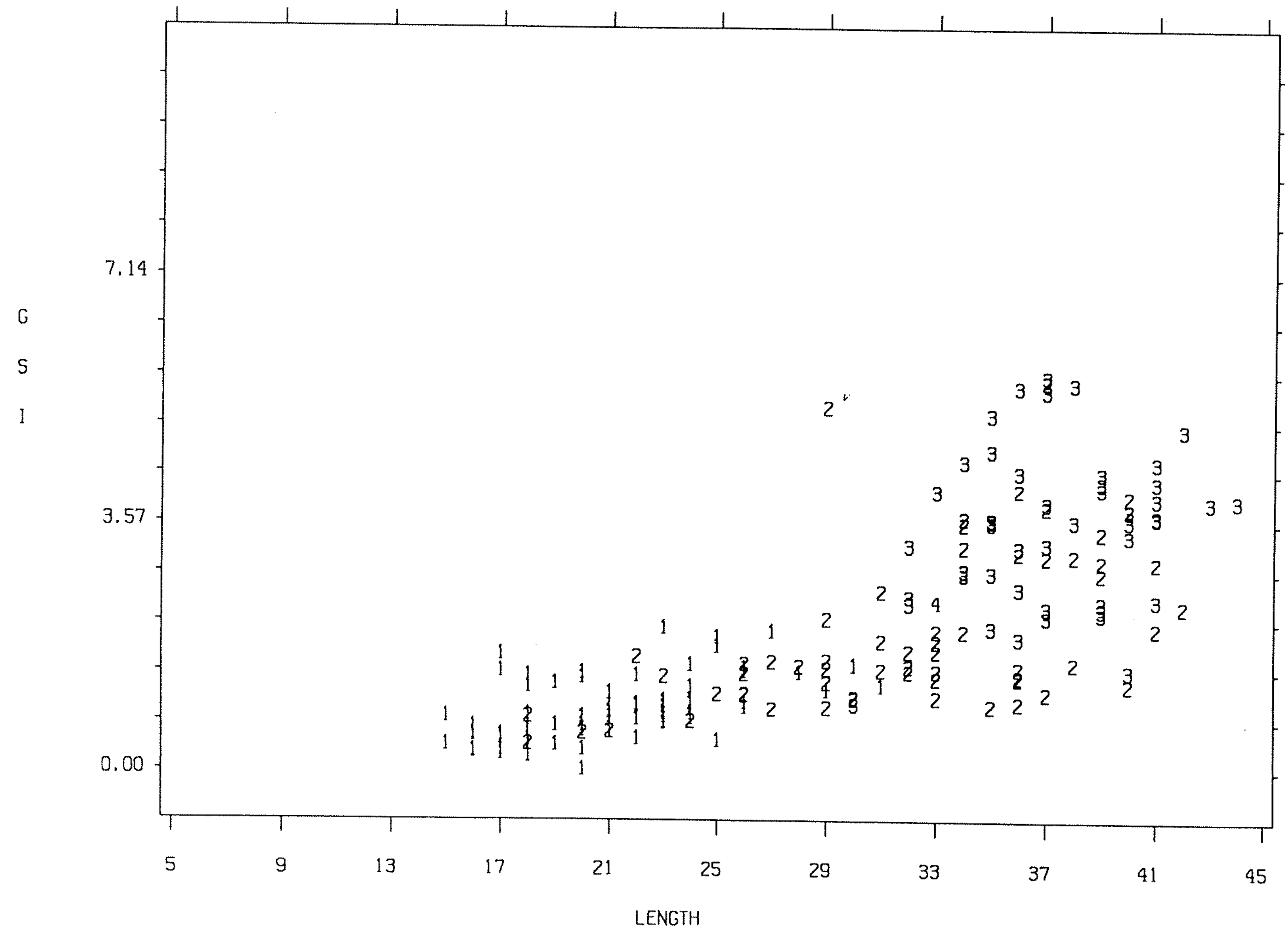

DOCUMENT 5

FISHERIES BULLETIN U.S.

Larval development of three roughy species (Pisces: Trachichthyidae), from southern Australian waters.

A. Jordan[1,2] and B. D. Bruce[3]

1. CSIRO Division of Fisheries Research, GPO Box 1538, Hobart TAS 7001
2. Present address: Tasmanian Department of Sea Fisheries, Crayfish Point, Taroona, Tas. 7006, Australia.
(T) - 002 27 8867 ; (FAX) - 002 27 8035
3. South Australian Department of Fisheries, GPO Box 1625, Adelaide SA 5001.

Abstract

The larval development of the three roughy species, *Paratrachichthys* sp., *Aulotrachichthys* sp. and *Optivus* sp. is described and illustrated from larvae collected from Tasmanian and New South Wales waters. Larvae were identified using mersitic and morphological characters, and are characterised by differences in head and dermal spination, size at caudal flexion, and size and pigmentation of the pelvic fins. Development of a luminous organ and the anterior migration of the anus occurs much earlier in *Aulotrachichthys* than *Paratrachichthys* and are notably absent in *Optivus*. Possible reasons for the absence in our samples of larvae attributable to orange roughy (*Hoplostethus atlanticus*) are discussed.

Introduction

The family Trachichthyidae, of the order Beryciformes, consists of some 31 species, of which at least 15 occur in southern temperate waters of Australia (May and Maxwell 1986). Seven genera are known from Australian waters: *Hoplostethus, Paratrachichthys, Aulotrachichthys, Optivus, Gephyroberyx, Trachichthys* and *Sorosichthys*. The various species inhabit depths from near the surface to greater than 1200 m, with most occuring in depths greater than 200 m. There is considerable confusion with the taxonomy of the group and a number of the species occuring in Australian waters are undescribed. The genera *Hoplostethus* consists of at least 3 Australian species *H. intermedius*, *H. latus* and the orange roughy (*H. atlanticus*) (May and Maxwell 1986) which supports a recently developed fishery. *Paratrachichthys* is represented in Australian waters by the sandpaper fish (*Paratrachichthys* sp.), an undescribed species that is closely related to and has only recently been distinguished from the New Zealand endemic *P. trailli* (M. Gomon pers. comm.). Specimens have been recorded from New South Wales, Victoria, South Australia, Tasmania and southern Western Australian waters (May and Maxwell 1986). Both *Aulotrachichthys* and *Optivus* contains two closely related and undescribed Australian species (M. Gomon pers. comm.). *Aulotrachichthys* sp.1 occurs in shallow waters of South Australia while *Aulotrachichthys* sp.2 occurs in deeper water off the east coast (May and Maxwell 1986). Similarly, *Optivus* contains both eastern and western Australian representatives, *Optivus* sp.1 along the east coast as far north as southern Queensland and *Optivus* sp.2 off southern Western Australia (May and Maxwell 1986). The remaining 3 genera are monotypic, represented by *Gephyroberyx darwini, Trachichthys australis* and *Sorosichthys anannassa*.

Little is known about the ecology or early life history of trachichthyids, and there is nothing in the literature on the early life history of Australian species. Parr (1933) and Johnson (1970) described 19 mm and 21.5 mm juvenile *Korsogaster* respectively, a genus subsequently synonomized with *Hoplostethus* by Woods and Sonoda (1973). Crossland (1981) illustrated a trachichthyid larva, possibly of *Optivus elongatus*, from northeastern New Zealand. Robertson (1975) described an egg tentatively ascribed to *Paratrachichthys trailli*. Kotlyar (1984) described juveniles of four species of *Hoplostethus* (including a 36 mm *H. atlanticus*), the smallest of his specimens being a 15 mm *H. melanopterus*. Okiyama (1988) figured and briefly described single specimens of an unidentified *Hoplostethus* (10.7 mm), *Gephyroberyx japonicus* (11.0 mm) and *Paratrachichthys prosthemius* (27.5 mm).

M. Gomon, Museum of Victoria, 238 Swanston Street, Melbourne, Victoria 3000, Australia, pers. commun. November 1990.

Recent commercial interest in the orange roughy (*H. atlanticus*) has emphasised the need for information on the early life history of this species. As yet, despite considerable effort in ichthyoplankton sampling, no *H. atlanticus* larvae have been reported from Australian waters. The current study details larval development of the related trachichthyid species, *Paratrachichthys* sp, *Aulotrachichthys* sp. and *Optivus* sp. obtained from plankton samples collected primarily in Tasmanian and New South Wales coastal waters from 1984 to 1986. These descriptions are presented in order to further define larval characteristics that may be of use in trachichthyid systematics and to help determine those characters that may be useful in the identification of orange roughy larvae.

Materials and methods

Specimens were largely obtained from ichthyoplankton samples collected in 1984-1986 by the CSIRO Division of Fisheries, as part of a study aimed at documenting the distribution and abundance of larval fishes in Tasmanian coastal and neritic waters. Details of sampling locations and protocol are provided by Thresher *et al* (1989). In brief, larvae were obtained from oblique tows to a depth of 200 m (bottom depth permitting) at a series of stations covering shelf and slope waters using a 1 m diameter ring net (500 micron mesh). Additional material was obtained from samples collected with identical gear in New South Wales shelf and slope waters by A. Miskiewicz.

Larval samples were fixed in either 3.7% aquaeus formaldehyde, buffered with sodium tetraborate, or 95% ethanol. Morphometric analysis and illustrations were based on formaldehyde fixed specimens of *Paratrachichthys* and *Optivus*. However, only ethanol fixed material was available for *Aulotrachichthys*. No allowance was made for shrinkage or distortion in preservative.

Larvae were examined using a Wild M5 dissecting microscope and all drawings were made with the aid of a camera lucida. Larvae were identified using the existing literature (Keene and Tighe 1984, Okiyama 1988), by comparison to juvenile and adult features of identified species, and by the establishment of developmental series.

All unspecified body lengths refer to notochord length, in preflexion and flexion larvae, and standard length in postflexion larvae and juveniles. We define 'snout to anal fin length' as the horizontal distance from the tip of the snout to the anterior origin of the anal fin or anal fin anlagen. 'Body depth at anus' is the vertical distance between body margins through the centre of the anal opening. 'Body depth at pectoral' is equivalent to 'body depth' of Leis and Rennis (1983). Other definitions such as body shape follow Leis and Trinski (1989). Nomenclature of head spination follows that of Ahlstrom *et al*

(1976). Larval measurements were made using an ocular micrometre. Juveniles were measured with vernia calipers.

Results

During the 18 months of sampling, 119 *Paratrachichthys*, 147 *Optivus* and 25 *Aulotrachichthys* larvae were collected. The distribution of larvae from both Tasmanian New South Wales samples is shown in Figure 1. No larvae that could be attributed to *Hoplostethus* were collected. A representative series of each species was deposited in the I.S.R Munro Fish Collection CSIRO Hobart, Tasmania. Reference numbers - *Optivus* CSIRO L179 - 184; *Paratrachichthys* CSIRO L185 - 190; *Aulotrachichthys* CSIRO L191 - 196.

Identification. Comparatively little is known of trachichthyid larval characters, although precocious pelvic fin development, heavy pigment, a stocky body form approaching the shape of adults (in larger larvae), a myomere count of 26-30 and the presence of minute spines or dermal papilli over the body surface appear to be common (Keene and Tighe 1984, and references therein).

In larger specimens of two of our series the anus was located between the pelvic fins. Only three trachichthyid genera have this character - *Paratrachichthys*, *Aulotrachichthys* and *Sorosichthys* (May and Maxwell 1986). *Sorosichthys* is separated easily on the basis of a pelvic count of I,5 compared to the I,6 of the other two genera. The only character reported in the adult literature to distinguish *Aulotrachichthys* from *Paratrachichthys* is the presence in the former of striated silvery tissue on the bases of the pectoral fin, on the isthmus beneath the gill cover and in a narrow strip along the ventral edge of the body. However examination of juvenile and adult specimens also reveals a difference in anal counts, *Paratrachichthys* with a count of III,10 and *Aulotrachichthys* with III,8. On the basis an anal count of III,8 and the presence of striated tissue in the largest specimen of only one of our series we assign it to *Aulotrachichthys* and the other to *Paratrachichthys*. We were unable to determine whether or not our *Aulotrachichthys* series represented more than one species. *Optivus* larvae were separated on the basis of a dorsal count of IV,11 an anal count of III,9 and the position of the anus which remains static.

Similar larvae. Small trachichthyid larvae can be confused with zeids and some gadoid larvae that also have precocious, heavily pigmented pelvic fins. However, zeid larvae are more evenly pigmented, have pigment extending into the finfolds in small larvae, generally have a higher myomere count (29-42, Tighe and Keene 1984), and have a more tightly coiled gut with consequently a longer postanal length. The sequence in which fin ray elements form also serves to distinguish zeid larvae. In zeid larvae examined during this study, the anterior-most bases and rays were the first dorsal fin elements to form. This appears to be similiar to other reported zeid larvae (Tighe and Keene 1984) and may be characteristic of the family. In trachichthyids, however, the middle or posterior elements are the first to form. When it occurred, supraocular spination was also a useful feature to distinguish trachichthyids from zeids (the latter did not develop supraocular spines until after flexion). Although this may be useful locally, some zeid species (eg *Zeus faber*) do have supraocular spines at sizes similar to trachichthyid larvae (Sanzo 1931). Larger zeid larvae are easily distinguished from trachichthyid larvae by their longer dorsal and anal fin bases often with elongate anterior rays, a larger mouth and a rhomboid, laterally compressed, body shape.

Small gadoid larvae with precocious, heavily pigmented pelvics (eg *Gaidropsarus*) differ from trachichthyids in having a higher myomere count (>40), pelvics set higher on the body, and a more slender post-anal body form. Larger gadoid larvae are easily distinguished by morphology, fin meristics and pigment (see Dunn and Matarese 1984 for details).

***Paratrachichthys* sp. (Figure 2)**

Larval development. *Paratrachichthys* larvae have a moderate body depth (Table 1). Head length is about equal to body depth at pectoral until flexion after which body depth increases to approximately 50% of body length. The mouth is large, reaching to approximately the centre of the eye in our smallest specimen (3.2 mm) and beyond the eye in larvae greater than 4.5 mm. The body depth at anus increases markedly during flexion associated with the anterior migration of the anus during this period. The gas bladder is inflated and prominent in all specimens. There are 27 - 29 myomeres.

Initially the gut is straight and tube like. It quickly thickens, coils and becomes triangular by approximately 5.0 mm. The anus begins to migrate anteriorly by 6.5 mm and is in the adult location (between the pelvics) by 8.7 mm.

Development of the pelvics is precocious. Slight swellings on either side of the gut are present in our smallest specimen (3.2 mm). Distinct buds are present by 3.9 mm. The pelvics develop rapidly having a full complement of 7 elements by 5.6 mm, and reaching up to 34% body length by 7.6 mm. Anlagen of both dorsal and anal fins are present by 4.3 mm. The anlagen first appear as hyaline zones located within the median fin folds and connected to the body by a series of filamentous extensions inserted at each myoseptum (Fig. 2B). Bases are present by 4.7 mm and posterior incipient rays first appear above these bases by 5.4 mm. Incipient rays appear in the pectoral fin shortly thereafter (5.5 mm).

Notochord flexion commences at about 5.9 mm and is complete by 7.6 mm. Ossification of dorsal, anal, pelvic and pectoral fins occurs during flexion with full complements in all fins present by 8.7 mm.

Paratrachichthys larvae have only weakly developed head spination. A low supraocular ridge is present at 3.3 mm and this develops 1-2 spines by 3.9 mm. The number of supraocular spines increases to 2-3 by 4.0 mm, reaching a maximum of 5-6 just prior to flexion. During flexion, the supraocular spines disappear.

The single opercular spine is present by 6.9 mm and is retained in the adult. Similarly, single preopercular and posttemporal spines are present by 8.7 mm and are retained. Cranial ridges are present by 5.4 mm; however, even by 10.0 mm these have not yet become denticulate as they are in juveniles and adults.

The light organ surrounding the anus first appears in 5.4 mm larvae as an unpigmented, thickened ring. By 6.1 mm, the light organ is lightly pigmented and by 6.9 mm the organ is heavily pigmented and rugose.

Juvenile and adult *Paratrachichthys* have small, adherent, ctenoid scales covering the body and a series of strong ventral scutes between the anus and the anal fin (Woods and Sonoda 1973). Our largest larva (10 mm) has no sign of scalation and lacks the minute spines of other genera, although a weak fleshy ridge develops along the ventral midline between the anus and the anal fin by 7.6 mm - probably a precursor to the characteristic ventral scutes of juveniles and adults. The 39.7 mm juvenile examined was, in effect, a minature adult, having completed scalation, including the ventral scutes.

Pigmentation. *Paratrachichthys* larvae are moderately to heavily pigmented (with the exception of the last 2-8 myomeres, including the notochord tip) throughout the entire larval period. Pigment tends to be concentrated over the dorsal and ventral surfaces of the body and the dorsal surface of the gut. Otherwise, there are few useful distinguishing features based on patterns of pigmentation.

The pelvic fins are heavily pigmented by 4.2 mm and remain so in our largest postflexion larva (10.0 mm).

Some variation was introduced by the obviously faded pigment of certain specimens, the result being a series of heavily pigmented and a series of moderately to lightly pigmented individuals. As the major pigment concentrations, morphology, and meristic information were otherwise identical for the two series, it is unlikely that variations in the intensity of pigmentation indicate the presence of more than one species.

Aulotrachichthys sp. (Figure 3)

Larval development. *Aulotrachichthys* larvae have a moderate body depth (Table 2). Head length is about equal to body depth at the pectoral fin until flexion, after which body depth increases to 50% body length. The mouth is moderately large reaching to the posterior margin of the eye in our smallest specimen (2.8 mm), falling to just short of the margin in our largest specimen (7.9 mm). The body depth at the anus increases markedly prior to flexion associated with the anterior migration of the anus. The gas bladder is inflated and prominent in all specimens. There are 27-29 myomeres.

The gut is a convoluted tube in our smallest specimen (2.8 mm). It quickly thickens, coils and becomes triangular by 4.4 mm. The anus begins to migrate by 3.9 mm and is in the adult location (between the pelvic fins) by 4.9 mm. Development of the pelvic fins is precocious. Even our smallest specimen has a full pelvic complement of 7 elements (although ossification is not completed until 4.4 mm). The pelvic fins are large, up to 35% body length at 4.9 mm, and reach beyond the anal fin origin in all specimens. The limited number of specimens precluded the documentation of initial dorsal and anal fin anlagen

development, however the separation from the body of the posterior most anal base in our 4.1 mm specimen suggests a finfold development similar to *Paratrachichthys*. Both dorsal and anal bases are present by 3.9-4.1 mm and incipient rays appear above these bases by 4.4 mm. Incipient rays appear in the pectoral fin shortly thereafter (4.9 mm).

Insufficient specimens were available to fully document flexion; however a 4.9 mm specimen was just about to commence, flexion was well underway in a 5.7 mm specimen and had been completed in our 7.9 mm specimen.

Aulotrachichthys larvae have well developed head spination. Our smallest specimen has a low supraoccular ridge with a single spine. The number of supraoccular spines increases to 3-4 by 4.4 mm, they become quite robust and reach a maximum number of 8-9 during flexion. Generally, the posterior group of these spines are the largest and are recurved. Preopercular spines are present by 4.4 mm with an anterior preopercular series added by 4.9 mm. By 5.7 mm, preopercular spination is quite robust with secondary ridging and branching of the largest spines (particularly at the angle). Nuchal, supracleithral and posttemporal spines as well as nasal and cranial ridges are developed prior 5.7 mm. During flexion the supracleithral and posttemporal series fuse to form a hard bony plate extending posteriorly to the level of the opercular margin. This plate extends beyond the opercular margin by 7.9 mm, and is retained in the adult. During flexion spines also develop on the dentary, infraorbital and several cranial and opercular ridges.

A single spine is present immediately posterior to the anus by 4.9 mm. Spines develop on the pelvic bases by 5.7 mm, and by 7.9 mm a cluster of spines is also present immediately anterior to the anus. Our 7.9 mm specimen has well developed dermal spination in longitudinal rows over the entire body surface and on the dorsal and anal fin bases. Additionally, this specimen has a row of strong spines extending posteriorly along the ventral midline from the anus towards the anal fin, and fine villiform teeth are present in both jaws.

The light organ surrounding the anus first appears in 3.6 mm larvae and is well developed, rugose in appearence and heavily pigmented by 4.4 mm. The characteristic ventral striated tissue of adults has commenced development in our 7.9 mm specimen.

Pigmentation. *Aulotrachichthys* larvae are heavily pigmented (with the exception of the last 5-6 myomeres, including the notochord tip) throughout the entire larval period. The pelvic fins are heavily pigmented in our smallest specimen and remain so in our 7.9 mm specimen. *Aulotrachichthys* larvae are more heavily pigmented than *Paratrachichthys* but, as with *Paratrachichthys,* there are few useful distinguishing features based on pigment pattern.

***Optivus* sp. (Figure 4)**

Larval development: *Optivus* larvae have a moderate body depth (Table 3). Body depth increases rapidly to 49% BL during flexion although body depth at anus increases only slightly compared to *Paratrachichthys* and *Aulotrachichthys* as the anus position in *Optivus* remains static. Head length increases from 36% BL in preflexion larvae to 44% BL in juveniles. Eye diameter remains relatively constant. The mouth is moderate to large reaching to the centre of the eye in our smallest specimen (2.5 mm) and beyond the eye in larvae greater than 4.0 mm.

The gut, which is initially straight, quickly thickens, coils and becomes broadly triangular by 3.5 mm.

Pelvic fins first appear in larvae of 3.0 mm as slight swellings on either side of the gut. These develop rapidly and distinct buds are present by 3.2 mm and the developing fin reaches up to 25% BL by 6.2 mm. Ossification commences by 5.1 mm and a full complement of seven elements is present by 8.0 mm. Anlagen of both dorsal and anal fins are present by 2.7 mm and appear as hyaline zones located within the median finfolds as in *Paratrachichthys*. Bases are first visible in both fins by 3.5 mm and incipient rays are present by 4.0 mm. Incipient rays appear in the pectoral fin by 4.5 mm.

Notochord flexion commences at about 4.0 mm and is complete by 7.1 mm. Ossification of the dorsal, anal and pectoral fins commences in early flexion stage larvae with a full complement in all fins present by 7.1 mm.

Head spination is only weakly developed in preflexion *Optivus* larvae. A low supraocular ridge is present by 2.7 mm with 4 - 5 spines developing by 3.4 mm. By 4.5 mm these supraocular spines have disappeared. Cranial ridges are present by 4.7 mm and a series of spines develop on the preopercular and opercular margins by 5.1 mm.

Small dermal spines appear on the body by 4.7 mm and extend over the entire body surface including the head by 5.1 mm. Small ctenoid scales develop in association with each single dermal spine by 8.0 mm, and by 23.0 mm each scale has 3 associated spines. A row of larger spines appear on the ventral surface between the anus and the pelvic fins by 7.2 mm and form the characteristic ventral scutes of juveniles and adults by 15.0 mm. *Optivus* larvae do not develop a light organ.

Pigmentation. Pigmentation in preflexion *Optivus* larvae is moderate and concentrated on the dorsal surface of the gut as well as the dorsal and ventral surfaces of the trunk. Pigment is absent from the last 5-6 myomeres (including the notochord tip) as in *Paratrachichthys* and *Aulotrachichthys*. During flexion, the entire body and head become moderately pigmented and the dorsal surface of the gut becomes heavily pigmented. This pattern of pigmentation remains in our largest specimen (23.0 mm).

The pelvic fins are moderately pigmented by 5.1 mm after which pigment contracts towards each base. During flexion, this pigment fades and dissappears by 7.2 mm.

Discussion

Considerable confusion exists in the systematics of beryciform fishes. Current classifications are based almost entirely on adult characters. Keene and Tighe (1984) noted the usefulness of including early life history characters in these studies but the lack of such data at that time for ten of the beryciform families precluded an adequate appraisal. The three genera featured here together share characters common to other described trachichthyid larvae including moderate to heavy pigment, a moderate to large mouth, a stocky body form, precociously developing and heavily pigmented pelvic fins, cranial ridges, opercular spination and a myomere count of 26-30. Pelvic fin pigmentation is most pronounced in *Aulotrachichthys* and *Paratrachichthys* and least developed in *Optivus*. Dermal spination is most developed in *Aulotrachichthys* and *Optivus* however is notably absent in *Paratrachichthys*. Cranial ridges and opercular spines are present in all of our series, however, *Aulotrachichthys* develops by far the most pronounced head spination of the three and perhaps of any reported trachichthyid larvae.

A feature of this study has been that despite extensive sampling throughout the year covering pelagic environments from the nearshore to the mesopelagic and epipelagic zones (see Thresher *et al* 1989 for details), no larvae attributable to the genus *Hoplostethus* have been identified. This is also despite the fact *Hoplostethus* species, and in particular orange roughy (*Hoplostethus atlanticus*), are by far the most abundant trachichthyid in Tasmanian waters. New Zealand researchers have also been unable to locate *H. atlanticus* larvae (Pankhurst and Conroy 1987) even though spawning aggregations have been located (Beardsell 1984).

Kotlyar (1984) recorded a 36 mm *H. atlanticus* taken in a bottom trawl from the Atlantic Ocean at a depth of 965-990 m. Our 26 mm specimen represent the smallest *H. atlanticus* reported to date (Figure 5) caught in a demersal trawl between 400 and 950 m off St Patricks Head, eastern Tasmania (CSIRO. H1141).

Several possibilities exist as to why *H. atlanticus* larvae have not yet been located:
1. The bimonthly sampling frequency was too coarse to capture larvae. Although this cannot be discounted due to the lack of information on larval duration, the likelihood of completely missing all larvae seems low.
2. They occur further off the shelf or slope than sampled (>10 N. miles from the shelf break).
3. *H. atlanticus* larvae may occur in greater depths than those sampled in 'standard' ichthyoplankton surveys. This provides the most reasonable hypothesis and has previously been suggested by Kotlyar (1984) for *Hoplostethus* less than 15-19 mm (based on the capture of three *H. melanopterus* juveniles 15.0-18.2 mm in Isaacs Kid trawls between 1000 and 1500 m in the Sulu Sea). It is also possible that larvae occur close to the bottom on the continental slope as supported by the capture of our 26 mm specimen and that by Kotlyar (1984).

H. atlanticus adults occur in depths of 500-1200 m (May and Maxwell 1986). Spawning has been confirmed from both the east coast of Tasmania (Lyle *et al* 1989) and New South Wales (Williams 1989). *H.atlanticus* eggs (2.12-2.45 mm in diameter with a conspicuous orange oil droplet) have been collected in plankton tows above 400 m in Tasmanian (Lyle *et al* 1989) and New Zealand waters (Beardsell 1984), and are presumably bouyant. The lack of larvae in surface waters, however, suggests that egg density, the presence of a thermocline, or a combination of both factors may confine eggs and larvae to deep water. Although logistically more diffcult than shallow water sampling, it is becoming increasingly obvious that such exercises cannot be ignored if we are to fully understand the early life histories of certain deep water species.

Acknowledgments

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Table 1. Body proportions of larvae and juveniles of Paratrachichthys sp (expressed as mean proportions of body length with standard deviations parentheses). Specimens between dashed lines were undergoing notochord flexion. Characters lacking standard deviation are based on one individual only. n, number of individuals.

Size range	n	Snout to anal fin	Pre-anal length	Body depth (at pectoral)	Body depth (at anus)	Head length	Eye diameter	Pelvic fin length
3.32	1	-	0.62	0.19	0.10	0.22	0.13	-
3.90	1	-	0.68	0.22	0.09	0.28	0.12	0.06
4.01-4.50	5	-	0.59(0.03)	0.26(0.02)	0.12(0.01)	0.29(0.01)	0.12(0.01)	0.11(0.04)
4.51-5.00	7	0.63(0.02)	0.62(0.02)	0.28(0.03)	0.14(0.01)	0.30(0.01)	0.14(0.01)	0.18(0.02)
5.01-5.50	8	0.63(0.02)	0.62(0.02)	0.34(0.02)	0.19(0.04)	0.31(0.02)	0.14(0.01)	0.25(0.03)
5.51-6.00	3	0.61(0.02)	0.57(0.01)	0.35(0.02)	0.26(0.04)	0.33(0.02)	0.15(0.01)	0.27(0.02)
6.01-6.50	2	0.60(0.05)	0.54(0.07)	0.38(0.03)	0.29(0.05)	0.33(0.01)	0.15(0.01)	0.29(0.01)
6.95	1	0.70	0.55	0.43	0.39	0.35	0.14	0.30
7.60	1	0.74	0.43	0.53	0.43	0.41	0.17	0.34
10.00	1	0.71	0.48	0.42	0.42	0.34	0.17	0.26
35.80	1	0.58	0.38	0.38	0.38	0.34	0.14	0.18
39.70	1	0.60	0.37	0.39	0.39	0.36	0.12	0.18

Table 2. Body proportions of larvae of Aulotrachichthys sp (expressed as mean proportions of body length with standard deviations parentheses). Specimens between dashed lines were undergoing notochord flexion. Characters lacking standard deviation are based on one individual only. n, number of individuals.

Size range	n	Snout to anal fin	Pre-anal anus	Body depth (at pectoral)	Body depth (at anus)	Head length	Eye diameter	Pelvic fin length
2.51-3.00	5	-	0.59(0.05)	0.25(0.03)	0.14(0.02)	0.24(0.02)	0.11(0.01)	0.23 (0.01)
3.01-3.50	3	-	0.63(0.01)	0.25(0.01)	0.14(0.01)	0.27(0.02)	0.13(0.01)	0.27(0.03)
3.51-4.00	3	-	0.60(0.03)	0.34(0.03)	0.18(0.04)	0.31(0.02)	0.13(0.01)	0.33(0.03)
4.01-4.50	2	0.62(0.01)	0.54(0.01)	0.34(0.02)	0.22(0.02)	0.31(0.01)	0.13(0.01)	0.31(0.00)
4.91	1	0.59	0.38	0.39	0.37	0.34	0.13	0.35
5.66	1	0.64	0.30	0.35	0.51	0.30	0.16	0.28
7.85	1	0.72	0.44	0.50	0.50	0.43	0.17	0.31

Table 3. Body proportions of larvae and juveniles of Optivus sp (expressed as mean proportions of body length with standard deviations parentheses). Specimens between dashed lines were undergoing notochord flexion. Characters lacking standard deviation are based on one individual only. n, number of individuals.

Size range	n	Snout to anal fin	Pre-anal anus	Body depth (at pectoral)	Body depth (at anus)	Head length	Eye diameter	Pelvic fin length
2.51-3.00	3	0.66(0.03)	0.68(0.04)	0.34(0.01)	0.18(0.01)	0.36(0.01)	0.13(0.01)	-
3.01-3.50	8	0.66(0.03)	0.66(0.03)	0.38(0.03)	0.20(0.02)	0.35(0.02)	0.14(0.01)	0.05(0.01)
3.51-4.00	9	0.69(0.08)	0.65(0.05)	0.40(0.05)	0.20(0.02)	0.36(0.03)	0.14(0.02)	0.08(0.02)
4.01-4.50	11	0.67(0.04)	0.65(0.04)	0.44(0.05)	0.24(0.04)	0.40(0.03)	0.15(0.02)	0.12(0.02)
4.51-5.00	5	0.69(0.04)	0.67(0.04)	0.45(0.04)	0.26(0.05)	0.40(0.04)	0.15(0.01)	0.14(0.01)
5.01-5.50	3	0.74(0.01)	0.70(0.04)	0.45(0.04)	0.30(0.03)	0.45(0.04)	0.14(0.04)	0.20(0.02)
6.01-6.50	2	0.72(0.03)	0.69(0.06)	0.49(0.01)	0.29(0.02)	0.46(0.01)	0.16(0.02)	0.25(0.02)
7.15	1	0.71	0.70	0.48	0.30	0.43	0.15	0.20
8.00	1	0.72	0.69	0.47	0.31	0.45	0.15	0.20
10.01-10.50	2	0.70(0.07)	0.69(0.08)	0.44(0.02)	0.30(0.01)	0.44(0.01)	0.15(0.01)	0.21(0.03)
15.00	1	0.62	0.60	0.39	0.28	0.36	0.13	0.23
17.40	1	0.63	0.61	0.37	0.28	0.36	0.13	0.19
17.80	1	0.62	0.60	0.38	0.27	0.36	0.13	0.20
18.40	1	0.65	0.64	0.38	0.27	0.35	0.14	0.21
19.60	1	0.63	0.62	0.37	0.27	0.34	0.13	0.18
23.00	1	0.65	0.63	0.37	0.27	0.35	0.12	0.19

Figures

Figure 1. Distribution of Trachichthyid larvae from Tasmanian and New South Wales samples. • *Paratrachichthys* sp. ; * *Optivus* sp ; Δ *Aulotrachichthys* sp.

Figure 2. Development stages of *Paratrachichthys* sp.
A. 3.9mm ; B. 4.3mm ; C. 4.7mm ; D. 5.5mm ; E. 7.6mm.

Figure 3. Development stages of *Aulotrachichthys* sp.
A. 2.9mm ; B. 3.4mm ; C. 4.4mm ; D. 7.9mm.

Figure 4. Development stages of *Optivus* sp.
A. 3.4mm ; B. 4.7mm ; C. 5.1mm ; D. 7.2mm.

Figure 5. *H. atlanticus* juvenile, 26mm.

Figure 1.

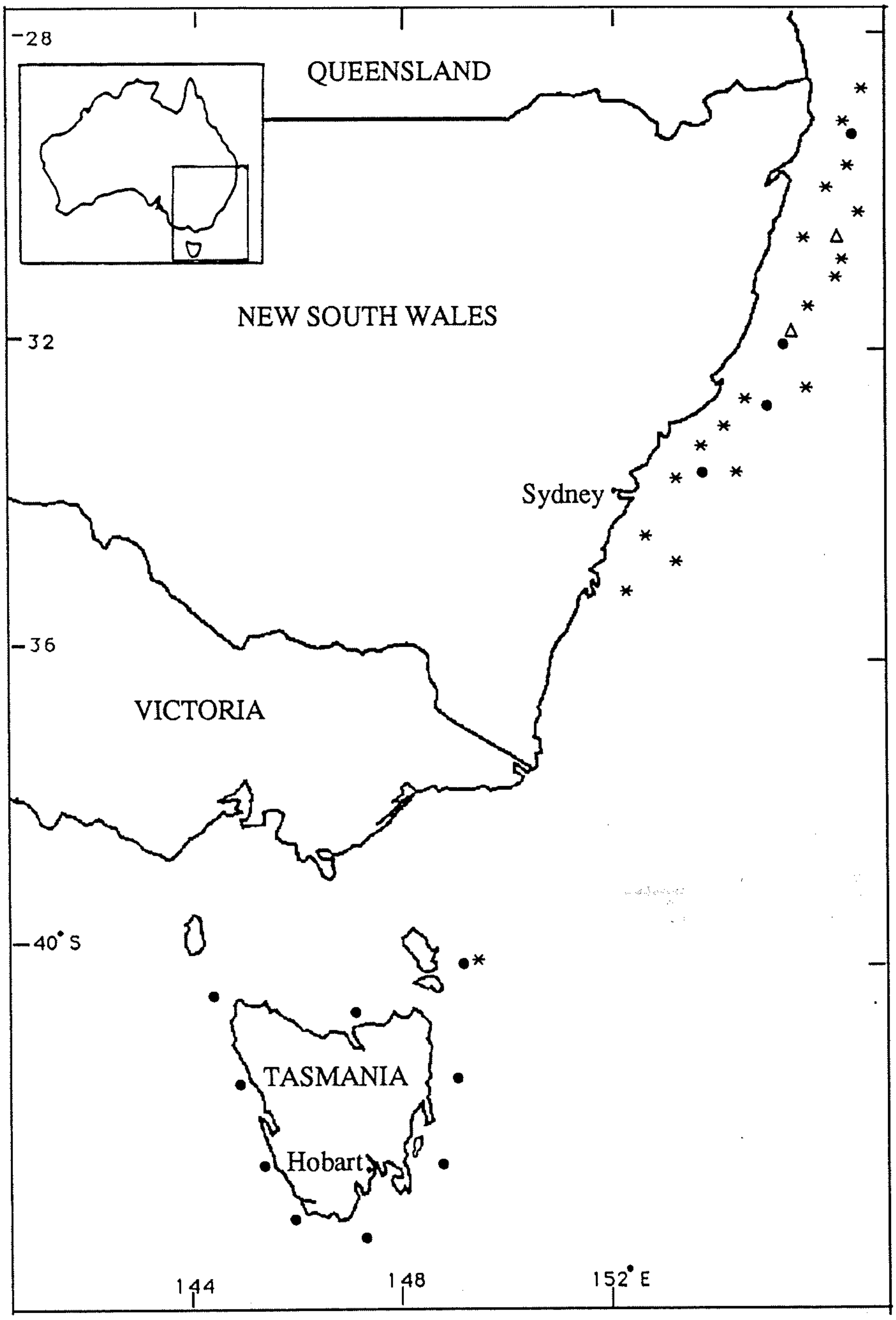

QUEENSLAND
NEW SOUTH WALES
Sydney
VICTORIA
TASMANIA
Hobart
28
32
36
40° S
144
148
152° E

Figure 2.

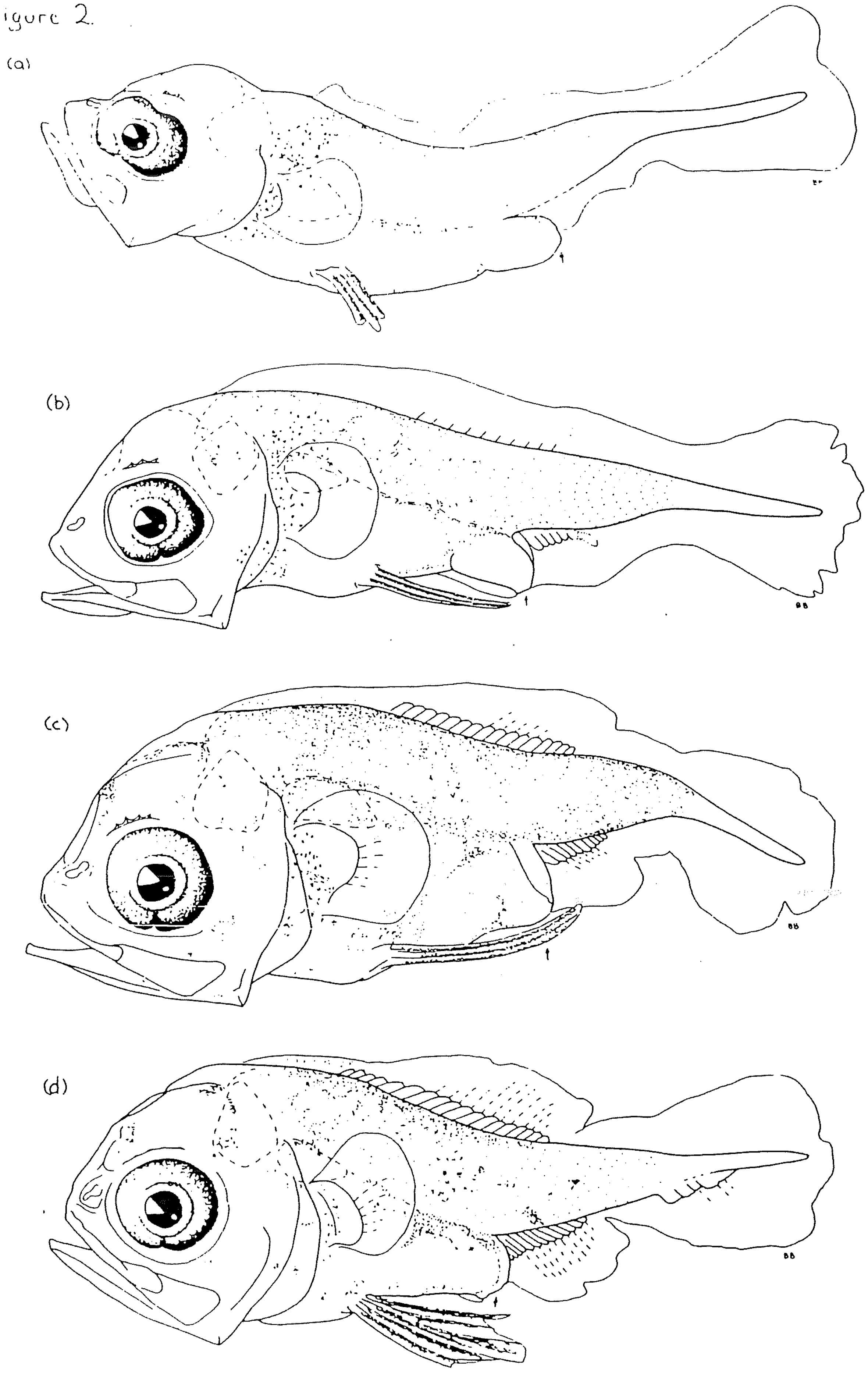


Figure 2.

(e)

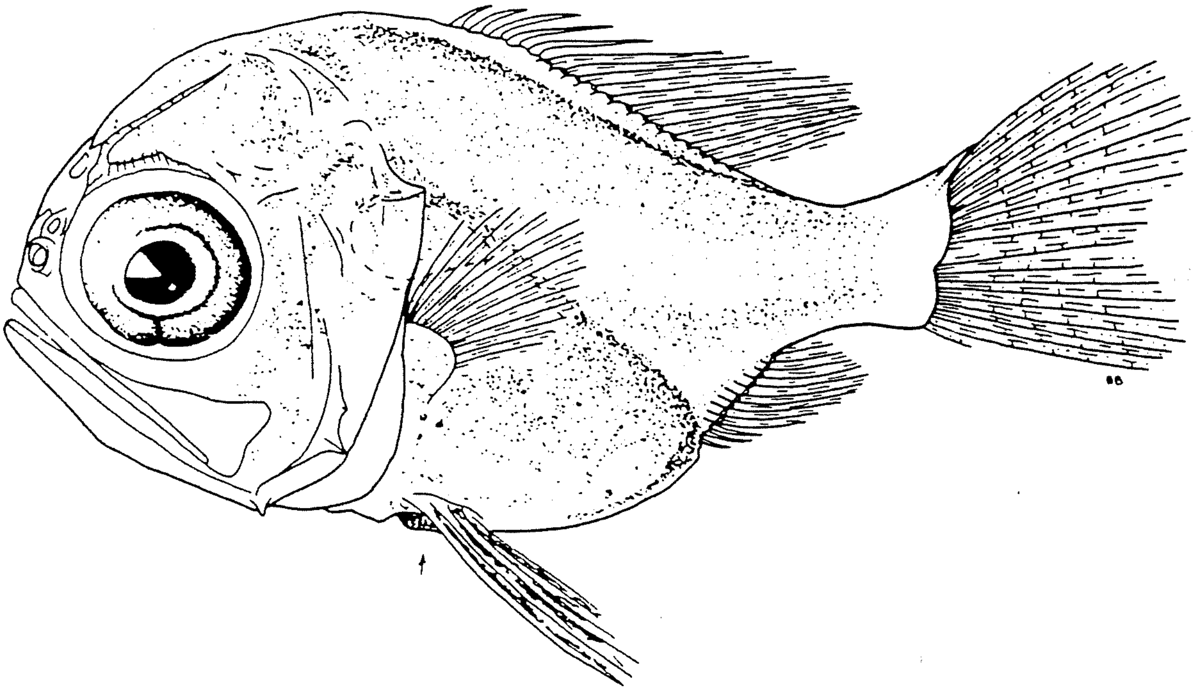


Figure 3.

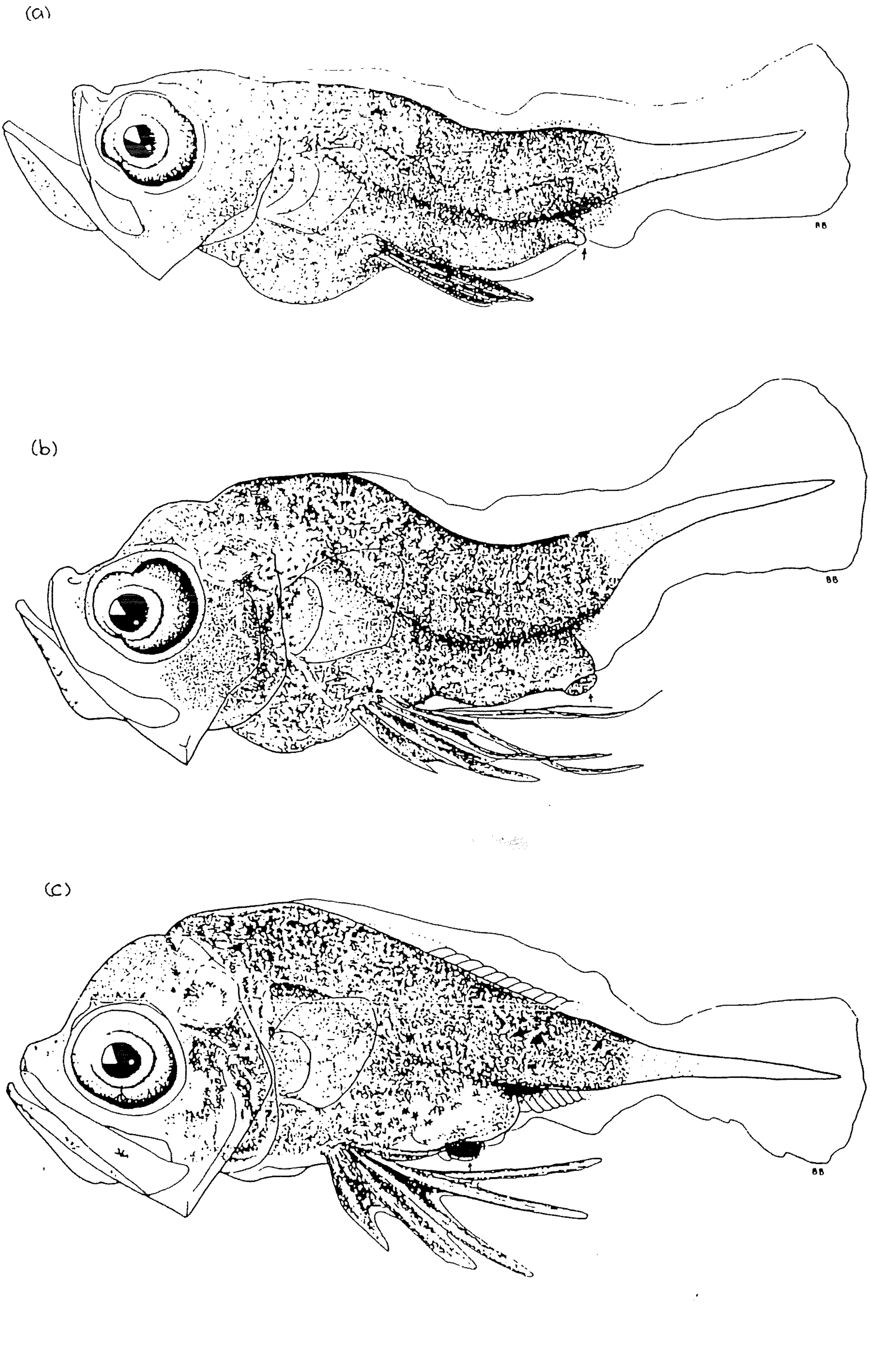


Figure 3.

(d)

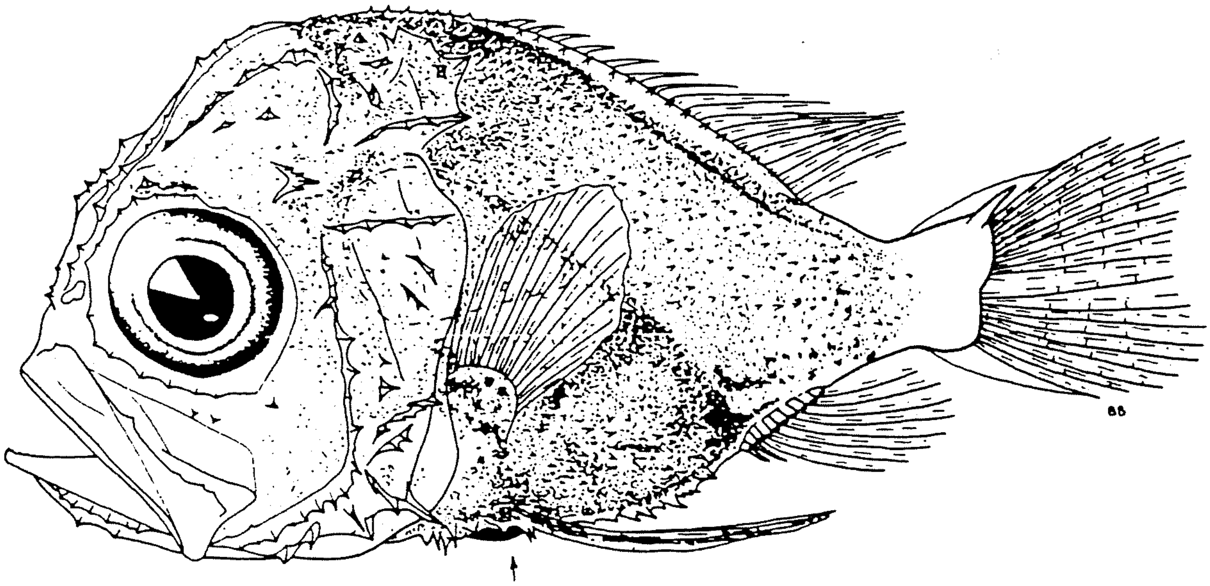


Figure 4.

(a)

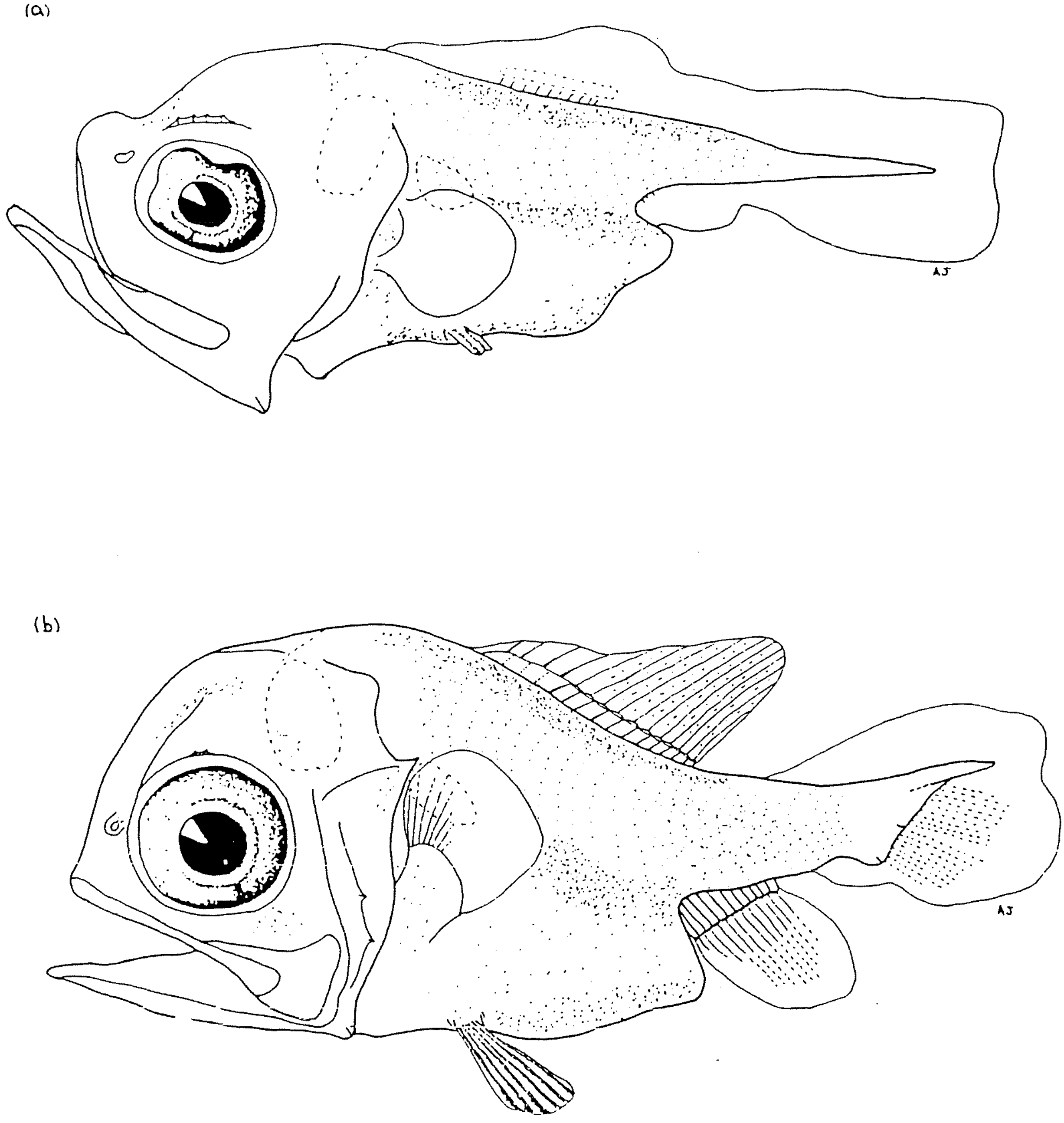


Figure 4

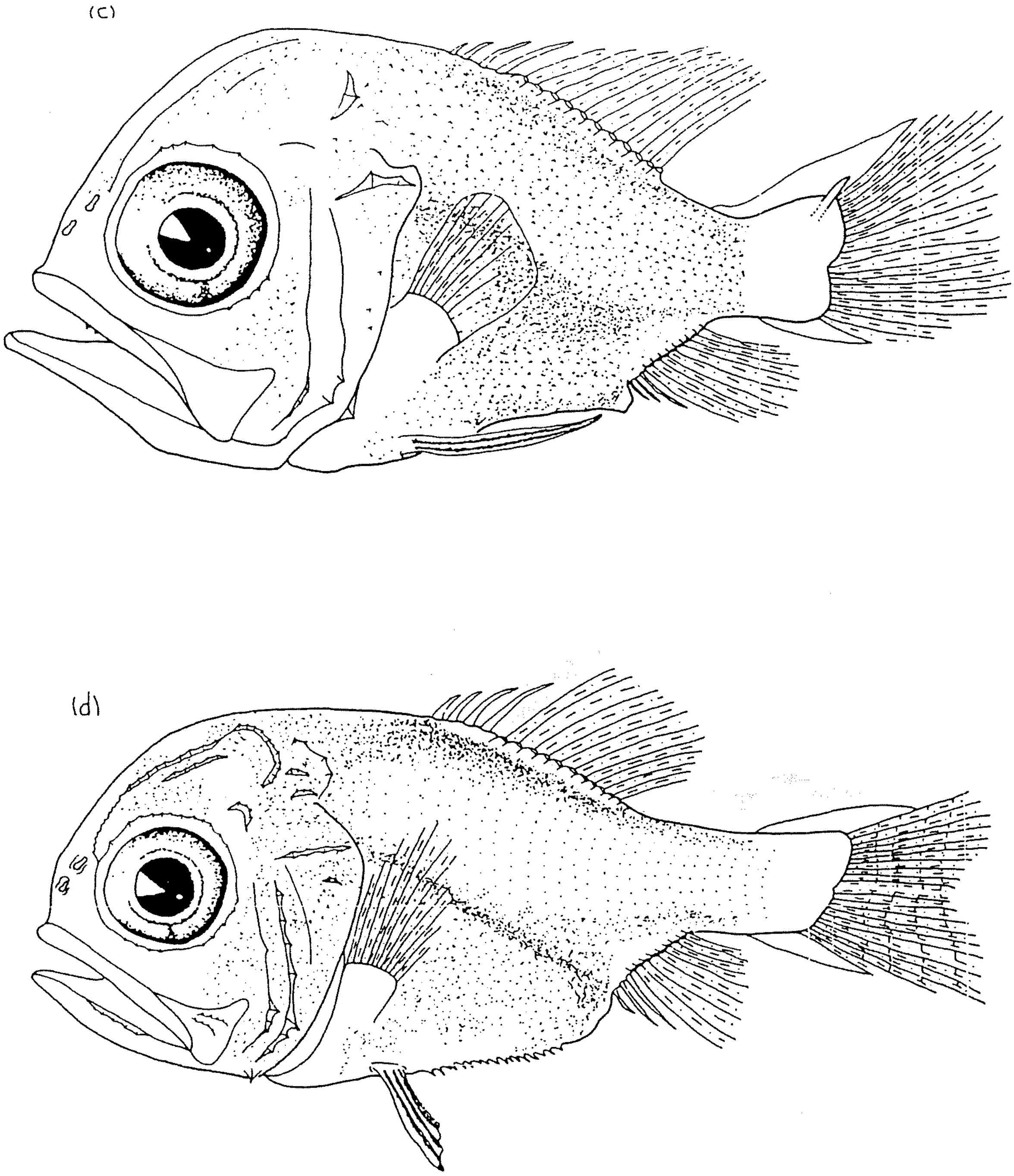
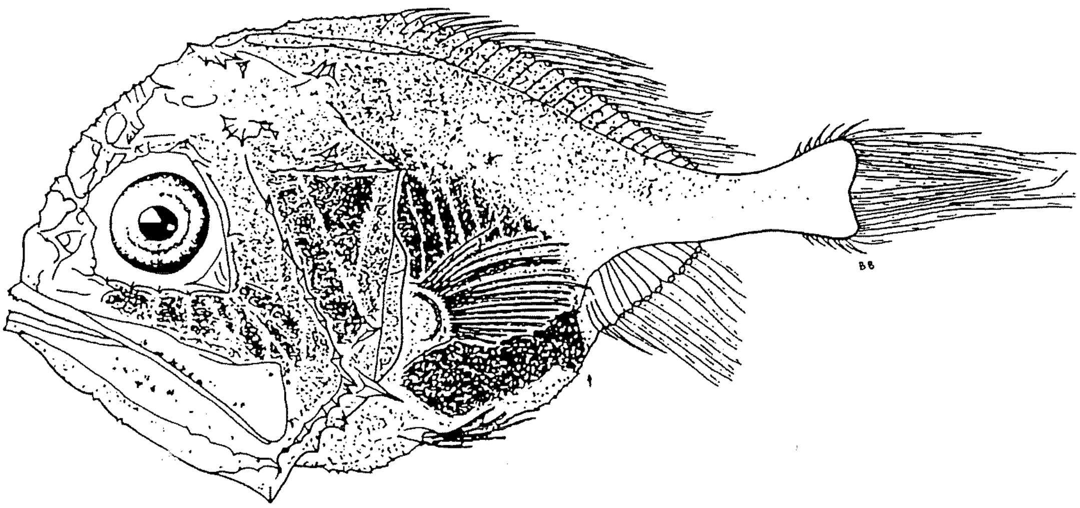


Figure 5:



DOCUMENT 6

MARINE ECOLOGY PROGRESS SERIES

Diet and food consumption of a deep-sea fish, orange roughy *Hoplostethus atlanticus* (Pisces: Trachichthyidae), from southeastern Australian waters

C. M. Bulman and J. A. Koslow

CSIRO Division of Fisheries, GPO Box 1538, Hobart, Tasmania, Australia, 7001.

ABSTRACT

The diet of nearly 7500 orange roughy, Hoplostethus atlanticus, from southeastern Australian waters caught during trawl surveys in 1988 and 1989 was examined. Juveniles feed mainly on bentho- and meso-pelagic crustaceans, while the mature fish eat predominantly fish and a new item, squid. The composition of the diet changed significantly with depth, geographical area and year. Resource partitioning between juveniles and adults was suggested by the patterns of prey selection. Evidence of diel feeding periodicity found in adults at a station sampled over 42 h was consistent with patterns of stomach fullness and digestion stage in the full data set. The daily rates of food consumption were estimated as 1.47% body weight for adults and 1.16% for juveniles. The metabolism of orange roughy, as calculated on a mass balance model, is similar to that of active, migratory mesopelagic fishes and substantially higher than that of non-migratory mesopelagic fishes. The proximate bodily composition of orange roughy, which is high in lipid and protein and low in water, is also similar to that of active mesopelagic fishes. Many non-migratory benthopelagic fishes typically have high growth rates, low food consumption and exceptionally low metabolic rates. Orange roughy, however, has an exceptionally low growth rate and relatively high rates of food consumption, perhaps due to high metabolic costs.

INTRODUCTION

The food consumption and metabolism of deep-sea fishes have seldom been studied. They are of particular interest in orange roughy, Hoplostethus atlanticus Collett 1889, because of the recent development of deepwater fisheries for this species off New Zealand and Australia. Orange roughy are found in the north-east Atlantic (Mauchline and Gordon 1984), around the southern coast of South Africa to Madagascar and on the West Australian ridge in the Indian Ocean (Kotlyar 1980), but commercially significant quantities are not known from these regions. Studies in several parts of the world ocean (Kotlyar and Lipskaya 1981, Mauchline and Gordon 1984; Gordon and Duncan 1987, Rosecchi et al. 1988) show consistently that orange roughy feeds on bentho- and mesopelagic crustaceans, fish and squid. Crustaceans predominate in the diet of small orange roughy, and their diet shifts to fish with as the roughy grow (Rosecchi et al. 1988). Orange roughy seems to be an opportunistic, generalized benthopelagic predator similar to other fish at these depths (Mauchline and Gordon 1986, Blaber and Bulman 1987).

Benthopelagic fishes are generally believed to consume less food than shallower species, but because their metabolism rather than their growth rate is lower (Torres et al. 1979, Childress et al. 1980, Mauchline 1988). The food consumption of orange roughy has not been studied. The species has not been maintained under laboratory conditions, and Rosecchi et al. (1988) found no evidence of diel periodicity, from which digestion rate and, hence, food consumption might be estimated (Eggers 1977, Clarke 1978). However, orange roughy is an exceptionally slow-growing fish, which requires 20-30 years to attain a size at maturity of 30 cm and thereafter grows only 15-20 cm over ~75 years as an adult fish (Mace et al. 1990, Fenton et al. submitted). It might be expected, therefore, that orange roughy has a particularly low rate of food consumption, if its metabolism is similar to that of other non-migratory benthopelagic species.

Orange roughy is widely distributed in temperate Australian waters in depths from about 750 m to greater than 1200 m, where it is often the dominant species (Bulman et al. in press). This study of orange roughy feeding is based upon a large collection of stomachs (at least 10-fold more than previous studies of orange roughy feeding) that was obtained in southeastern Australian waters (including a single station sampled regularly over 82 hours) over two five-month field seasons.

Our objectives in this paper are:

1) to describe the diet of orange roughy in Australian waters in relation to area, depth, and size, and year; and

2) to examine the food consumption and metabolism of orange roughy based upon an analysis of their diel feeding periodicity and digestion rate.

MATERIALS AND METHODS

Field collection. In 1988 and 1989, an area of about 13 000 km^2 off southeastern Australia was surveyed by FRV Soela, using an Engel High-rise trawl (Fig 1). The survey was based on a random depth-stratified design consisting of 100 m depth strata from 700-1200 m in 1988 and 800-1200 m in 1989. Cruises were undertaken from January to May in both years. The number of valid stations at which orange roughy were caught was 162 in 1988 and 167 in 1989. The survey area was divided into subareas corresponding to broad geographical regions: Great Australian Bight (GAB), western Tasmania and western Bass Strait (WTas), eastern Tasmania (ETas), eastern Bass Strait (EBass), and in 1988, New South Wales (NSW) (Fig 1). A site off NSW was sampled at regular intervals over 82 hours to obtain data on diel feeding periodicity.

Laboratory analysis. The stomachs of up to 40 orange roughy from each tow were examined in the 1988 survey and 20 per tow in the 1989 survey. The whole stomach was assessed for digestion on a scale of 1 (little or no digestion) to 4 (almost complete digestion). Prey items were identified to species or genus where possible, and weighed after excess moisture had been removed.

Data analysis. The numbers in many prey categories were too low to permit statistical analysis, so prey items were grouped into more general taxa (sergestids, pasiphaeids, oplophorids, mysids, amphipods, other Crustacea (mostly unidentified), fish, squid and other prey (miscellaneous)). The percentage of the total weight of the prey and the frequency of occurrence of prey items in stomachs containing food were calculated for each prey category. Stomach fullness for each tow (g/kg) was calculated by dividing the summed weight of prey items in all the stomachs by the weight of all fish examined.

The data were analysed by subarea, by depth, by year, and by 5 cm size-classes. In all analyses except by length, data from fish greater than 30 cm (mature) were analysed separately from the rest (immature). The number of tows in the EBass area in 1989 were too few to compare with the 1988 results and there were no NSW data in 1989. Consequently only data from GAB, WTas and ETas in both years were analysed. Data from tows within aggregations of orange roughy were compared with data from the rest of the subarea.

The overall similarity of diets from different areas was tested with Kendall's coefficient of concordance, W (Tate and Clelland 1957), a nonparametric ranking test and Friedman's rank two-way classification, T (Conover 1971). More detailed analyses of variation in diet in relation to fish size, depth, year, subarea, and aggregation were made with contingency-table analyses or logistic regression, based upon the frequency of occurrence of the different prey items in the roughy stomachs. The prey items were grouped into major sub-categories (crustaceans, fish, squid) in carrying out more complex statistical analyses.

Two types of data were used to investigate diel periodicity of feeding. Mean stomach fullnesses per tow and the proportions of stomachs at each digestion stage were each averaged per four-hour interval. Digestion stages 1 and 2 were combined because of low numbers in both stages, and stages 3 and 4 were combined, since both indicated late stages of digestion and were apparently reached many hours after intake. These data were plotted and contingency analyses carried out to test for differences between time periods. Analyses were carried out on both the full data set and that of the 82-hour station off NSW.

Mean daily food consumption (C) was estimated from the data for stomach fullness per tow obtained at the single station off New South Wales. The method of Eggers (1977, 1979) was used:

$$C = 24 \times S \times R, \qquad (1)$$

where S is the mean stomach fullness (g/kg body weight) over 24 hours, and R is the digestion rate per hour. R is determined from the apparent rate of food evacuation, based upon diel differences in stomach fullness:

$$S_t = S_0 \, e^{-R_t}. \qquad (2)$$

Using the natural logarithmic transformation of Equation 2, R was estimated by linear regression analysis, in which the data for stomach fullness are weighted for the number of fish examined per tow:

$$\ln(S_t) = \ln(S_0) - R_t. \qquad (3)$$

Eggers' (1977, 1979) method appears more robust for use with field data than the method of Elliott and Persson (1978), particularly when digestion rate cannot be determined in the laboratory (Boisclair and Leggett 1988). Our estimate of digestion rate and food consumption will have a conservative bias if the orange roughy do not entirely cease feeding during the period of greatest decline in mean stomach fullness.

RESULTS

Diet

A total of 7486 stomachs was examined, 4573 from 1988 and 2913 from 1989. Of this total, 41% of stomachs (3049) contained food (45% from 1988 and 34% from 1989). The diet of orange roughy in southeastern Australian waters was found to consist of natant decapods, mysids, amphipods, benthopelagic fish and squid (Tables 2-5, Fig. 2). Acanthephyra pelagica and an unidentified species of Pasiphae were the most common carid prawns found, and Sergestes (Sergestes) arcticus was the predominant penaeid. Gnathophausia sp. was the largest mysid identified; smaller mysid specimens were difficult to identify but were probably Boreomysis sp. (B. Griffiths, CSIRO, pers. comm.). Two species of amphipods from the family Lyssianassidae were identified: Eurythenes grillus and Trischizostoma nicaeense. Most fish were unidentifiable, but Chauliodus sloani was easily identified even in advanced stages of digestion because the jaws of this species are distinctive and digested at a slower rate than the rest of the fish. Myctophids were common in orange roughy stomachs but in their half-digested state could not always be identified further. However, Lampanyctus spp. and Lampichthys spp. were identified and most of the unidentified myctophids were thought to be from these genera. The rapid deterioration of squid made identification impossible, but some beaks from the families Onychoteuthidae, Histioteuthidae, Cranchiidae and Brachioteuthidae were identified.

Changes in diet with size and depth

The diet of orange roughy shifted from predominantly Crustacea in the smaller fish to fish in the larger animals (Fig 3). Squid became important in the diet of roughy greater than 20 cm, comprising 15-20% of prey weight.

The frequency with which crustaceans and fish were eaten by orange roughy varied significantly with depth (Fig. 4). The effect of depth varied both in the two years of the study and with different size groups of orange roughy (Table 1). However, the effect of size became consistent when juveniles and adults were separated for analysis i.e. size was always a significant effect in the juvenile classes but not in the adult classes.

Depth-related changes in the diet of adults was often inversely related to those of the juveniles (Fig. 4). Crustaceans occurred least frequently in the diet of juvenile roughy at a minimum of 900 m in 1988 and at 900-1000 m in 1989 but became more frequent in deeper water (Fig 4a), whereas crustaceans in the adult diet peaked at 800 m depth in 1988 and at 900 m in 1989 and then declined in deeper water (1989) (Fig 4b). In contrast, fish were most frequent in juvenile orange roughy at a depth of 900 m in 1988 and at around 900-1000 m in 1989 and then declined in deeper water (Fig 4c). Fish were least common in the largest orange roughy ($\geq$ 35 cm) at 900 m but increased significantly in both years at deeper depths (Fig 4d; year (adults): Table 1). Both size-classes fed to a greater extent on fish and lesser on crustaceans in 1989 (year x depth (adults): Table 1) than in 1988. The frequency with which squid occurred in the diet of adult and juvenile roughy did not vary significantly with depth, but the larger juveniles ate proportionately more squid than the smaller classes (Figs 4 e & f).

Regional and interannual differences in diet

The rank order of prey categories in the diets of orange roughy throughout the survey area and between years did not differ significantly using frequency of occurrence data (W (adults) = 0.695, T = 58.25, $p < 0.005$; W (juveniles) = 0.859, T = 69.58, $p < 0.005$) or prey weight (W (adults) = 0.892, T = 64.22, $p < 0.005$; W (juveniles) = 0.713, T = 57.79, $p < 0.005$) but there were significant differences in the actual proportions of some prey categories.

Juveniles

The incidence of feeding in juvenile fish was significantly higher in 1988 than in 1989 (Pearson's $x^2_{(1)} = 31.73$, $p < 0.005$) (Tables 2 & 3). Crustaceans constituted a large proportion of the diet of juveniles: about 50% by weight in 1988 and 40% in 1989 (Figs 2 a & b).

Amphipods occurred with variable frequency but was most common in the GAB samples in 1988 (time x area: $x^2_{(2)} = 12.24$, $p < 0.005$). Pasiphaeids and mysids were found more frequently in roughy in 1989 ($x^2_{(1)} = 14.86$, $p < 0.001$ and $x^2_{(1)} = 10.34$; $p < 0.005$ respectively) and oplophorids were more frequent in the GAB fish (area: $x^2_{(2)}$

=75.51, $p < 0.001$). Juveniles in WTas in 1989 ate fish most frequently (time x area: $x^2_{(2)}$ = 21.17, $p < 0.001$).Juveniles on the east coast of Tasmania ate not squid at all but there were no differences in its consumption in the other two areas.

Adults

The overall rate of feeding in adult fish was, as in juveniles, higher in 1988 than in 1989 (Pearson's $x^2_{(1)} = 67.75$, $p < 0.005$), particularly in the GAB and WTas areas where the mean rate of fullness per tow was higher by about 20% in 1988 than in 1989 (Tables 4 & 5).

Only a few regional differences in diet were significant. Amphipods were twice as common in stomachs in 1988 than in 1989 ($x^2_{(1)}$= 9.69, $p < 0.01$) and also occurred in stomachs of fish from the GAB 4 to 10 times more frequently than anywhere else ($x^2_{(2)}$= 94.16, $p < 0.01$). Mysids were less frequent on the west coast of Tasmania than in the GAB or east Tasmania ($x^2_{(2)} = 10.42$, $p < 0.01$). The occurrence of fish in stomachs varied significantly but exhibited no consistent patterns (time x area: $x^2_{(2)} = 6.03$, $0.01 < p < 0.05$); fish were most frequent in 1989 stomachs in the WTas area. The occurrence of squid also varied with time and area ($x^2_{(2)} = 14.56$, $p < 0.01$), but the greatest proportion of fish eating squid occurred in the GAB in 1989, and the least on the east coast.

Diet within aggregations

An aggregation of orange roughy consisting wholly of adult fish was sampled in the GAB in 1988. The inciaence of feeding was significantly higher in the aggregation (69%) then in the adult fish from the rest of the GAB area (52%) (Pearson's $x^2_{(1)} = 8.53$, $p < 0.005$). However, the mean stomach fullness (± S.E. of mean) of the three tows in the aggregation (6.6 ± 1.8 g/kg) was not significantly different ($t_{(48)} = 9.349$) to that of the rest of the GAB tows (5.9 ± 1.3 g/kg) . Amphipods occurred significantly more frequently in fish from the aggregation than in 'non-aggregation' fish (Pearson's $x^2_{(1)} = 13.46$, p =

0.002), but pasiphaeids occurred significantly less often (Fishers Exact test, $p = 0.0033$) (Fig 5). Fish sampled from a small aggregation off east Tasmania in 1989 were no different from fish from the rest of the region in either incidence of prey or stomach fullness.

Diel feeding periodicity

Periodicity in stomach fullness

At the NSW 82-hour sampling, station a peak in stomach fullness was observed in the middle of the night, after which stomach fullness declined steadily until midday, when stomachs were empty (Fig. 6). Based upon the rate of decline during this period, the instantaneous hourly digestion rate (R) was estimated to be 0.124/h (regression ANOVA, $F = 12.73$, $n = 6$, $r^2 = 0.76$, $p < 0.05$).There was supporting evidence of diel periodicity in the full data set although the pattern was not quite significant (Fig 7a; Kruskal-Wallis test: $x^2_{(272)} = 10.68$, $p = 0.056$).

The data for stomach fullness for juveniles at this station were more variable, and no significant pattern was observed for this station nor for the whole data set (Fig 7b).

Periodicity in digestion stage

Although a significant diel pattern of stomach fullness was not observed in juvenile orange roughy, the juveniles showed significant diel differences in the digestion stage of the stomach contents (Fig 8) (juveniles: $x^2_{(10)} = 30.97$, $p < 0.001$). The highest proportions of food in the early stages of digestion were observed in the afternoon, evening and midnight hours (1200-2000 h and 0000-0400 h), while the highest proportion of stomachs with food in the later stages of digestion was obtained in early morning (0400-0800 h), with an increased proportion of empty stomachs in late morning (0800-1200 h). These results are again consistent with a pattern of feeding in the afternoon and first half of the night, with littlr feeding from midnight to midday. However, it should be noted that over 50% of juvenile and adult roughy stomachs were empty at all times, and the highest proportion of stomachs containing food were consistently in the most advanced stage of digestion. This suggests a relatively rapid initial stage of digestion, the later stages of digestion are slow. The lack of clearer diel patterns in the full data set is not surprising considering that the depths, areas and time periods of the study were compressed for our analysis.

Food consumption

Based upon our estimate of R and the mean stomach fullness (4.94 g/kg for adults (Tables 4 & 5)), orange roughy were stimated to consume 14.70 g/kg (= 1.47% body wt) over the 24-hour day. The rate of digestion of the juveniles was not estimated separately. However, their mean stomach fullness was similar to that of the adults (3.90 g/kg body wt (Tables 2 & 3), and if the same digestion rate is assumed, their daily food consumption may be estimated to be 11.61 g/kg (= 1.16% body wt).

DISCUSSION

The results of our dietary analyses of Australian Hoplostethus atlanticus are consistent with those obtained elsewhere in the species' geographical range. H. atlanticus feeds on bentho- and mesopelagic crustacea, fish and squid. Pasiphaeids, oplophorids and sergestids were the major decapod taxa consumed, as in New Zealand (Rosecchi et al. 1989). Kotlyar and Lipskaya (1980) found pasiphaeids to be important in the diet of fish off the West Australian and Madagascar Ridges. The main families of the fish eaten by H. atlanticus were the chauliodontids and myctophids, as in the New Zealand study (Rosecchi et al. 1989). Squid comprised about 10% of the diet in terms of frequency of occurrence, which is consistent with previous reports (Kotlyar and Lipskaya 1980, Rosecchi et al. 1989).

The diet of the orange roughy in the three areas and between the two years was broadly similar in terms of the overall ranking of prey groups. However, there were some significant differences in the incidence of particular prey groups in the diet among areas or between years. The dietary data suggest orange roughy are opportunistic feeders, so the variability in the data may reflect spatial and temporal variation in the abundance of prey species.

As Hoplostethus atlanticus grows, fish become increasingly important in its diet, as Kotlyar and Lipskaya (1980) and Rosecchi et al. (1989) reported. Similar shifts in the diet have been observed in other fishes that are predominantly piscivorous as adults (e.g. Atlantic cod (Daan 1973) and lake trout (Kerr and Martin 1970)), and such benthopelagic predators, such as Cyttus traversi and Helicolenus percoides (Blaber and Bulman 1987). On the other hand, three benthopelagic macrourid species in Tasmanian waters (Coelorinchus spp. 2 and 4 and Lepidorhynchus denticulatus), do not exhibit this ontogenetic shift in dietary composition (Blaber and Bulman 1987).

Squid appeared first in the diet of fish over 15 cm.The proportion in the diet was about the same level throughout the larger size classes. Squid was observed in the diet of orange roughy in the northeast Atlantic and off New Zealand in fish over 20 cm (Mauchline and Gordon 1984; Rosecchi et al. 1989). The importance of squid in terms of proportion of the diet by weight is likely to be under-estimated since it is digested at a greater rate than fish or crustaceans. Often only their beaks remained in a stomach.

Resource-partitioning between adult and juvenile orange roughy is suggested by the observed inverse patterns of prey selection. Resource-partitioning among size classes of meso-pelagic fish may be a mechanism to reduce intra-specific competition in midwater where prey are not abundant (Baird and Hopkins 1981). Such a mechanism might be effective for a species such as Hoplostethus atlanticus that is the dominant component of the biomass at these depths in the region (CSIRO unpub. data). However, hypotheses on competitive interactions are difficult to test with field survey data.

Diel feeding periodicity has not been previously reported for orange roughy

(Rosecchi et al. 1988). It may have become apparent in our study due to our 10-fold larger sample size and concentrated sampling at a single site. Diel feeding periodicity is commonly reported for upper slope fishes that make diurnal feeding migrations (e.g. Kinzer and Shulz 1985, Young and Blaber 1986), but non-migratory slope fishes generally do not exhibit diel variation in feeding (Merrett and Roe 1974, Macpherson 1981, Blaber and Bulman 1987). There is no evidence that orange roughy migrate diurnally, but many of the prey species eaten by Hoplostethus atlanticus do: Chauliodus sloani migrates to the upper 800 m from 1000–1800 m (Haedrich & Henderson 1974, Morrow 1964); several species of Lampanyctus migrate upwards from daytime depths of 500–1000 m (Smith & Heemstra 1986); Acanthephyra pelagica migrates from 800 m to a minimum of 450 m at night (Roe 1984); and Sergestes (Sergestes) arcticus rises from 600 m to 100 m (Roe 1984). Orange roughy's crepuscular feeding pattern suggests that it is benefiting from migrators rising from mid-slope depths. Diel feeding periodicity was reported in the mesopelagic Valenciennellus tripunctulatus, which also does not itself migrate but feeds upon migrators that are available only during the day (Merrett and Roe 1974).

The high incidence of orange roughy with empty stomachs (> 50%) fits a general pattern noted for meso- and bathypelagic predators feeding on large invertebrates and fish (Legand and Rivaton 1969, Merrett and Roe 1974). These authors have speculated whether this pattern indicates infrequent feeding or rapid digestion rates. The evacuation rate of benthopelagic predators has not been directly measured, but our estimate of gut residence time (<1 d) suggests that the rate of digestion is comparable to that of other cold-water piscivorous fishes (e.g. Atlantic cod; Jones 1978), but that feeding is infrequent. We found no evidence that orange roughy regurgitate their stomach contents, unlike the macrourids, which were commonly observed to do so (C. Bulman pers.obs.). Orange roughy have an oil-filled swim bladder unaffected by pressure changes which often cause an air-filled swim bladder to force out the stomach contents.

Our estimate of orange roughy food consumption (1.16% and 1.47% body weight/d for juveniles and adults, respectively) is closer to estimates of the food consumption of several mesopelagic migrators (0.87%/d), which are relatively active fishes, than to estimates for bathypelagic non-migrators (0.68% BW/day) (Childress et al. 1980). However it is somewhat less than the estimate for another bathypelagic non-migrator, Danaphos oculatus, (1.7% BW/d) (Clarke 1978). Childress et al.'s (1980)estimates of food consumption were calculated indirectly from data for growth and shipboard metabolism (Torres et al. 1979), whereas Clarke, like us, made field estimates from stomach content data.

Thus, this level of agreement among these studies may, therefore, be reasonable in view of the crude and very different methods of estimation used. However, one might expect orange roughy to have a rate of food consumption lower than even the bathypelagic non-migrators studied by Torres et al. (1979) and Childress et al. (1980), which were generally small animals (15-29 cm), short-lived (4-8 years), and with rapid growth rates. Not only does orange roughy not make diel migrations but it grows exceptionally slowly, maturing at 18-20 years at ~30 cm and achieving a standard length of between 45 and50 cm at an estimated 50-75 years (Mace et al. 1990; Fenton et al. in press).

There are no direct measurements of themetabolic rate of orange roughy, but metabolism can be estimated from data on their food consumption, growth, and reproduction, using the mass balance equation:

$$aR = G + T, \qquad (1)$$

in which a is the coefficient of assimilation, (which we assume equal to 0.8), R is ration, G represents growth and reproduction, and T is metabolism. Available data indicate that the mean growth of orange roughy juveniles (10-20 years old) is 11%/year and of adults (20-50 years) is 2.8%/year (Mace et al. 1990; Evans and Wilson 1987). Annual reproductive effort of orange roughy is ~10% of body weight (Pankhurst and Conroy 1987), so G for adult roughy is approximately 15%/year, assuming that the energetic content of gonadal tissue is 1.2 that of somatic tissue (Ware 1980). Using our values for daily food consumption (R), daily metabolism may be estimated to be 0.90%

body weight for juveniles and 1.13% for adults. This translates to estimates of oxygen consumption for the juveniles of 0.14 l O_2/kg wet wt/h and of adults of 0.18, assuming conversions of 1750 kcal/kg wet wt, which is typical of mesopelagic fishes with a similar body composition to that of orange roughy (Table 6), and 4.63 kcal/l O_2 (Brett and Groves 1979).

Based upon this exercise, metabolism of orange roughy is comparable to that of mesopelagic migratory species and approximately an order of magnitude higher than that of the bathypelagic non-migrators studied by Torres et al. (1979) (~0.01 l O_2/kg wet wt/h) (Table 6). Torres et al. (1979) apparently reported resting metabolic rates, whereas our estimates are of total field metabolism, so their values should be approximately doubled for comparison. However, the apparent metabolism of orange roughy remains closer to that of mesopelagic migrators than of other bathypelagic non-migrators. This is reasonable considering the ecology of orange roughy and the proximate composition, which Torres et al. (1979) showed is closely related to metabolism. Orange roughy does not have the higher water and reduced protein, lipid, and ash content that is typical of low-energy bathypelagic non-migrators (Table 6). Many bathypelagic species are not very active, whereas orange roughy may aggregate in areas of high near-bottom currents (~25-30 cm/sec (V. Lyne CSIRO, pers. comm.)), and photographs indicate that they maintain a position oriented into the current (unpubl. data).

Related to their apparently high metabolism, the life history of orange roughy is also atypical of the bathypelagic environment. Bathypelagic non-migratory fishes typically have high rates of growth and growth efficiency, and non-asymptotic growth, which may conserve energy through lower activity, and through reduced body structure and caloric content (Childress et al. 1980, Mauchline 1988). In contrast, growth in orange roughy is exceptionally slow, highly asymptotic, and very inefficient (about 4%) (Table 6). Orange roughy is widely distributed in temperate midslope habitats of the southern oceans and North Atlantic, but is ecologically dominant in areas off Australia and New

Zealand. Its dominance, which has led to the development of substantial fisheries, may be limited to regions of high currents and, we speculate, high energy input that can support its requirements Clearly, the metabolic and gut evacuation rates of orange roughy should be measured directly, if possible, to test some of the assumptions underlying our preliminary energic calculations for orange roughy. The biological oceanography of deepwater regions supporting this fish has yet to be characterized.

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Table 1. Significant chi-squared statistics from four-way contingency table analyses to determine the relationship between occurrence of prey, depth of capture, size of orange roughy and year.

Prey Effect	All data x^2, d.f., p	Juveniles x^2, d.f., p	Adults x^2, d.f., p
Crustacea			
depth x size	51.32, 12, ***		
year x depth	10.04, 3, *	8.03, 3, *	9.17, 3, *
size		69.92, 2, ***	
Fish			
depth x size	54.35, 12, ***		12.65, 3, **
year x depth	9.20, 3, *	8.95, 3, *	
year			11.77, 1, ***
size		66.88, 2, ***	
Squid			
year		4.37, 1, *	
size	45.49, 4, ***	28.95, 2,***	

* 0.01 < p < 0.05; ** p < 0.01: *** p < 0.001.

Table 2. Hoplostethus atlanticus. Percentage of total prey weight (%W) and frequency of occurrence (%F) of prey items in the diet of juveniles during 1988.

Prey species	GAB		W Tas		E Tas		E Bass		NSW		Total	
	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F
CRUSTACEA												
Unidentified	10.3	27.9	22.2	44.8	12.1	30.9	29.7	45.2	15.9	36.0	16.0	36.5
Copepoda	0	0	0	0	1.9	1.2	0	0	0	0	0.1	0.1
Mysidacea												
Unidentified	2.2	5.0	1.7	2.3	1.8	3.7	5.1	14.4	2.3	5.4	2.3	6.2
Gnathophausia sp.	1.2	0.2	0	0	0.5	1.2	6.7	2.3	1.2	1.3	1.4	0.8
Amphipoda	6.7	18.7	0.7	3.0	0.4	1.2	3.0	5.7	0.3	0.8	3.4	8.6
Decapoda												
Penaidae												
Unidentified	0.2	0.8	0.1	0.3	11.4	6.2	0	0	0	0	0.7	0.7
Sergestes (Sergestes) arcticus	0.7	2.3	2.4	7.4	0	0	1.1	1.9	0	0	1.0	2.8
Caridae												
Unidentified	1.5	3.1	2.5	2.0	23.2	38.3	1.5	1.1	1.1	0.4	2.8	4.0
Pasiphae spp.	3.2	5.0	2.4	3.0	0	0	15.8	11.4	3.2	3.8	4.0	5.3
Acanthephyra pelagica	16.9	18.3	5.9	6.0	0	0	5.2	3.0	3.3	3.3	9.8	9.0
Oplophorus novaezelandiae	1.2	1.0	0	0	0	0	0	0	0	0	0.5	0.4
PISCES												
Unidentified	26.5	20.8	24.2	21.1	19.9	6.2	17.0	10.6	50.6	45.6	29.2	22.4
Gonostomatidae	4.6	0.8	1.2	0.3	0	0	0	0	0	0	2.3	0.4
Chauliodontidae												
Chauliodus sloani	1.9	0.6	0.8	0.3	0	0	3.8	0.4	2.7	0.4	1.9	0.4
Myctophidae												
Unidentified	1.7	0.8	5.8	1.7	2.2	1.2	1.4	1.1	0	0	3.7	1.7
Lampanyctus spp.	1.6	0.6	1.6	0.7	0	0	0	0	0	0	1.1	0.4
Lampichthys sp.	0	0	0.2	0.3	6.7	2.5	0	0	7.1	4.2	0.4	0.2
Macrouridae												
Coryphaenoides spp.	0.3	0.2	0	0	0	0	0	0	0	0	0.1	0.1
Apogonidae												
Epigonus lenimen	0	0	0	0	19.9	7.4	0	0	0	0	1.0	0.4
MOLLUSCA												
Cephalopoda	19.2	10.2	28.3	12.4	0.1	1.2	9.8	5.3	12.3	11.7	18.3	9.5
Total weight of prey (g)	3359.8		1850.9		406.0		688.6		1443.7		7749.0	
Total stomachs examined	1140		650		168		673		526		3157	
Stomachs with food present (%)	481 (42.3)		299 (46.0)		81 (48.2)		263 (39.1)		239 (45.4)		1363 (43.2)	
Mean of average stomach fullness per tow (g/kg)	5.16 ± 4.73		6.67 ± 6.56		4.07 ± 3.93		2.96 ± 1.83		3.86 ± 2.03		5.02 ± 4.80	
No. of tows	61		41		12		23		21		158	

Table 3. Hoplostethus atlanticus. Percentage of total prey weight (%W) and frequency of occurrence (%F) of prey items in the diet of juveniles during 1989.

Prey species	GAB %W	GAB %F	W Tas %W	W Tas %F	E Tas %W	E Tas %F	E Bass %W	E Bass %F	Total %W	Total %F
POLYCHAETA	0.1	0.5	0	0	0	0	0	0	0.1	0.3
CRUSTACEA										
Unidentified	6.2	22.9	11.7	30.4	25.7	42.1	7.3	27.8	8.7	27.0
Mysidacea										
Unidentified	1.4	6.8	0.9	6.78	5.2	13.2	0	0	1.3	7.4
Gnathophausia sp.	1.0	1.2	0	0	2.6	1.3	0	0	0.8	0.9
Amphipoda	3.3	13.0	0.1	1.2	4.3	11.8	0	0	2.3	9.7
Decapoda										
Penaidae										
Unidentified	0	0	0	0	4.2	1.3	0	0	0.2	0.1
Plesiopenaeus edwardsianus	0.8	0.2	0	0	0	0	0	0	0.5	0.1
Sergestes (Sergestes) arcticus	1.4	2.6	0.4	1.9	2.1	2.6	0	0	1.1	2.4
Caridae										
Unidentified	1.3	2.1	0.6	0.6	4.7	5.3	0	0	1.2	2.1
Pasiphae spp.	6.1	9.4	5.1	6.8	5.8	9.2	0.6	5.6	5.6	8.7
Acanthephyra pelagica	10.5	13.9	3.5	4.3	0	0	0	0	7.6	9.7
A. quadrispinosa	0.9	1.7	4.6	5.6	0	0	0	0	1.9	2.4
Oplophorus novaezelandiae	0.7	0.5	0	0	0	0	0	0	0.5	0.3
Plesionika martia	0.4	0.2	0	0	0	0	0	0	0.3	0.1
Lipkius holthuisi	1.7	0.9	0.1	0.6	0	0	0	0	1.1	0.7
Nematocarcinus sigmoideus	0.2	0.2	0	0	0	0	0	0	0.1	0.1
PISCES										
Unidentified	17.8	14.4	40.7	35.4	26.1	19.7	48.4	38.9	25.8	20.6
Gonostomatidae	3.6	0.7	1.7	1.9	0	0	0	0	2.7	0.9
Neoscopelidae										
Neoscopelus sp.	1.0	0.2	0	0	0	0	0	0	0.7	0.1
Chauliodontidae										
Chauliodus sloani	3.9	0.9	1.8	1.2	0	0	0	0	3.0	0.9
Myctophidae										
Unidentified	0	0	1.0	1.89	0	0	0	0	0.3	0.4
Lampanyctus spp.	0.1	0.2	3.5	1.9	19.3	3.9	10.3	5.6	2.4	1.2
Bathylagidae	1.3	0.5	1.1	0.6	0	0	0	0	1.1	0.4
Macrouridae										
Coryphaenoides spp.	0	0	2.9	0.6	0	0	0	0	0.8	0.1
Other fish	5.8	2.1	0.7	1.2	0	0	0	0	3.8	1.6
MOLLUSCA										
Cephalopoda	30.3	14.9	19.5	9.9	0	0	33.4	27.8	25.9	12.4
TUNICATA										
Pyrosoma sp.	0.4	0.9	0	0	0	0	0	0	0.3	0.6
Total weight of prey	2508.7		1100.8		191.3		155.5		3956.3	
Total stomachs examined	1050		642		181		56		1929	
Stomachs with food present (%)	424 (40.4)		1641 (25.0)		76 (42.0)		18 (32.1)		679 (35.1)	
Mean av.stomach fullness per tow (g/kg)	5.24 ± 5.78		3.61 ± 3.61		2.16 ± 1.72		6.99 ± 2.72		2.81 ± 2.47	
No. of tows	78		63		19		3		163	

Table 4. Hoplostethus atlanticus. Percentage of total prey weight (%W) and frequency of occurrence (%F) of prey items in the diet of adults during 1988.

Prey species	GAB %W	GAB %F	W Tas %W	W Tas %F	E Tas %W	E Tas %F	E Bass %W	E Bass %F	NSW %W	NSW %F	Total %W	Total %F
POLYCHAETA	<0.1	0.4	0	0	0	0	0	0	0.5	2.2	<0.1	0.3
CRUSTACEA												
Unidentified	3.5	16.1	4.6	20.1	3.5	12.5	2.9	28.6	12.4	37.0	4.7	19.2
Copepoda	0.1	0.9	0	0	2.8	2.3	0	0	0	0	0.3	0.6
Mysidacea												
Unidentified	2.0	9.4	0.9	3.4	3.6	6.8	0	0	1.3	2.2	1.5	5.6
Gnathophausia sp.	4.9	1.8	1.2	0.9	7.4	6.8	40.1	28.6	7.6	4.3	4.2	2.5
Amphipoda	5.4	27.4	0.3	2.7	0.9	8.0	0	0	0.1	2.2	1.8	11.3
Decapoda												
Penaidae												
Unidentified	0	0	0.1	0.6	2.2	5.7	0	0	0	0	0.3	1.0
Sergestes (Sergestes) arcticus	0.2	1.3	0.4	2.7	0	0	0	0	0	0	0.3	1.7
Caridae												
Unidentified	0.2	0.9	0.2	0.3	1.1	5.7	5.0	14.3	1.4	2.2	0.3	1.3
Pasiphae spp.	1.5	4.0	3.6	7.3	2.3	4.5	0	0	0.9	2.2	2.7	5.5
Acanthephyra pelagica	7.9	16.6	6.7	16.5	0	0	3.2	14.3	1.4	6.5	6.0	13.7
A. quadrispinosa	0.1	0.4	0	0	0	0	0	0	0	0	<0.1	0.1
Oplophorus novaezelandiae	1.3	2.2	0.3	0.9	0	0	0	0	0	0	0.5	1.2
Pontophilus sp.	0	0	0	0	0.3	1.1	0	0	0	0	<0.1	0.1
PISCES												
Gonostomatidae	7.0	2.2	1.3	0.6	2.0	1.1	0	0	0	0	2.9	1.2
Unidentified fish	21.7	18.4	44.8	40.9	22.6	23.9	48.8	42.9	50.8	50.0	36.3	32.1
Chauliodontidae												
Chauliodus sloani	24.1	8.5	5.2	1.5	10.2	3.4	0	0	0	0	10.9	3.9
Myctophidae												
Unidentified	2.6	1.8	4.0	4.3	8.6	5.7	0	0	2.9	6.5	3.8	3.8
Gymnoscopelus sp.	0	0	0	0	3.4	2.3	0	0	0	0	0.3	0.3
Lampanyctus spp	0.6	0.9	0.2	0.3	0	0	0	0	0	0	0.3	0.4
Lampichthys sp.	0	0	1.1	0.6	3.0	3.4	0	0	0	0	0.9	0.7
Paralepididae												
Lestidiops pacifica	0	0	0.9	0.3	0	0	0	0	0	0	0.5	0.1
Macrouridae												
Lepidorhynchus denticulatus	0	0	0	0	6.9	1.1	0	0	0	0	0.7	0.1
Coryphaenoides spp.	0	0	1.9	0.9	8.0	2.3	0	0	0	0	1.8	0.7
Apogonidae												
Epigonus lenimen	0	0	0	0	11.1	8.0	0	0	0	0	1.1	1.0
MOLLUSCA												
Cephalopoda	16.9	15.2	22.2	20.7	0.1	1.1	0	0	20.7	17.4	17.9	16.0

	GAB	W Tas	E Tas	E Bass	NSW	Total
Total weight of prey (g)	3092.1	5530.3	1001.6	240.8	590.2	10455.0
Total stomachs examined	401	649	263	16	87	1416
Stomachs with food present (%)	223 (55.6)	328 (50.5)	88 (33.5)	7 (43.8)	46 (52.9)	692 (48.9)
Mean of average stomach fullness per tow (g/kg)	5.56 ± 8.89	6.53 ± 6.45	2.73 ± 1.97	11.13 ± 14.35	4.55 ± 3.16	6.16 ± 8.10
No. of tows	50	40	13	12	14	129

Table 5. Hoplostethus atlanticus. Percentage of total prey weight (%W) and frequency of occurrence (%F) of prey items in the diet of adults during 1989.

Prey species	GAB %W	GAB %F	W Tas %W	W Tas %F	E Tas %W	E Tas %F	E Bass %W	E Bass %F	Total %W	Total %F
CRUSTACEA										
Unidentified	3.8	12.5	2.8	9.0	2.8	11.1	0	0	3.0	10.5
Mysidacea										
Unidentified	0.4	3.4	0.1	2.8	0.1	1.2	0	0	0.2	2.5
Gnathophausia sp.	2.1	2.3	2.1	2.1	1.5	3.7	0	0	1.9	2.5
Amphipoda	1.2	13.6	<0.1	0.7	0.3	4.9	0	0	0.4	5.4
Decapoda										
Penaidae										
Sergestes (Sergestes) arcticus	0.5	2.3	0	0	0	0	0	0	0.1	0.6
Caridae										
Unidentified	0.3	2.3	0	0	0.4	1.2	0	0	0.2	1.0
Pasiphae spp.	1.4	6.8	2.6	89.0	2.8	4.9	0	0	2.4	7.3
Acanthephyra pelagica	2.7	10.2	1.9	4.8	0	0	0	0	1.6	5.1
A. quadrispinosa	3.0	10.2	3.9	10.3	0.3	1.2	0	0	2.6	7.9
Oplophorus novaezelandiae	3.9	1.1	0	0	2.6	7.4	0	0	1.7	2.2
PISCES										
Unidentified	11.7	22.7	51.6	56.6	48.0	49.4	0	0	41.0	45.4
Gonostomatidae	2.1	1.1	0	0	0	0	0	0	0.5	0.3
Scopelasauridae										
Scopelosaurus sp.	2.2	1.1	0	0	0	0	0	0	0.5	0.3
Chauliodontidae										
Chauliodus sloani	10.2	3.4	2.0	0.7	7.0	3.7	0	0	5.4	2.2
Myctophidae										
Unidentified	0	0	3.6	3.4	3.5	1.2	0	0	2.7	1.9
Lampanyctus spp.	0.7	1.1	3.9	4.1	0	0	0	0	2.0	2.2
Bathylagidae	0	0	8.0	1.4	0	0	0	0	3.7	0.6
Macrouridae										
Coryphaenoides spp.	0	0	2.5	2.1	2.1	2.5	0	0	1.7	1.6
Other fish	16.3	4.5	6.7	2.1	5.6	1.2	0	0	8.7	2.5
MOLLUSCA										
Cephalopoda	36.8	20.5	8.3	11.0	23.0	11.1	100	100	19.4	13.7
TUNICATA										
Pyrosoma sp.	0.7	3.4	0	0	0	0	0	0	0.2	1.0
Total weight of prey	1280.9		2387.1		1439.9		41.0		5148.9	
Total stomachs examined	248		483		249		4		984	
Stomachs with food present (%)	88 (35.5)		145 (30.0)		81 (32.5)		1 (25)		315 (32.0)	
Mean av. stomach fullness per tow (g/kg)	4.10 ± 9.89		3.47 ± 3.63		3.82 ± 3.45		6.86 ± 9.70		3.83 ± 7.00	
No. of tows	61		60		20		2		143	

Table 6. Body composition and estimates of rates of food consumption (R), metabolism (T), growth and reproduction (G) and gross production efficiency (K = G/R) of Hoplostethus atlanticus, mesopelagic migrators and bathypelagic non-migrators.

	Hoplostethus atlanticus Juveniles	Hoplostethus atlanticus Adults	Mesopelagic migrators: Stenobrachius leucopsaurus[a]	Leuroglossus stilbius[a]	Lampanyctus ritteri[a]	Lampanyctus alatus (40-44 mm)[b]	Bathypelagic non-migrators: Borostomias panamensis[a]	Lampanyctus regalis[a]	Bajacalifornia burragei[a]	Danaphos oculatus[h]
Minimum depth (m)	750	750	surface	surface	75	40[e]	500	500	1000	450
Maximum SL (cm)	30	>50	8.6	11.8	11.8	6.1[e]	29	19.8	19.8	
Body composition										
% water		67[d]	67	81	71		82	86	89	
% lipid		18	13	6	12		6	2		
% protein		12	11	7	12		4	6		
% ash		3	2	1	2		<1	1		
Caloric value (kcal/g wet wt)			1.82	1.00	1.76		0.70	0.60	0.57	
R (% body weight/d)	0.76	1.08	0.87	0.87	0.87	2.3	0.68	0.68	0.68	1.7
T (l O_2/kg body weight.h)	0.09	0.13	0.07	0.095	0.059		0.017	0.011	0.005	
G (% body weight/yr)	11	15	93[f]	138[f]	102[f]		116[f]	140[f]	105[f]	
K (%)	4.0	3.8	15	23	26		38	52	68	

a Data from Childress and Nygaard 1973 and Childress et al. 1980.

b Data from Hopkins and Baird 1985.

c Data from Clarke 1978.

d Body composition from Vlieg 1983.

e Data from Smith and Heemstra 1986.

f Does not include reproduction.

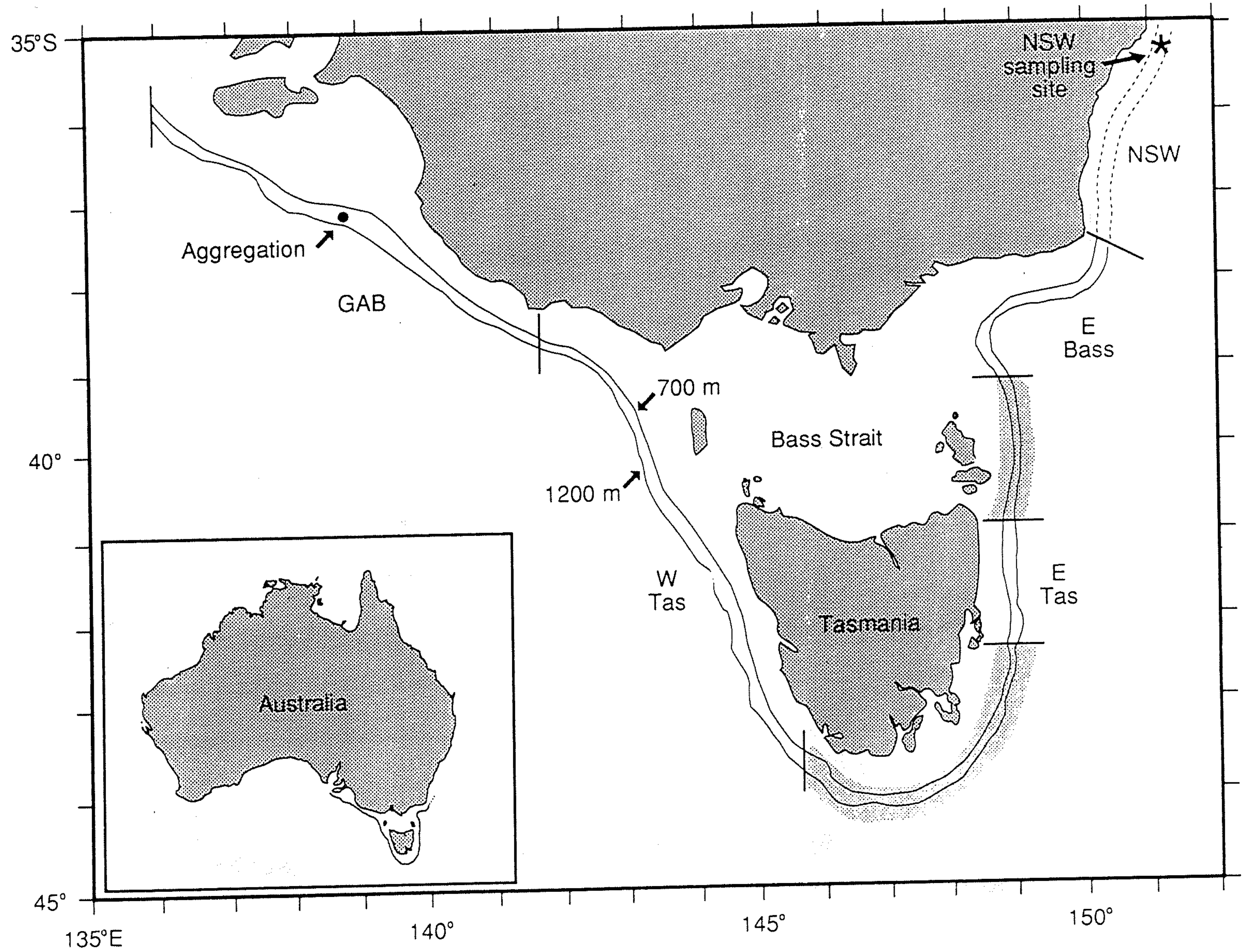


Figure 1. Survey area off southeastern Australia showing the 700 m and 1200 m depth contours, boundaries of the regional survey strata, and location of the orange roughy aggregation. The shaded areas represent untrawlable grounds, which were not surveyed. The NSW sampling station is indicated. (GAB=Great Australian Bight; WTas=West Tasmania and Bass Strait; ETas=East Tasmania; EBass=East Bass Strait; NSW=New South Wales).

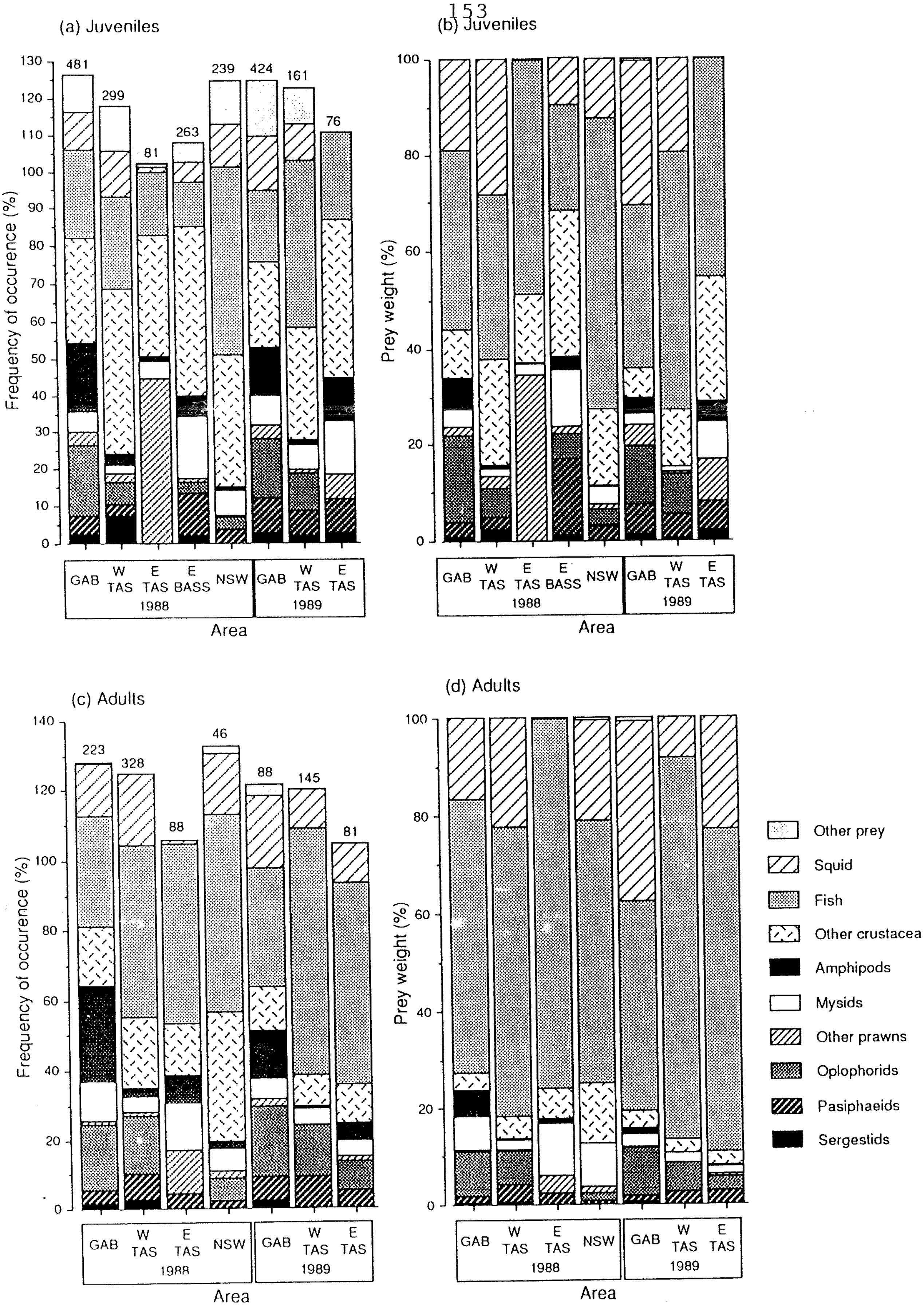


Figure 2. *Hoplostethus atlanticus*. Dietary composition by sampling region based upon (a) frequency of occurrence and (b) total prey weight for juveniles (≤30 cm SL); and (c) and (d) similarily for adults (< 30 cm SL).

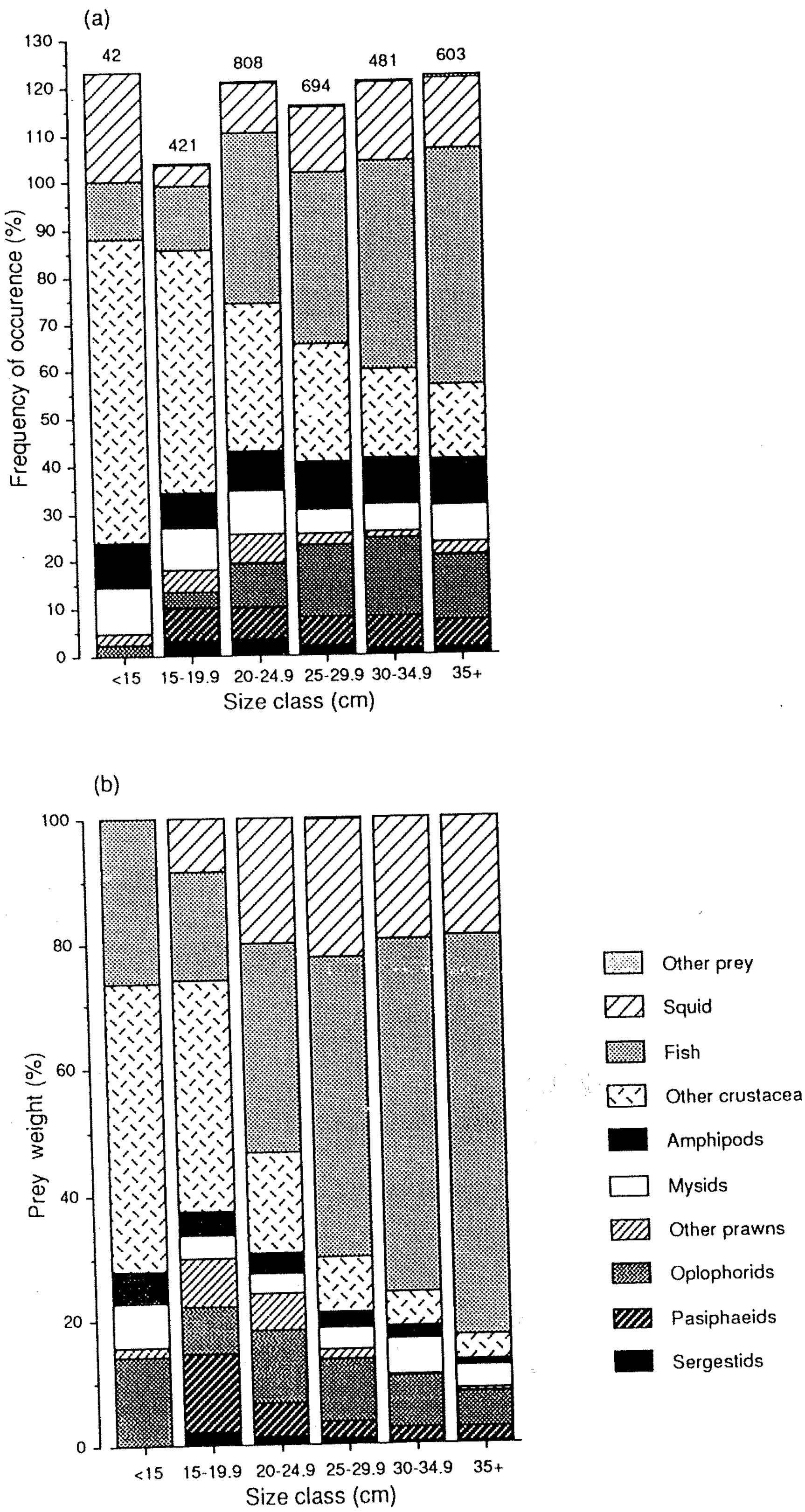


Figure 3. Hoplostethus atlanticus. Dietary composition of size classes by (a) frequency of occurrence and (b) percentage of total prey weight.

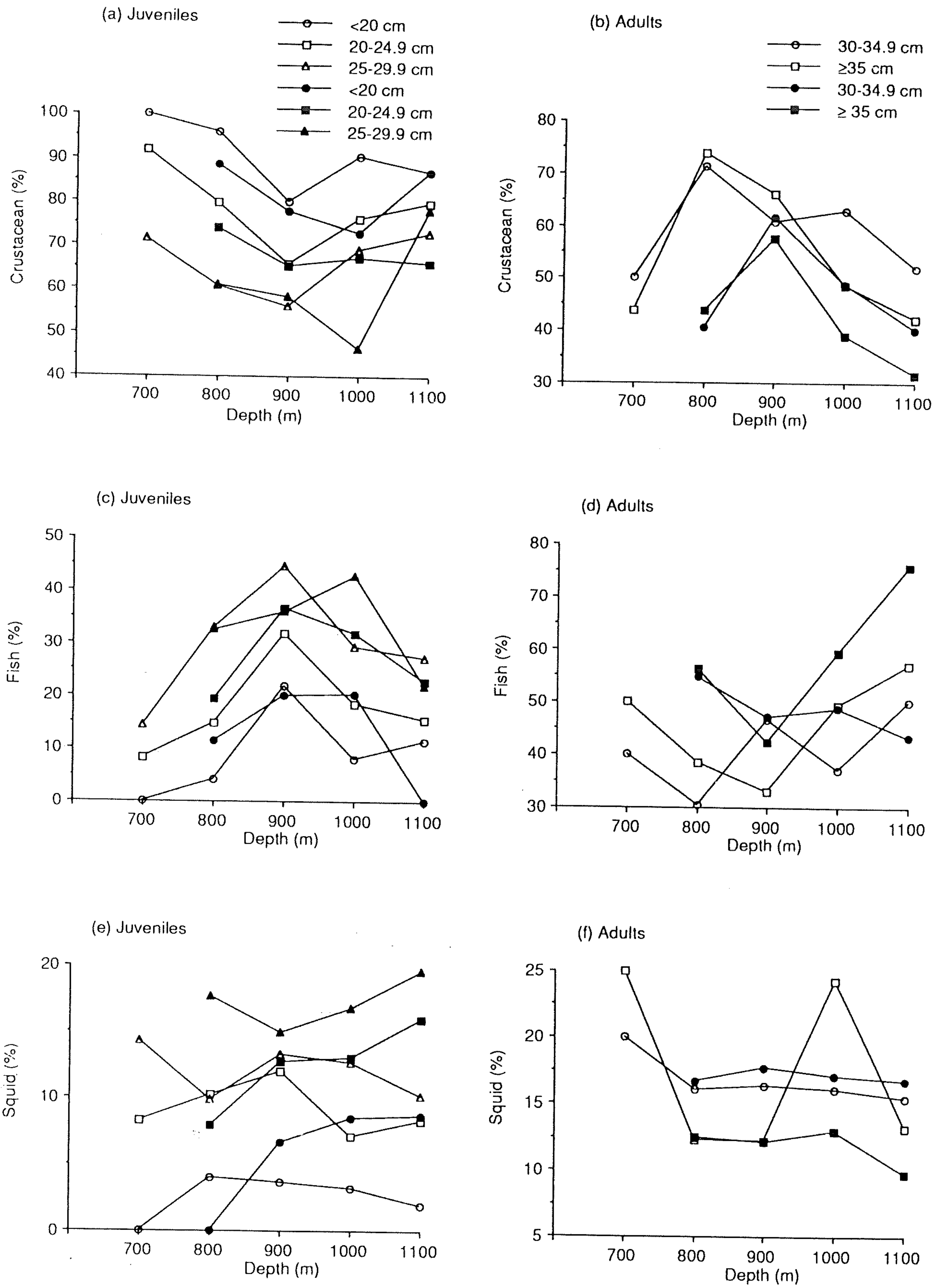


Figure 4. Hoplostethus atlanticus. Proportions of prey in the diet by depth, size, and year (open symbols: 1988; solid symbols: 1989). Consumption of crustaceans by (a) juveniles and (b) adults ; consumption of fish by (c) juveniles and (d) adults ; and consumption of squid by (e) juveniles and (f) adults.

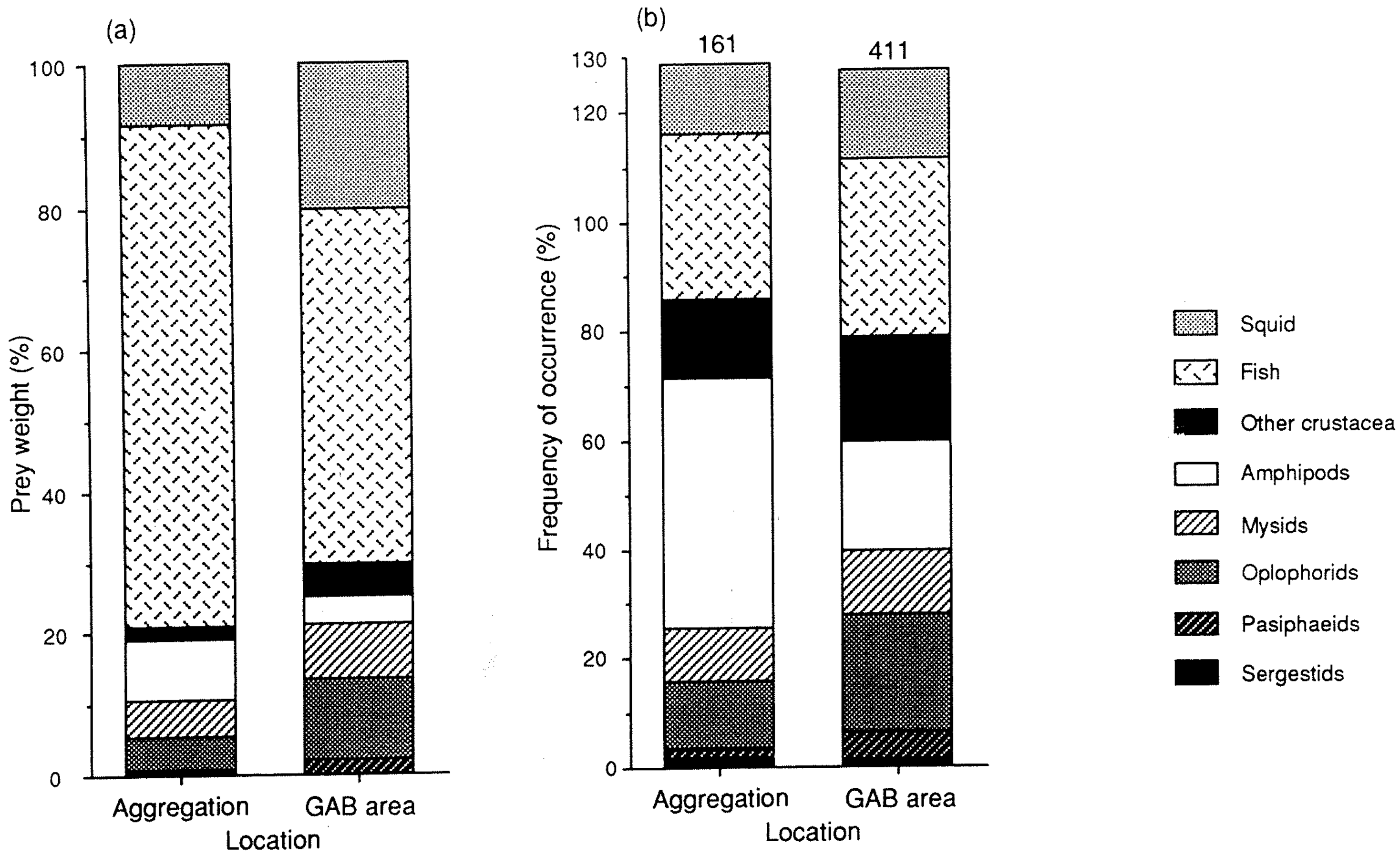


Figure 5. Hoplostethus atlanticus. Comparison of diet of fish from an aggregation in the Great Australian Bight in 1988 and fish from the Bight area excluding the aggregation sites by (a) prey weight and (b) frequency of occurrence of adults (> 30 cm SL).

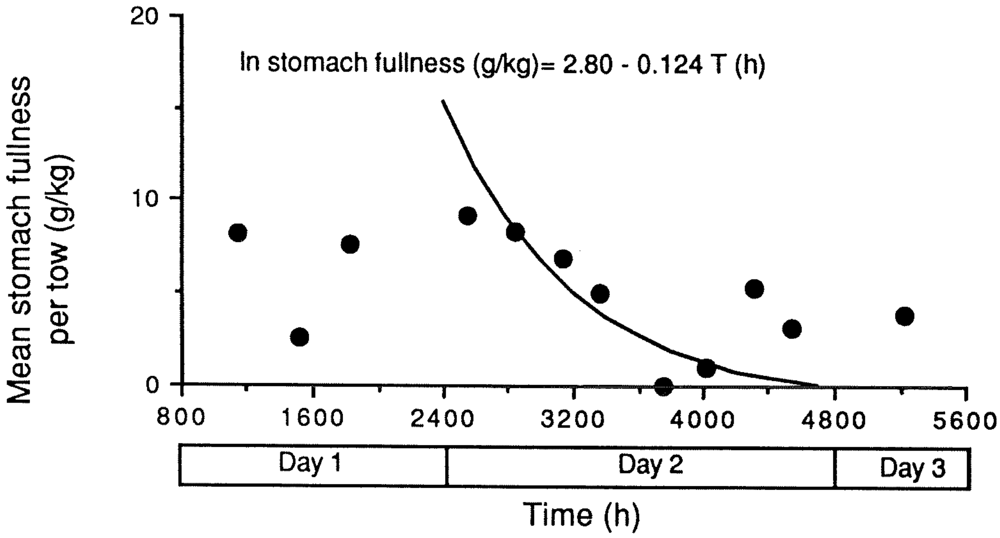
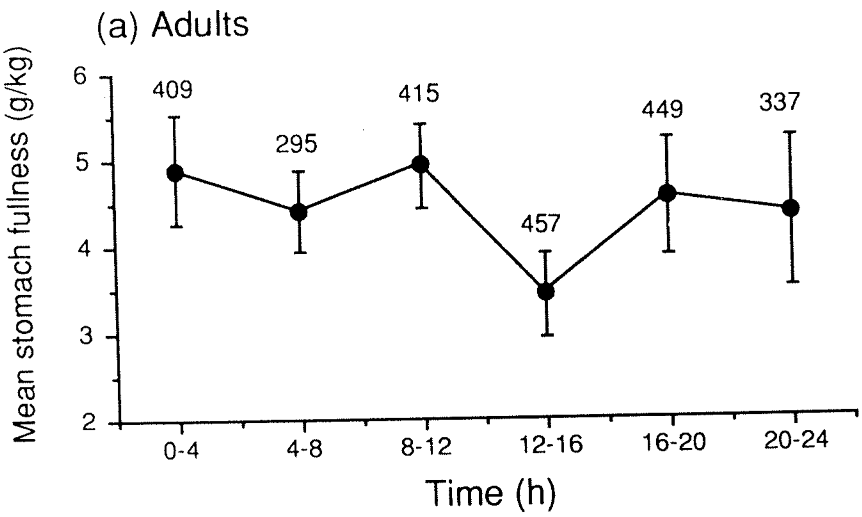


Figure 6. Hoplostethus atlanticus. Mean stomach fullness per tow (g/kg body weight) of adults at the NSW sampling site, showing the regression for the decline in stomach fullness from 0155 h to 1619 h on 17 May 1988 (day 2).



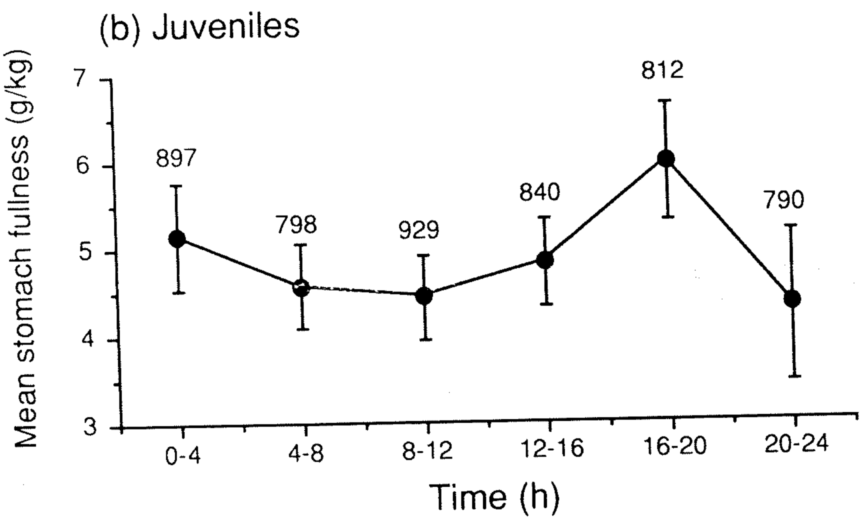


Figure 7. Hoplostethus atlanticus. Mean stomach fullness per tow (g/kg body weight) over 4 h intervals for (a) adults (> 30 cm SL) and (b) juveniles (≤ 30 cm SL).

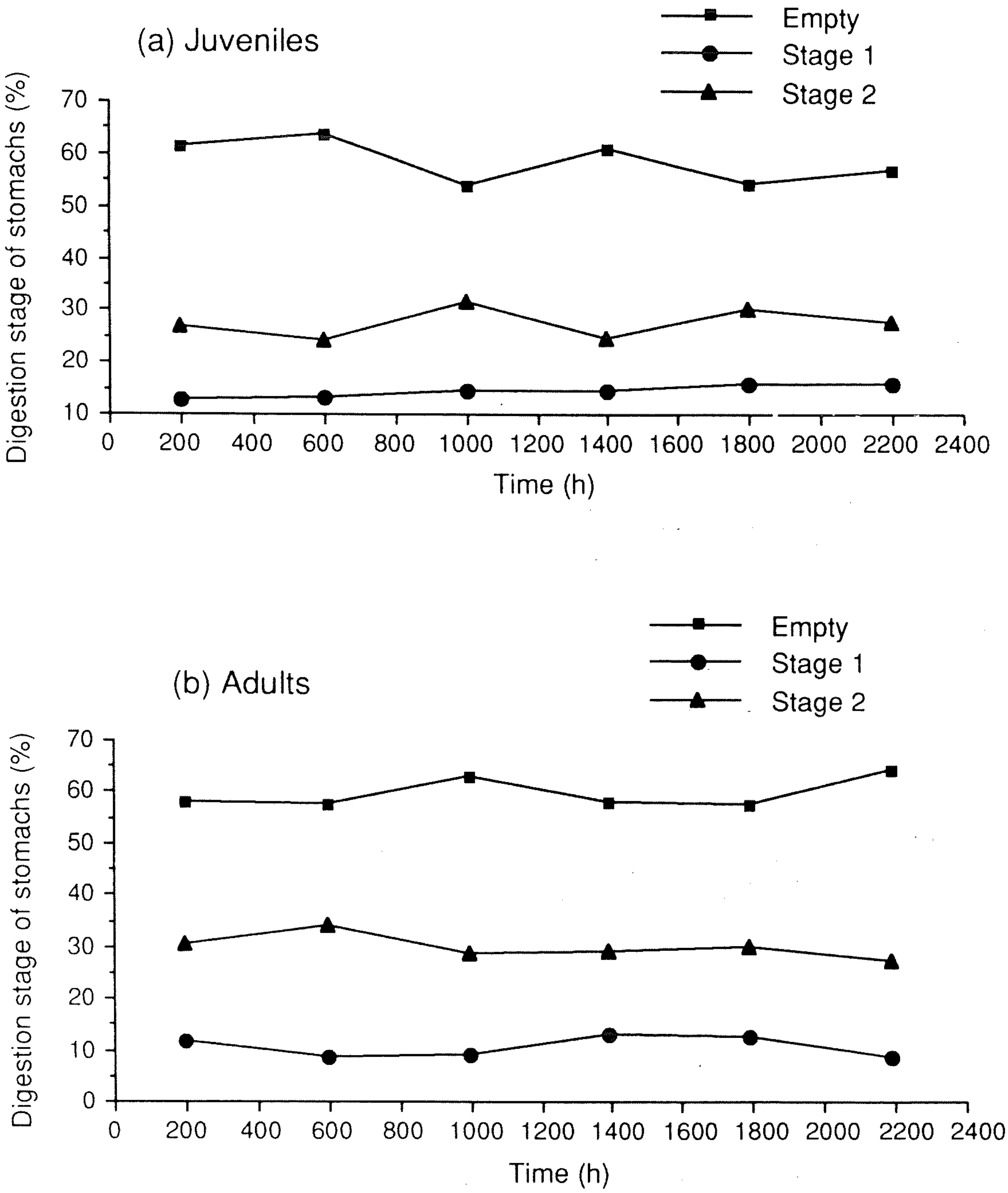


Figure 8. Hoplostethus atlanticus. Proportion of (a) juveniles (≤ 30 cm SL) and (b) adults (> 30 cm SL) at each of three digestion stages by four-hourly intervals: empty; stage 1 (little or no digestion); stage 2 (advanced digestion).

DOCUMENT 7

INTERNAL REPORT

Live holding of orange roughy

(Hoplostethus atlanticus).

C.A.Stanley

Division of Fisheries

CSIRO Marine Laboratories, Hobart

Abstract

Orange roughy can be held alive in holding tanks supplied with iced sea water, but only survive for up to 5 hours. The main problems were too high a water temperature and sediment and oil build up in the tank. Although these problems can be solved by using a refrigerated water system, physiological damage caused by the pressure differences experienced during a tagging operation will still be a problem.

Introduction

As a first step in investigating the feasibility of bringing orange roughy to the surface, tagging and releasing them, selected specimens were held in a deck tank on board FRV *Soela* to observe their condition and survival.

Methods

Fish were selected from the cod end of an Engel high rise net after 30 minute tows and were held on deck in a holding tank, the dimensions of which were approximately 6'x4'x3'.This was one-third filled with sea water and blocks of sea ice were used as required to reduce and maintain water temperatures at as low a level as possible. With the equipment it was possible to reduce temperatures from ambient (14°C to 17°C) to between 8°C and 10°C in about two hours.

As the supply of suitable specimens from fishing operations could never be anticipated and as reducing the holding temperature in the deck tank with ice was a long and time consuming affair, only three experiments were carried out during two cruises.

Results

Experiment 1

Two fish were selected from a catch containing 7 kg of orange roughy. Their condition was poor. They appeared to be paralyzed. many scales were missing, there were only faint gill movements, and they did not feel cold to the touch. The tank was completely filled and supplied with ambient temperature running water (15°C).

0.00 hours (15°C)

Faint gill movements.

0.25 hours (15°C)

Faint intermittent gill movements.

1.00 hours (15°C)

No signs of life.

Experiment 2.

Three fish were selected from a catch containing 15 kg of orange roughy. Their condition was much better than in the previous experiment. They felt much colder to the touch, and although they still appeared to be paralyzed, there were some gill and eye movements. The tank was one-third filled, and had been precooled to 9.5°C. Sea conditions produced a noticeable surge within the tank

0.25 hours (9.5°C)

Weak tail movements in one specimen, other two floating on their sides.

0.50 hours (10°C)

All three specimens exhibiting very weak swimming movements.

1.00 hours (8°C)

All three specimens floating vertically (tails towards the surface), exhibiting weak swimming movements, and attempting to face the tank surge.

2.00 hours (8.5°C)

All three specimens floating vertically (tails towards the surface), and one exhibiting weak swimming movements. One further specimen in the same initial condition as these three added from a fresh shot

2.50 hours (8.5°C)

All four specimens exhibiting weak swimming movements. Fresh specimen not distinguishable from others.

2.75 hours (8.0°C)

All four specimens exhibiting weak swimming movements.

3.15 hours (8.0°C)

Only one specimen observed exhibiting weak swimming movements. Water in tank filling with rust sediment created by wave surge.

4.00 hours (8.5°C)

All four specimens swimming weakly, tails towards the surface. Tank full of rust sediment and much oil has leaked from the fish.

5.00 hours (9.0°C)

All four specimens possibly alive, but weak movements observed may probably be only passive in response to wave surge in the tank. Tank water heavily contaminated with rust sediment and fish oil.

Experiment 3.

Four specimens, showing the most vigorous muscle and gill movements, were selected from a catch of 3.69 tonnes of orange roughy. The holding tank was again one-third filled and had been precooled to 10.5°C.

0.50 hours (9.5°C).

One fish swimming weakly (intermittently), one floating tail up, and two floating on their sides.

1.00 hours (9.5°C).

Two fish swimming weakly, and two floating on their sides.

1.75 hours (9.5°C).

Two fish swimming weakly, more vigorously than in Experiment 2, and two floating on their sides.

3.00 hours (10.0°C).

One fish swimming moderately, and three floating on their sides. Water discoloured with large amounts of fish oil.

3.50 hours (10.0°C).

Two fish swimming moderately, but only in bursts of several seconds, after which they float on their sides. Two fish swimming weakly.

5.50 hours (10.5°C).

Two fish swimming moderately, but only in bursts of several seconds. When removed from the water and replaced, they floated on their sides for approximately one minute and then resumed bursts of moderate swimming, but less powerfully than before. Two fish floating on their sides with no signs of life.

Discussion

There were two main problems in holding orange roughy alive in this set of trials, namely obtaining fish in a suitable condition, and providing a suitable sea water supply.

Even with small catches, eg Experiment 2, the fish obtained were not in reasonable condition. Obvious signs of poor condition (eg missing scales) can be minimized by the selection of specimens from the cod end and could be further improved by lining the cod end, installing escape windows to minimize catch and by restricting the duration of the shot. But physiological signs of damage (the appearance of being paralyzed) were also apparent in all fish that were still alive when retrieved from the cod end. This would have been caused by the reduction in pressure between their normal habitat and the surface.

The sea water supply for these initial experiments was also not ideal. Temperatures, even with the addition of large amounts of ice, could only be maintained in the 8 to 10°C range. These are above the range normally experienced by orange roughy which has been observed to be 3 to 6°C. The build up of rust sediment caused by the constant surge within the tank was also not ideal, and the problem was compounded by the constant leaching of fish oil into the water.

With these problems even when the best results were obtained (Experiment 3) and 50% of the fish were alive after five hours, it was apparent that the possibility for recovering to a reasonable condition were minimal. Although in a tagging exercise fish would be tagged and returned to the sea bed immediately, the above results raise some doubts as to whether the fish would revive.

Despite our apparent lack of success there have been reports of fish swimming in the brine tanks of commercial vessels for periods of up to 24 hours when only a few fish have been held. Based on this it would appear that if fish are obtained in good condition, the major cause of failure in retaining them alive is too high a temperature in the holding tank. A refrigerated water system would provide a constant temperature of a suitable range, and would also eliminate the build up of rust sediment and minimize the leaching of fish oil into the water.

This latter problem is also due to the change in pressure experienced by the fish, and this combined with suspected physiological damage may mean that even if fish are alive when released they may not survive. To investigate this further tests are required, consisting of returning fish which have survived on board to the sea bed in cages and observing survival rates after varying time periods.

DOCUMENT 8

INTERNAL REPORT

A preliminary report on the use of the deepwater stereo camera system.

C.A.Stanley
CSIRO Division of Fisheries, Hobart

Abstract

The density of various fish species groups observed with a camera system attached to the net head line was correlated with the the catch weight of these groups, indicating that the camera provides a comparable record to that obtained from trawl catches. However the correlation for orange roughy was weak and a higher biomass estimate was obtained from the camera than from a trawl survey. This may be due to net avoidance or prolonged swimming in front of the net.

There was a correlation bertween orange roughy catch and the presence of sessile benthos. A similar relationship exists for motile benthos after a small number of samples obtained from previously fished areas are eliminated. Roughy thus appear to be more abundant in areas of locally high organic production, except where fishing has occurred in which case, at least in the short term, adjacent roughy do not move into the area to re-occupy it.

Introduction

A crude estimate of orange roughy biomass in aggregations can be obtained if the dimensions of the aggregation and its packing density are known. Packing density may be measured through the use of a stereo camera with which the position of objects can be calculated in three dimensions, the x,y, and z planes.

To carry this out a Photosea 2000 stereo camera system was purchased in 1988. The system consists of a camera housing (rated to 3000m) containing two 28mm lenses mounted approximately 6cm apart, two 1500watt-second strobes, and a self contained timer system which gives two delay settings, the first allowing time for the system to be lowered to the sea bottom and the second for triggering the camera and firing the strobes at any desired interval.

The system was tested on the last 1988 research cruise in July when it was mounted in a frame attached to the headline of the Engel High Rise net. No aggregations were discovered during the 1989 field work, so the system was used to compare quantities of fish in the photographs to those obtained in the trawl in order to assess possible net avoidance and to investigate the relationship between the density of fish and benthos.

Material and Methods

During the 1989 random trawl survey, the camera system used in a mono mode, was attached to the net headline for many of the trawl shots. 67 films were obtained, mainly from the area between Kangaroo Island and Strahan on the west coast of Tasmania and in depths of between 700 and 1200m. Each film consisted of up to approximately 90 frames taken at 24sec intervals. From a few trial shots in stereo it was determined that objects up to 6m from the camera could be identified and that the area viewed for each frame was $16.8m^2$. For each readable frame of each film the numbers present of the following species groups were recorded:

(a) Easily identifiable fish groups (orange roughy, dories, eels, sharks and whiptails)

(b) Motile benthic species (Starfish, brittle stars, sea urchins, sea cucumbers and prawns)

(c) Sessile benthic species (sea pens, sea whips, sponges, and tentacle crowns protruding from the substrate).

For the analyses the basic data unit derived from this information for each film was the mean number sighted per frame read. To investigate relationships between fish caught and both sighting rate and the presence of benthos, films where less than 50 frames were readable were discarded.

Results

The relationships between trawl catch of species groups and the corresponding number of fish sighted per frame for each of these groups are listed in Table 1, and the relationships for eels and orange roughy are illustrated in Figs.1 and 2. Although all are significant, the probability level for orange roughy is lower than for the other species. Thus the variance explained ranges from 45 to 82% for other species groups, but is only 14% for orange roughy (Table 1). There are a number of zero sightings for orange roughy with increasing catch weight in comparison with other species groups and also several instances of large sightings and only average catches (compare Figs. 1 and 2).

The correlations between fish caught and sessile and motile benthic organisms observed, also expressed as the number of individuals sighted per frame, are listed in Table 2. The only significant relationship is between orange roughy and the presence of sessile benthos. However a noticeable feature of the data scatter in the orange roughy and motile benthos relationship is the presence of 6 outlying points where large numbers of motile benthos were sighted (from 0.5 to 1.4 individuals per frame read) and orange roughy catches were low (Fig.3). If these data points are omitted from the analyses (Table 2), a significant relationship is also obtained between orange roughy catch and the presence of motile benthos. All samples were obtained, among others, from a restricted area to the south (one sample) and south west (five samples) of Portland, Victoria.

For 67 films data were also available from the random trawl survey (**Document 1**), and a comparison of abundance from the two data sources was made. For each film the total area observed (number of frames read x area viewed in each frame (16.8 m^2)) and the number of orange roughy were noted. Density estimates (numbers of fish per m^2) were then obtained for each of the six areas listed in Document 1 in two ways, by averaging the estimates derived from each sample, or by dividing the total number of roughy sighted by the total area viewed. The resultant densities were raised to fish weight per km^2, using a conversion of 0.8109kg per fish (the average weight of fish sampled during the trawl survey) and listed for each area (Table 3). Both methods resulted in density estimates 1.7 and 2.5 times higher, than for the random trawl survey.

Discussion

For the data presented the camera system was not used independently, but was attached to the head line of the Engel High Rise net. Most of the results are thus a comparison of what was seen as against what was caught. The camera suffers the disadvantage in that each frame views only a small area (16.8m^2), and even though many frames are taken during each net shot, the resultant total area viewed is much less than the area swept by the net. This total area viewed is reduced by further factors. Occasionally the timer delay did not start the system when the net started fishing, or started it while still in the water column and thus the camera ran out of film before the end of the tow. Tension on the net head line can also intermittently swivel the camera in the frame so the standard oblique view of the sea bed was not obtained - often the camera pointed up into the water column. Occasionally sediment stirred up the the trawl doors obscures the entire field of view. As a result of these factors some films had many unreadable or missing frames. Even after discarding films with less than 50 readable frames, variances in the resultant data sets were large. Despite these factors, highly significant relationships with a large amount of the variance explained were found between camera sightings and catches for all species groups examined, except for orange roughy, indicating that what is seen on the film frame is comparable to what is caught. The amount of the variance taken into account for orange roughy is much lower even in comparison with dories, a species group which occupies much the same habitat as roughy, occurring both on the bottom and up in the water column for feeding. So although there is a significant relationship between the number of roughy sighted and the net catch, it is a much weaker one than for the other species. There could be several explanations. The avoidance reaction to the approaching net may be variable, or there may be escapment under or around the ground line or the roughy may be aggreagated, which would increase the variance.

The relation between roughy catch and the presence of sessile benthos indicates that roughy are more abundant in areas where organic production levels are high, in contrast to the other species groups. A relationship should also exist with the presence of motile benthos. Although this was not true in the first instance, a significant relationship does exist when 6 data points representing high benthos sightings but low roughy catches are removed. The stations were these samples were obtained were all in the Portland area where small aggregations of orange roughy had been fished the previous year. The motile benthos may have been aggregating on organic debris left from the fishing operations. Sea cucumbers and sea urchins in particular are known to behave in this fashion. If so it would appear that once a spot favored by roughy is fished, animals do not move in from surrounding areas, at least in the short term, to re-occupy it.

Despite the small area surveyed by the camera during each operation in comparison to the area swept by the Engel net, camera abundance indices are higher by factors of between 1.7 and 2.5. This may be due to avoidance of the trawl, in which case the trawl abundance estimates should be increased by this factor. However it may also result from the roughy swimming in front of the net and accumulating there before tirying and falling back into the net.

Table 1. Relationships between net catch (kg) and camera sighting rate (number of fish per frame) for various species groups. (n=66).

Species	Minimum and maximum values		r^2	Probability
	net catch	camera sighting rate	value	level
Dories	18 - 500	0 - .276	.791	.0001
Eels	0 - 98	0 - .576	.624	.0001
Sharks	0 - 315	0 - .137	.646	.0001
Whip tails	2 - 115	.022 - 1.225	.530	.0001
Orange roughy	0 - 80	0 - .167	.131	.0031

Table 2. Relationships between net catch (kg) and camera sighting rate of motile and sessile benthos (number of benthic items sighted per frame) for various species groups. Two sets of figures are listed, a) for all data (n=65), and b) with the omission of 7 samples (see text for discussion).

MOTILE BENTHOS

	(a)		(b)	
Species	r^2 value	Probability level	r^2 value	Probability level
Sharks	.004	.6340	.005	.5951
Whip tails	.023	.2251	.002	.7183
Dories	.004	.6214	.022	.2679
Orange roughy	.0002	.9005	.198	.0005
Eels	.017	.3007	.013	.4024

SESSILE BENTHOS

	(a)		(b)	
Species	r^2 value	Probability level	r^2 value	Probability level
Sharks	.015	.3299	.015	.3590
Whip tails	.008	.4914	.007	.5339
Dories	.011	.4119	.010	.4509
Orange roughy	.261	.0001	.295	.0001
Eels	.004	.6032	.004	.6376

Table 3. Abundances (tonnes per area) for each of six geographic areas obtained from a random trawl and a camera survey. For the camera survey abundances were obtained both by averaging and by summing all samples within an area.

Area	Sample Size	Random Trawl Survey	Camera Survey	
			averaging	summing
1	9	162.8	786.5	853.2
2	14	748.6	1682.7	2310.7
3	22	4381.5	11108.6	5475.0
4	15	707.5	2403.8	1826.0
5	4	303.6	300.6	235.4
6	3	816.0	1620.2	1374.6
Total		7120.0	17902.4	12074.9

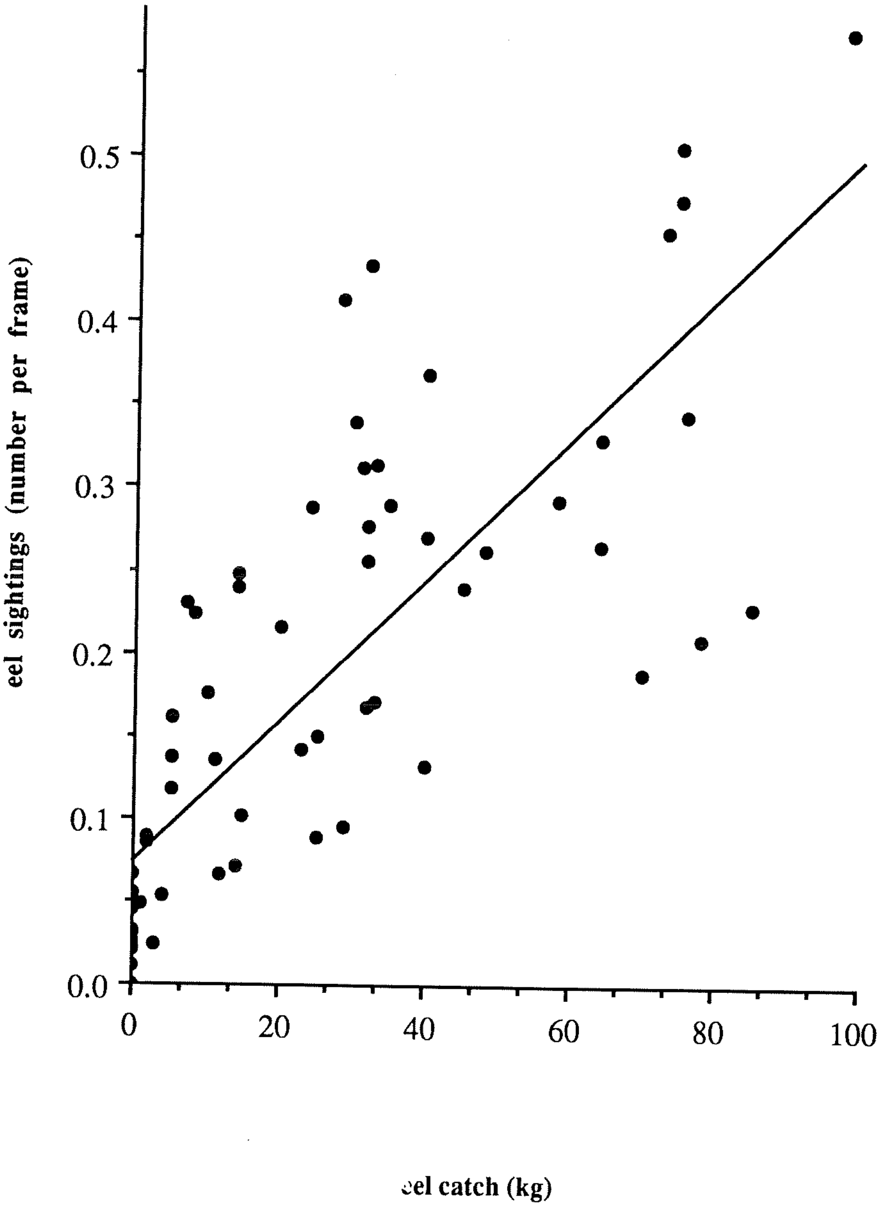


Fig. 1. The relationship between net catch and camera sighting frequency of eels.

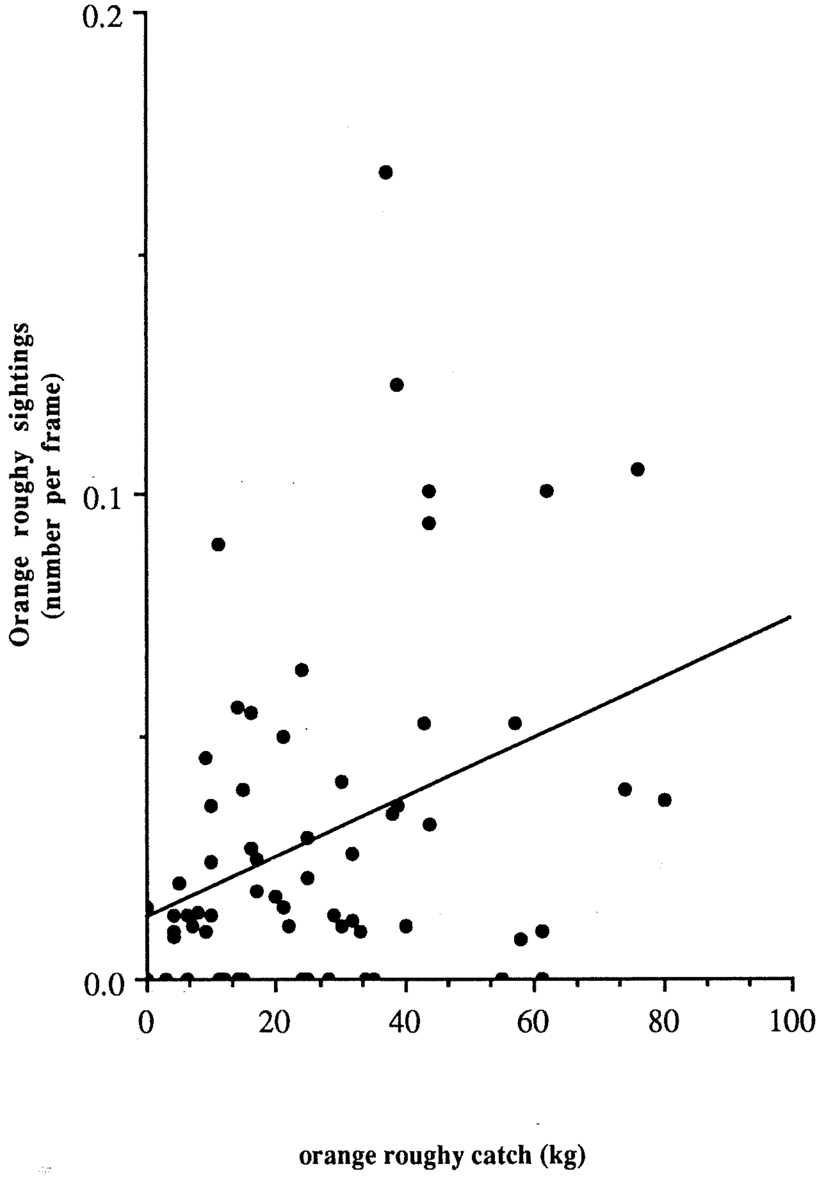


Fig. 2. The relationship between net catch and camera sighting frequency for orange roughy.

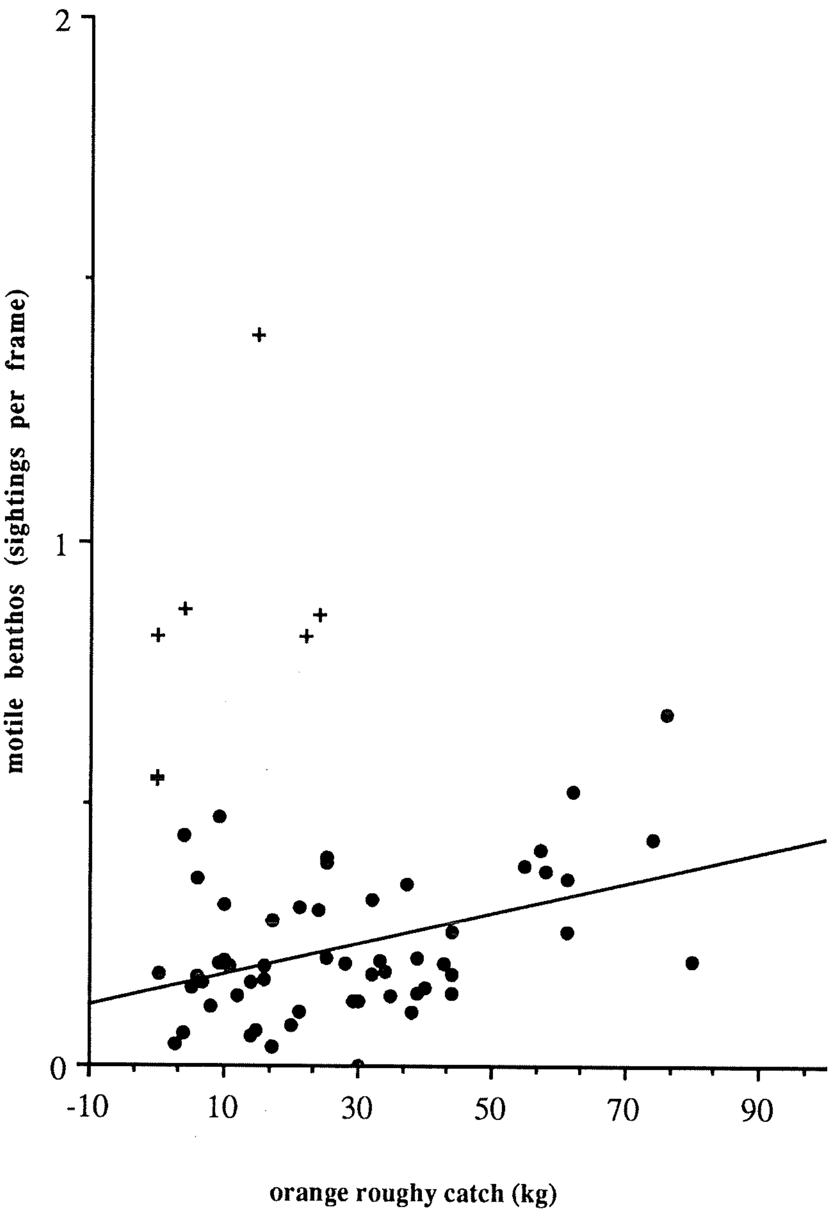


Fig. 3. The relationship between orange roughy catch and camera sighting frequency of motile benthos. Points displayed as crosses are discussed in the text.

DOCUMENT 9

CSIRO MARINE LABORATORIES REPORT

DRAFT

CSIRO MARINE LABORATORIES REPORT

Comparison of Acoustic and Trawl Results of the 1989 CSIRO Deepwater Survey in Southeast Australian Waters

Elliott, N.G. and Kloser, R.J.

CSIRO Division of Fisheries, Hobart

Abstract

Demersal trawl catch and echointegration data taken during a deepwater demersal trawl survey of southeastern Australian waters are compared. Trawl catches showed a dominance by deepwater sharks which proved to be the main catch component affecting the acoustic returns. Whilst a very low direct correlation between trawl and acoustic data was obtained in this study, this can be partially explained by the high degree of heterogeneity in the catch composition. There were also limitations on the acoustic data obtained using a single-beam system, as well as a lack of target strength information for the species concerned. The results, however, do suggest that it may be possible to use acoustics to not only identify fish schools but also estimate the biomass of demersal deepwater fish stocks in a multispecies fishery. Results also suggest that previously published mean target strength figures for the orange roughy may be too high.

Introduction

The objective of this study was to compare the results from acoustic transects with trawl catch data obtained from demersal tows over the same area. The study was undertaken as part of the 1989 CSIRO random deepwater trawl survey for orange roughy (*Hoplostethus atlanticus* Collett 1889) on the continental slope (800 - 1199 m) in southeastern waters of Australia (Bulman et al 1991). The area surveyed consists of a multispecies fishery with large aggregations of orange roughy dominating the fishery in various areas and at certain times of the year.

Dickie et al (1984) have reported comparable acoustic and net sampling estimates of demersal fish densities from laboratory and shelf water (100 m) studies using a dual-beam transducer. Species classification of schooling fish was deemed possible using acoustics in areas of low species diversity by Rose and Leggett (1988), yet differentiation between species in a multispecies fishery has yet to be determined.

Target strength information for the species present in this Australian multispecies deepwater fishery have yet to be obtained. Thus reliable acoustic estimation of fish density is not possible in this study. Likewise, reliable density estimates using the trawl net are subject to numerous errors in relation to the volume of water swept by the trawl gear. Wing spread and mouth opening can be monitored during a trawl but there is considerable variance in these during the tow depending on towing and bottom conditions. Catchability, or behaviour towards the trawl gear, of the deepwater species in this fishery are also unknown. Therefore in this study we aimed to standardize our sampling procedures in order to minimize the effects of some of these uncertainties, and attempted to compare estimates of relative fish densities as sampled by the two independent procedures.

A reliable comparison of these two methods would enable researchers to better utilize acoustics in large scale deepwater fish surveys, possibly increasing the effectiveness and efficiency of the surveys. Regular sampling by trawling during the survey would still be required to obtain species composition and fish sizes.

Materials and Methods

Equipment

The trawling and acoustic measurements were conducted from the FRV *Soela* (Table 1). An Engel high-rise bottom trawl was used throughout the survey, rigged for rough bottoms with no lower wings (Table 2).

A Simrad EK400 scientific echo-sounder was coupled to a 38 kHz (Simrad 38-29/25-E) hull-mounted transducer and a modified BioSonics 121 echo-integrator. The system configuration is shown in Figure 1. A modified TVG amplifier was designed to cover the depths and water absorption ranges of concern in this study.

A Furuno 50 kHz/75 kHz net recorder was used on all trawls, to provide information on headline height above bottom, and actual net-time on the bottom.

Survey Positions

The area covered by the depth-stratified random trawl survey was from south of Kangaroo Island (136°E) to the northeast coast of Tasmania (148°E) (Figure 2). The continental slope between 800 m and 1199 m (7,165 km^2) was divided into four 100 m depth strata and survey positions were randomly allocated in each at a rate of 1 per 30 km^2. The number of positions was allocated in proportion to the area within each stratum, all ground was assumed trawlable and the abundance and degree of aggregation of fish was assumed to be the same in all strata (Bulman et al. 1991).

Three cruises were conducted in order to complete the survey - SO1/89 (January - February), SO2/89 (March) and SO3/89 (April - May).

Station data

Station logs for each occupied survey position recorded such details as position and time at completion of paying out trawl gear, time of net reaching bottom, position and time of net leaving bottom, wind direction and force, direction and height of sea and swell, vessel speed, direction of tow, and net headline height above bottom.

Catch data

A 30 minute, bottom time, demersal tow was attempted at each survey position. Actual time on bottom for the net was recorded using the headline net recorder. Tows of less than 15 minutes bottom time were not included in calculations. The total catch from each tow was sorted and weighed, by nine major catch components, these being:

Roughy (*Hoplostethus atlanticus*)

Morids (e.g. *Mora moro, Halargyreus johnsonni*)

Macrourids (e.g. *Lepidorhynchus denticulatus, Coelorinchus spp. and Coryphaenoides spp.*)

Dories (e.g. *Neocyttus rhomboidalis, Allocyttus verrucosus*)

Eels (e.g. *Diastobranchus sp.*)

Sharks (e.g. *Deania calcea, Centroscymnus spp.*)

Slickheads (*Alepocephalus spp.*)
Other commercial species (e.g. *Macruronus novaezelandiae)*
Others.

For each station the trawl catch was standardized by conversion to a catch rate. Two catch rates were calculated - catch per time (of net on the bottom) expressed as kg per hour, and catch per swept area of the tow expressed as kg per km^2. The swept area was calculated from:

swept area = speed of tow(knots) x 1,852 (m per nm) x tow duration
(bottom time, mins) x 1/60 x 19 (ave. wing spread in m).

A biomass estimate for each catch component for the area surveyed was obtained from the product of the mean catch rate and area surveyed. It was assumed in calculating these estimates that the accessibility of the fish to the net was 100% and there was no escapement or avoidance by fish from the effective path swept by the net, which was equal to the measured wing spread.

Acoustic theory

The application of acoustic methods to abundance estimates of fish is summarized by Johannesson and Mitson (1983). An appropriate acoustic pulse is transmitted through the water column and the corresponding echo recorded. A 'time-varied-gain' (TVG) amplifier applied to each returned echo compensates for the spreading and absorption loss of the acoustic pulse in the water column. The amplitude of the returned signals therefore are independent of the distance of the target from the transducer. The strength of the returned echo is termed the volume backscattering strength (Sv, in dB re 1μPa), and is defined as the proportion of incident acoustic energy reflected back towards the transducer by targets within a unit volume of water. It is related to the voltage measured across the transducer by the logarithmic equation:

$$Sv = VRT - (SL + SRT + G) - 10 \log c\tau/2 - 10 \log \psi + (20 \log R + 2\alpha R) \qquad 1.$$

where, VRT = voltage measured across transducer (20 log V in dB re 1 volt)
SL = source level (dB re 1μPa)
SRT = receiving sensitivity of transducer (dB re 1 volt μPa^{-1})
G = gain constant of system
c = sound velocity (m s^{-1})
τ = pulse length (ms)
ψ = two-way equivalent beam width of transducer (steradian)
R = range from transducer to target volume (m)
α = absorption coefficient of sound in water (dB m^{-1})
(modified from Johannesson and Mitson 1983).

The values for SL, SRT and G were determined from calibration data. The absorption coefficient and the speed of sound in sea water were calculated using data obtained from CTD casts conducted at regular intervals during the survey and using the formulae of Francois and Garrison (1982a, b) for α and MacKenzie (1981) for c. The two-way equivalent beam width, ψ, of the transducer was obtained form the specification sheet with a possible deviation of $\pm$ 1.1 dB. The acoustic system was calibrated on three occasions (at the start, mid-way through and at the end of the survey) using a standard 60 mm copper sphere and the method described by Foote et al. (1983). Calibrated system parameters and EK400 settings used during the survey are presented in Table 3.

The output signal from the sounder is passed to an echo-integrator where the mean volume backscatter strength (MVBS, in dB re m^{-1}) is obtained by integrating Sv over a number of predetermined transmissions and in a number of predetermined depth layers. MVBS is proportional to the mean number of organisms in the volume insonified (n_v, in fish m^{-3}):

$$MVBS = 10 \log n_v + TS \qquad 2.$$

where TS is the mean target strength of the individual organisms (dB re m^2). Target strength of an organism is the ratio of the reflected (echo) intensity at 1 m from the organism to the incident intensity which strikes it. Target strength of fish is proportional to their back scattering cross-section and body length.

The relationship between target strength and fish size is a complex relationship and dependent upon fish behaviour and species specific factors such as morphology and presence or absence of gas filled swimbladder. Two standard equations relating target strength to fish length and wavelength (λ) are provided in Johannesson and Mitson (1983):

Love (1971)	$TS = 19.1 \log (\text{length, m}) + 0.9 \log \lambda - 23.9$
McCartney and Stubbs (1971)	$TS = 24.5 \log (\text{length, m}) - 4.5 \log \lambda - 26.4$.

Acoustic data

Echo-integration was performed over eight consecutive acoustic pings and in 25 two metre depth-layers above the bottom window. The bottom window is the depth interval around the last known bottom depth within which the sounder searches for the next bottom echo. A bottom window of either 4, 6 or 8 m was programmed into the integrator depending on the perceived changes between successive signals of the bottom depth; thus the depth of the bottom layer was either 2, 3 or 4 m..

At each survey position integration of the acoustic signal was performed from the time of shooting the trawl gear to the time of hauling. A 30 minute time period (approximately 96 integrated intervals) of relatively constant vessel speed was later selected for analysis.

Ambient noise measurements were recorded with the transducer in passive mode at each station. The maximum noise measured referred to 900 m (the average bottom depth) was -85.9 dB (= 3.16×10^{-4} $V_{TVG}{}^2$). Maximum noise has been allowed for in all data analyses.

Due to the water depth and slope of the bottom experienced during the survey, two factors affecting the accuracy of the acoustic data must be considered. Firstly, the dead zone, caused by the geometry of the acoustic beam, which exists close to the sea bed and within which no target detection is possible.The closest point to the sea bed at which detection/estimation of fish is possible is equivalent to half the physical length of the transmitted pulse ($c\tau/2$; Johannesson and Mitson, 1983), which in this study was 2.25 m. This is the minimum height of the dead zone at the axis of the transmitted beam, the height increasing with increasing angle from axis, and with increasing slope of the sea bed. This source of error has been disregarded in the following analyses as it was variable along each station transect and there was no information available for estimating either the extent of the zone or the fish density in the zone.

The second factor concerns the elimination during data processing of false bottom echoes. This was achieved by both simultaneous visual evaluation of the echograms and the integration data, and via the following routine. Maximum change in voltage recorded between successive mid-water integrated layers was found to be less than a factor of five (in V_{TVG}^2). Bottom layer data was then discarded if there was a greater than five-fold increase in voltage between bottom layer and the layer above.

The output data from the echo-integrator consisted of the mean square value of the voltage measured at the transducer following TVG compensation (V_{TVG}^2). The average V_{TVG}^2 during the selected 30 minute interval, with noise and bottom effects removed, was then calculated for individual depth layers and for combinations of depth layers for each station, and these were then converted into MVBS using Equation 1 and the system parameters shown in Table 3.

Comparison of trawl and acoustic data

Whilst the acoustic measurements were taken simultaneously with the trawling operation there is no attempt to obtain direct comparison of trawl-densities with acoustic-densities. This is due to the uncertainties associated with both methods as described above, and due to the uncertainty of the position of the trawl gear in relation to the vessel's path. The trawl gear when 1800 m to 2600 m of warp is paid away is likely to be out to one side of the vessel's path depending on wind, sea, current and tidal influence. Hence direct comparison between the acoustic (hull mounted) transect and the trawled transect is not feasible, but rather a standard representation of the relative fish density in the area is provided by each procedure.

The degree of linear relationship between the acoustic data, expressed as MVBS in dB, and the trawl data, expressed as catch rate in kg/hr, was analysed using the correlation coefficient. The total catch rate and that for each catch component from each station were analysed with the mean MVBS from individual integrated depth layers and combinations of depth layers for that station. The distribution of the catch rate data was found to violate the assumption of normality and so the data was subjected to logarithmic transformation which provided normality, i.e. normal statistics were applied to log(X) or log(1+X), where X is the observed catch rate. As each component of the catch, due to different acoustic properties in terms of target strength, was likely to have a unique effect upon the MVBS at each station the data were further analysed using a multiple regression model. This model assumes that the individual catch rates may predict more variance collectively than each could predict independently. A forward stepwise regression model was also used in the analyses. This model attempts to produce the most efficient regression equation with the smallest number of variables (catch rates), and predicting as much of the variance of the MVBS as possible from the combination of individual catch rates.

Results

177 random stations were occupied during the survey; of these 153 were valid stations for this study. A valid station was one at which both a demersal tow and echo-integration of the near bottom water column were performed. Of the 24 invalid stations, 14 were due to aborted shots, gear damage, or the net fishing incorrectly, 9 had no acoustic data, and one was deleted with corrupt acoustic data due to ship movement in a swell of 3-4 m.

Trawl data

Of a total catch of 43,338 kg from the 153 trawls, orange roughy was the dominant species caught with a total of 13,931 kg (Table 4); however, 69% of this amount was taken in only four trawls. The dominant species group in the survey was the sharks, representing a mean 23% of each catch (Table 5). The sharks were the main component in 50 tows, with the dories the main component in a further 40 (Table 6). The macrourids were the only catch component present in all tows, and were the main component in 22.

A single catch component made up more than half of the total weight in 22% of the tows. These comprised the four large catches of orange roughy, plus 15 dominated by sharks, 13 by dories and one each by eels and macrourids (Table 7). Biomass estimates for the area surveyed for each catch component are shown in Table 8.

The dominance of the shark component of the catches was only present in tows in the 800 m and 900 m depths, with the dories predominating in the deeper tows (Tables 5 and 6). The sharks constituted an average of 42% of each catch in the 800 m depths and 28% in those taken in the 900 m depths, but only 8 to 11% in deeper trawls. Dories made up an average of 27% of each catch in the 1,000 m depth zone and 23% in the 1,100 m zone. Also more prevalent in the deeper trawls were the eels comprising 22% of each catch in the 1,100 m depths. The macrourids and orange roughy were relatively consistent components of all catches at all depths (16% and 14% respectively).

Individual trawl catch rates covered three orders of magnitude, ranging between 14 to 11,250 kg per hour bottom time. Of the 153 tows 66% had catch rates of less than 500 kg/hr, and 88% less than 800 kg/hr. 29% of catch rates were between 150 to 300 kg/hr and a further 20% between 400 to 500 kg/hr. The four highest catch rates (all > 2,000 kg/hr) were for the orange roughy dominated catches. Two other tows had a catch rate greater than 1,000 kg/hr, one dominated by a combination of dories and sharks and the other dominated by a combination of sharks and orange roughy. Of the 40 highest catch rate stations (>600 kg/hr), sharks were the main species in 19, dories in 10 and roughy in 6. The mean catch rates shown in Table 4 again demonstrate the dominance of sharks in the catches from the 800 m and 900 m depth zones, with an increase in the presence of dories and eels in the two deeper zones.

Generally, significant ($p<0.001$), but low correlations were found between the catch rates (with log(1+X) transformation) of the individual catch components. The highest positive correlation was 0.49 for shark and morid catch rates, with other relatively high coefficients for slickheads and eels (0.43), and sharks and roughy (0.41). A relatively high negative correlation of 0.55 was obtained for shark and eel catch rates, and 0.47 for morid and eel catch rates.

No day/night variation was observed for catch rates.

Acoustic data

The highest MVBS value per integrated depth layer at all but seven stations was for the bottom layer. The other seven stations had maximum values for midwater layers such as Layer 10 (20 m above the bottom layer); there was nothing significant about the catches from these seven stations. The general trend, however, was for a decrease in mean MVBS with increasing water column height integrated above the bottom, as shown in Figures 3a and 3b. Stations at which sharks were the main component of the trawl returned significantly (ANOVA, $p = 0.0001$) higher mean MVBS than other stations. This difference was more pronounced in the midwater layers, rather than close to the bottom. Of the 30 stations with the highest MVBS values for the total depth integrated (56 m), 90% had sharks as the main component of the catch. Whilst sharks were the main component in only 64% of the 31 stations with the highest MVBS values in depths from the bottom up 20 m (18% had macrourids and 14% dories), and in only 54% of the 28 stations with highest MVBS in depths from the bottom up 4 m (16% had macrourids and 10% roughy).

For the total depth integrated, the mean MVBS at each station ranged from -85.0 dB to -68.0 dB, with 41% of the stations having values between -77.9 dB and -75.0 dB. The mean V_{TVG}^2 for the total depth integrated for the 153 stations was 0.008496 (s.e.

± 0.000535), which converts to a mean MVBS of -74.6 dB (s.e. ± 0.3 dB). Other mean MVBS values for varying integrated depths are:

Bottom to layer 2 (8 m)	-72.6 (± 0.3) dB
Layers 1 to 2 (4 m)	-73.7 (± 0.2) dB
Bottom to layer 4 (12 m)	-73.3 (± 0.2) dB
Layers 1 to 4 (8 m)	-74.1 (± 0.2) dB
Bottom to layer 10 (24 m)	-74.1 (± 0.2) dB
Layers 1 to 10 (20 m)	-74.6 (± 0.3) dB
Layers 1 to 26 (52 m)	-74.9 (± 0.3) dB.

The mean V_{TVG}^2 at each station, for the entire depth integrated (56 m), was found to decrease with increasing bottom depth of the station (Table 9).

Comparison of acoustic and trawl data

Correlation

Significant but low correlations (<0.35, p<0.01) were obtained between the mean acoustic values and the trawl catch rates per station, for any depth interval considered, and with log transformation of the data. The highest values recorded were for the greatest depth integrated.

The only relatively large correlation coefficient was for the correlation between the mean MVBS and shark component catch rates . The correlation coefficient for the MVBS of the total depth integrated and shark catch rate (with log(1+X) transformation) was 0.63, suggesting approximately 39% of the variance in the MVBS may be explained. The linear regression model (F = 98.35; DF = 1, 151; p = 0.0001) is:

$$\text{MVBS} = 3.30 \text{ Log}(1+ \text{Shark catch rate}) - 81.46.$$

The correlation between shark catch rate and MVBS increased with depth off the bottom integrated. For example for the integrated depth from the bottom to 4 m above the bottom layer a coefficient of 0.42 was obtained, while for the depth from the bottom to 20 m above the bottom layer the coefficient was 0.57.

Figure 4 shows the general trend for an increase in total catch rate with increase in MVBS. This trend is shown for the individual catch rates of sharks (Figure 5a), morids and macrourids, while a negative slope is obtained from the catch rates of eels (Figure 5b) and slickheads. Catch rates for dories and orange roughy showed no variation with MVBS.

Very low (but significant, $p<0.01$) correlation coefficients for component catch rates and total MVBS were obtained when stations were grouped by depth interval, the highest catch component correlations per depth zone were:

800 m	40 stations	Sharks = 0.50
900 m	38 stations	Sharks = 0.61
		Orange Roughy = 0.54
1,000 m	46 stations	Macrourids = 0.36
1,100 m	29 stations	Macrourids = 0.49

Multiple regression model

The multiple regression model for the individual catch rates (log(1+X) transformed) of the nine catch components with the mean MVBS for the full depth integrated (56 m) accounted for a statistically significant portion of the variance ($F = 18.53$; $DF = 9, 143$; $p = 0.0001$). The adjusted R-squared value indicating approximately 51% of the variance was accounted for by the regression model. Whilst the mean MVBS for the other combinations of integrated depth layers returned significant ($p = 0.0001$) multiple regression models, the proportion of variance accounted for was not as high as that returned for the mean MVBS for the full depth integrated; the proportion accounted for increased with the depth integrated. For example, compared to full depth integrated:

MVBS bottom to Layer 2 (Bottom layer plus 4 m), $F = 5.04$; $DF = 9, 143$; $P = 0.0001$; adj. R-squared = 0.19.

MVBS bottom to Layer 10 (Bottom layer plus 20 m), F = 12.23; DF = 9, 143; P = 0.0001; adj.R-squared = 0.40.

For the mean total (depth integrated 56 m) MVBS multiple regression model the following component catch rate (log(1+X) transformed) coefficients were significant:

Sharks	p = 0.0005
Eels	p = 0.0044
Dories	p = 0.0075
Morids	p = 0.0104.

The general regression equation from the model is:

MVBS = 1.64Sh - 1.08E + 0.85D + 1.06Mo + 0.06R +
1.06Mac + 0.69C - 0..46Sl + 0.10Ot - 81.33

where: Sh = sharks, E = eels, D = dories, Mo = morids, R = roughy, Mac = macrourids, C = other commercial, Sl = slickheads, and Ot = others.

The stepwise regression model for total MVBS and the nine component catch rates (log(1+X) transformed) gave the following results:

Step 1. variable entered - Sharks adj. R-squared = 0.39
F = 98.35 DF = 1, 151 p = 0.0001

Regression equation:

MVBS = 3.30Sh - 81.46

Step 2. variable entered - Eels adj. R-squared = 0.45
F = 63.03 DF = 2, 150 p = 0.0001

Regression equation:

MVBS = 2.55Sh - 1.19E - 78.68

Step 3. variable entered - Macrourids adj. R-squared = 0.48
F = 47.98 DF = 3, 149 p = 0.0001

Regression equation:

$$MVBS = 1.96Sh - 1.50E + 1.64Mac - 80.04$$

Further steps did not explain significantly any more of the variance.

Single catch component stations

While shark and dory dominated stations (i.e. > 50 % of catch) had similar catch rates (mean ± se, 578.3 ± 68.8 kg/hr and 666.6 ± 118.6 kg/hr, respectively), the dory dominated stations had significantly ($p = 0.0001$) lower total MVBS values (mean ± s.e.: -72.1 ± 0.5 dB and -76.7 ± 0.9 dB respectively) (Figure 6). Figure 6 also shows that the four roughy dominated stations had catch rates an order of magnitude higher (mean ± se, 6.133.7 ± 1733.1 kg/hr) yet the MVBS values (mean ± s.e. -73.5 ± 1.3 dB) were not significantly different to those from the shark dominated stations, and significantly higher only at $p = 0.03$ with dory dominated stations.

Target strengths

Orange roughy

Orange roughy made up 95% and 96% of the total catch from two stations in this survey. The work of Do and Coombs (1989) suggested the mean target strength for orange roughy was -36 dB. By applying this value for target strength, and the mean MVBS values obtained at each of these two stations, into equation 2 above ($MVBS = 10 \log n + TS$), acoustic estimates of the density of orange roughy at these two stations could be obtained (assuming 100% orange roughy). Table 10 shows such estimates (fish m^{-3}) using various integrated depths, as well as the trawl based estimates of density in kg m^{-3} and fish m^{-3} at the two stations. The latter was obtained using a mean weight per orange roughy, as measured from these two trawl catches, of 1.6 kg. The ratios of the fish density as measured by the trawl to that measured by the acoustics are also presented in Table 10.

Whilst the acoustic fish densities are too low to obtain equivalent biomass densities to the trawl data, they do show an equivalent ratio to the trawl catches between stations. The nearest estimates of acoustic and trawl densities was obtained using the entire integrated depth of 56 m, and assuming the trawl sampled with 100% efficiency a depth equal to 56 m above its swept area. Even then there is a factor of four difference.

To increase the acoustic densities, either the mean target strength must be lower or the mean MVBS higher. Two assumptions were noted above on the mean MVBS calculations, however both would tend to increase the value rather than decrease it. Therefore it appears that the mean target strength of -36 dB for the orange roughy may be too high.

Of course two other possibilities also exist in that the fish were predominantly near the bottom and within the dead zone, and/or the fish were within an area sampled by the trawl gear but not passed over by the acoustic equipment.

The actual trawl density and MVBS (for the full 56 m integrated) per station can be applied to equation 2 to obtain a mean target strength for that station (TS = MVBS - 10 log n). The results for the two stations with 95% and 96% orange roughy, provided mean target strengths for this species of -41.4 dB and -42.1 dB, respectively. These calculations assume the efficiency and swept volume of the trawl as discussed above, the catch was 100% orange roughy and an average weight per fish of 1.6 kg.

Dories and sharks

Using similar assumptions, apart from the average weight per fish, with seven stations that had over 70% of their catches as one catch component, the mean target strengths for dories and sharks were estimated (Table 11). These estimates of target strength appear reasonable given that dories have air-filled swim bladders and the sharks represent sizeable targets. Average weight per fish for dories was taken as 1.5 kg and for sharks 3.0 kg. In any of these calculations an increase in the average weight per fish would increase the estimated mean target strength obtained.

Average TS and fish density

Using a guesstimate of average length of 30 cm for fish from this survey, and applying it to the target strength equations of Love (1971) and McCartney and Stubbs (1971) the following mean target strengths from the survey area are obtained. Given the mean total MVBS from the area is -74.6 dB, these target strengths are converted to mean fish densities:

	Love	McCartney and Stubbs
mean TS	-35.2 dB	-32.9 dB
density (fish m^{-3})	11.48×10^{-5}	6.78×10^{-5}

To convert these densities to kg m^{-3} to be able to compare them with that obtained from the trawl results would require an average fish weight from the survey of 1.0 kg and 1.7 kg respectively; neither of which are that unrealistic.

Day/night variation

The only day/night variation with MVBS values compared to catch rate was a possibly lower acoustic return per catch rate at night (i.e. higher catch rates per acoustic return) for dory dominated catches; the number of dory dominated stations were too few however for results to be conclusive.

Discussion.

The lack of a strong correlation between the acoustic data and trawl data is not unexpected when one considers the high degree of heterogeneity in the families and size of fish caught. Most catches consisting of a wide range of acoustic targets from the macrourids to sharks to orange roughy. Such factors prevent a accurate estimation of the acoustic conversion factor (TS in equation 2) necessary for transforming acoustic data into fish density. This is a general feature of single-beam acoustic surveys, but can be greatly improved upon using a dual or split beam approach (Dickie et al 1984). Had it been possible to obtain size distribution data, there is still the basic problem that there is no information on in-situ target strength relationships for any of the species located in this survey.

Without an acoustic estimate of fish sizes and numbers a biomass estimate based on the acoustic data would not be reliable. The target strength, and thus the conversion factor, is very complex and dependent on many factors beyond the scope of this study, such as species difference, fish behaviour and density at each station, and so using a mean value would not provide an accurate estimate of fish density. However, with these limitations in mind and the assumptions previously outlined, the density estimates obtained using the two general equations for mean target strength are not unrealistic compared to the trawl results.

Our results, in light of the findings of Dickie et al (1984) and Rose and Leggett (1988), suggest that it may well be possible to not only estimate the biomass of deep-water demersal fish stocks, but also to classify aggregations of single species using acoustics. Acoustic data obtained from a dual or split beam system will enable both sizing and enumeration of the stock. Rose and Leggett (1988) found that an array of discriminators from the acoustic signal can be used to discriminate single species schools. Such discriminators include standardized peak to trough distance, mean distance between voltage peaks, target strengths and such features as distance of target from the bottom. The results from the few single catch component dominated stations obtained in this survey suggest that with such additional information it would be possible to distinguish between the three main components of this fishery - orange roughy, sharks and dories.

The catchability of the trawl gear is just one of a number of assumptions made when estimating biomass indices from trawl surveys. Very little is known about the behaviour of the gear or of the many species found at the depths of this survey. The results above do, however, tend to indicate that the influence of the trawl gear, in terms of the volume swept, extends well above the net headline, possibly extending as high as or above 50 m.

The biomass estimates from the trawl data had relatively good precision with 95% confidence limits of 29%. This overall confidence being as high as it was despite the high variability in the catches of the orange roughy; the confidence limits for that species being 83%, while for macrourids it was 15% and sharks 21%.

The dissimilar distribution of mean MVBS and catch rates between stations highlights the difference between these two estimation techniques in that the acoustics is dependent, among other things, upon the number and length of the fish rather than the total weight as is trawl data. Therefore in future comparisons of these techniques more emphasis should be placed upon size distribution of the catch components.

The mean target strength for orange roughy presented by Do and Coombs (1989) of -36 dB does appear from the results obtained in this survey to be too high. There are of course limitations to the accuracy of our figures yet it would appear that a target strength of ca. -42 dB may be closer to the mean value. In-situ measurements are required to verify this, as there are inherent problems in performing measurements on dead specimens, as conducted by Do and Coombs, in depths and temperatures dissimilar to the norm, particularly with the deepwater orange roughy that has a swim bladder filled with wax esters rather than gas.

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Table 1. Details of FRV *Soela* used for this survey.

FRV *Soela*:	stern trawler built in 1963
LOA:	52.8 m
Beam:	9.5 m
Draft:	4.9 m
Displacement:	500 tons
Power:	2 Deutz diesel engines of 900 b.h.p. supplying power to 2 Siemens electric propulsion motors each of 515 kW; controllable pitch propeller
Winches:	2 automatic spooling winches with 2600 m of 24 mm trawl wire
Trawl doors:	Polyvalent, each door 800 kg + 200 kg
Navigation:	Trimble 10X Navigator global positioning system and Magnavox MX 1105 Satellite navigator; Taiyo TP-C10 colour course plotter, Taiyo TP-R14 data recorder and an Epson LX-86 printer.

Table 2. Details of Engel high-rise bottom trawl used throughout this survey.

Headline:	35.5 m
Footrope:	50 m
	16 m chain on each wing, bosom with rubber bobbins
Wings:	rigged flying; mesh only attached to ground rope in the bosom
Bridles:	upper and lower - 50 m wire no sweeps
Mesh size:	180 mm to 100 mm
Codend mesh size:	90 mm with 40 mm liner of knotted 400/60 twine in final 2 m
Wing spread:	av. 19 m wingtip-to-wingtip (53.5% of headline length) measured by Scanmar net monitoring system in depths of 400-500 m at vessel speed of 2.5 knots.
Net opening:	3 - 5 m (recorded by headline monitoring unit).

Table 3. Calibrated acoustic system parameters and EK400 settings used throughout the survey. (G is gain constant)

System parameter	Symbol	Calibrated value/setting
Operating frequency		38 kHz
Beamwidth (-3 dB full angle)		8/8 uncalibrated
Ideal beam angle	10 log ψ	-19.6 dB
Attenuation constant	α	9.3 dB km^{-1}
Source level	SL	194.9 dB re 1μPa at 1 m
Receiving sensitivity	SRT	-178.9 dB re 1 V $(\mu Pa)^{-1}$
Pulse length	τ	3 ms
Receiver bandwidth		1 kHz
Power		High
Mode		Dynaline
Main range		7
Gain (Sub Bottom Gain)		6 (6)
Sound Speed		1498 m sec^{-1}
TVG		20 log R
Calibration parameters	SL+SRT+G	67.9 dB

Table 4. Total catch (kg) and catch rates (kg/hr) overall and by bottom depth zone for each catch component. Bracketed figures are those when large orange roughy dominated catches are removed (four from Total, two from 800 m, and one each from 1,000 and 1,100 m).

Component	Total	Catch rate (kg/hr)				
	Catch (kg)	Total	800 m	900 m	1,000 m	1,100 m
Roughy	13,931	194 (59)	462 (71)	53	121 (62)	126 (45)
Sharks	8,818	118	239	121	62	36
Dories	7,097	97	33	61	179	103
Macrourids	5,247	69	87	60	75	47
Eels	3,379	45	2	21	78	84
Morids	1,796	24	47	21	13	12
Slickheads	1,789	24	8	16	29	48
Other Comm.	185	2	8	2	0	0
Others	1,096	15	16	13	15	14
Total	43,338	558 (439)	901 (514)	368	573 (492)	471 (352)
No. Stns	153	153	40	38	46	29

Table 5. Mean percentage of each catch component per trawl, overall and by bottom depth zone of the trawl.

Component	Mean percentage per trawl				
	Total	800 m	900 m	1,000 m	1,100 m
Roughy	14.9	16.4	14.0	14.3	14.7
Sharks	22.8	42.3	28.0	10.8	8.0
Dories	18.7	7.5	17.0	26.9	23.3
Macrourids	16.0	16.7	17.1	16.7	12.4
Eels	11.6	1.0	7.3	17.5	22.3
Morids	5.8	8.9	7.0	3.4	3.7
Slickheads	5.6	1.7	4.0	6.3	11.8
Other Comm.	0.7	2.0	0.6	0.8	0.0
Other	4.0	3.4	5.0	3.8	3.8

Table 6. Number of trawls in which each catch component was the main component of the catch, for all stations and by bottom depth zone.

Component	Number of Trawls				
	Total	800 m	900 m	1,000 m	1,100 m
Roughy	20	5	3	8	4
Sharks	50	30	19	0	1
Dories	40	1	6	21	12
Macrourids	22	3	7	10	2
Eels	14	0	0	7	7
Morids	1	0	1	0	0
Slickheads	3	0	0	0	3
Other Comm.	0	0	0	0	0
Other	3	1	2	0	0
Total no. trawls	153	40	38	46	29

Table 7. Number of trawls dominated (> 50% of catch) by single catch component, separated by catch rate (kg/hr).

Component	Catch rate kg/hr		
	≤ 500	500 to 1,000	≥1,000
Sharks	7	6	2
Dories	6	5	2
Orange roughy	-	-	4
Eels	1	-	-
Macrourids	1	-	-

Table 8. Mean catch rates (kg/km^2) and estimated biomass (tonnes) of each catch component in the area surveyed (7,165 km^2) in 1989. 95% confidence limits expressed as percentage.

Component	Catch rate (kg/km^2)		Biomass (tonnes)		
	Mean	s.e.	Mean	s.e.	95% CL
Roughy	2,099	885	15,036	6,338	83
Sharks	1,291	136	9,251	977	21
Dories	1,073	146	7,689	1,048	26
Macrourids	758	59	5,432	424	15
Eels	518	49	3,711	352	19
Morids	261	29	1,869	208	22
Slickheads	272	27	1,949	195	20
Other Comm.	28	6	200	42	41
Other	167	18	1,194	132	22
Total	6,466	947	46,331	6,786	29

Table 9. Comparison of mean values (± s.e.) of trawl data (kg/hr) and acoustic data (Mean V_{TVG}^2, and MVBS, dB) by trawl depth strata. Acoustic data is for the total integrated depth to 56 m above the bottom.

Depth stratum	No Stations	Trawl data kg/hr	Acoustic data V_{TVG}^2	MVBS
800 m	40	900.9 ± 294.1	0.0141 ± 0.0013	-72.4 ± 0.4
900 m	38	368.2 ± 42.1	0.0092 ± 0.0010	-74.3 ± 0.4
1000 m	46	573.1 ± 91.5	0.0057 ± 0.0004	-76.3 ± 0.3
1100 m	29	470.7 ± 122.6	0.0041 ± 0.0006	-77.8 ± 0.5

Table 10. Comparison of density estimates of orange roughy obtained from trawl and acoustic data for two stations in which orange roughy dominated the catch. Four volumes of assumed trawl influence are examined. Average weight per fish, measured from trawl catches, is 1.6 kg. Ratio T/A is the ratio of fish density measured by the trawl to that measured by acoustics.

	Station 3/16	Station 3/27
Total catch (kg)	2630	5625
% orange roughy	95	96
Swept area (m^2)	52,782	43,985
Areal density ($kg\ m^{-2}$)	4.98×10^{-2}	12.79×10^{-2}
Depth integrated - 56 m (bottom window plus 26 layers)		
Mean MVBS (dB)	-73.9	-70.6
Acoustic density ($fish\ m^{-3}$)	1.62×10^{-4}	3.47×10^{-4}
Trawl density ($kg\ m^{-3}$)	8.90×10^{-4}	2.28×10^{-3}
Trawl density ($fish\ m^{-3}$)	5.56×10^{-4}	1.43×10^{-3}
Ratio T/A	3.43	4.12
Depth integrated - 6 m (bottom window plus layer 1)		
Mean MVBS (dB)	-70.9	-68.9
Acoustic density ($fish\ m^{-3}$)	3.24×10^{-4}	5.13×10^{-4}
Trawl density ($kg\ m^{-3}$)	8.30×10^{-3}	2.13×10^{-2}
Trawl density ($fish\ m^{-3}$)	5.19×10^{-3}	1.33×10^{-2}
Ratio T/A	16.02	25.93
Depth integrated - 12 m (bottom window plus 4 layers)		
Mean MVBS (dB)	-72.1	-69.2
Acoustic density ($fish\ m^{-3}$)	2.46×10^{-4}	4.78×10^{-4}
Trawl density ($kg\ m^{-3}$)	4.15×10^{-3}	1.07×10^{-2}
Trawl density ($fish\ m^{-3}$)	2.60×10^{-3}	6.66×10^{-3}
Ratio T/A	10.57	13.93
Depth integrated - 24 m (bottom window plus 10 layers)		
Mean MVBS (dB)	-72.7	-69.1
Acoustic density ($fish\ m^{-3}$)	2.14×10^{-4}	4.89×10^{-4}
Trawl density ($kg\ m^{-3}$)	2.08×10^{-3}	5.33×10^{-3}
Trawl density ($fish\ m^{-3}$)	1.30×10^{-3}	3.33×10^{-3}
Ratio T/A	6.08	6.81

Table 11. Estimated mean target strengths (TS) for dories and sharks obtained from seven stations in which the single catch component represented over 70% of the total catch. Percentage composition of catch attributed to the main single species are also shown. Estimation assumes single component is 100% of catch. The average weight per fish used for dories was 1.5 kg and for sharks 3.0 kg.

Component	% of catch	Main species	% of catch	Mean TS
Dories	71.5	*A. verrucosus*	71.5	-37.3 dB
Dories	75.4	*A. verrucosus*	75.4	-39.3 dB
Dories	86.2	*A. verrucosus*	86.2	-35.0 dB
Sharks	70.1	*C.crepidater*	49.0	-28.8 dB
		D.calcea	17.5	
Sharks	74.6	*D.calcea*	65.3	-31.6 dB
Sharks	76.8	*D.calcea*	37.7	-26.8 dB
		C.crepidater	32.6	
Sharks	86.3	*C.crepidater*	54.8	-28.9 dB
		D.calcea	26.3	

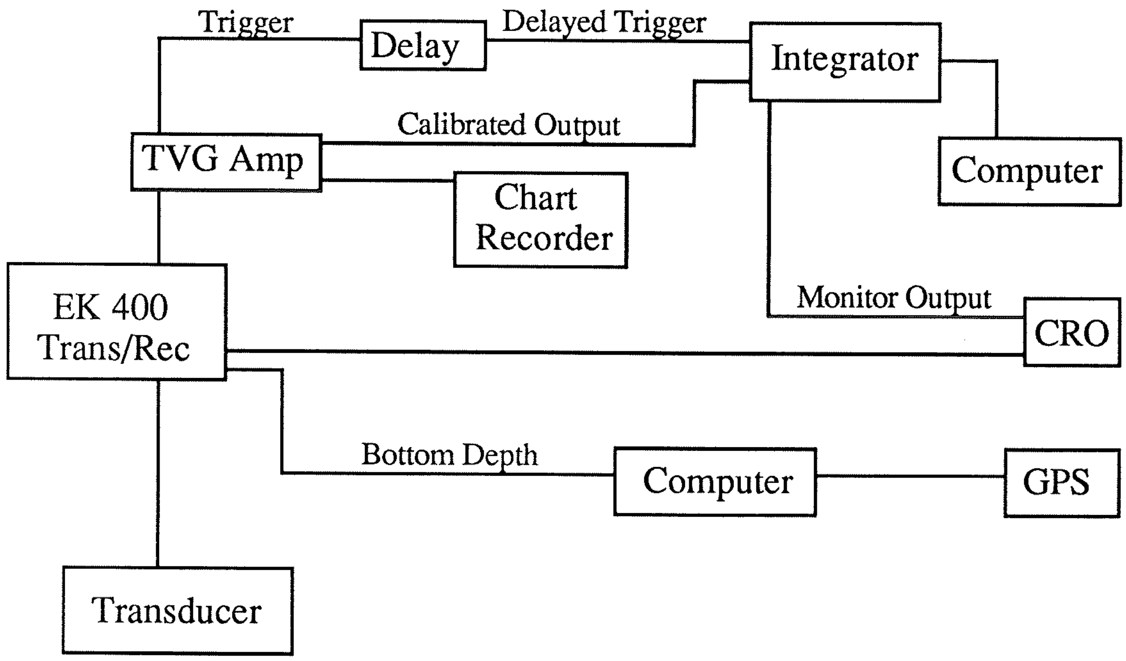


Figure 1. Configuration of acoustic system on the FRV *Soela* used during the survey.

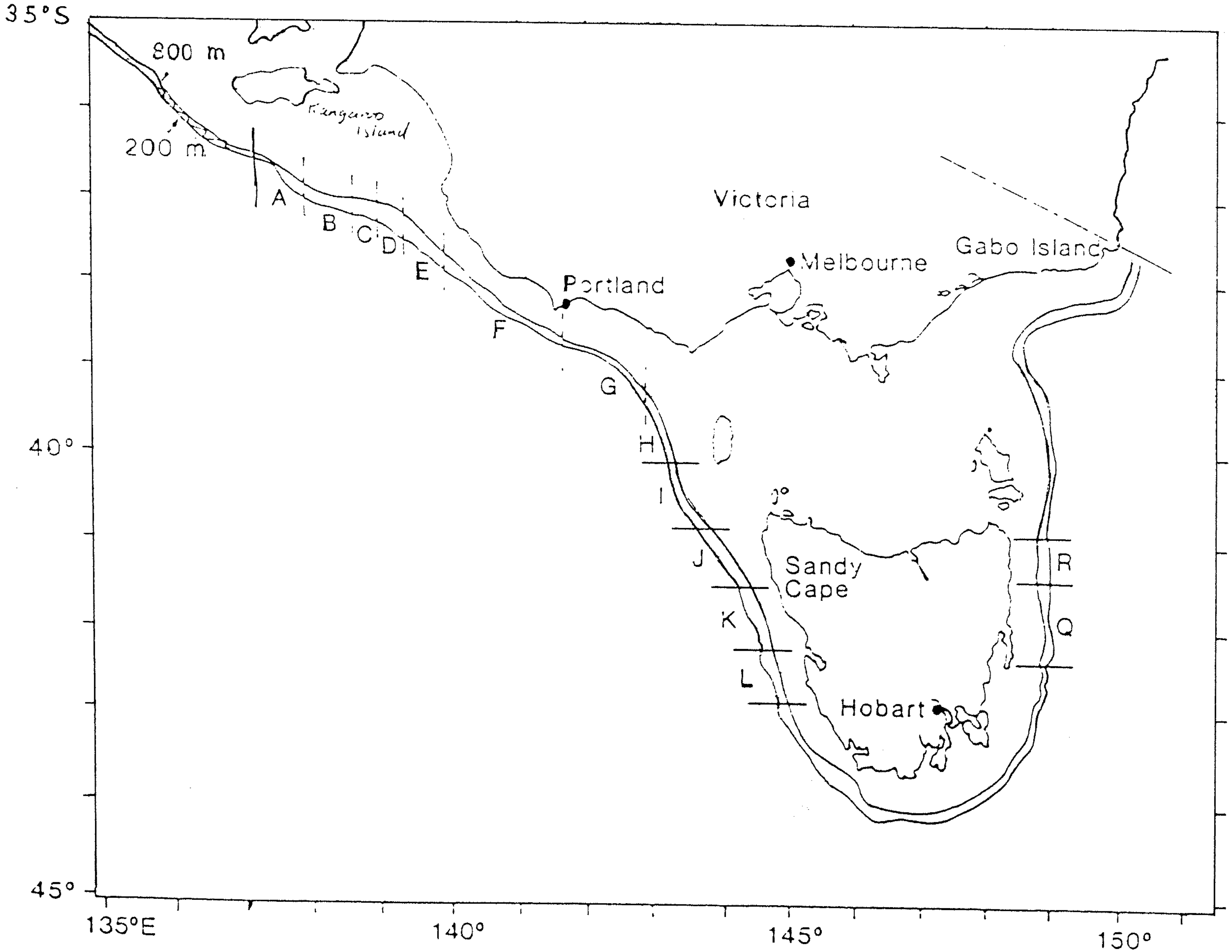


Figure 2 The South East Trawl area of Australia surveyed by the CSIRO in 1989.

Figure 3a. Change in mean MVBS (dB) with change in water column height integrated above the bottom layer. Showing the general trend for all stations and Station 1/85, one of seven stations that differed from the general rule.

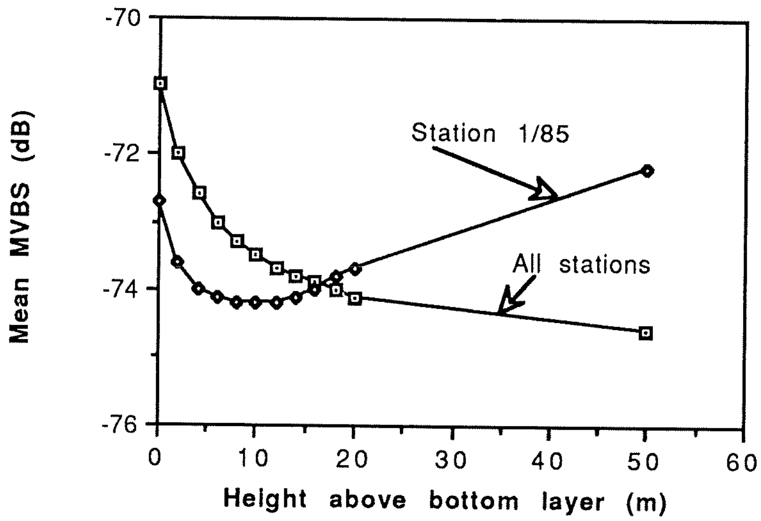


Figure 3b. Change in mean MVBS (dB) for each individual depth layer from the bottom up to 20 m above the bottom layer. Showing the general trend for all stations and Station 1/72, an example of the seven that differed to the general trend. Bot - Bottom layer, L1 to L10 - 2m depth intervals above the bottom layer.

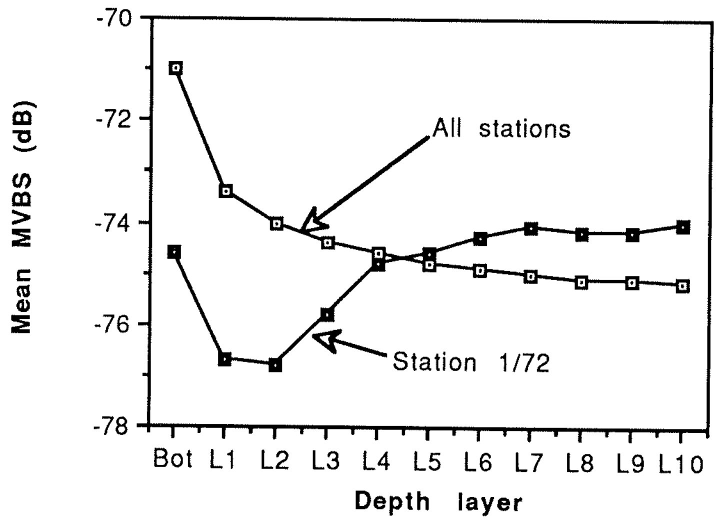


Figure 4. Change in log total catch rate (kg/hr) with change MVBS (dB) for total volume integrated (56 m), showing mean and one standard deviation for each one dB range for all 153 stations.

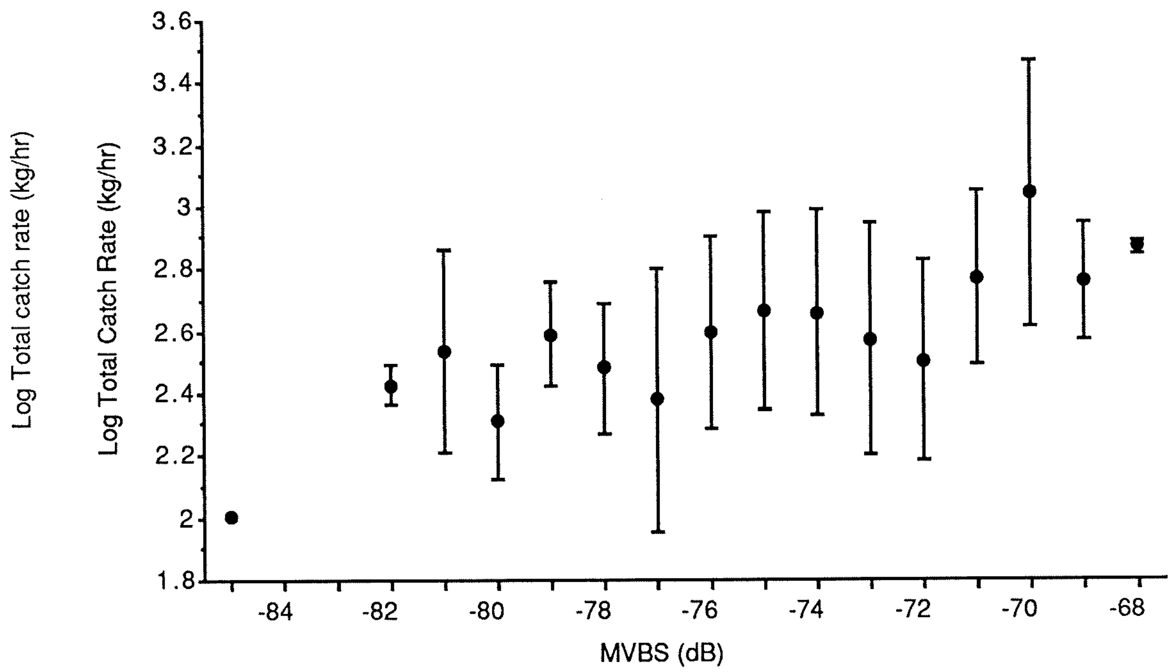
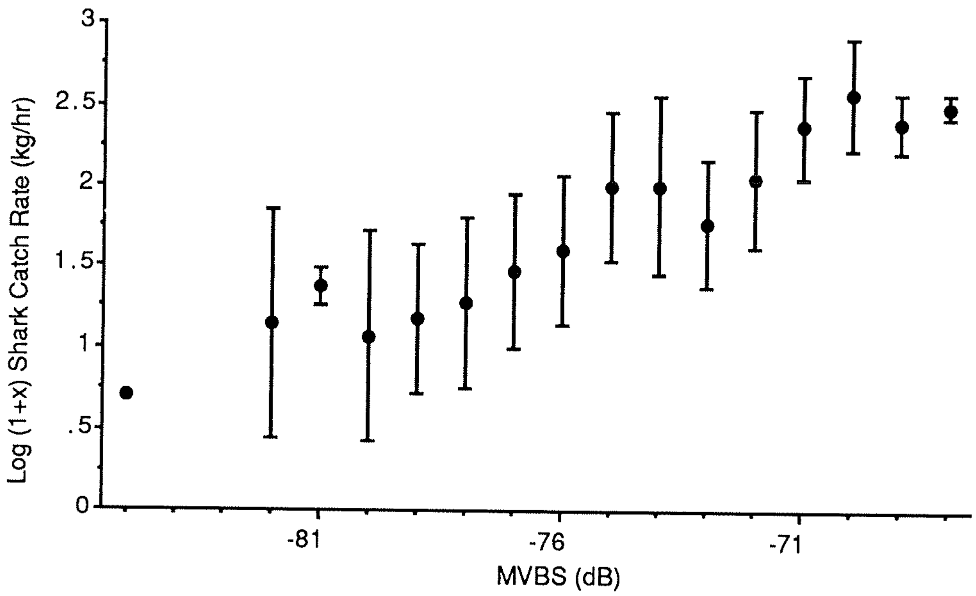


Figure 5. Change in individual catch component catch rates (kg/hr) with change in MVBS (dB), for a) sharks and b) eels. Mean and one standard deviation per one dB range shown for all 153 stations.

a) Sharks



b) Eels

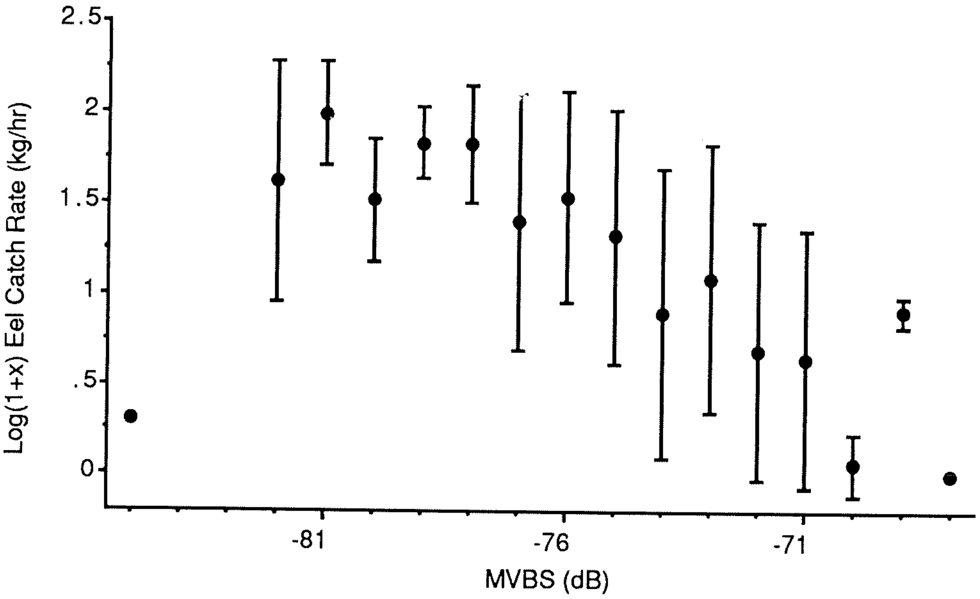
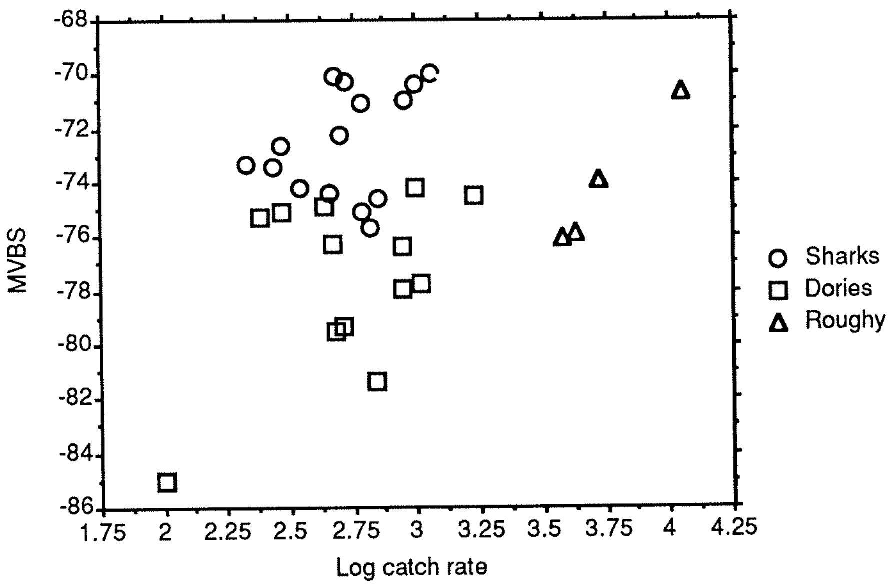


Figure 6. Mean MVBS values (dB) and catch rates (kg per hour) for the single species dominated stations, showing the differentiation between the three species. (- sharks, dories, and orange roughy)



DOCUMENT 10

INTERNAL REPORT

Towed body development

Rudy Kloser, Nick Elliott and Ian Helmond

CSIRO Division of Fisheries Research

Hobart

Summary of results for *R.V. Soela* cruise S01/89 Jan. 19th to Feb. 9th

The acoustic sampling system used on S01/89 is as shown in Figure 1. The hull mounted or towed transducers were selected via the EK400 front panel.

The hull mounted transducer system was calibrated using a standard target. The fish density detection capability for a 36 cm orange roughy with a target strength of -36 dB and a detection threshold of 10 dB is 0.29 fish/1000m³ in smooth seas at 3 knots. Echo integration data ~~was~~ collected to study echo reverberation to catch figures using a new TVG amplifier that covers the depth and absorption ranges of interest.

The in-house designed towed body and EDO Western transducer were tested for stability and fish detection. The hydrodynamic stability of the towed body will need to be rectified before any comparison with the hull mounted transducer can be made. The towing depth requirement for the transducer of 200 metres at 5 knots was achieved.

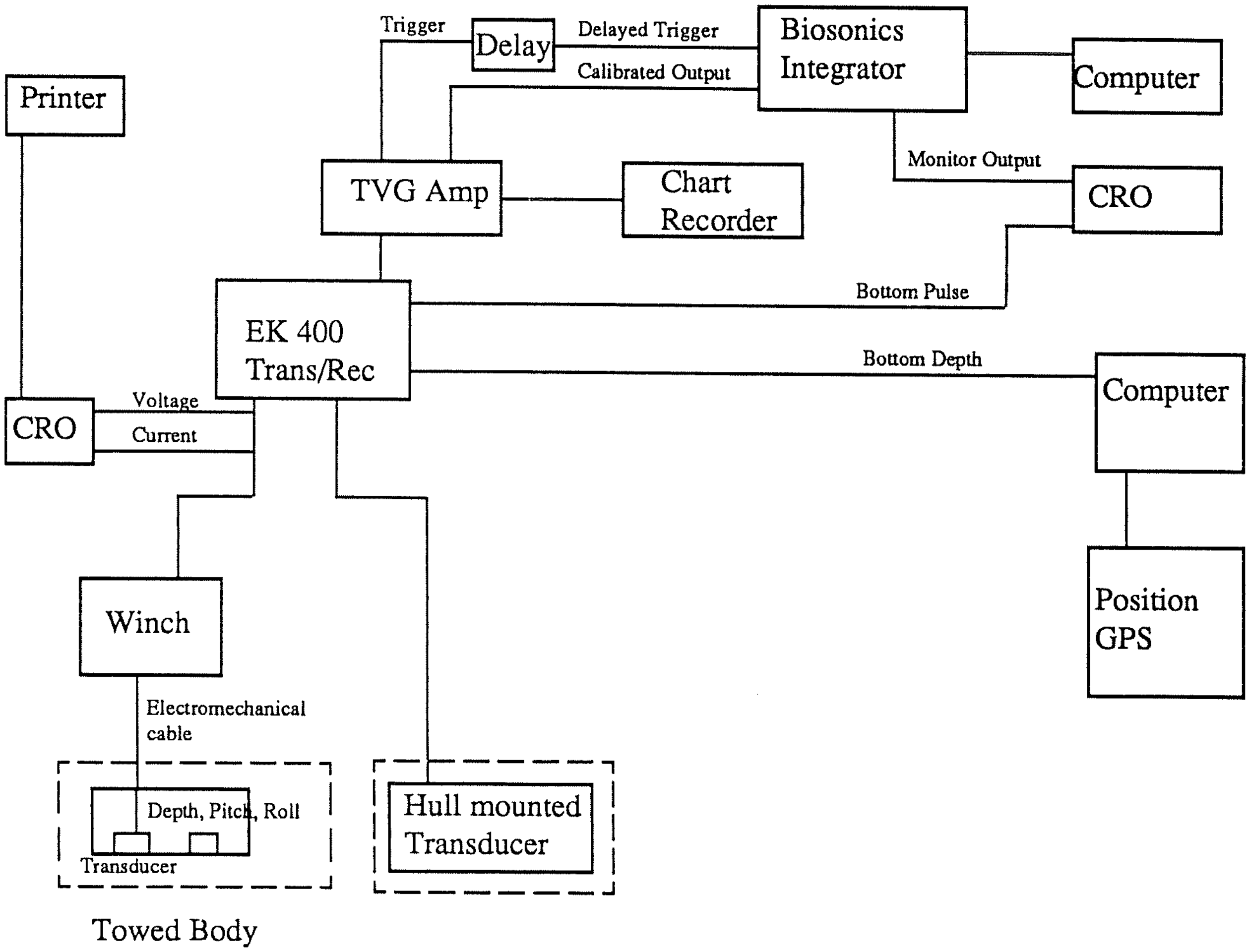


Figure 1. Acoustic Sampling System

Performance of Hull Mounted Transducer System

The hull mounted transducer was calibrated against a standard copper sphere as outlined in reference 1. The detection capability of the 38 kHz sounder can be calculated using the calibration data and the sonar equation (Johansson and Mitson, 1983) with a 10 dB (factor of 3) signal to noise ratio. This gives a theoretical fish detection in smooth seas at trawl speeds of 3 knots of:

$$n = 0.29 \text{ fish}/1000 \text{ m}^3$$

The fish are assumed to be 36 cm orange roughy with a target strength of -36 dB. The detection capability degrades quickly as the sea state or speed increases. The theoretical figure is supported by initial trawl catch and echo gram data. Figure 2 shows an echo gram taken at station 15 trawling for half an hour with a catch of 15 kg at 900 metres. Marks close to the bottom are clearly visible.

A new Time Varied Gain (TVG) amplifier that compensates for the absorption and spreading losses on orange roughy grounds at 38 kHz was installed. This TVG amplifier allows the echo integrator (borrowed from the Australian Maritime College) to be used in the bottom lock mode and a study of trawl catch to echo reverberation to be made. Results from this work are being processed.

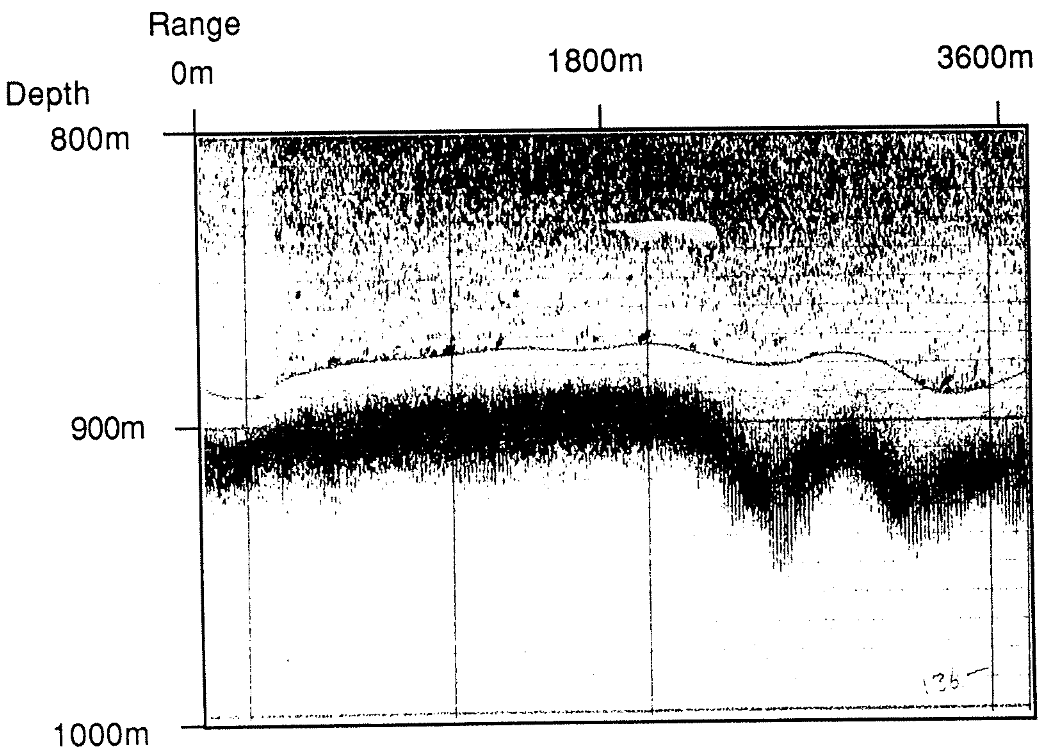


Figure 2. Echogram of trawl station 15, towing speed 3 knots.

Performance of Towed Transducer System

The in-house manufactured towed body (plan in Figure 5, photos in Figure 6) was tested for stability on the east coast of Tasmania at the beginning of S01/89. The trials showed that a larger tail fin was required to improve the hydrodynamic stability of the system. Figure 3 shows the pitch and roll performance of the towed body with 600 metres of wire out at a speed of 5-6.7 knots in smooth seas. The sensitivity to speed is clearly visible on the roll plot. The towing depth requirement for the echo integration work of 200 metres at 5 knots was achieved.

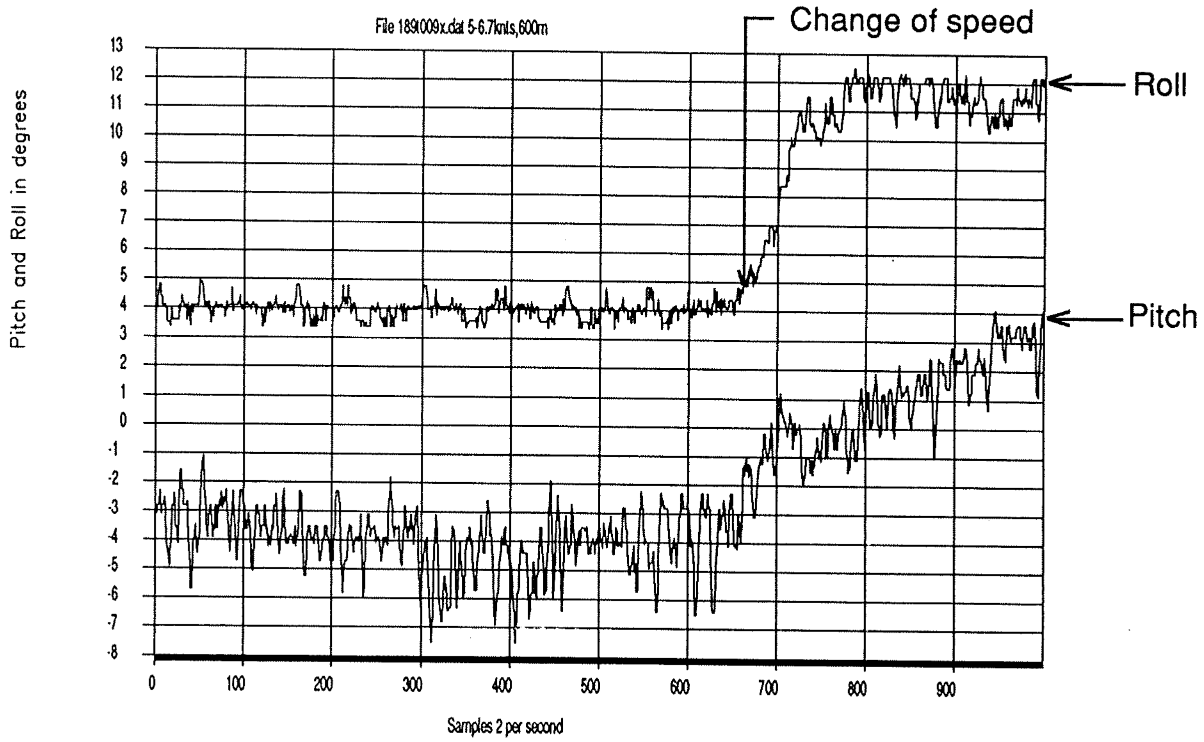
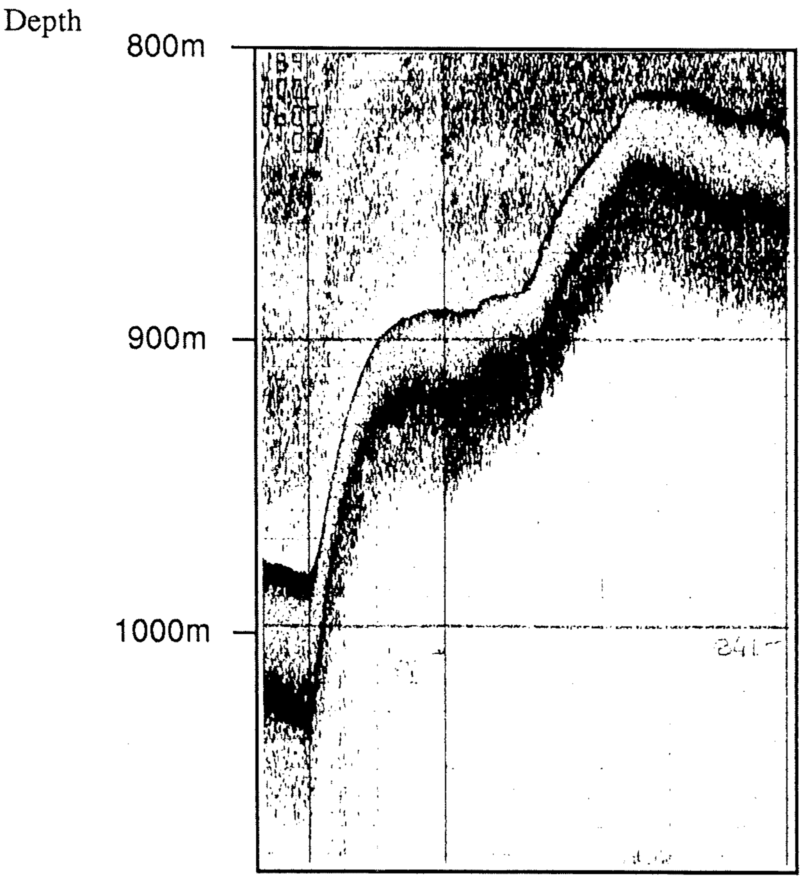


Figure 3. Pitch and Roll of Acoustic Towed Body

Initial tests with the EDO Western transducer are shown on the echogram in figure 5. The noise experienced with the transducer in circuit was about twice that of the hull mounted transducer. A calibration is required to give the signal-to-noise performance of the system so that it can be compared to the hull mounted system. It is expected that the performance of the towed system will be greatly improved on the new ship with the extra conductors in the electromechanical cable allowing preamplifiers to be used.



During this tow the body was inclined 10° to the right (starboard) which acounted for the thickened bottom echo.

Figure 4. Echogram from towed transducer speed 5knots.

The main advantages of the towed body system are:

i. stable platform
ii. detection capability not sensitive to sea state
iii. detection capability not sensitive to vessel course
iv. smaller sample volume possible with the shorter pulse length used

These could not be verified in S01/89 due to mechanical and electrical problems.

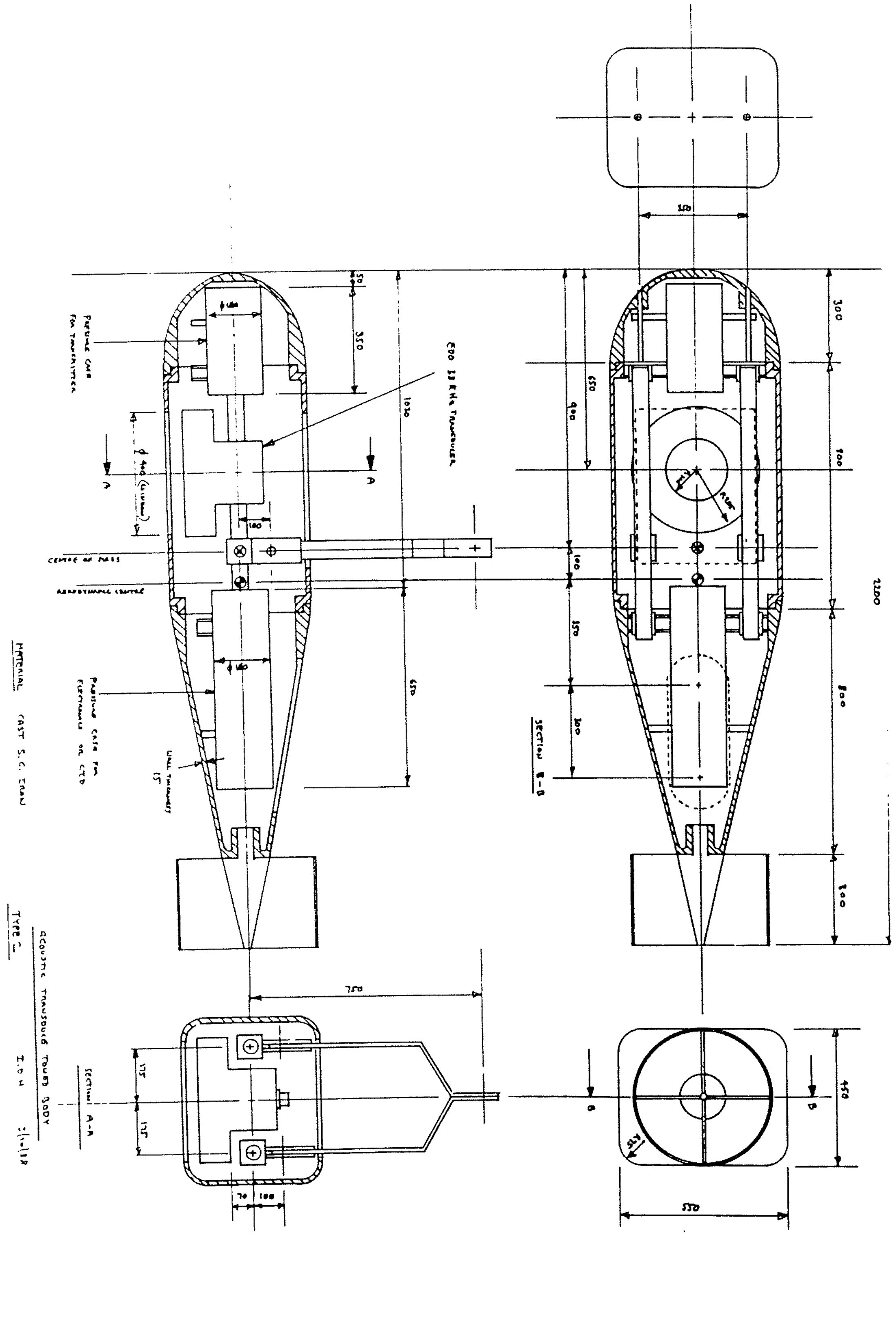
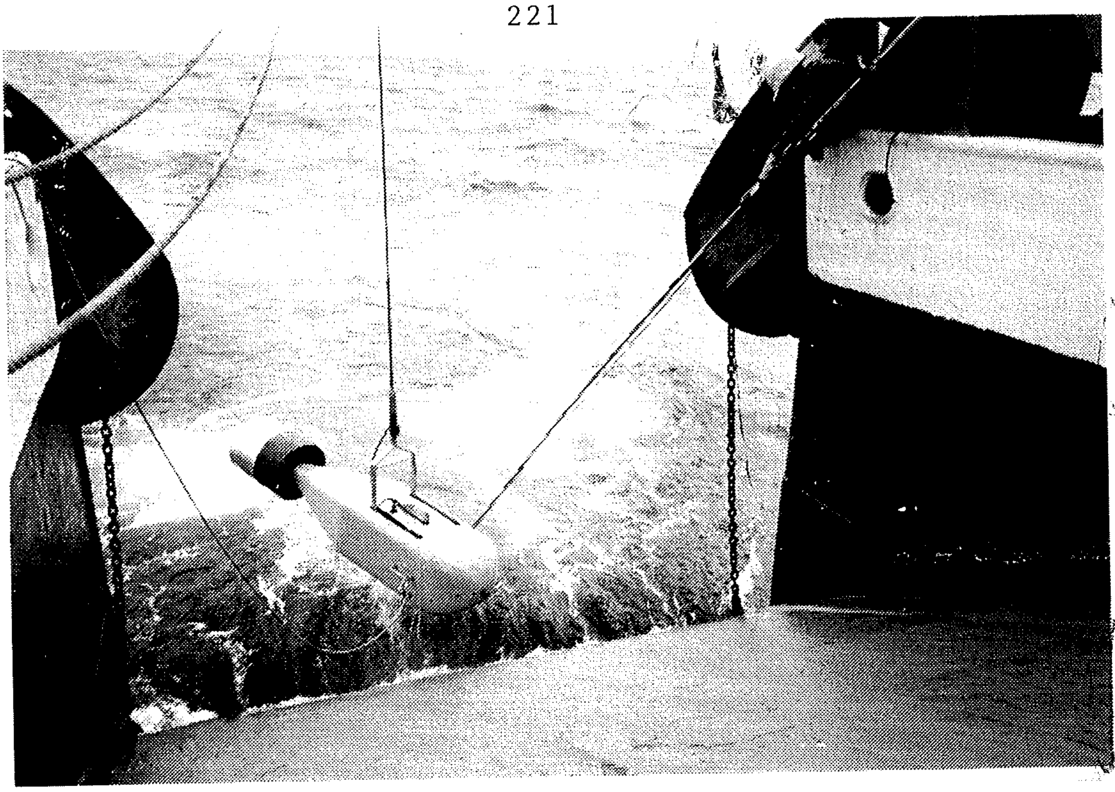
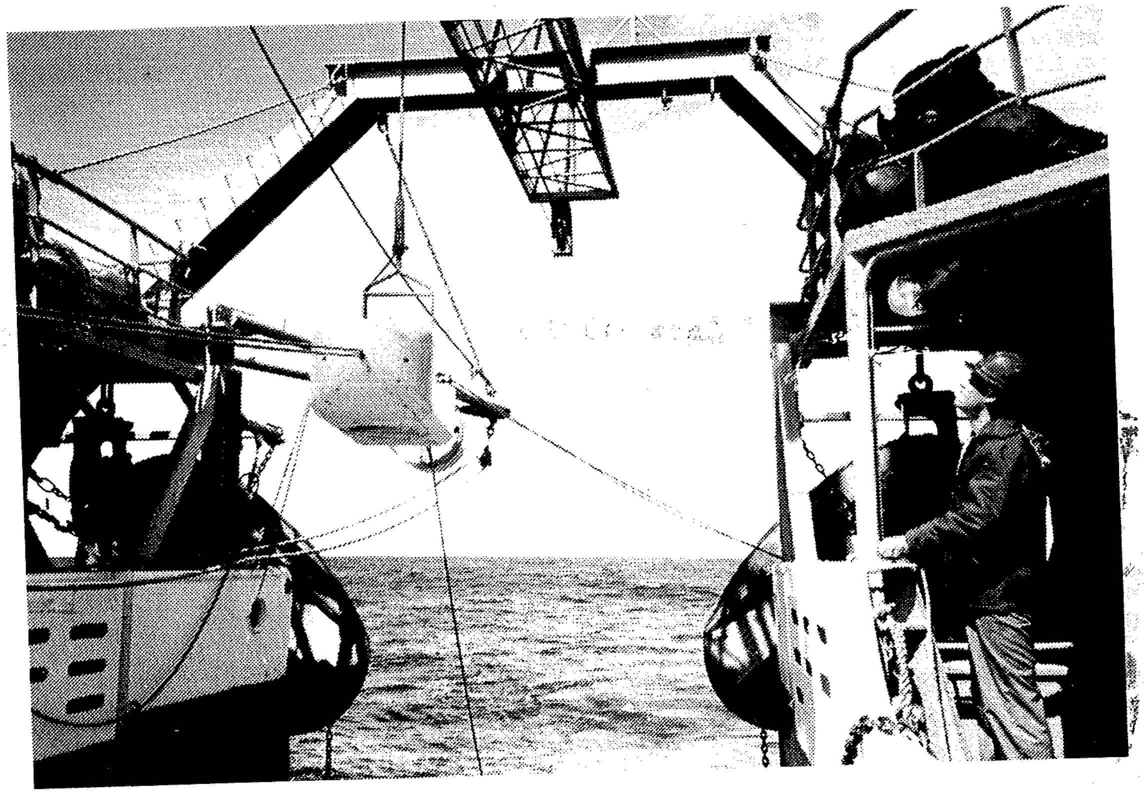


Figure 5. Assembly drawing of acoustic towed body.



a. Retrieval of the towed body using hooker poles.



b. Deploying the towed body, acoustic window visible.

Figure 6. Photos of the Acoustic Towed Body.

References

1. Foote, K.G., Knudsen, H.P., Vestnes,G. MacLennan, D.N., Simmonds,E.J. 1987:Calibration of Acoustic Instruments for Fish Density Estimation: A Practical Guide. Cooperative Research Report : 144

2. Johannesson, K.A., Mitson, R.B. Fisheries Acoustics 1983: A practical manual for aquatic biomass estimation. FAO Fisheries Technical Paper :240 pp76-83

Summary of results for *R.V. Franklin* cruise FRV13/89 Nov.11th to 14th

R.V. Franklin is fitted with 2500 meters of 7 core electromechanical cable compared to 700 meters available on *R.V. Soela.* This extra cable enabled deep water trials to be conducted.

Towed body

Since the last cruise several modifications were carried out in the laboratory;

1. the tail fin was modified to improve pitch stability,
2. larger skids were fitted underneath the towed body,
3. the body was smoothed then galvanized and painted to reduce flow induced noise,
4. three handles were fitted to help with deployment and retrieval,
5. preamplifiers were built to drive the 2500 meters of tow cable,
6. the pressure case and power supply for the transmitter were fitted,
7. pitch and roll sensors for the *F.R.V. Franklin* were built and logged simultaneously with the towed body pitch and roll sensors

The following tests were performed during the trials,

1. the phase and amplitude relationship of the towed body and ships pitch/roll sensors were measured whilst the towed body was on the deck. The cable noise of the system was also measured to determine the background noise.
2. the towed body was deployed with the pitch/roll and transducer noise monitored at various speeds and cable lengths.
3. the towing point was then adjusted to improve dynamic pitch stability and static roll stability. The towed body was redeployed with the pitch/roll and transducer noise monitored at various speeds and cable lengths.

4. The trim tabs were adjusted to counter speed dependent pitch stability. 50 meters of fairing was added to the cable to observe the reduction, if any, in cable-induced flow noise. The towed body was redeployed with the pitch/roll and transducer noise monitored at various speeds and cable lengths.

Results

The 7 conductor electromechanical cable used had no special means to eliminate crosstalk and this proved unsuitable to simultaneous operation of the pitch/roll/depth communications and the transducer preamps. It was necessary to disconnect the preamp circuit for this test and to obtain noise measurements without preamplifiers. This reduced the signal to noise performance of the system but it was still possible in the very calm conditions to detect prevailing variation in flow induced noise.

The towed body was successfully deployed to 1000 meters with approximately 2200 meters of cable steaming at 3 knots. This satifies our design requirement for obtaining in-situ target strength measurements of orange roughy down to 1200 meters at a speed of 2 knots. The pitch/roll plot at this speed is shown in Figure 7a and b.

The towed body was flown at 4 to 8 knots on a short length of cable to perform various trials as outlined above. The final adjustments on the towed body towed at a speed of 6 knots and 200 meters deep are shown in Figure 8a and b.

The 50 meters of fairing added to the cable appeared to reduce the flow induced noise by approximately 10dB. Further tests are required with amplifiers to validate this figure.

The trials provided quality data that gave simultaneous pitch/roll information from the ship and towed body. This enabled towing position and trim tab adjustments to be made after each tow with results observed. The pitch/roll performance at 1000 meters depth towing at 3 knots was achieved, satisfying the last of our design requirements.

A future priority for the towed body is to obtain a suitable electromechanical cable that will screen out unwanted crosstalk noise. The tests showed that special care is required in preventing crosstalk affecting the acoustic signals. The electronic work on placing the transmitter in the towed body is well advanced with the successful trials of the power supply and pressure case. A prototype preamplifier has been bench tested but could not be field tested due to excessive cable crosstalk.

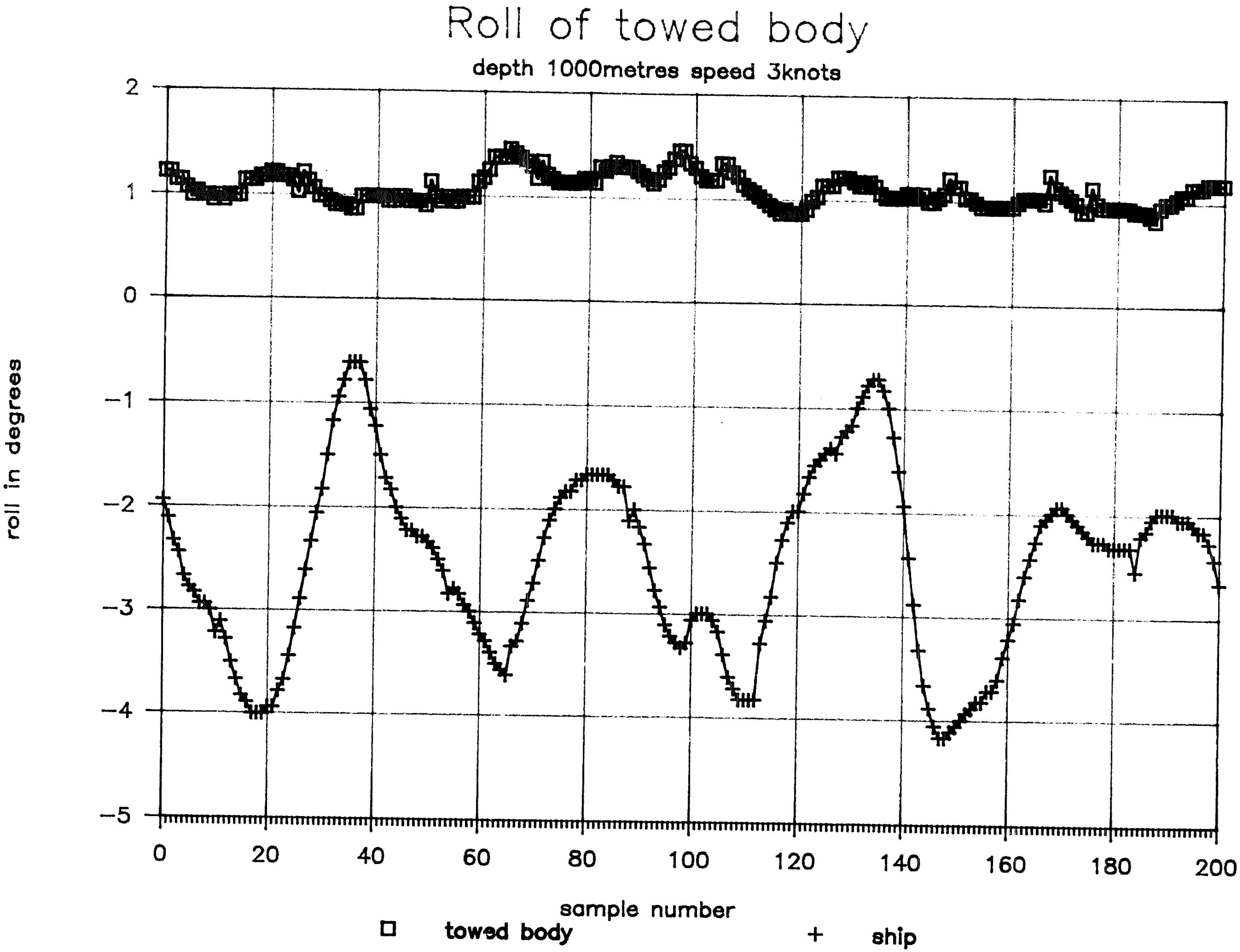
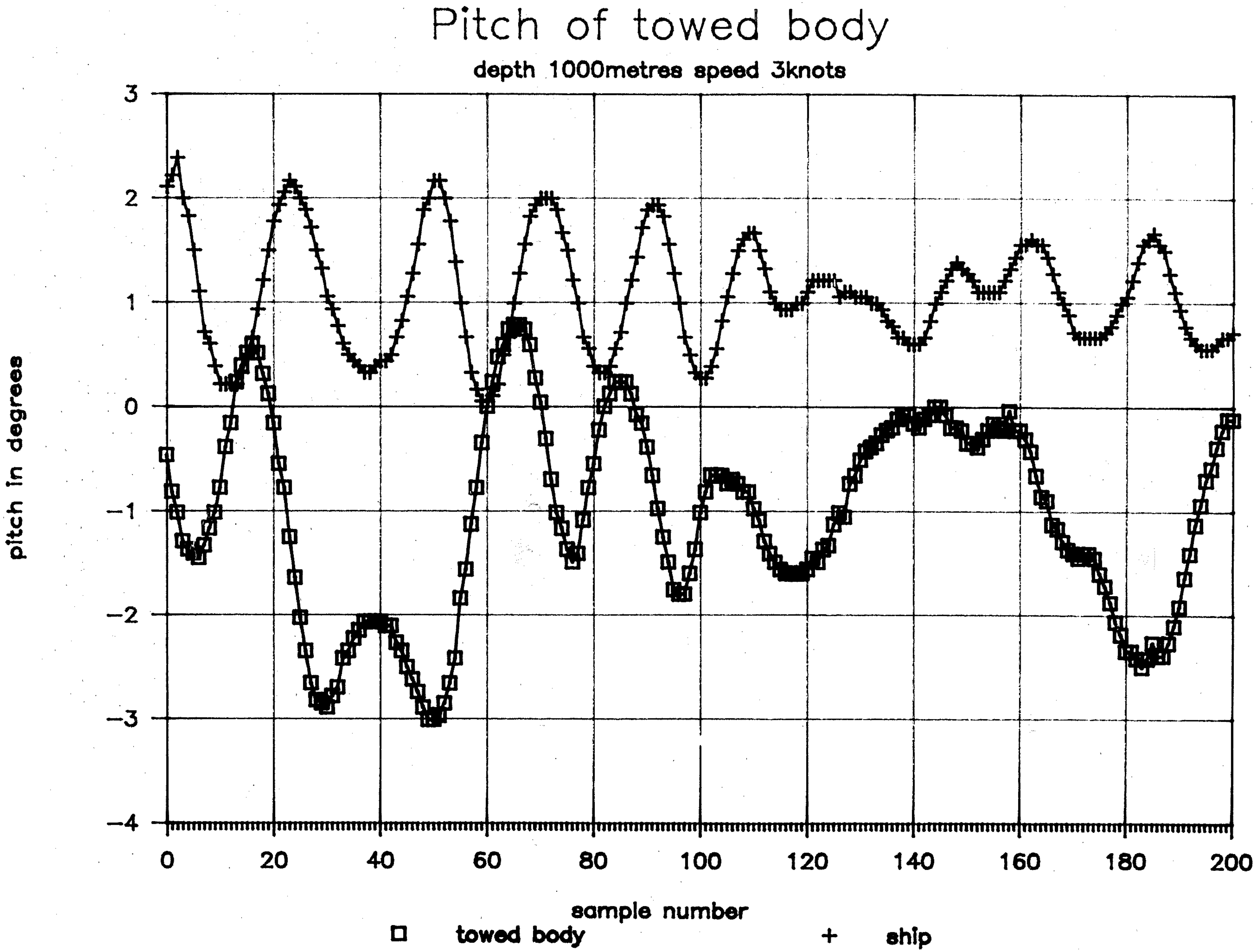
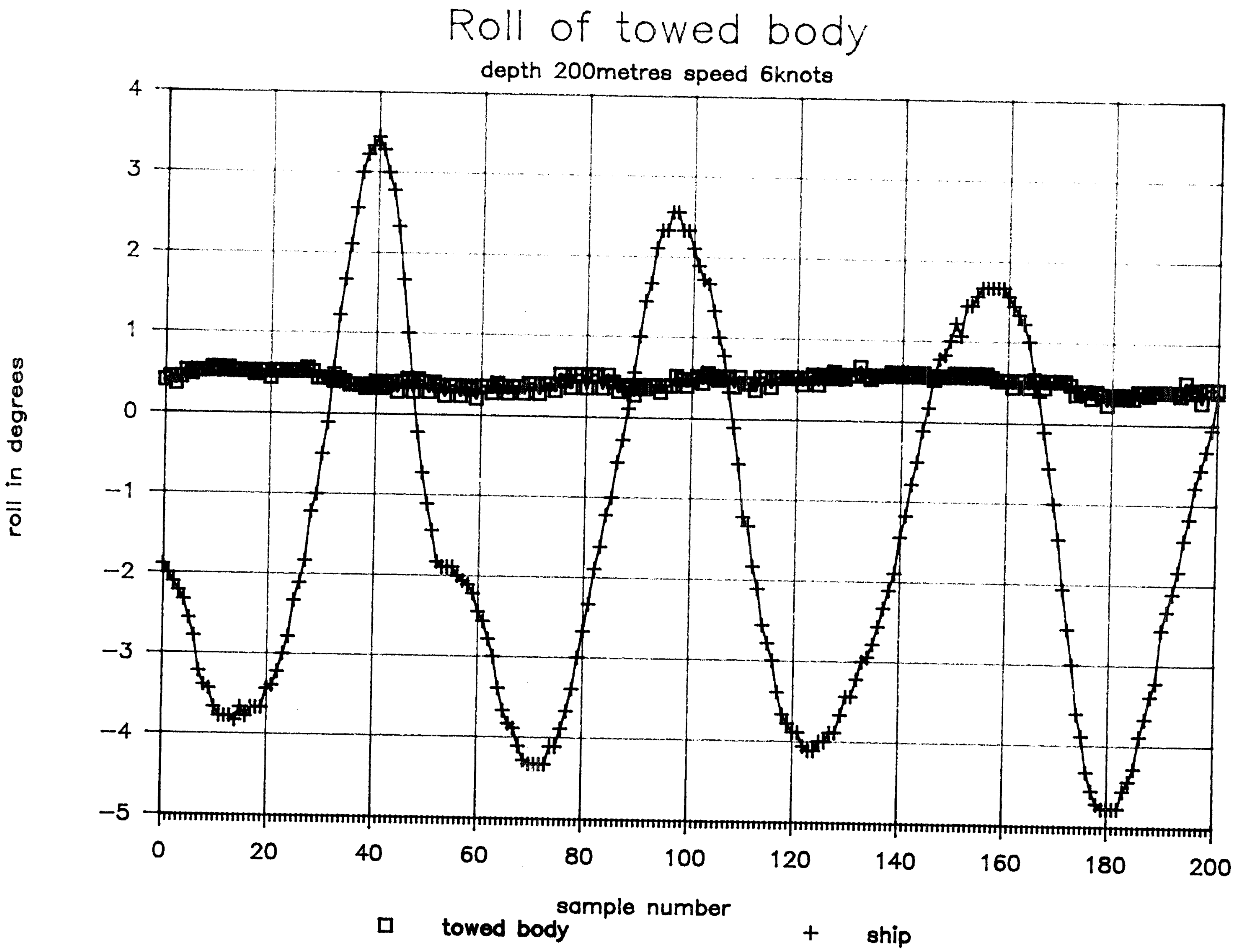

Roll of towed body
depth 1000metres speed 3knots
roll in degrees
2
1
0
-1
-2
-3
-4
-5
0
20
40
60
80
100
120
140
160
180
200
sample number
towed body
+ ship

Figure 7a.



Pitch of towed body
depth 1000metres speed 3knots
pitch in degrees
3
2
1
0
−1
−2
−3
−4
0
20
40
60
80
100
120
140
160
180
200
sample number
□ towed body
+ ship

Figure 7b.



Roll of towed body
depth 200metres speed 6knots
roll in degrees
4
3
2
1
0
−1
−2
−3
−4
−5
0
20
40
60
80
100
120
140
160
180
200
sample number
towed body
ship

Figure 8a.

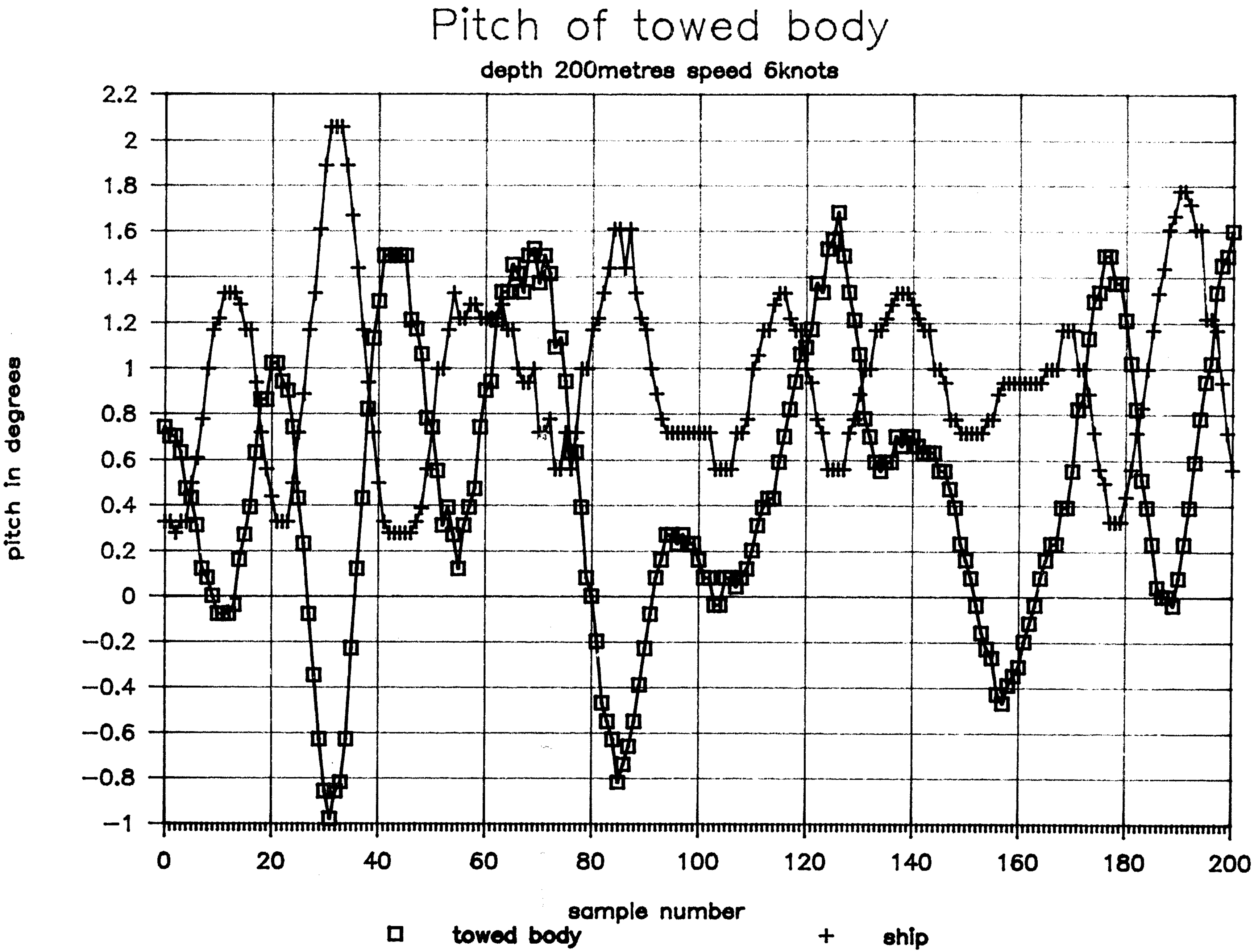

Pitch of towed body
depth 200metres speed 6knots
pitch in degrees
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
120
140
160
180
200
sample number
towed body
ship

Figure 8b.

DOCUMENT 11

AUSTRALIAN JOURNAL OF MARINE AND FRESHWATER RESEARCH

Use of acoustics to assess a small aggregation of orange roughy, *Hoplostethus atlanticus* (Collett), off the east coast of Tasmania.

Elliott, N.G. and Kloser, R.J.
CSIRO Division of Fisheries, Hobart

Abstract

A relatively small aggregation of orange roughy (*Hoplostethus atlanticus*) was located in April 1989 off the east coast of Tasmania. A Simrad EK400 (38 kHz) scientific sounder was used to survey the aggregation over a period of eight days. The aggregation was commercially fished during this period. The area occupied by the aggregation was approximately 4 km^2, with the dimensions of the aggregation varying within and between days. High densities of orange roughy were located near the bottom on some days and more than 24 m off the bottom on others. Average fish densities during the survey are presented. *In-situ* target strength measurements of orange roughy have not yet been made, so an estimate of the extremes of densities (nm^{-3}) was made. Estimates of the original biomass of this aggregation obtained from acoustic data and commercial catch and effort data are compared, and an estimated mean population target strength is presented.

Introduction

Commercial deepwater fisheries for orange roughy (*Hoplostethus atlanticus*) exist on the continental slopes of Australia and New Zealand, generally targeting on dense single-species aggregations of adult fish in depths between 700 m and 1300 m. The aggregating behaviour of this species renders it suitable for acoustic surveying techniques for biomass estimation. Acoustic assessment is possible despite the depth at which they occur and the presence of an oil filled, rather than gas filled, swimbladder (Grigor *et al.* 1983). The first acoustic survey on this deepwater species was carried out on a spawning aggregation off New Zealand (Do and Coombs 1989). This paper describes an acoustic assessment of a relatively small aggregation of non-spawning orange roughy located during a random trawl survey off the east coast of Tasmania in April 1989. The aggregation was first located and surveyed on 20 April. The size and extent of this aggregation was surveyed on three further occasions over a seven day period during which it was fished commercially. Acoustic estimates of the original biomass are compared with that obtained using the commercial catch and effort data. Possible sources of error are also discussed.

Methods

Acoustic theory

The application of acoustic methods to abundance estimates of fish is summarized by Johannesson and Mitson (1983) and Do and Coombs (1989). An appropriate acoustic pulse is transmitted through the water column and the corresponding echo recorded. A time-varied-gain (TVG) amplifier applied to each returned echo compensates for the spreading and absorption loss of the acoustic pulse in the water column. The amplitude of the returned signals therefore are independent of the range of the target from the transducer. The strength of the returned echo is termed the volume backscattering strength (Sv, in dB re 1μPa), and is defined as the proportion of incident acoustic energy reflected back towards the transducer by targets within a unit volume of water. It is related to the voltage measured across the transducer by the logarithmic equation:

$$Sv = VRT - (SL + SRT + G) - 10 \log c\tau/2 - 10 \log \psi + (20 \log R + 2\alpha R) \qquad 1.$$

where,

VRT	= voltage measured across transducer (20 log V in dB re 1 volt)
SL	= source level (dB re 1μPa)
SRT	= receiving sensitivity of transducer (dB re 1 volt μPa^{-1})
G	= gain constant of system
c	= sound velocity (m s^{-1})
τ	= pulse length (s)
ψ	= two-way equivalent beam width of transducer (steradians)
R	= range from transducer to target volume (m)
α	= absorption coefficient of sound in water (dB m^{-1})

(modified from Johannesson and Mitson 1983).

The values for SL, SRT, G and ψ are determined from calibration data.

The output signal from the sounder is passed to an echo-integrator where the mean volume backscatter strength (MVBS, in dB re m^{-1}) is obtained by integrating Sv over a number of predetermined transmissions and in a number of predetermined depth layers. MVBS is proportional to the mean number of organisms in the volume insonified (n_v, in fish m^{-3}):

$$\mathrm{MVBS} = 10 \log n_v + \mathrm{TS} \qquad 2.$$

where TS is the mean target strength of the individual organisms (dB re m^2) (Do and Coombs 1989). The target strength of an organism is the ratio of the reflected (echo) intensity at 1m from the organism to the incident intensity which strikes it. Target strength of fish is proportional to the back scattering cross-section.

Acoustic equipment and system calibration

A Simrad EK400 scientific echo-sounder was coupled to a 38 kHz hull-mounted transducer and a modified BioSonics 121 echo-integrator. The system configuration is shown in Figure 1. A modified TVG amplifier was designed to cover the depths and water absorption ranges of concern in this study. The equipment was installed on the 53 m stern trawler F.R.V. *Soela* equipped with a Trimble 10X Navigator global positioning system (GPS).

The acoustic system was calibrated for the combined parameters of SL, SRT and G using a standard 60 mm copper sphere and the method described by Foote *et al.* (1987). The two-way equivalent beam width, ψ, of the Simrad 38-29/25-E transducer was obtained from the specification sheet with a possible deviation of $\pm$ 1.1 dB. The absorption coefficient, α, and the speed of sound in sea water, c, were calculated from temperature and salinity depth profiles obtained from CTD casts in the immediate vicinity of the aggregation using the formulae of Francois and Garrison (1982a, b) for α, and MacKenzie (1981) for c. The calibrated system parameters are presented in Table 1 and are specified where appropriate to an average integrating depth of 900 m, the average bottom depth around the aggregation.

Acoustic data analysis

The output data from the echo-integrator consisted of the mean square value of the voltage measured at the transducer following TVG compensation (V_{TVG}^2). Integration was performed over eight consecutive acoustic pings and in 25 two metre depth-layers above the bottom window. A bottom window of 4 m was programmed into the integrator.

The average V_{TVG}^2 for each depth-layer was then calculated for each transect over the aggregation, and this was then converted into MVBS using Equation 1 and the system parameters shown in Table 1. Mean fish densities (n_v) were calculated from the MVBS values using Equation 2. The target strength of orange roughy has yet to be validated, therefore three values are used in the calculations below , -36 dB, -39 dB and -42 dB. The former value is the mean target strength measured in a tank from dead orange roughy (standard length 35 cm) by Do and Coombs (1989) assuming a ± 30° roll about the dorsal aspect. These authors recommended that this value be treated with caution due to the unknown orientation of live fish. Their mean value was reduced by 3 dB (to -39 dB) based upon a pitch and roll about the dorsal aspect of ±5° rather than ± 30°. The -42 dB value was obtained from work on catch rates and volume reverberation (Elliott and Kloser ??).

Mean fish densities were converted to mean biomass per unit volume (b_v) using

$$b_v = n_v \, w$$

where w is the mean weight per fish obtained from length and weight data collected from demersal trawls within the aggregation.

Ambient noise measurements were recorded with the transducer in passive mode throughout the survey period. The maximum noise measured referred to 900 m (the average bottom depth around aggregation) was -85.9 dB (= 6.32×10^{-4} V_{TVG}^2). The aggregation of orange roughy was deemed to commence along a transect when the average MVBS of a sequence of eight pings was above -75.9 dB (aggregation threshold). This threshold gives a signal-to-noise ratio of 10 dB. Maximum noise has been allowed for in all reported data.

Due to the water depth and slope of the bottom over which the orange roughy were found two factors affecting the accuracy of the acoustic data must be considered. Firstly, the dead zone, caused by the geometry of the acoustic beam, which exists close to the sea bed and within which no target detection is possible. This source of error has been disregarded in the following analyses as it was variable along each transect and there was no information available for estimating either the extent of the zone or the fish density in the zone. The minimum height of this zone above the bottom is 2.25 m due to the pulse length and the speed of sound in water. Whilst this must be borne in mind when interpreting the biomass results the error is not considered to be large as Do and Coombs (1989) reported the main bulk of orange roughy in their survey to be above 5 m from the bottom. Likewise trials of a towed acoustic system which reduced the the dead zone by at least two thirds showed no signs of large concentrations of fish on or near the bottom over our survey area.

The second factor concerns the elimination during data processing of bottom echoes. This was achieved by both simultaneous visual evaluation of echograms and integration data. The maximum change in voltage recorded between successive mid-water integrated layers was found to be less than a factor of five (in V_{TVG}^2). The bottom window data was therefore discarded if there was a greater than five-fold increase in voltage between bottom window and the layer above.

Aggregation survey

The aggregation was first located and surveyed on 20 April 1989 (Day 1). All acoustic data on the aggregation that has been analysed was collected during the GPS window. This allowed for accurate positioning of the transects and so the extent of the aggregation.

Six transects were run on Day 1. Only three transects crossed the aggregation and echo-integration data was not available for one. On 21 and 22 April (Days 2 and 3) five east to west and six (no data for two) north to south transects were completed, respectively.

Echo-integration data was collected from the aggregation on 23 April (Day 4), however no survey transects were conducted. The area was surveyed again on 27 April (Day 8) with five transects.

Four demersal trawls were made to identify the targets within the aggregation; two on 20 April (Day 1), and one on 22 and 23 April (Days 3 and 4). The trawl gear used was an Engel high-rise bottom trawl (35.5 m headline, 50 m footrope with 16 m chain on each wing, bosom with rubber bobbins, 50 m wire upper and lower bridles) rigged for rough bottoms with no lower wings, and 180 mm to 100 mm mesh with a 40 mm liner in the 90 mm mesh codend. Ten CTD casts were made within and around the aggregation.

Catch and effort analyses

Catch and effort data from seven commercial vessels working this aggregation over a ten day period (21 to 30 April) were used in the Leslie method (Everhart *et al.* 1975) to estimate the original biomass of the aggregation, prior to any fishing effort. The Leslie method utilizes the relationship between daily catch per unit effort and the accumulated catch, with the original biomass estimate calculated from the ratio of the intercept and slope of the regression equation. This method assumes variable effort, constant catchability coefficient, no mortality (other than fishing) and a stable closed population.

Results

Of the four demersal tows made on the aggregation, three contained greater than 95% orange roughy, while the fourth contained 75% orange roughy and 17% of the dogfish *Deania calcea*. The size composition of the orange roughy caught in these trawls is shown in Figure 2. The mean weight per fish obtained from length and weight data collected was calculated to be 1.5 kg.

The approximate area occupied by the aggregation over the survey period is shown in Figure 3, with the position of the Day 2 and 3 transects over the aggregation indicated. An echogram through the high density area of the aggregation is presented in Figure 4. On occasions the aggregation extended to the east and/or north of the main area shown in Figure 3. It is estimated that the aggregation occupied an area of approximately 4 km^2 on each of the survey days. The spatial distribution of the aggregation varied each day and within each day around the area of highest density and within the water column. As Figure 5 shows, on Day 1 the highest MVBS returns were obtained from above 24 m off the bottom, whilst on Day 4 the highest returns came from below this depth. The mean MVBS in this high density area was -64.9 dB on Day 1 and -64.4 dB on Day 4.

Daily depth profiles of average MVBS are shown graphically in Figure 6. The high values close to the bottom must be treated with some caution as they may be exaggerated due to bottom echoes not removed during our processing of the data. However these daily average profiles show, as in Figure 5, that on Day 1 the main bulk of fish were off the bottom, the highest MVBS returns coming from above 36 m off the bottom. On Day 8, whilst lower MVBS values were recorded overall, there was again some evidence of higher densities of fish in the water column. On Days 2 and 3 the average daily profiles show a continuous decrease in MVBS with increase in height above the bottom up to 20 m off the bottom. This was not consistent however on all transects. Two of the five transects on Day 2 recorded higher MVBS values above 20 m off the bottom.

The average MVBS values for each transect and for each day are presented in Table 2. Echo-integration data collected during the demersal trawls are not included. There was a decrease in average MVBS recorded over the period of eight days. Table 3 shows this decrease in terms of average fish density within the aggregation, for the three assumed mean target strengths of orange roughy. Converting these densities into biomass of orange roughy within the assumed aggregation volume (4 km^2 by 52 m depth) indicates a loss of either 64.6, 128.8 or 257.0 tonnes over the eight survey days, depending upon the mean target strength of the population employed in the calculation (Table 4). The corresponding original biomass estimations for the aggregation are 110.7, 220.9 or 440.7 tonnes respectively.

The acoustic data indicated a 42% decrease in average fish density over the area by Day 3 and 58% decrease by Day 8 of the survey (Table 3). Table 5 shows that 139 tonnes of orange roughy had been caught by Day 3 and 204 tonnes by Day 8. Assuming no immigration of fish to the aggregation and no emigration other than by fishing, the original biomass of the aggregation was estimated to be 328.2 tonnes from the Day 3 data and 349.1 tonnes from the Day 8 data (mean value 338.7 tonnes). Converting this mean value to fish density using the mean weight per fish of 1.5 kg (1.0856×10^{-3} fish m^{-3}), then applying this and the average MVBS value for Day 1 (-70.5 dB) into equation 2 above, the mean target strength for this aggregation with a mean standard length of 36 cm, was -40.9 dB.

Using the catch and effort data in Table 5 with the Leslie method for the estimation of the original biomass, a value of 235.2 tonnes, with 95% confidence intervals of 190.8 to 345.0 tonnes, was obtained for this aggregation (regression equation: CPUE = 32.96 – 0.14 Acc. Catch).

Discussion

Assuming a mean population target strength of -39 dB, similar estimates of the original biomass of this aggregation were obtained from the acoustic and catch and effort data. Yet using this target strength the loss of biomass from the aggregation was only 60% of that actually caught, with an assumed target strength of -42 dB providing a closer estimate of biomass caught. Both methods for estimating the original biomass however suffer from possible invalid assumptions, high variances and technical sources of error.

The catch and effort data suffer from log book recording errors, particularly in regard to actual fishing effort when target fishing on such an aggregation. The commercial fishing was possibly also targeted only on the highest concentration within the aggregation, therefore invalidating the initial assumption of a closed population. The MVBS values from this area of high concentration were the same on Days 1 and 4 despite large catches having been taken and a significant decline in average MVBS for the entire aggregation over this period.

High coefficients of variation (30% - 90%) were obtained with the calculations of the mean MVBS per transect, and there were only a small number of transects each day. The absorption coefficient formula used in this study was derived from data for northern hemisphere waters (Francois and Garrison, 1982a, b). The alternative formula of Fisher and Simmons (1977), based on measurements of a standard water sample, provides a lower coefficient differing by 1.7 dB km^{-1}. Such a difference can vary the biomass estimates by a factor of two, for an average integrated water depth of 900 m. Future experimentation can minimize possible errors due to this parameter.

The appropriate target strength to use is an obvious source of error in the acoustic calculations. It does appear from our results that a mean population target strength of -36 dB for orange roughy as suggested by Do and Coombs (1989) may be too high, despite their value being for a mean standard length of 35 cm compared to our 36 cm. Our results indicate that a value of ca. -41 dB may be more realistic. This source of error can be over come in future surveys by obtaining *in-situ* values for each population.

There may have been some immigration of fish into the aggregation volume. This could have been from outside the general geographic area of the surveyed aggregation or that the aggregation may have extended outside the bounds of the volume integrated: there was evidence at times of both high concentrations of fish above 52 m from the bottom and of the dispersed phase extending outside the 4 km^2 area. The biomass would then have been under estimated. However this error may be compensated in that it was assumed that the aggregation was all orange roughy. In parts of the aggregation this may be a valid assumption, but in the more dispersed parts where there was possibly only 75% orange roughy in a catch, over estimation may occur. The main component of the by-catch were dogfish which due to their size more than likely have a higher target strength than the orange roughy.

The average MVBS value for Day 1 is approximately 7 dB (a factor of 5 in density) lower than values reported from the New Zealand spawning population (excluding their hot spot) on Chatham Rise in 1986 (Do and Coombs 1989). This comparison utilizes their correction value of +2.7 dB for their MVBS estimates due to the use of different formulae for the calculation of the absorption coefficient. MVBS values of -64.9 and -64.5 dB from within our higher density area are comparable to those non-hot spot values recorded in the

New Zealand survey.

The aggregation was relatively dynamic during the survey period. The fish aggregated and dispersed during the period of a day, with the aggregation phase more prevalent in the early hours of the day, yet the highest concentration of fish was predominantly associated with the one area. There was no evidence of increased feeding or sexual maturity, nor any significant oceanographic conditions existing within the area to suggest why this aggregation of orange roughy existed where it was.

Acknowledgements

This study was part of a project funded by FIRDC research grant 87/129. Our gratitude is extended to the Australian Maritime College for the loan of the BioSonics echo-integrator that allowed us to conduct this and other acoustic experiments in 1989. We thank Ms. C. Bulman for the collection of the commercial catch data and biological data; and Ms. L. Clementson for the collection and analysis of the CTD data. Our gratitude is also extended to the master and crew of the FRV *Soela.*

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List of Tables and Figures.

Figure 5. MVBS depth profiles in high density area of aggregation on Days 1 and 4. Mean MVBS was -64.9 dB on Day 1 and -64.4 dB on Day 4.

Figure 6. Depth profiles of the average MVBS for each survey day

Table 1. System parameters of the Simrad EK 400 equipment and Simrad 38-29/25-E transducer on the FRV *Soela.*

System parameter	Symbol	Values
Operating frequency		38 kHz
Beamwidth (-3 dB full angle)		8°/8° (± 1°) uncalibrated
Ideal beam angle	10 log ψ	-19.6 dB (± 1 dB) uncalibrated
Attenuation constant	α	9.3 dB km^{-1}
Source level	SL	194.9 dB re 1µPa at 1 m
Receiving sensitivity	SRT	-178.9 dB re 1 V $(\mu Pa)^{-1}$
Pulse length	τ	3 ms
Receiver bandwidth		1 kHz
Calibration parameters	SL + SRT + G	67.5 dB

Table 2. Average MVBS values for each transect, and for each survey day, averaged over 26 layers (0 to 52 m off the bottom).

Day	Transect	MVBS (dB) per transect	MVBS (dB) per day
1	16D	-69.1	-70.5
	16E	-73.0	
2	21A	-75.3	-71.1
	21B	-69.5	
	21C	-72.3	
	21D	-74.5	
	21E	-70.2	
3	27A	-72.5	-72.9
	27B	-71.9	
	27C	-74.0	
	27D	-73.3	
8	52D	-74.8	-74.3
	52E	75.5	
	52F	-75.3	
	52G	-73.8	
	52H	-73.1	

Table 3. Daily average MVBS values converted to average fish density (within 52 m off the bottom) using three different assumed target strengths (TS) for orange roughy.

Survey Day	MVBS (dB)	Density (fish m^{-3})		
		TS = -36 dB	TS = -39 dB	TS = -42 dB
1	-70.5	3.548×10^{-4}	7.079×10^{-4}	1.413×10^{-3}
2	-71.1.	3.090×10^{-4}	6.166×10^{-4}	1.230×10^{-3}
3	-72.9	2.042×10^{-4}	4.074×10^{-4}	8.128×10^{-4}
8	-74.3	1.479×10^{-4}	2.951×10^{-4}	5.888×10^{-4}

Table 4. Biomass (tonnes) estimations of orange roughy at the start and end of the survey period.Assume aggregation occupying an area of 4 km^2 and mean weight of 1.5 kg per fish. Values for three target strengths presented.

	TS = -36 dB	TS = -39 dB	TS = -42 dB
Day 1	110.7	220.9	440.7
Day 8	46.1	92.1	183.7
Difference	64.6	128.8	257.0

Table 5. Orange roughy catch (tonnes), fishing effort (hours) and catch per unit effort (CPUE tonnes per hour) of vessels working the aggregation over the period 21 to 30 April. These figures include the 10.2 tonnes taken by the FRV Soela. (-, end of survey period; * zero effort omitted from calculation).

Date (April)	Survey Day	Catch	Effort	CPUE	Acc.Catch
21	2	40.0	1.2	33.3	40.0
22	3	99.4	3.9	25.5	139.4
23	4	42.5	4.2	10.1	181.9
24	5	7.2	1.1	6.5	189.1
25	6	14.0	0.6	23.3	203.1
26	7	0	0	*	203.1
27	8	0.4	4.0	0.1	203.5
28	-	0.3	1.9	0.2	203.8
29	-	8.9	8.1	1.1	212.7
30	-	0.9	4.0	0.2	213.6

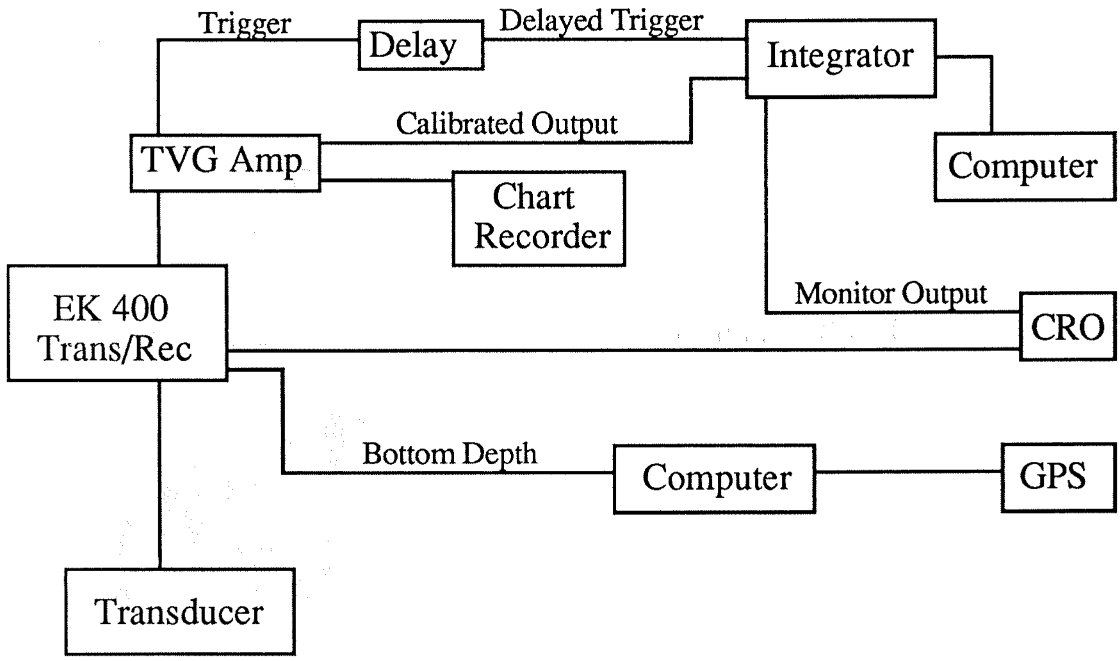


Figure 1. Configuration of acoustic system on the FRV *Soela* used during the survey.

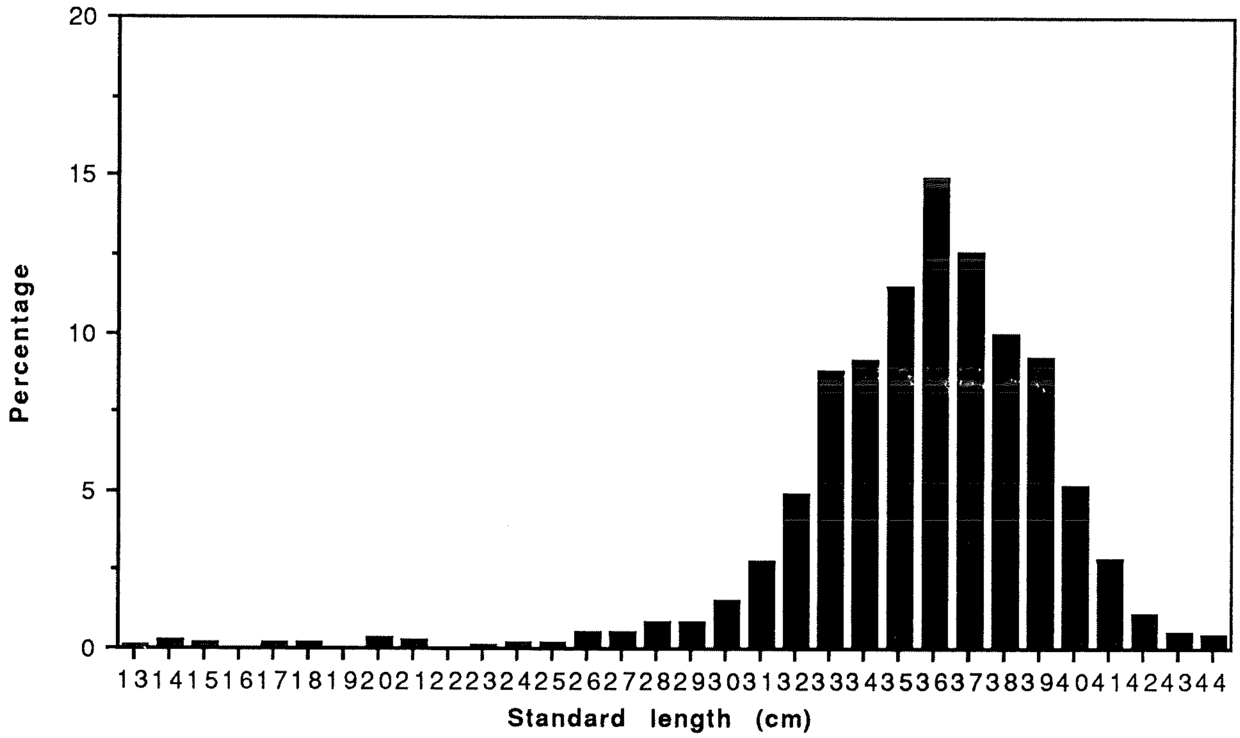


Figure 2. Length frequency distribution of orange roughy caught from aggregation.

Figure 3. Site of orange roughy aggregation off the east coast of Tasmania, showing location of high density area (dashed line) and position of Day 2 and Day 3 survey transects. A-B location of echogram shown in Figure 4.

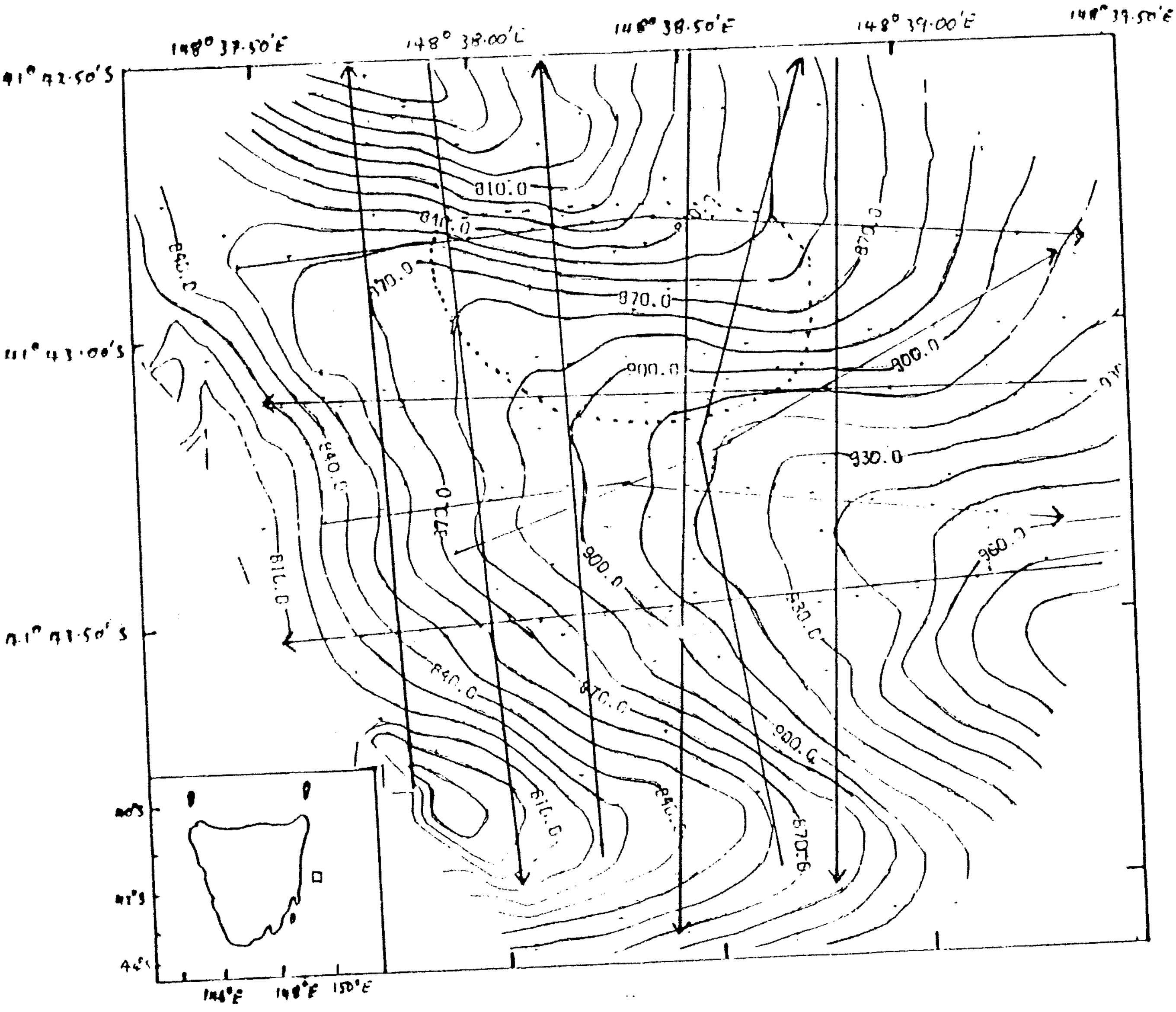
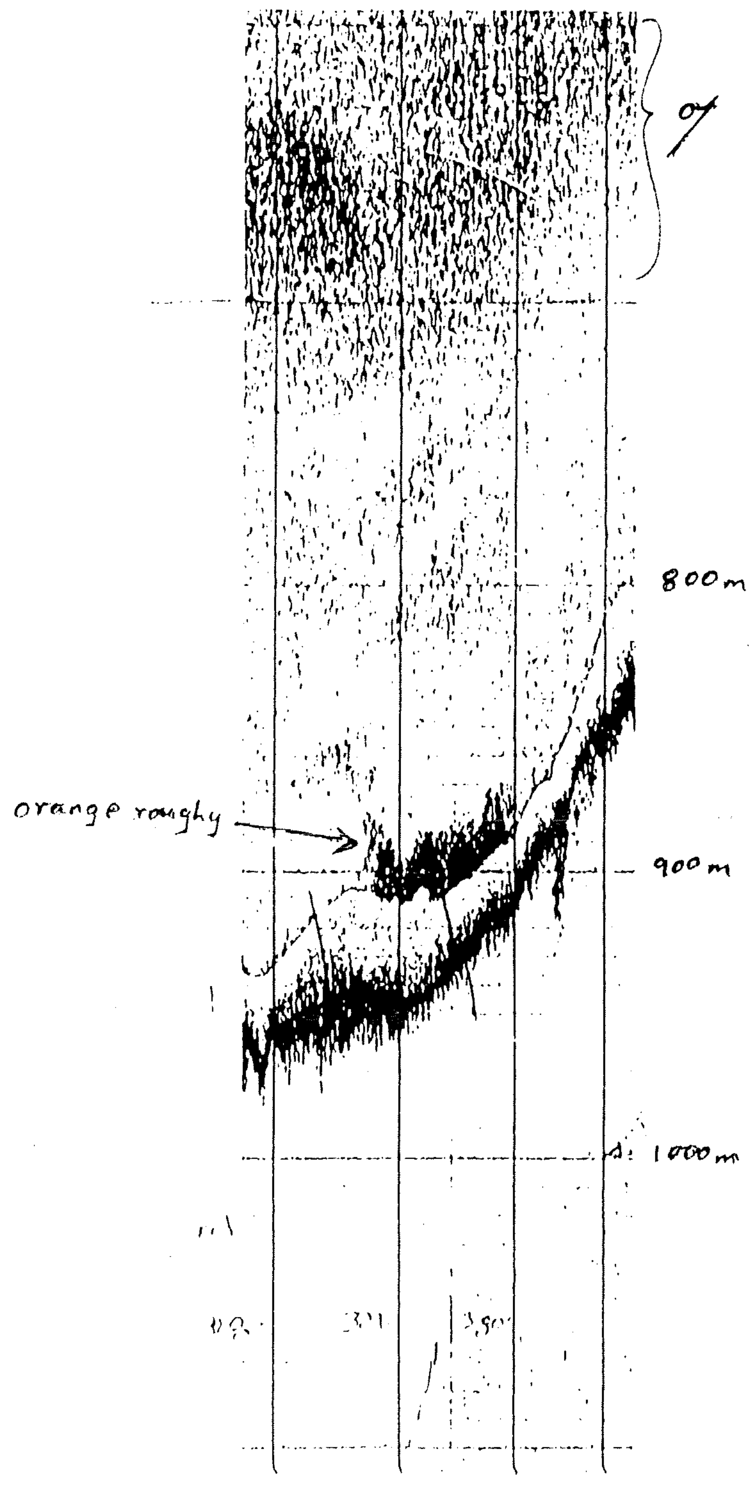


Figure 4. Echogram through high density area of aggregation, location shown on Figure 3, as transect 21B.



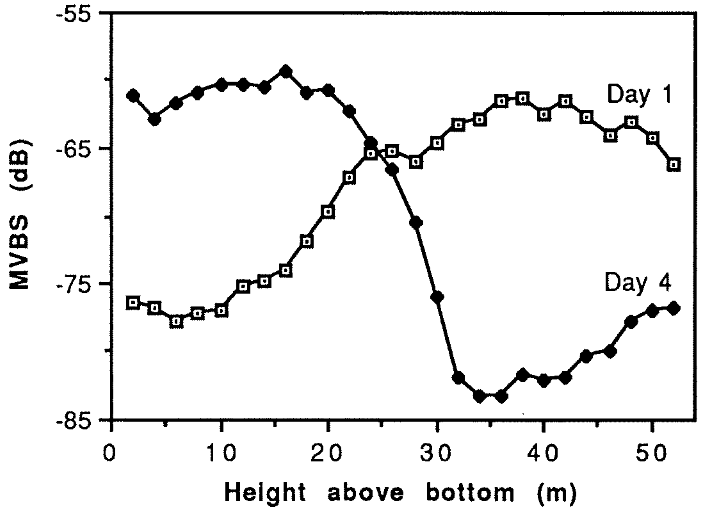


Figure 5. MVBS depth profiles in high density area of aggregation on Days 1 and 4. Mean MVBS was -64.9 dB on Day 1 and -64.4 dB on Day 4.

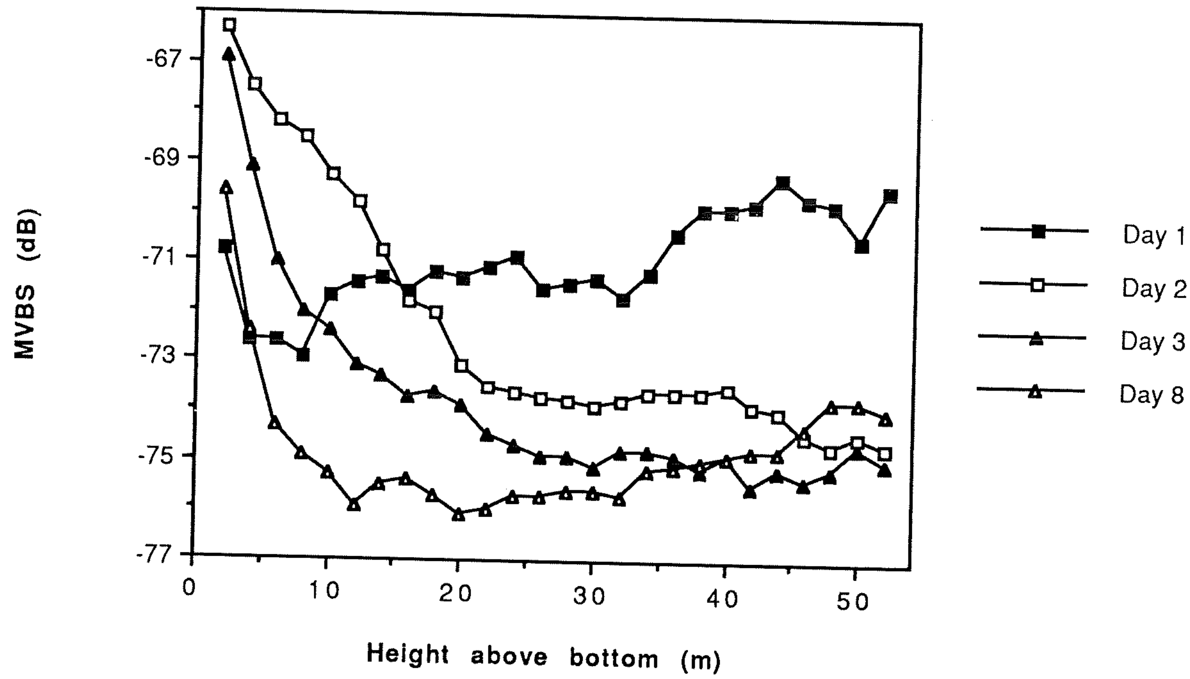


Figure 6. Depth profiles of the average MVBS for each survey day

DOCUMENT 12

INTERNAL REPORT

Acoustic Survey of
Orange Roughy (*Hoplostethis atlanticus*)
on the St. Helens Hill Ground,
August 1989

By: Rudy Kloser, Tony Koslow and Clive Stanley

Introduction

A large spawning aggregation of orange roughy was discovered on the St. Helens Hill ground (41 14.0' S 148 45.5' E) off the east coast of Tasmania in May-June 1989 (figure 1). Increasing fishing effort on the spawning stock with large catches (ca. 30-100 tonnes) being landed pointed to the need for a biomass estimate which could provide the basis for management of the stock. A trawl survey of this area by CSIRO only a few months before failed to detect this aggregation, although larger catches on the east coast of Tasmania were recorded, in particular east of Bicheno (figure 1). CSIRO was developing an acoustic survey capability, which would be well-suited to surveying such aggregations. However the system had not yet been fully developed and no research vessel was available, so a preliminary survey was organised to be carried out aboard a ship of opportunity. The overall plan was to map out the area and apply elementary acoustic theory to the echo sounder recordings to estimate the biomass present.

Theory

The established method of estimating abundance of high density fish stocks using acoustics is by echo integration. The standard equation in logarithmic form when applied to fisheries echo sounders is given by Johannesson and Mitson (1983):

$Sv = VRT - (SL + SRT) - 10 \log (0.5 * c * t) - 10 \log \psi + TL$

where,

Sv = Volume backscatter strength - the proportion of incident acoustic energy reflected back towards the transducer by targets

VRT = measured voltage across the transducer

SL = source level of the transducer

SRT = sensitivity of receiving transducer

c = speed of sound in sea water

t = pulse length

$10 \log \psi$ = equivalent beam width of transducer

$TL = 20 \log R + 2\alpha R$ is the transmission loss due to absorption and spreading, dependent upon depth (R), and absorption coefficient (α) of sound in seawater.

In this instance where only a relative biomass estimate is required of the acoustic estimation, SL, SRT, t ,c and ψ are constant to the echo sounding system and the equation reduces to:

$$Sv = VRT + TL + \text{constant}$$

Sv is related to fish density by:

$$Sv = 10 \log n + TS$$

where:

n = mean density of fish / m^3

TS = mean target strength of fish in dB re m^2.

A relative biomass assessment after compensating for transmission loss TL, reduces to,

$$\Delta \text{VRT} = \Delta\, 10 \log n.$$

The only means to measure the voltage of the transducer (VRT) without specialised equipment is to grade the echosounding paper, which yields a relative voltage assessment. The compensation of spreading loss TL is achieved by choosing a reference depth, in this instance 600 metres, and make the midpoint of all density ranges relative to this depth by the equation,

$$\Delta \text{TL} = 20 \log R + 2\alpha R - 66.7 \text{ dB re 1 m}.$$

This provides a relative biomass whose accuracy is only dependent on the relative grading of the echo sounding paper.

History of the ground

The St. Helens Hill ground was acoustically surveyed by CSIRO in June 1987 on the research cruise S04/87 aboard the R.V. Soela. The acoustic system used on the vessel at that time was an EK 400 Simrad echo sounder with a 12kHz, 14/17 degrees beamwidth transducer. The echograms obtained show high intensity unidentified echos on the top of the hill and some less reflective echos on the slopes. The echos on the slopes are now known to be characteristic of orange roughy marks, but trawling at the time failed to identify these marks. An analysis of the 12kHz transducer used on the R.V.Soela at the time showed that it was susceptible to low frequency ship noise and not as suitable as a 38kHz, 8/8 degrees beamwidth transducer which was subsequently fitted. The lack of heavy marks recorded in 1987 compared to the data collected this year with a 38kHz transducer could be due to the poorer performance of the 12kHz transducer and not a lower abundance of orange roughy. The recording of marks in June 1987 indicates that the spawning event is annual.

Equipment used on Petuna Endeavour with relevant settings.

The fishing vessel selected for the survey, was equipped with a Global Positioning System (GPS) navigation system and a Simrad ET 100 paper recording echo sounder similar to the equipment used on our research vessel.

The Petuna Endeavor is a 24 metre long vessel with stern trawling capabilities and a holding capacity of 80 tonnes the equipment settings are;

Trimble 10X GPS	Geoid Datum	Australian
	Averaging	5 sec.
Simrad ET 100		
Echo Sounder	Beamwidth	8/8 degrees
	Speed of Sound	1498 m/s
	TVG 20 log R ends at 581m	
	Mode	Dynaline
	Gain	6
	Power	Low approx. 400 W
	Pulse Length	3 mS

Method

The plan of the trip was to obtain as much information as possible on the biomass of orange roughy given the constraints of working on a commercial vessel.

The objectives were to:

i. Conduct acoustic transacts of the ground during a GPS window.

ii. Lower a stereo camera into the highest density part of the school to obtain a density estimate.

iii. Monitor the commercial catch and obtain biological data.

The spawning aggregation was surveyed with a rectangular grid pattern at 6 knots with a distance between transacts of approximately 500m which ensured non-overlapping transacts due to spherical spreading. The echo sounder was marked at 50 metre depth intervals with the time, depth, position, speed and heading regularly recorded at each mark as shown in figure 2. The survey took approximately 3 hours for the nine transacts with 87 sampling points recorded. The stereo camera was then attached to the headline of the trawl and the gear shot away. Unfortunately the gear came fast just prior to the camera firing and no usable pictures were obtained.

To produce a density and area plot of the region, the echograms were analysed against a gray scale. The four levels of gray scale (light, medium, heavy and saturated) were attributed to different depth layers at each sampling point (Figure 2). The dynamic range of the sounder paper was given by the manufacturers as approximately 12dB with 3dB steps from light to saturated (3dB represents a doubling of the density).

The relative density regions needed to be adjusted for energy loss due to spherical spreading and sea water absorption, for which the sounder did not compensate. The absorption coefficient (α) used for this survey was 9.3 dB, which is appropriate for the East Coast of Tasmania water in winter at the depths surveyed, Francois and Garrison 1982. To scale the relative densities, the highest echo strength on the echogram after adjusting for spreading and absorption losses was assigned an arbitrary density of 1fish/m^3 and all other echos calculated relative to this. The volume measurements were converted to an area measurement of fish/m^2 at each sample point by multiplying the density of fish by the height of the echo. This relative density data was processed on the VAX computer using the National Centre for Atmospheric Research (NCAR) contouring package.

Results

Apart from our acoustic survey work the fishing operation yielded approximately 80 tonnes of orange roughy from three shots with two earlier shots yielding only small catches.

The position and depth data were processed on the VAX computer using the NCAR contouring package and a bathymetric chart was produced (figure3).

In analysing the acoustic returns, we assumed that all acoustic returns from greater than 600 metres depth came from orange roughy. There was no evidence of any other large species being caught on the ground at the time of the survey. The relative density chart in fish/m2 is shown in figure 6.

To convert the relative density estimate to an absolute estimate required an independent estimate of fish density from the stereo camera. Without stereo camera photographs, the only packing density indicator was from the trawl catches. Using the trawl catches to estimate packing densities is fraught with assumptions related to catchability and actual fishing time. The trawl gear passes through a plume of fish often rising over 100m above bottom and actually fished on bottom for only a few minutes, so such assumptions are particularly difficult to assess in this fishery. Further there was a burst panel on the net set at 25 tonnes, which was activated on every large shot so the actual fish that passed through the net could not be assessed.

Although it was not possible to accurately assess fish density, we made a first-order approximation of maximal fish density. If 25 tonnes of fish is obtained from a 4 minute tow, fish density is 0.5 fish/m^3, assuming a catchability of one for a net opening 5 m high and 20 m wide, a 3 knot (1.5 m/s) tow speed, and an average fish weight of 1.4 kg. This figure is similar to that obtained by Do and Coombs 1989 for an orange roughy " Hot Spot " aggregation off New Zealand. The highest reverberation 5 - 10 metres off bottom for a 870 metre transect was -45.1 dB which is equivalent to 0.4 fish/m^3, assuming a target strength for orange roughy of -39dB, and the absorption coefficient of Francois and Garrison 1982.

If the maximal density of 0.5 fish/m^3 is applied to the relative densities they can be turned into absolute densities. To do so the area bounded by the cruise track was separated into 3 strata of equal sampling intensity and a biomass of each stratum obtained. The table of results are as outlined below.

Table 1.

	Samples #	**Average fish/m2**	**Area km2**	**number of fish fish (millions)**
Strata 1	26	11.8	8.5	100
Strata 2	43	15.5	4.9	76
Strata 3	18	8	6.2	50
		Total number of fish (millions)		230
		Total weight of fish		**320 000 tonnes**

Discussion

Given the nature of the equipment used in this survey and the assumptions made in the calculations (Table 2) our confidence in the survey estimate is only within a factor of 3 - 5. This is of limited use for management purposes.

However all the problems mentioned in table 2 can be resolved with use of the proper equipment such as the Simrad EK500 echo sounder, which was subsequently purchased and CSIRO's deepwater towed body .

Table2.

Problem	Magnitude	Solution
Echo classification	Unknown	Echo integrator
Beam Spread	Dependant on dynamic range of paper	Appropriate amplifier
Dynamic range of paper	+/- 50 %	Echo Integrator
Density Estimate	Unknown	In-Situ target strengths with calibrated acoustics Stereo Camera

Conclusion

Useful information can be obtained from acoustic surveys carried out on fishing vessels using uncalibrated " fishing " echo sounders such as bathymetry, relative school size, and density. However it is not possible to estimate absolute biomass without properly calibrated acoustic equipment. The figure of 320 000 tonnes should be used only as an order of magnitude guide until a better estimate becomes available.

Acknowledgements

We are particularly grateful to Petuna Fisheries for the use of the *Petuna Endeavor* and to Captain Chris Shera and his crew. Mark Palmer analysed the acoustic records.

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Figure 1.

Location of Orange roughy spawning and non-spawning aggregations in 1989.

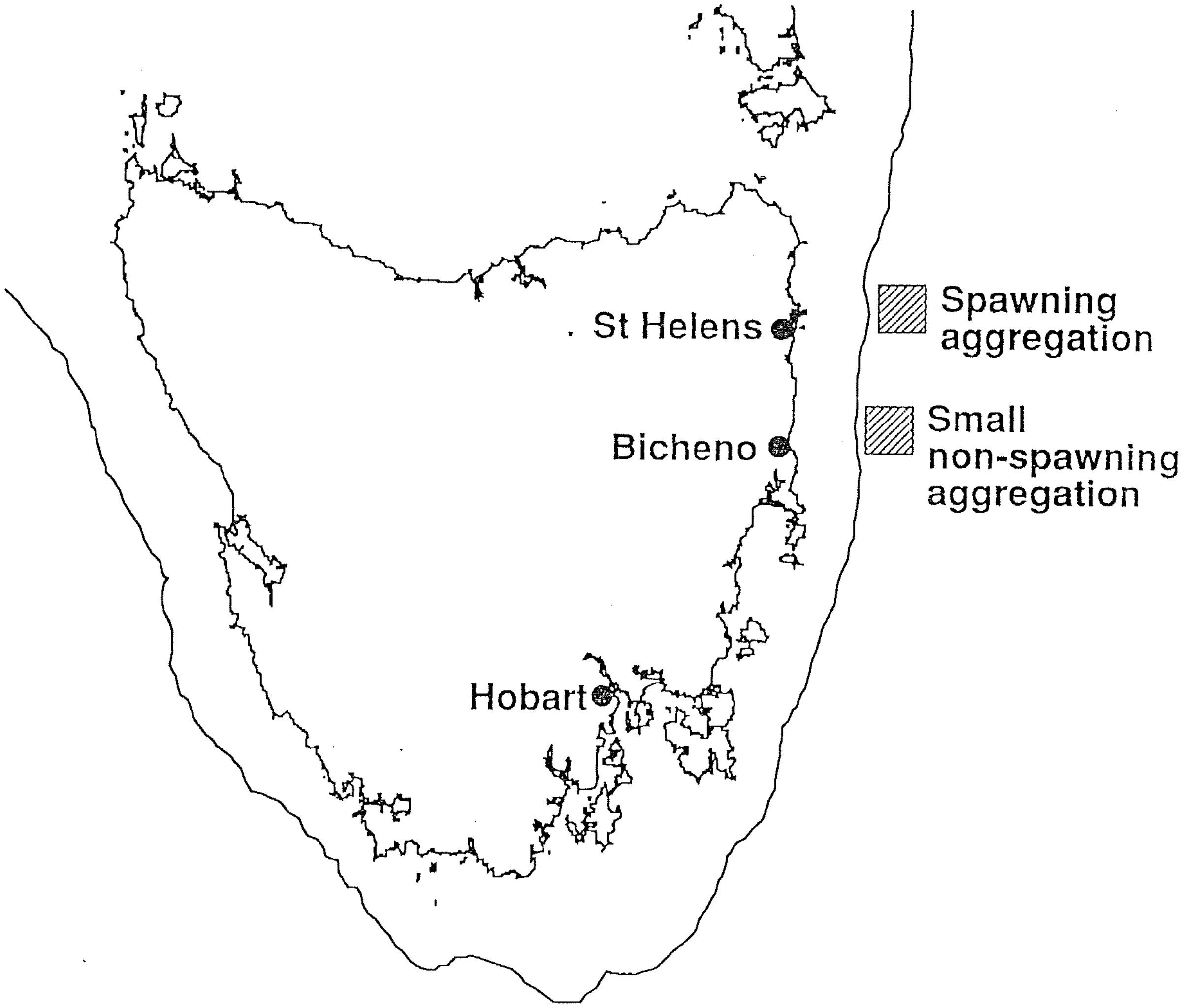
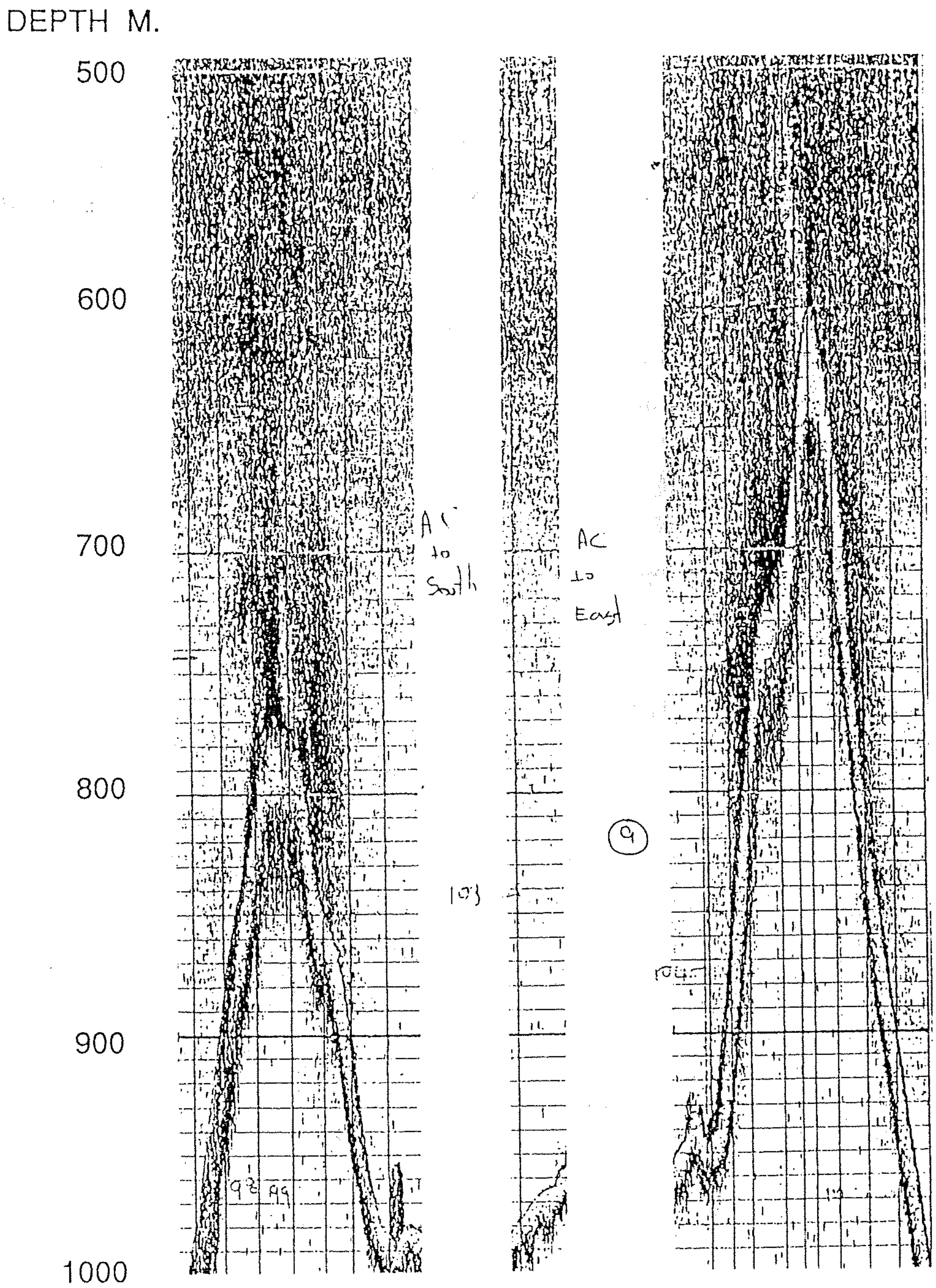


Figure 2.

Echograms used to produce bathymetric and density charts.



Transect #8

Transect #9

Figure 3.

Bathymetric chart showing transect lines. Depth interval is 30m.

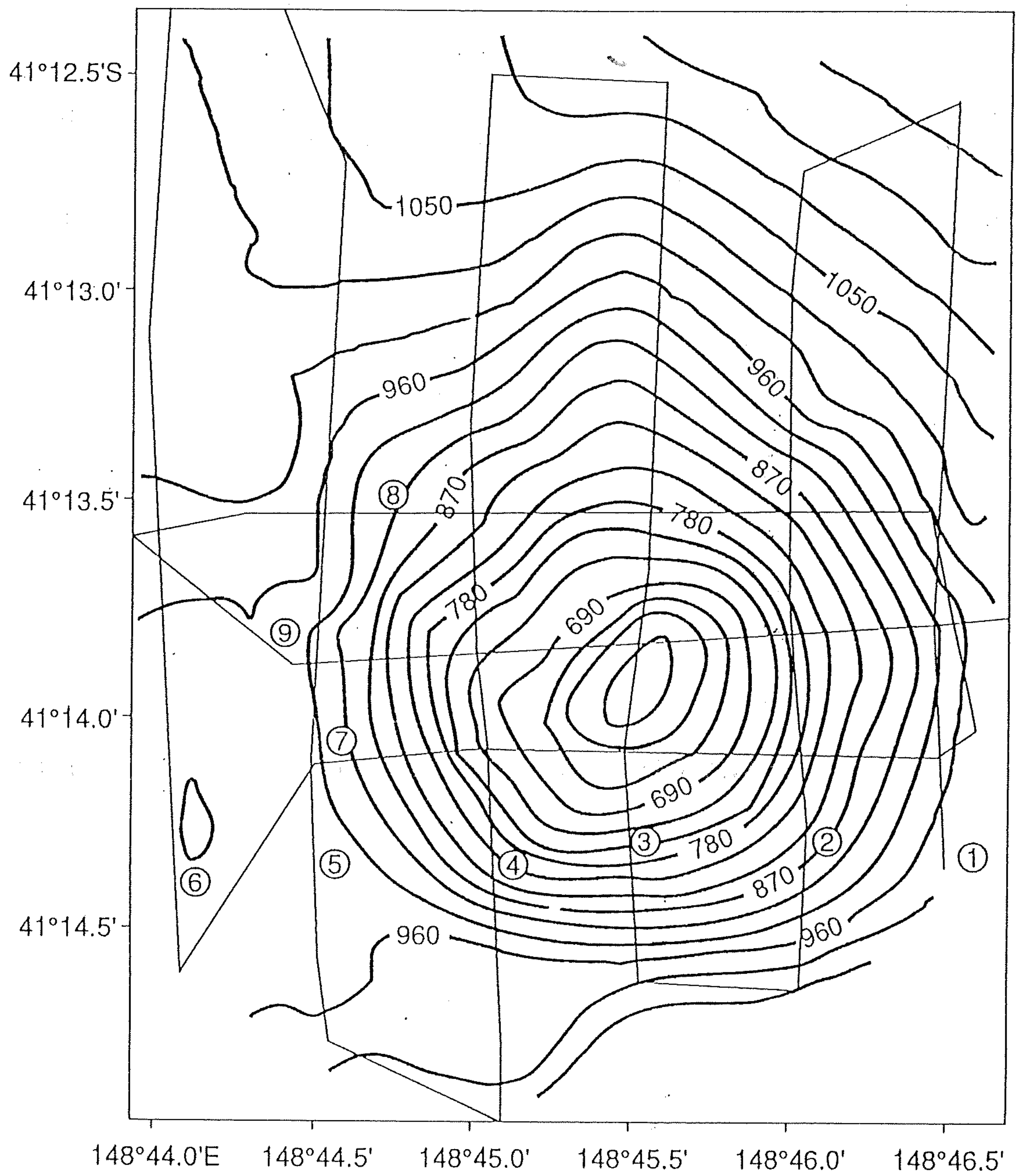
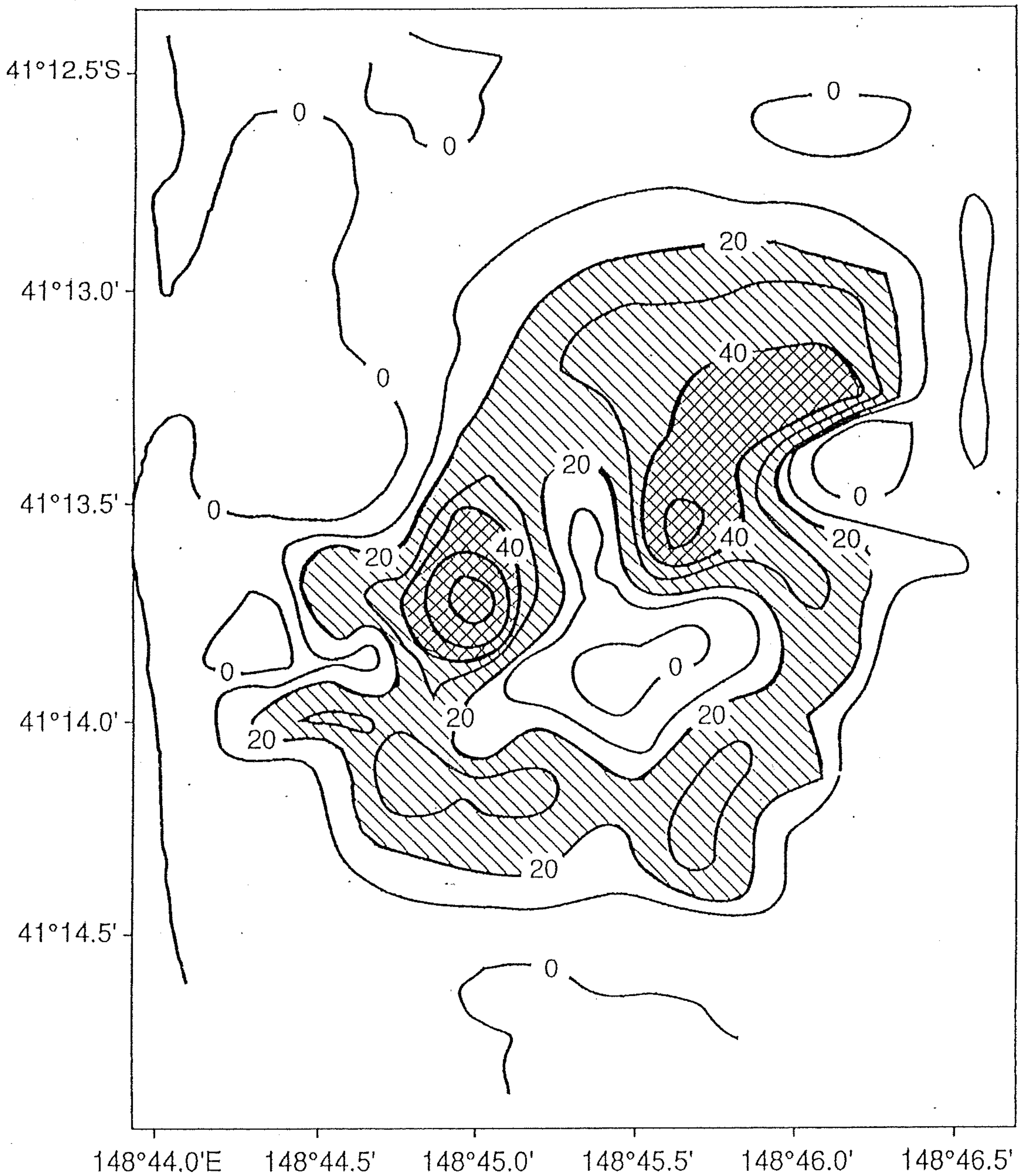


Figure 4.

Density chart of orange roughy in relative units of fish / m^2



DOCUMENT 13

DEEP-SEA RESEARCH

The Mid-slope Demersal Fish Community off Southeastern Australia

J. Anthony Koslow[1], C.M. Bulman[1], and J.M. Lyle[2]

[1] Division of Fisheries, CSIRO, GPO Box 1538, Hobart, Tasmania, Australia 7001
[2] Tasmania Department of Sea Fisheries, Taroona, Tasmania, Australia 7053

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Abstract

Stratified, random demersal trawl surveys based upon a total of 376 stations were carried out at mid-slope depths (800-1200 m) off southeastern Australia. The mean density of demersal species was 4.82 g/m^2, which is comparable to the density of fish observed at similar depths in the temperate North Atlantic and North Pacific. However, the density of orange roughy (*Hoplostethus atlanticus*) on rough, untrawlable ground was estimated from acoustic surveys to be 39.0 - 67.3 g/m^2. Although 37 families and 118 species were represented in the catch, 96% of the catch was obtained from 7 dominant families: Trachichthyidae (i.e. orange roughy) (23%), Squalidae (22%), Oreosomatidae (20%), Macrouridae (13%), Synaphobranchidae (8%), Alepocephalidae (5%), and Moridae (4%). The species abundance pattern was characterized by the dominance of a few species combined with a relatively large number of rare species: 37.6% of species occurred only once or twice in the survey. Due to the lack of a mode of species of intermediate abundance, the dominance-diversity curve for the community was distinctly concave, which is inconsistent with the log-normal and log-series models for the distribution of species abundance. Nonhierarchical cluster analysis indicated that the species could be sub-divided into assemblages by depth (shallow, intermediate and deep stations) and area (east and west Tasmania). The assemblages were defined in terms of the species' relative abundance rather than their presence or absence, but the clusters were robust to classification of the stations using discriminant function analysis based upon the 'jackknife' procedure. However, there is a distinct break in the species composition of demersal fishes between mid-slope (800-1200 m) and upper-slope (500 m) depths off southeast Australia, only 20% of upper-slope species being found in the mid-slope region. Comparison across biogeographic provinces indicated no overlap in species composition of the community in our study with demersal fish communities at similar latitudes and depths in the North Pacific, but there were affinities with fish communities in the North Atlantic. This is consistent with the circulation pattern of intermediate-depth water masses: the southeast Australian mid-slope fishes reside in Antarctic Intermediate Water, the flow of which can be clearly traced into the North Atlantic but not the North Pacific.

Introduction

In the waters off southeastern Australia, trawl fisheries began to exploit mid-slope depths (700-1200 m) within the past five years due to interest in the orange roughy (*Hoplostethus atlanticus*). This species presently forms the largest and most valuable of Australia's trawl fisheries with annual landings of up to 25,000-35,000 tonnes since 1989. Although orange roughy is found in the mid-slope region throughout temperate Southern Hemisphere oceans and in the North Atlantic (Smith and Heemstra 1986), it forms the basis of substantial fisheries only in the Southern Hemisphere, in particular off New Zealand and temperate Australia.

To examine the potential for development of this fishery, trawl surveys were conducted from 1987-89 at mid-slope depths around southeastern Australia. Although their primary objective was to assess the distribution and abundance of orange roughy, the surveys provided an opportunity to examine the abundance, species composition, and structure of the demersal fish community in this region. Such a study would permit comparison with the upper slope (500 m depth) fish community in this region described by May and Blaber (1989), as well as with fish communities at similar depths and latitudes that have been investigated in the North Atlantic and Pacific (Haedrich et al. 1980; Pearcy et al. 1982; Gordon and Duncan 1985; Haedrich and Merrett 1988). Does development of commercial fisheries in the mid-slope region off southeast Australia indicate differences in the density, diversity, and structure of the fish community there compared with its counterparts in the Northern Hemisphere? There is a distinct water mass, the Antarctic Intermediate Water, at mid-slope depths off southeast Australia and New Zealand that penetrates well into the North Atlantic but not into the North Pacific, which produces its own Pacific Intermediate Water (Sverdrup et al. 1942). How are biogeographic patterns among these oceans related to the distribution of water masses at mid-slope depths? Finally, our study is based upon a relatively large number of stations over a limited depth range (800-1200 m) unlike most studies of deepwater communities, which typically span several thousands of metres in depth, often with relatively few stations. We will therefore primarily examine fine-scale depth-related changes in community structure rather than the primary zonation patterns generally described in the literature (Menzies et al. 1973; Haedrich et al. 1980; Pearcy et al. 1982; Carney et al. 1983; Gordon and Duncan 1985).

Methods

Field sampling

The samples were obtained as part of random trawl surveys carried out by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Tasmania Department of Sea Fisheries (TDSF). The surveys were carried out aboard the organizations' respective fishery research vessels, *Soela* and *Challenger* as well as a commercial fishing vessel, *Petuna Endeavour*. Commercial demersal otter trawl gear was used throughout: an Engel high-lift fishing trawl on *Soela* (35.5 m headline, 50 m footrope, average mouth opening (wingspread) of 19 m as measured with a Scanmar net monitoring system, and 90 mm mesh in the cod end with a 40 mm mesh liner); a modified Atlantic Western trawl aboard *Challenger* (34.9 m headline and 42 m footrope, with 19 m wingspread and 11 cm mesh in the cod end); and a Milligan orange roughy trawl aboard *Petuna Endeavour* (36.6 m headline, 37 m footrope, and 20 m wingspread with 11 cm mesh in the codend). CSIRO tows aimed to be 30 minutes duration, and TDSF tows were generally an hour. All catches were normalized either per hour or per km^2 swept area.

The surveys were carried out by TDSF off east and west Tasmania, and the CSIRO survey extended across western Bass Strait and into the Great Australian Bight (GAB) (Table 1; Figure 1). The surveys were stratified by 100 m depth intervals from 800 to 1200 m (i.e. 4 depth strata) and stations were randomly allocated within these strata and the trawlable portions of these areas.

The two groups consulted with each other in designing the field sampling and used similar methods of collection. However, the surveys were carried out independently and the samples processed differently. As a result, when it was decided *post hoc* to combine the two data sets for analysis, most analyses could be carried out on only one or the other data set.

Both groups sorted and identified the catches to species. TDSF consistently enumerated the catches by species but did not have balances available to weigh them. CSIRO recorded all species that were present but did not enumerate them. Major species were weighed by species, but minor species from diverse groups (e.g. the Macrourids) were generally recorded as present and weighed by family.

Data analysis

There were two stages to the data analysis. We first examined patterns of abundance and species diversity within the demersal fish community. The distribution of biomass by depth and area was analyzed for the major fish families with the CSIRO data. Due to the non-normality of the catch-weight data even after log-transformation, differences by area and depth were tested for significance with the nonparametric Kruskal-Wallis (K-W) test.

The diversity and distribution of species within the fish community were examined with the TDSF data set. Species diversity was examined in terms of the number of species recorded and the Shannon-Wiener index of species diversity (H'):

$$H' = -\sum_{i=1}^{s} p_i \cdot \ln(p_i) \qquad (1)$$

where p_i is the proportion of the community in species i, and s is the number of samples. Because the number of species recorded is a function of sample size, Hurlbert's (1971) rarefaction method was also used to estimate the expected number of species (E(s)) as a function of sample size:

$$E(s) = \sum_{i=1}^{s} \left[1 - \frac{\binom{N - N_i}{N'}}{\binom{N}{N'}} \right] \qquad (2)$$

where N is the total number of specimens, N_i is the number of specimens in species i, and N' is the standardized sample size.

The evenness of the species distribution was examined on the basis of several types of plots in addition to H', which is a function of evenness as well as of the number of species. The distribution of abundance, frequency of occurrence, and percent of total catch represented by each species were plotted across the species sampled.

The vertical and horizontal spatial distribution of the species was analysed using nonhierarchical cluster analysis, as recommended by Gauch (1982), followed by discriminant function analysis to test the degree of separation among clusters. The abundance data were log-transformed initially. Stations were assigned to clusters based upon nearest centroid sorting, i.e. each station was assigned to the cluster to whose centre it was closest based upon the Euclidean distance (Norusis 1990). The resulting assignment of stations among clusters was examined in relation to depth and area. The analysis requires initial specification of the number of clusters, and the number presented here (5) represents the maximum number of distinct clusters that could be formed in terms of the Euclidean distance between clusters and the distinctness of the area and depth strata represented. The Euclidean distance (D_E) between clusters (k_j, k_l) was calculated from the mean values for each of n species (S_i) within the two clusters:

$$D_E = [\sum_{i=1}^{n}(S_{i,kj}-S_{i,kl})^2]^{0.5}$$

The distinctness of the resulting clusters was also examined based upon a c^2 test of the distribution of stations within the clusters by area and depth strata. This test is not statistically rigorous, however, because the clusters were determined *a posteriori* based upon an algorithm that maximized the distance between them. A 'jackknife' method was therefore used in conjunction with discriminant function analysis to test the validity of the clusters. Discriminant functions based upon the cluster placement of 90% of the stations were used to classify the remaining 10% of stations. This was carried out ten times over successive 10% portions of the data set until all stations were classified, and the proportion correctly classified was examined.

Differences in species composition among clusters was assessed from scatterplots of mean species abundance between pairs of clusters. Data were used only from 'indicator' species that displayed a highly significant difference in distribution among clusters ($p \leq 0.001$) based upon analysis of variance (ANOVA) and the F-statistic. Again, this statistic was based upon an *a posteriori* test and was used for descriptive purposes rather than as a rigorous statistical test, because the clusters were formed by maximizing differences in species abundance between them.

Results

Biomass and Distribution

There were 376 stations covered by CSIRO in 1989 and by TDSF from 1987-89. Their distribution by date and area is shown in Table 1. There were relatively fewer stations in eastern Tasmania due to a higher proportion of rough untrawlable ground in that area.

In Table 2 we present the distribution of catch weight by family based upon the CSIRO data and the frequency of occurrence of species from the combined data sets. Catch data are presented only for demersal species. 47 species of mesopelagic and bathypelagic fishes from 29 families were also caught (Table 3) but were not incorporated in the analyses, because they were not sampled in a representative manner. The overall mean catch rate of demersal fishes was 4.82 g/m^2; the combined catch of pelagic fishes excluded from the analyses was only 0.01 g/m^2. The dominant species was the orange roughy, *Hoplostethus atlanticus*, which comprised 23% of the catch by weight. Although 38 families of demersal fishes were represented in the catch, only 7 were present at a mean overall density greater than 0.1 g/m^2. These families together comprised 96% of the fish caught by weight: Trachichthyidae (23%), Squalidae (22%), Oreosomatidae (20%), Macrouridae (13%), Synaphobranchidae (8%), Alepocephalidae (5%), and Moridae (4%).

There were significant differences in catch rate by depth and area (Table 4). The overall density of the fish community was higher around east and west Tasmania than in the GAB (K-W test, $p < 0.05$). (The apparently higher mean catch rate off east than off west Tasmania is due to a single high catch. The median catch rates for east and west Tasmania and the GAB were 4.36, 4.49, and 3.20 g/m^2.) There were also significant differences in overall fish density with depth, the highest biomass being at the shallowest depth stratum (800-900 m) and at 1000-1100 m (K-W test, $p < 0.01$). This pattern was found in the macrourids and was also derived from the combination of declining biomass of several fish families with depth and a low density of orange roughy at 900-1000 m.

Most of the 7 dominant families exhibited significant differences in density by area and depth (K-W test, $p < 0.05$; Table 4). Most of the fish families exhibited a significant overall trend with depth, density either decreasing (i.e. the Squalidae and Moridae) or increasing (i.e.

the Synaphobranchidae, Alepocephalidae, and Oreosomatidae). The density of four families was markedly lower in the GAB (the Squalidae, Moridae, Macrouridae, and Trachichthyidae), and the Synaphobranchidae and Alepocephalidae exhibited lower density off east Tasmania. There was an overall areal trend in density only in the Oreosomatidae, whose density increased westward from east Tasmania to the GAB.

Species diversity

A total of 118 demersal species were recorded from 376 trawls containing a total of 155,069 specimens. The total number of species recorded was highly dependent on sample size, as seen from the plot of species recorded with increasing numbers of trawl samples (Figure 2A). This pattern is closely followed by the Hurlbert index of the expected number of species observed as a function of number of specimens (Figure 2 B). This pattern arises from the large number of rare species. 37.6% of species occurred in only one or two samples (Figure 2C), so the number of species continued to increase steadily until approximately 140 trawls had been taken, although half the species were recorded from the first 20 trawl samples (Figure 2A).

The species abundance pattern was characterized by the dominance of a relatively few species, as well as the relatively large number of rare species. Ten species accounted for more than 90% of individuals (Figure 2D~~). Viewed slightly differently, only 13 of 109 species in the~~ TDSF data set contributed $\geq$1% of the total numbers caught (Figure 2E).

Species diversity was also examined with the Shannon-Wiener index. The index was highly variable until more than 40 stations were included, at which point it stabilized at a value of approximately 2.4 (Figure 2F).

A plot of the distribution of species based upon a logarithmic scale of abundance, which often approximates a log-normal or truncated log-normal distribution for undisturbed communities (May 1976), instead appeared distinctly concave and skewed to the right (Figure 2G). This is due to the relatively large number of both rare and highly abundant species and the lack of a mode of species of intermediate abundance. As a result, the plot of dominance-diversity for the community was also concave (Figure 2E), unlike the sigmoidal relationship expected from a log-normal distribution of species abundance. An alternate model of species abundance distribution, the log-series distribution, has been proposed for disturbed communities (May 1976). The log-series distribution is consistent with a linear dominance-diversity relationship, which also does not fit the observed relationship for the mid-slope fish community.

There was no consistent evidence for differences in species diversity by depth. However, the number of demersal fish species at mid-slope depths off west Tasmania appeared greater than off east Tasmania based upon the number of species obtained for a given number of samples (Figures 3). However, there was no indication of significant differences between area or depth strata in terms of the dominance-diversity structure of the fish community.

Spatial structure

Nonhierarchical cluster analysis on the TDSF data for species abundance at mid-slope depths off east and west Tasmania indicated that there were 5 clusters of stations that represented distinct area and depth strata (Table 5). Generally the cluster analysis indicated that the mid-slope region (800-1200 m) off Tasmania could be clearly delineated into three depth regions (shallow, intermediate, and deep). Differences between east and west Tasmania decreased with depth, such that the shallow stations were clearly separated by area, intermediate depth stations were less successfully separated, and deeper stations were found within a single cluster. Thus, two clusters were distinctly west Tasmanian, one (Cluster 4) based upon stations from the shallow portion of the mid-slope depth range (800-900 m) and one (Cluster 2) from intermediate mid-slope depths (900-1100). One cluster (5) was distinctly east Tasmanian and was based predominantly upon the shallowest stations (800-900 m). Cluster 3 comprised the deeper stations (1000-1200 m) from both east and west Tasmania. Cluster 1 was based predominantly upon intermediate depth (900-1000 m) stations with a higher than expected proportion of east Tasmanian stations. The Euclidean distance between clusters indicated that this last cluster (1) was least distinct (Table 6), which might be expected since its regional affinity was less distinct than the others, and its depth distribution overlapped that of Cluster 2. Cluster 5 was distinctly smaller than the others, containing only 10 stations of 220 in the TDSF data set. The distinctness of the clusters is indicated by the highly non-random distribution of stations by depth and area among clusters (Table 5: c^2 statistics, p <

0.001), but this should not be considered a statistical test of the significance of the clustering procedure.

84% of cases were correctly classified within the five clusters based upon use of the 'jackknife' with discriminant function analysis (Table 7). 63% and 50% of cases were correctly classified into clusters 1 and 5, respectively; >87% of cases were correctly classified into the remaining three clusters. This procedure indicates that the clusters are well-defined by the differences in species abundance among them.

Plots of the mean abundance of 'indicator' species between clusters enabled us to determine the species characteristic of different portions of the mid-slope habitat around Tasmania (Figure 4). Comparison of the shallow, intermediate and deep species assemblages indicates a gradual shift in relative species abundance with depth. Abundance generally declined in the deepest depth stratum (1100-1200 m). Only a single species, *Trachyrinchus longirostris,* could be considered indicative of the deepest depth stratum, insofar as it was markedly more abundant there than at intermediate depths (900-1100 m) (Figure 4A), and it was absent from the shallowest clusters (Figures 4B,C). However, several dominant and sub-dominant species were only marginally less abundant in the deepest than in intermediate depth strata, and their centres of distribution appeared tospan these depths: *Hoplostethus atlanticus, Alepocephalus* spp., *Allocyttus verrucosus*, and *Diastobranchus capensis. Halargyreus johnsoni, Coelorinchus kermadecus, Coryphenoides serrulatus* and *Coryphenoides subserrulatus* , were most abundant in the intermediate mid-slope depth range (Figures 4 A, B, C). Differences in species composition were somewhat sharper between the deepest (1100-1200 m: Cluster 3) and shallowest strata ((800-900 m: Clusters 4, 5) (Figures 4D, E). *Alepocephalus* spp, *Allocyttus verrucosus, Apristurus* spp., *Trachyrinchus longirostris, Ebinania* sp., and *Diastobranchus capensis* were characteristic of the deeper portion of the depth range, and *Lepidorhynchus denticulatus, Deania calcea, Mora moro, Halosaurus pecotralis, Genypterus blacodes, Macruronus novaezelandiae,* and *Neocyttus rhomboidalis* characterized the shallower species assemblage. Most species characteristic of the shallowest depth stratum have their centre of distribution at upper slope depths (~500 m) (May and Blaber 1989). It should be noted that although there were sufficient differences in species' depth distributions to clearly distinguish the assemblages from the shallow, intermediate, and deep portions of the mid-slope habitat, most species spanned the depth range that we sampled. The dominant species in the community, *Hoplostethus atlanticus* , showed no preference over the depth range sampled.

Differences in community composition between east and west Tasmania were apparent at shallow and intermediate mid-slope depths: Clusters 4 and 5 were composed predominantly of 800-900 m stations and Clusters 2 and 1 by intermediate-depth stations from west and east Tasmania respectively (Table 5b; Figures 4F, G). Generally species were more abundant off west Tasmania. *Coelorhinchus fasciatus* was the only species characteristic of the east Tasmania shallower stratum. Several species, such as *Epigonus* spp., *Centroscymnus crepidater*, *Allocyttus verrucosus, Oreosoma atlanticum,* and *Alepocephalus* spp. were particularly more abundant off west Tasmania.

Discussion

Fish Density

Although significant fisheries (25,000 – 35,000 tonnes/yr) have developed since 1989 for orange roughy off southeast Australia, there is no indication from our survey that the mean density of fish in this region at mid-slope depths (Table 2: 4.8 g/m^2) is particularly high. Trawl surveys at these depths in temperate latitudes in the northeast and northwest Atlantic and northeast Pacific have generally encountered comparable densities of demersal fish (Table 8: 2.5 – 6.1 g/m^2). However, our estimate of the mean density of orange roughy - and possibly of other species, such as several oreosomatids associated with the roughy - appears too low by approximately an order of magnitude. Based upon this survey, the biomass of orange roughy for the entire region was estimated to be 23,800 tonnes (Bulman et al. in press) – substantially less than subsequent commercial landings. An acoustic survey of a major spawning aggregation off eastern Tasmania in 1990 indicated that its biomass was approximately 110,000 tonnes prior to 1989 (Koslow and Kloser, unpubl. data). The abundance of orange roughy was apparently greatly undersampled because major aggregations in the region are associated with rugged topographic features, such as pinnacles, which were deemed untrawlable for the survey. Based upon the 1990 acoustic survey estimate, the mean density of orange roughy off eastern Tasmania, assuming that it is distributed between 800-1200 m (an area of 1635–2824 km^2, depending upon how stock boundaries are defined), was 39.0–67.3 g/m^2. This may indicate a substantially higher density of demersal fish at mid-slope depths off southeastern Australia than in the North Atlantic and Pacific (Table 8). However, since trawl surveys are generally restricted to relatively flat, easily trawlable grounds, there may be higher densities of fish at mid-slope depths in these regions as well.

This uncertainty in the mean density of benthopelagic fish has substantial implications for our understanding of mid-slope community bioenergetics. A preliminary estimate of the role of orange roughy in the regional energy budget may be obtained from their density and food consumption, which was estimated from field data obtained off southeast Australia to be 1.47% BW/d for adult fish (Bulman and Koslow submitted). Assuming a 5% wet weight/C conversion (Wiebe et al. 1975), orange roughy on the east coast of Tasmania consume 28.7–49.5 mg $C/m^2 \cdot d$ based upon the acoustic survey estimate of mean density, and only 0.8 mg $C/m^2 \cdot d$ based upon the trawl survey estimate. Productivity in the region is estimated to be 250 mg $C/m^2 \cdot d$ (Harris et al. 1987). Adult orange roughy do not vertically migrate and feed on large crustaceans and small midwater fishes (Rosecchi et al. 1988; Bulman and Koslow submitted), so they appear to occupy the fourth trophic level. Assuming a 15% ecological efficiency between trophic levels, there are 5.6 mg $C/m^2 \cdot d$ available to the fourth trophic level. This is adequate to maintain the mean density of mid-water fish observed in our trawl surveys. However, if the mean density of roughy (and possibly other fishes) is in fact more than an order of magnitude higher, it appears unlikely that this large biomass can be supported by the *in situ* production of the narrow mid-slope area. In this case, there is likely a substantial flux of material into the mid-slope region either from the shelf or from offshore as part of the flux of Antarctic Intermediate Water into the region. Neither of these fluxes can be estimated at this time.

Species Diversity

The number of species obtained at mid-slope depths off southeast Australia appeared higher than the numbers obtained from studies carried out in the Northern Hemisphere, even after the number of species is normalized for sample number (most studies were based on fewer tows) (Table 9). However, sampling in deepwater studies has generally been carried out with far smaller gears (e.g. beam trawls or shrimp trawls) than the commercial fish trawls used in the present study (Table 9). The composition of trawl catches varies significantly with trawl size (Gordon and Duncan 1985), so comparison of species number and diversity between areas may not be valid. The relatively small sample size of many studies, as well as the use of different gears, also invalidates comparison of the Shannon-Wiener index of species diversity, since the index was unstable for sample sizes < 50 (Figure 2F).

The relatively concave abundance-diversity curve (Fig. 2E) and lack of a mode of species of intermediate density (Fig. 2G) is inconsistent with the log-normal and log-series models that have been used to describe patterns of species abundance for undisturbed and disturbed communities, respectively (May 1976). The trawl fishery in this habitat, which is directed at orange roughy, was only initiated in the mid-1980's and landed insignificant quantities of fish in the period prior to completion of these surveys. Given the presumed stability of the environment at 1000 m depth, the mid-slope demersal fish community can be considered to have been undisturbed at the time of the survey.

Hughes (1984) showed that marine benthic communities typically exhibit abundance-diversity patterns similar to that observed in the present study. Hughes (1984) developed a model of community dynamics that gave rise to this distribution of species abundance, but the model appears specific to the dynamics of sessile benthic communities. Species diversity in the model was regulated primarily by inter- and intra-specific competition for space and by disturbance (catastrophes) as a means of preventing competitive exclusion. It is unlikely that the large number of rare species in our study is maintained by periodic catastrophic mortality among the dominant species.

The observed abundance distribution pattern may be explained in part by the lack of disturbance, which enables several species to dominate the community and suppress development of a mode of moderately abundant species. Such a mode may thereby be shifted toward the rare end of the abundance spectrum. The relatively large number of marginal species may be enabled to persist by the sparse, patchy distribution of both food resources and competitors over the vast deep sea habitat. Based upon this hypothesis, we predict that the number of moderately abundant species may increase as community dominants, such as orange roughy and several oreosomatids, are reduced by targetted fishing.

It should also be noted that environmental gradients on a vertical scale of several hundred metres and horizontal scale of several hundred kilometres seemed adequate to maintain several assemblages of species within the mid-slope community. Evolutionary adaptation to fine-scale features of the mid-slope demersal environment may significantly enhance species diversity within this habitat.

Community Composition

The temperate Australian mid-slope demersal fish community is distinct from fish communities at that depth in the northern hemisphere but has stronger affinities with the North Atlantic (and in particular, the northeast Atlantic) than the North Pacific (Table 9). Approximately twice as many species from the northeast Atlantic (18.2%) than from the northwest Atlantic (10.5%) have been recorded off southeast Australia. Several of the dominant species off southeast Australia (e.g. *Hoplostethus atlanticus, Deania calcea, Centroscymnus crepidater, and Mora moro*) are only found on the eastern side of the North Atlantic (Markle and Musick 1974; Gordon and Duncan 1985; Snelgrove and Haedrich 1985; Haedrich and Merrett 1988). There appeared to be virtually no overlap between mid-slope fish communities off southeast Australia and in the north Pacific (Pearcy et al. 1982; Ohta 1983).

This pattern is consistent with the global distribution of intermediate water masses. The fish community along the continental slope at 800-1200 m around temperate Australia coincides with the depth distribution of Antarctic Intermediate Water (Sverdrup et al. 1942). This water mass is advected at this depth into the North Atlantic but does not extend into the North Pacific, which produces its own intermediate water mass.

Despite its affinities with the North Atlantic, the mid-slope community off southeast Australia is distinctive. The community in this region is characterized by the dominance of the Trachichthyidae (*Hoplostethus atlanticus*), Oreosomatidae, and Squalidae which together comprise 65% of the biomass. Only the Squalidae contributes significantly to the biomass of comparable fish communities in the Northern Hemisphere, but its contribution is consistently reduced (<15%) (Table 8). Temperate North Atlantic demersal fish communities at these depths are dominated by the Macrouridae, Moridae, and in the northeast Atlantic, by the Alepocephalidae. These groups are present off southeast Australia, but their relative importance is considerable reduced, just as the Trachichthyidae and Oreosomatidae are relatively minor groups in the North Atlantic deepwater community.

Spatial structure

Studies of slope fish communities at temperate latitudes typically cover a wider depth range, and have often concluded that the mid-slope depth range of our study (800-1200 m) comprises a distinct faunal zone. In the northwest Atlantic, Haedrich et al. (1980) distinguished a mid-slope community between 653–1290 m; Hecker (1990) found two fish communities at different sampling sites in an upper-middle slope zone between 500/700–1200/1300 m. In the northeast Pacific, Pearcy et al. (1982) found three species groups in an upper slope region that extended from 300 to 1000-1400 m. On the other hand, no clear differences were observed in the fish species composition between upper and mid-slope depths off Newfoundland (Snelgrove and Haedrich 1985) and northwest Africa (Merrett and Marshall 1980). These zonation patterns were defined in terms of marked changes in species composition, such as the beginning and end of species' depth ranges – differences greater than those observed among species groups between east and west Tasmania and between our shallow, intermediate and deep depth strata.

Off Tasmania, marked changes in community structure were observed between the mid-slope community at 800-1200 m and the upper slope community at 500 m, described by May and Blaber (1989). Only 20.9% of species collected at 500 m were encountered at 800-1200 m (Table 9). Of the 10 most abundant species at 500 m (Table 5 in May and Blaber (1989)), 4 did not occur in our sampling, 4 were rare or uncommon, and the remaining 2 (*Lepidorhynchus denticulatus* and *Neocyttus rhomboidalis*) were characteristic of our shallow species groups. Similarly, of the 10 most abundant species (by weight) at 800-1200 m, 4 did not occur at 500 m: *Allocyttus verrucosus*, *Diastobranchus capensis*, *Centroscymnus owstoni*, and *Coryphaenoides serrulatus*. The similarity in species composition between the upper and mid-slope demersal fish communities off southeast Australia is comparable to that between the mid-slope communities off southeast Australia and in the northeast Atlantic.

The differences among species groups in our study were finer both in terms of spatial scale and in defining characteristics than those generally noted in studies of deepwater fish communities. The groups were defined more in terms of differences in relative abundance than of species' range limits. The spatial scale of the groups was on the order of one to several hundred meters vertical range and several hundred kilometers horizontally. However, these differences in our study were nonetheless definable, as evident from the ability of samples to be correctly classified using the 'jackknife' procedure in conjunction with discriminate function analysis. These more subtle differences in species assemblages may have emerged due to intensive sampling within a limited depth range (i.e. within a single major faunistic zone) over a relatively broad areal extent. Controversy as to the gradual or discontinuous nature of zonal boundaries (Carney et al. 1983) may depend in part upon the scale and intensity of observation.

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Table 1: Cruises by organization, vessel, and date, showing the numbers of stations in each area by cruise. Tas: Tasmania; GAB: Great Australian Bight.

Organization/Vessel	**Month**	**Year**	**East Tas**	**West Tas**	**GAB**
TDSF					
FRV Challenger	7	1987	1		
	8	1987	2		
	12	1987	1		
	2	1988	5		
	2	1988	5		
	4	1988	2		
	4	1988	1		
	5	1988	1		
	8	1988	5		
	8	1988	2		
	10	1988	1		
	11	1988	1		
TDSF					
FV Petuna Endeavour	2	1988		18	
	4	1988		20	
	8	1988		21	
	11	1988		26	
TDSF					
FRV Challenger	2	1989	2		
	2	1989	2		
	7	1989	1		
	7	1989	1		
	8	1989	3		
	9	1989	1		
	10	1989	3		
TDSF					
FV Petuna Endeavour	2	1989		25	
	5	1989	7	19	
	8/9	1989		22	
	11	1989		24	
CSIRO					
FRV Soela	1/2	1989			64
	2/3	1989		60	19
	4	1989	11		
		Total	58	235	83

Table 2 . Catch composition of demersal fish by weight for families (CSIRO data only) and percent occurrence by species for the CSIRO and TDSF data sets. * – occurrence only in CSIRO data set; ** – occurrence only in TDSF data set.

Species name	% Occurrence	ensity (g/m^2)
Total		4.82
Hexanchiformes		
*Hexanchus griseus***	0.53	
Scyliorhinidae		0.0116
*Apristurus sp1.***	1.6	
*Apristurus sp2.***	22.97	
*Apristurus spp.**	12.78	
Squalidae		1.0797
Centrophorus squamosus	2.4	
*Centroscyllium sp**	0.53	
Centroscymnus coelolepis	12.77	
Centroscymnus crepidater	79.49	
Centroscymnus owstoni	72.55	
Centroscymnus plunketi	6.12	
Dalatias licha	19.99	
Deania calcea	70.93	
*Deania quadrispinosa***	0.8	
Etmopterus baxteri	42.7	
Etmopterus lucifer	1.58	
*Etmopterus unicolor**	2.66	
*Isistius brasiliensis**	0.25	
Squalus mitsukurii	0.8	
Oxynotidae		
*Oxynotus bruniensis***	0.53	
Torpedinidae		0.0007
*Torpedo macneilli**	0.25	
Rajidae		0.0031
*Bathyraja sp 1.***	2.67	
*Pavoraja sp (bule)***	3.47	
*Raja gudgeri***	0.27	
*Raja sp (Deep water)***	0.27	
*Raja sp 1.***	5.08	
*Raja sp 2.***	4.54	
*Raja sp B.***	1.87	
Chimaeridae		0.0324
*Hydrolagus lemures**	4.79	
Hydrolagus sp. (Black)	33.9	
Rhinochimaeridae		0.0326
Rhinochimaera pacifica	45.63	
Harriotta raleighana	3.18	
Congridae		0.0018
Bassanago bulbiceps	6.1	
*Bathyuroconger sp***	0.27	
Synaphobranchidae		0.4129
Diastobranchus capensis	39.11	

Nettastomatidae**		
*Nettastoma sp***	0.27	
Simenchelyidae*		0.0004
*Simenchelys parasiticus**	4.79	
Halosauridae		0.0172
*Halosauropsis macrochir**	9.05	
Halosaurus pectoralis	8.8	
Notacanthidae		0.009
Notacanthus sexspinis	35.94	
Alepocephalidae		0.2177
*Alepocephalus sp.1**	16.51	
*Alepocephalus sp.2**	20.48	
*Alepocephalus spp.***	52.12	
Aleposomus squamilateralis	12.77	
*Holtbyrnia sp***	0.27	
*Rouleina squamilatera***	0.27	
Xenodermichthys copei	1.86	
Synodontidae		0.0056
Bathysaurus ferox	7.97	
Chloropthalmidae		< 0.0001
*Bathysauropsis sp**	0.25	
Neoscopelidae		< 0.0001
*Neoscopelus macrolepidotus***	2.67	
Chaunacidae		< 0.0001
*Chaunax sp**	0.78	
Moridae		0.196
Antimora rostrata	5.58	
*Euclichthys polynemus***	0.53	
Halargyreus johnsonii	82.16	
*Laemonema sp***	1.07	
Lepidion microcephalus	37.89	
*Lepidion schmidti**	0.53	
Lepidion sp	2.38	
Lyconodes sp	6.92	
Mora moro	48.83	
Merlucciidae		0.0259
Macruronus novaezelandiae	21.61	
Ophidiidae		0.0023
Genypterus blacodes	3.47	
*Monomitopus sp***	0.53	
Carapidae**		
*Carapus homei***	0.27	
Bythitidae**		
*Cataetyx sp***	0.53	
Macrouridae		0.6432
*Cetonurus crassiceps***	2.67	
*Cetonurus/Mesobius spp**	14.09	
Coelorinchus fasciatus	6.14	
Coelorinchus innotabilis	51.73	
Coelorinchus kaiyomaru	39.22	
Coelorinchus kermadecus	42.72	
Coelorinchus matamua	44.82	
*Coelorinchus sp.D**	0.53	

*Coelorinchus sp2.***	0.27	
Coryphaenoides murrayi	6.39	
Coryphaenoides serrulatus	89.07	
Coryphaenoides spp.	30.95	
Coryphaenoides subserrulatus	74.73	
Gadomus sp	23.18	
*Idiolophorhynchus andriashevi**	0.25	
Lepidorhynchus denticulatus	33.88	
Macrourus carinatus	24.84	
*Malacocephalus laevis***	0.27	
Mesobius antipodum	14.4	
*Nezumia loricata***	0.8	
Nezumia sp.A	15.47	
*Nezumia spp.**	3.97	
*Trachonurus sp.1**	1.06	
*Trachonurus sp.2**	0.25	
*Trachonurus sp.A**	0.25	
Trachyrinchus longirostris	20.8	
Ventrifossa nigromaculata	1.6	
Diretmidae		0.0017
Diretmus argenteus	25.89	
Diretmoides parini	5.06	
Trachichthyidae		1.1242
Hoplostethus atlanticus	97.6	
Zeidae		0.001
Cyttus traversi	0.51	
Oreosomatidae		0.9746
*Allocyttus niger***	1.33	
Allocyttus verrucosus	78.68	
Neocyttus rhomboidalis	57.34	
*Oreosoma atlanticum***	8.55	
Pseudocyttus maculatus	37.11	
Scorpaenidae		0.0044
Helicolenus percoides	1.04	
*Neosebastes scorpaenoides***	0.27	
*Sebastodes sp**	0.25	
Trachyscorpia capensis	8.51	
Hoplichthyidae		<< 0.0001
Hoplichthys haswelli	1.05	
Psychrolutidae		0.0077
Ebinania sp	16.52	
*Neophrynichthys marcidus**	3.74	
*Psychrolutes marcidus**	1.6	
Serranidae	0.27	
Liparididae	2.38	< 0.0001
*Paraliparis sp***	0.53	
Apogonidae		0.0124
*Epigonus denticulatus**	1.31	
Epigonus lenimen	63.48	
*Epigonus robustus**	5.57	
*Epigonus spp.**	11.43	
*Epigonus telescopus**	0.25	
Gempylidae**		

*Paradiplospinus gracilis***	0.27
*Ruvettus tydemani***	0.53
Trichiuridae**	
*Benthodesmus elongatus***	0.27
*Lepidopus caudatus***	0.27
Bothidae**	
*Mancopsetta sp***	1.33

Table 3: Mesopelagic and bathypelagic families and species of fishes that were obtained in the surveys but excluded from analyses.

Squalidae
Etmopterus pusillus
Nessorhamphidae
Nessorhamphus sp
Derichthyidae
Derichthys sp
Nemichthyidae
Avocettina sp
Nemichthys sp
Photichthyidae
Photichthys argenteus
Bathylagidae
Bathylagus antarcticus
Bathylagus cf microps
Sternoptychidae
Argyropelecus gigas
Opostomias sp
Malacosteidae
Malacosteus niger
Chauliodontidae
Chauliodus sloani
Stomiatidae
Stomias boa
Scopelosauridae
Scopelosaurus meadi
Paralepididae
Macroparalepis macrogeneion
Melanostomiatidae
Echiostoma barbatum
Idiacanthidae
Idiacanthus fasciola
Idiacanthus atlanticus
Eurypharynx pelecanoides
Platytroctidae
Persparsia kopua
Normichthys sp
Linophrynidae
Linophryne sp
Myctophidae
Lampanyctodes hectoris
Diaphus watasei
Electrona risso
Lampadena speculigera
Lampanyctus sp
Himantolophiidae
Himantolophus appelii
Ceratiidae
Cryptopsaras couesii
Melanonous zugmayeri
Melanonous gracilis
Melamphaidae
Scopelogadus sp
Sio nordenskjoldii
Trachipteridae
Trachipterus arawatae
Macrorhamphosidae
Howella brodiei
Caristiidae
Caristius sp
Emmelichthyidae
Emmelichthys nitidus
Scombridae
Gasterochisma melampus
Centrolophidae
Tubbia tasmanica
Schedophilus huttoni
Centrolophus niger
Tetragonuridae
Tetragonurus cuvieri
Serrivomeridae
Serrivomer beanii
Serrivomer sp
Brotulotaenia crassa
Nomeidae
Cubiceps caeruleus

Table 4: Mean demersal catch (g/m^2) overall and of the seven dominant families by depth and area.

	Depth (m)				**Area**		
	800-900	900-1000	1000-1100	1100-1200	East Tas	West Tas	GAB
Sample Number	40	41	46	27	11	60	83
Total	5.54	3.09	5.37	4.45	8.02	5.05	3.91
Squalidae	2.28	1.00	0.57	0.28	1.00	1.50	0.78
Synaphobranchidae	0.01	0.19	0.75	0.77	0.25	0.42	0.43
Alepocephalidae	0.08	0.15	0.29	0.42	0.07	0.22	0.24
Moridae	0.34	0.17	0.14	0.11	0.30	0.27	0.13
Macrouridae	0.76	0.58	0.74	0.40	0.98	1.02	0.33
Trachichthyidae	1.76	0.43	1.17	1.16	5.24	0.98	0.68
Oreosomatidae	0.31	0.57	1.71	1.31	0.18	0.64	1.32

Table 5a: The distribution of TDSF stations grouped among five clusters by area: East Tasmania (East Tas) and West Tasmania (West Tas). The observed number is provided with the expected value in parentheses. $c^2 = 64.3$ (df=4), $p < 0.001$.

	Area	
Cluster	East Tas	West Tas
1	23 (9.6)	23 (36.4)
2	1 (11.1)	52 (41.9)
3	14 (17.6)	70 (66.4)
4	0 (5.6)	27 (21.4)
5	8 (2.1)	2 (7.9)

Table 5b: The distribution of TDSF stations grouped among five clusters by depth. The observed number is provided with the expected value in parentheses.. $c^2 = 263$ (df=12), $p << 0.001$.

	Depth (m)			
Cluster	800-900	900-1000	1000-1100	1100-1200
1	9 (9.0)	28 (14.2)	8 (12.3)	1 (10.5)
2	0 (10.4)	31 (16.4)	21 (14.2)	1 (12.0)
3	0 (16.4)	6 (26.0)	30 (22.5)	48 (19.1)
4	26 (5.3)	1 (8.3)	0 (7.2)	0 (6.1)
5	8 (2.0)	2 (3.1)	0 (2.7)	0 (2.3)

Table 6: The Euclidean distance between clusters obtained by nonhierarchical cluster analysis.

Cluster	1	2	3	4
2	2.13			
3	2.46	2.30		
4	2.97	3.46	4.63	
5	2.38	4.01	3.68	3.14

Table 7: Classification of stations into the five clusters obtained from nonhierarchical cluster analysis. Classification is based upon discriminant function analysis using the 'jackknife' procedure. The first number indicates the number of stations correctly classified, and the second the total number of stations within the cluster. The percentage correctly classified is in parentheses.

Cluster	1	2	3	4	5
Classification Success	29/46 (63%)	46/53 (87%)	80/84 (95%)	25/27 (92%)	5/10 (50%)

Table 8: Comparison of the mean density of the demersal fish community and percent composition by dominant families at mid slope depths in the temperate NE and NW Atlantic, NE Pacific, and off SE Australia, and along the upper slope off SE Australia.

Region	Depth	Density (g/m2)	Dominant families	% of Biomass
S.E. Australia (this study)	800-1200m	4.82	Trachichthyidae	23
			Oreosomatidae	22
			Squalidae	20
			Macrouridae	13
			Synaphobranchidae	8
			Alepocephalidae	5
			Moridae	4
S.E. Australia[1]	500m	5.27	Merlucciidae	22
			Squalidae	13
			Scorpaenidae	8
			Oreosomatidae	4
			Macrouridae	2
N.E. Atlantic[2]	1000m	6.08	Alepocephalidae	45
			Macrouridae	30
			Squalidae	15
			Moridae	3
N.E. Pacific[3]	400-2750m	4.0	Scorpaenidae	70
			Anoplopomatidae	13
			Pleuronectidae	6
			Elasmobranchs	2
N.W. Atlantic[4]	996m	2.45		
N.W. Atlantic[5]	200-1475m	4.23	Macrouridae	52
			Moridae	13
			Scorpaenidae	4
			Synaphobranchidae	2

(1) May and Blaber 1989.
(2) Gordon and Duncan 1983.
(3) Pearcy et al. 1982 derived from Alverson et al. 1964.
(4) Haedrich and Rowe 1977.
(5) Snelgrove and Haedrich 1985.

Table 9: Comparison of community composition between oceanic regions. The numbers of families, genera, and species at upper and mid-slope depths in different oceanic regions and the per cent occurring in the mid-slope region off SE Australia are shown, along with the number of trawls, depth range, and gear types used in the different studies. Numbers in parentheses indicate the expected number of species based upon a comparable number of trawls (see Figure 2A).

	S.E. Australia	N.E. Pacific	N.W. Pacific	N.E. Atlantic	N.W. Atlantic	U.Slope S.E. Australia
Families	37	8	8	21	16	13
Genera	85	8	3	31	21	25
Total Species	118	41(100)	15 (43)	77 (103)	76 (95)	58 (70)
% Occurrence						
Species		0%	6.7%	18.2%	10.5%	20.9%
Genera		9%	4%	36%	25%	29%
Families		22%	22%	57%	43%	35%
# Trawls	376	122	11	156*	108*	41
Depth range (m)	800-1200	800-1200	420-2830	750-1500**	750-1500**	500
Trawl type	37-50m otter	3m beam, 7m otter	2m beam, 5 m otter	2.3-27m otter	2.3-27m otter	50 m otter

* Number of trawls that included our depth range, within their depth range. The real number of comparable tows is less.
** Species occurring within this depth range were used. The depth range of the species concerned was greater in some cases.
Data sources: N.E. Pacific : Pearcy et al. 1982 ; N.W. Pacific : Ohta 1983 ; N. Atlantic : Haedrich and Merrett 1988 ; Upper slope, S.E. Australia : May and Blaber 1989.

Figure captions

Figure 1. Map showing the survey area and regional boundaries of east Tasmania (ET), west Tasmania (WT), and the Great Australian Bight (GAB)

Figure 2. Species diversity of the demersal fish mid-slope fish community. A) The cumulative number of species as a function of the number of samples examined. B) The Hurlbert index of the expected number of species in relation to sample size. C) The distribution of the frequency of occurrence of species. D) The cumulative percentage of the total catch (in numbers of individuals) by species ranked in order of abundance. E) Per cent of total catch (on a logarithmic scale) represented by species ranked in order of abundance. F) The Shannon-Wiener Index of diversity in relation to the cumulative number of samples examined. G) The distribution of number of species on a logarithmic scale of abundance.

Figure 3. The cumulative number of species in relation to number of samples examined for west and east Tasmania.

Figure 4. Plots on a logarithmic scale of the mean abundance of indicator species between groups of stations defined by nonhierarchical cluster analysis. The 1:1 line of equal abundance is shown. Species characteristic of particular clusters are distributed toward the abscissa or ordinate from the 1:1 line. D: deep; I: intermediate depths; S: shallow; WT: west Tasmania; ET: east Tasmania. 1: *Apristurus* spp.; 2: *Dalatias licha;* 3: *Deania calcea*; 4: *Centroscymnus crepidater*; 5: *C. owstoni*; 6: *Rhinochimaera pacifica*; 7: *Diastobranchus capensis*; 8: *Halosauropsis macrochir*; 9: *Alepocephalus* spp.; 10: *Neoscopelus macrolepidotus*; 11: *Mora moro*; 12: *Halargyreus johnsonii*; 13: *Lepidion microcephalus*; 14: *Genypterus blacodes*; 15: *Coelorinchus fasciatus*; 16: *Lepidorhynchus denticulatus*; 17: *Macruronus novaezelandiae*; 18: *Coelorinchus innotabilis*; 19: *Coryphaenoides serrulatus*; 20: *C. subserrulatus*; 21: *Nezumia sp.A*; 22: *Coelorinchus matamua*; 23: *Coryphaenoides* spp.; 24: *Trachyrinchus longirostris*; 25: *Coelorinchus kaiyomaru*; 26: *C. kermadecus*; 27: *Diretmoides parini*; 28: *Hoplostethus*

atlanticus; 29: *Allocyttus verrucosus*; 30: *Pseudocyttus maculatus*; 31: *Neocyttus rhomboidalis*; 32: *Oreosoma atlanticum*; 33: *Trachyscorpia capensis*; 34: *Ebinania* sp.; 35: *Epigonus* spp.

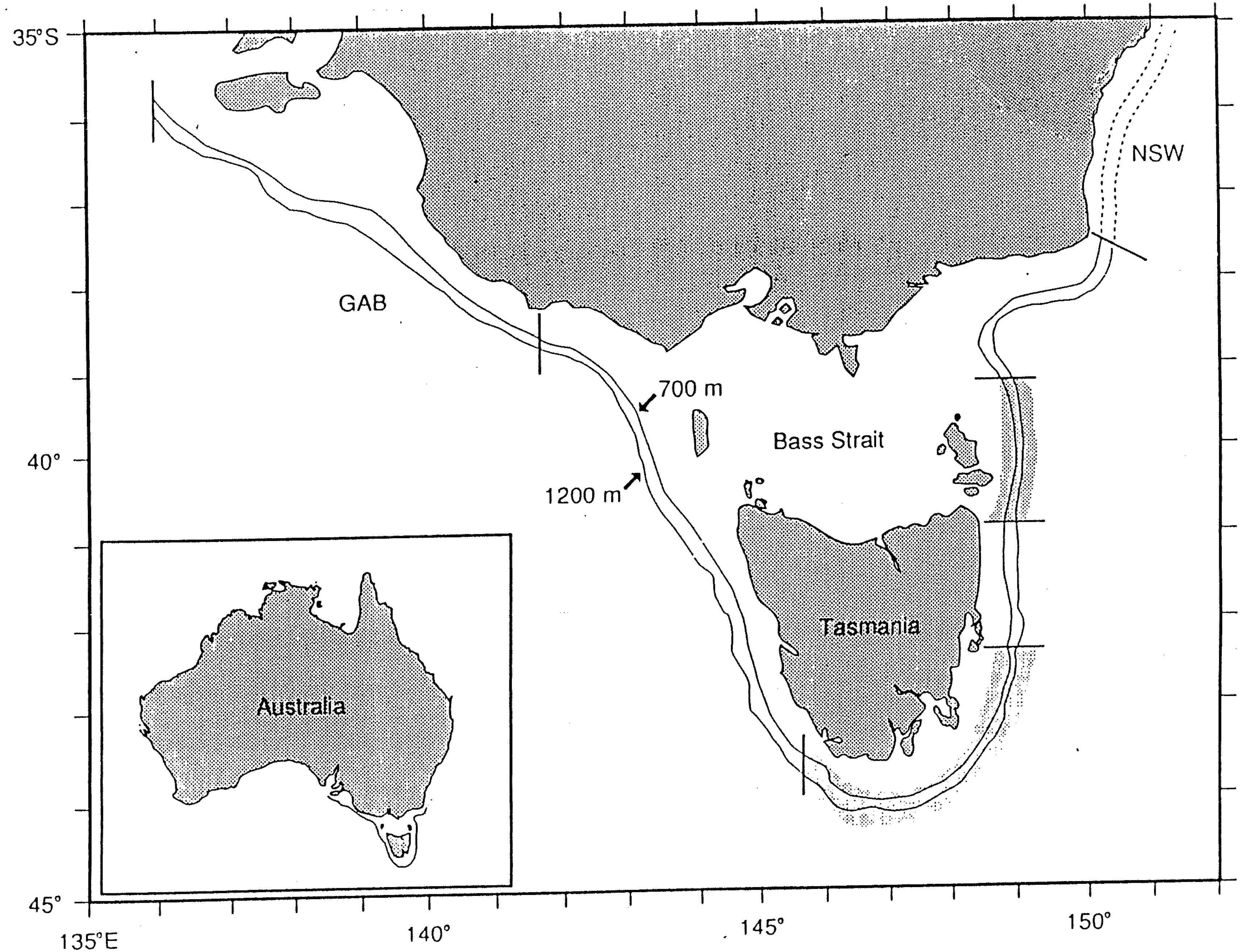

35°S
40°
45°
135°E
140°
145°
150°
NSW
GAB
700 m
1200 m
Bass Strait
Tasmania
Australia

Figure 1

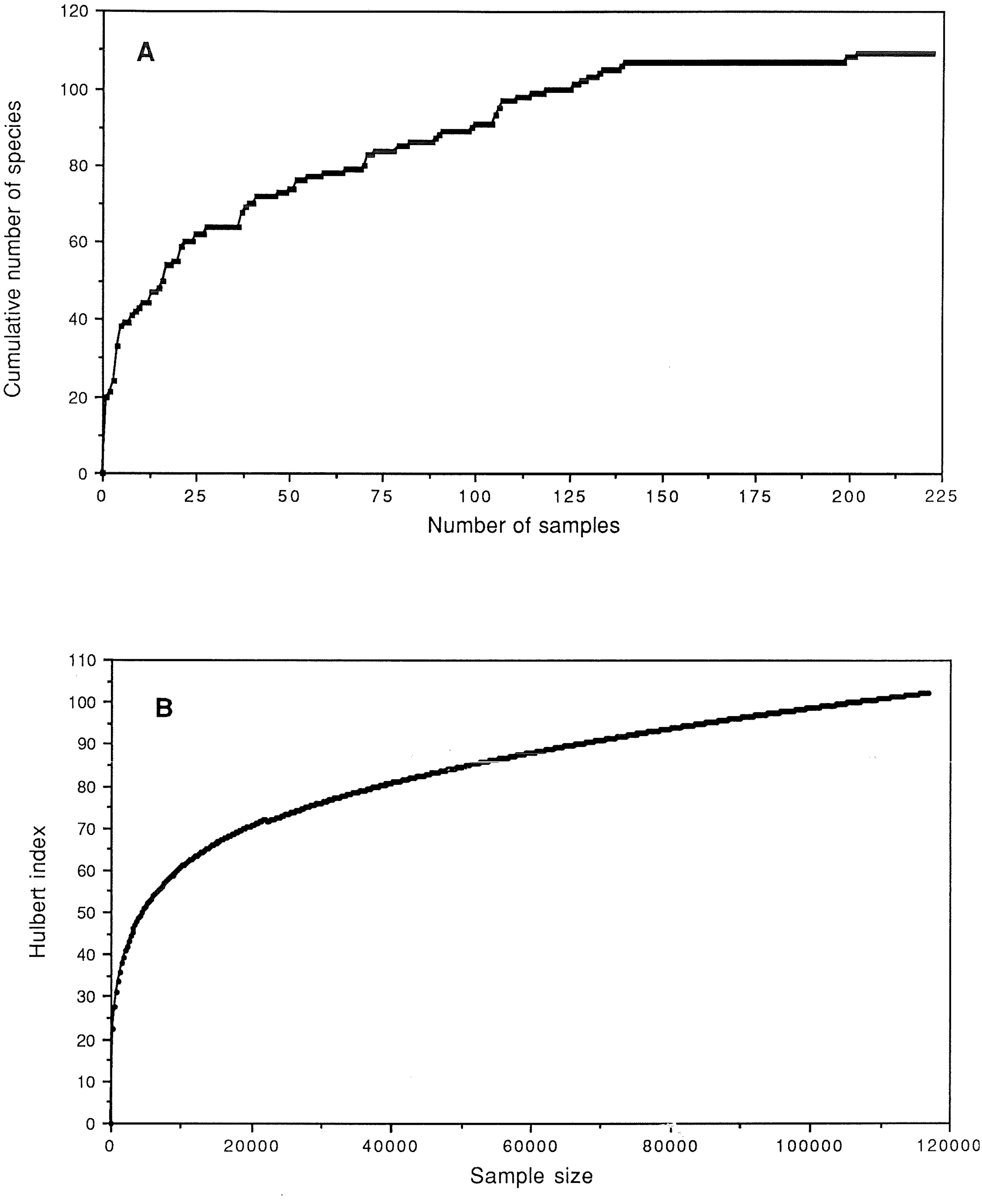
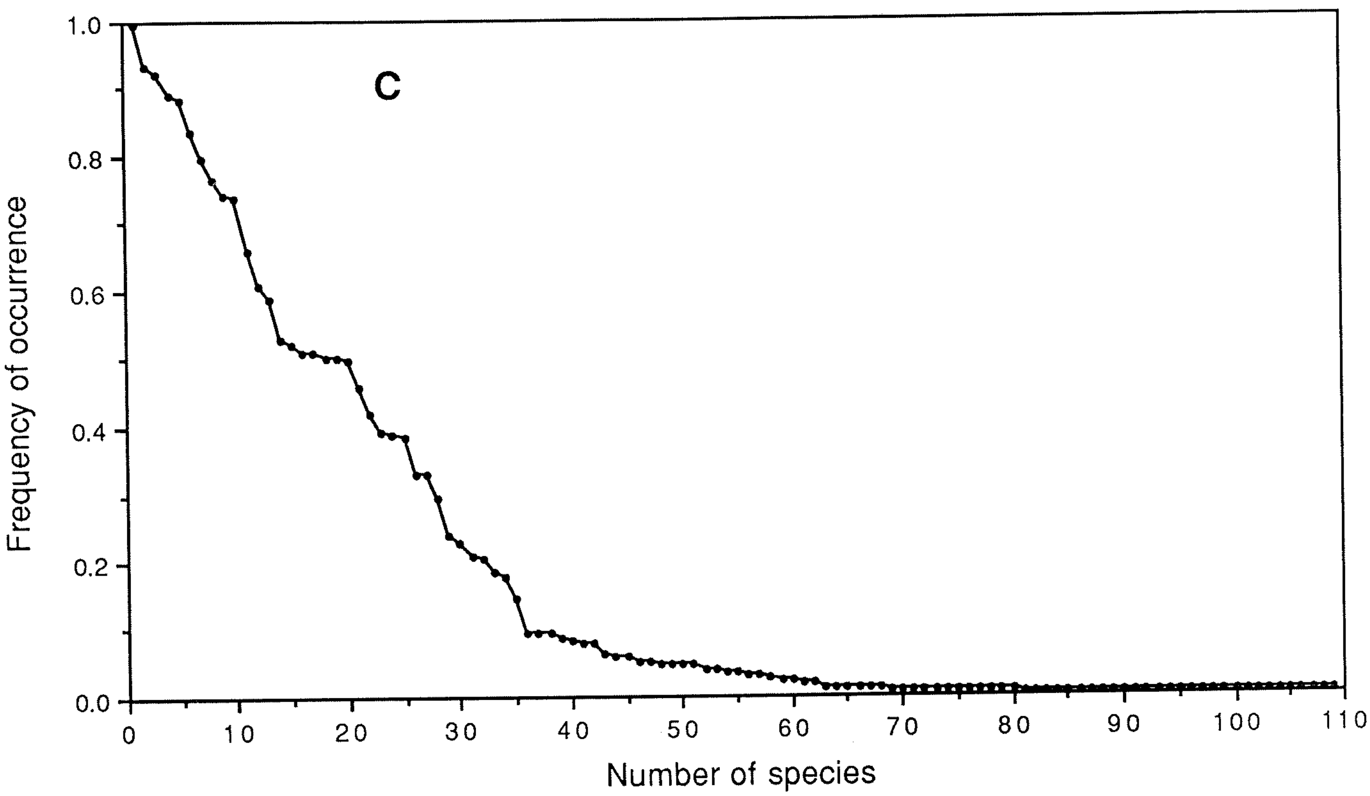

A
Cumulative number of species
Number of samples
0
25
50
75
100
125
150
175
200
225
0
20
40
60
80
100
120
B
Hulbert index
Sample size
0
20000
40000
60000
80000
100000
120000
0
10
20
30
40
50
60
70
80
90
100
110

Figure 2 A-B


C
Frequency of occurrence
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
110
Number of species

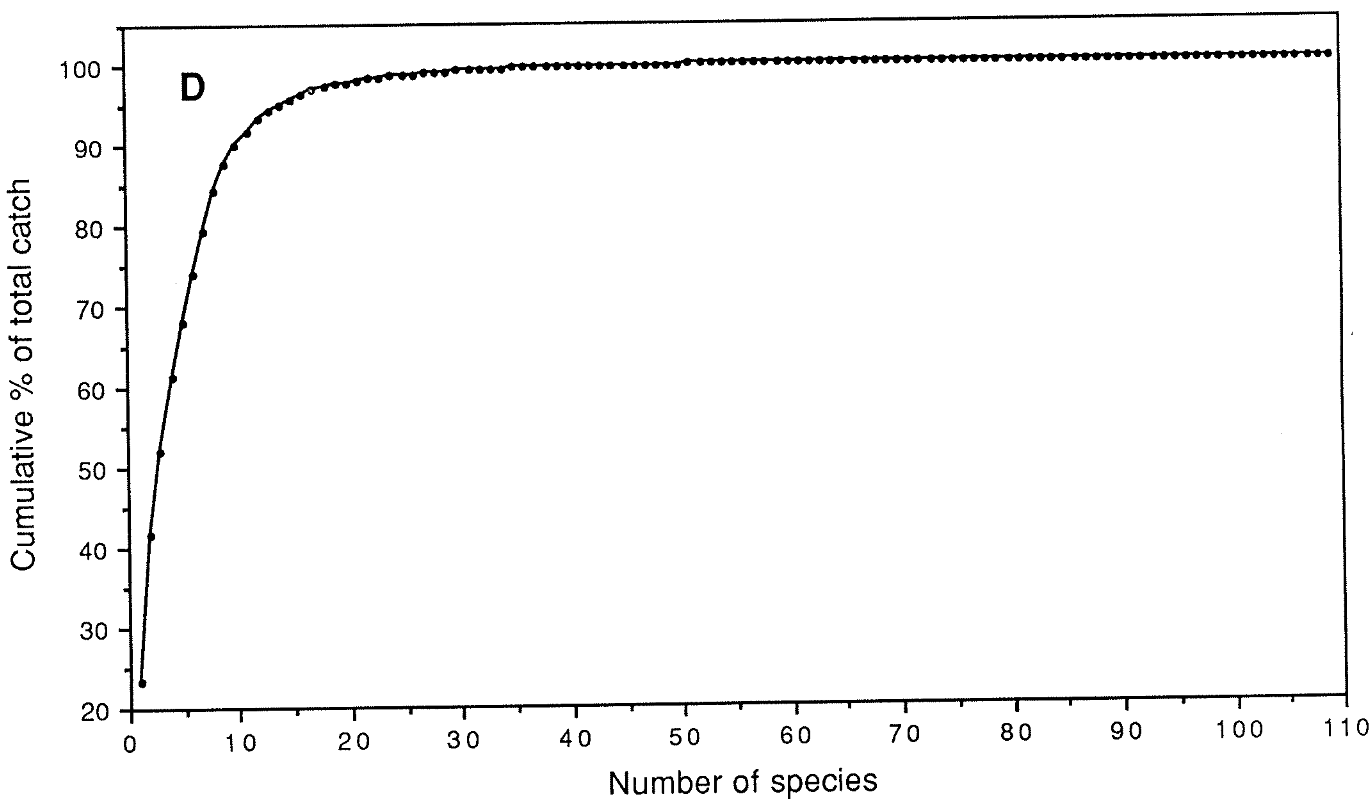

D
Cumulative % of total catch
100
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
100
110
Number of species

Figure 2 C-D

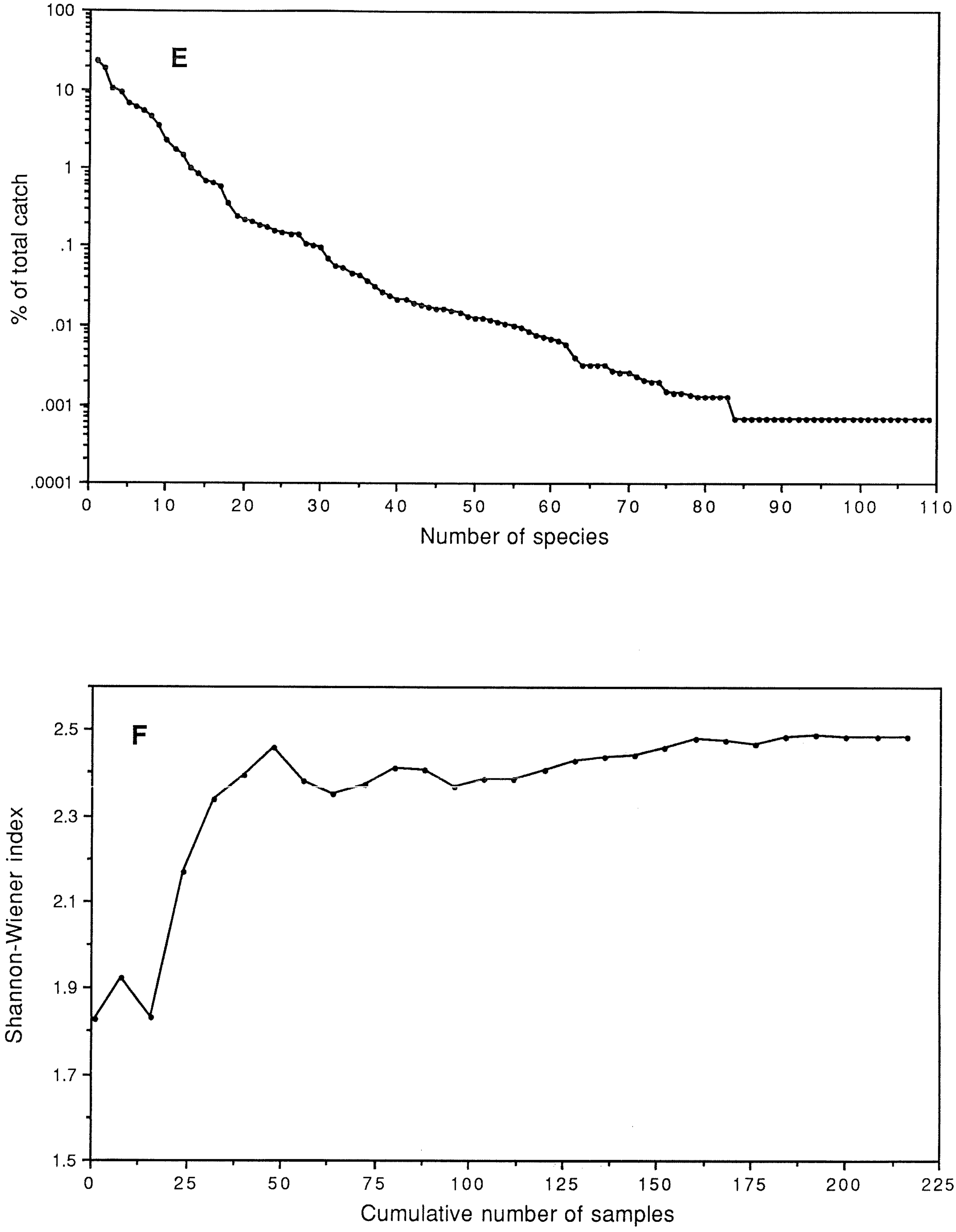

E
% of total catch
100
10
1
.1
.01
.001
.0001
0
10
20
30
40
50
60
70
80
90
100
110
Number of species
F
Shannon-Wiener index
2.5
2.3
2.1
1.9
1.7
1.5
0
25
50
75
100
125
150
175
200
225
Cumulative number of samples

Figure 2 E-F

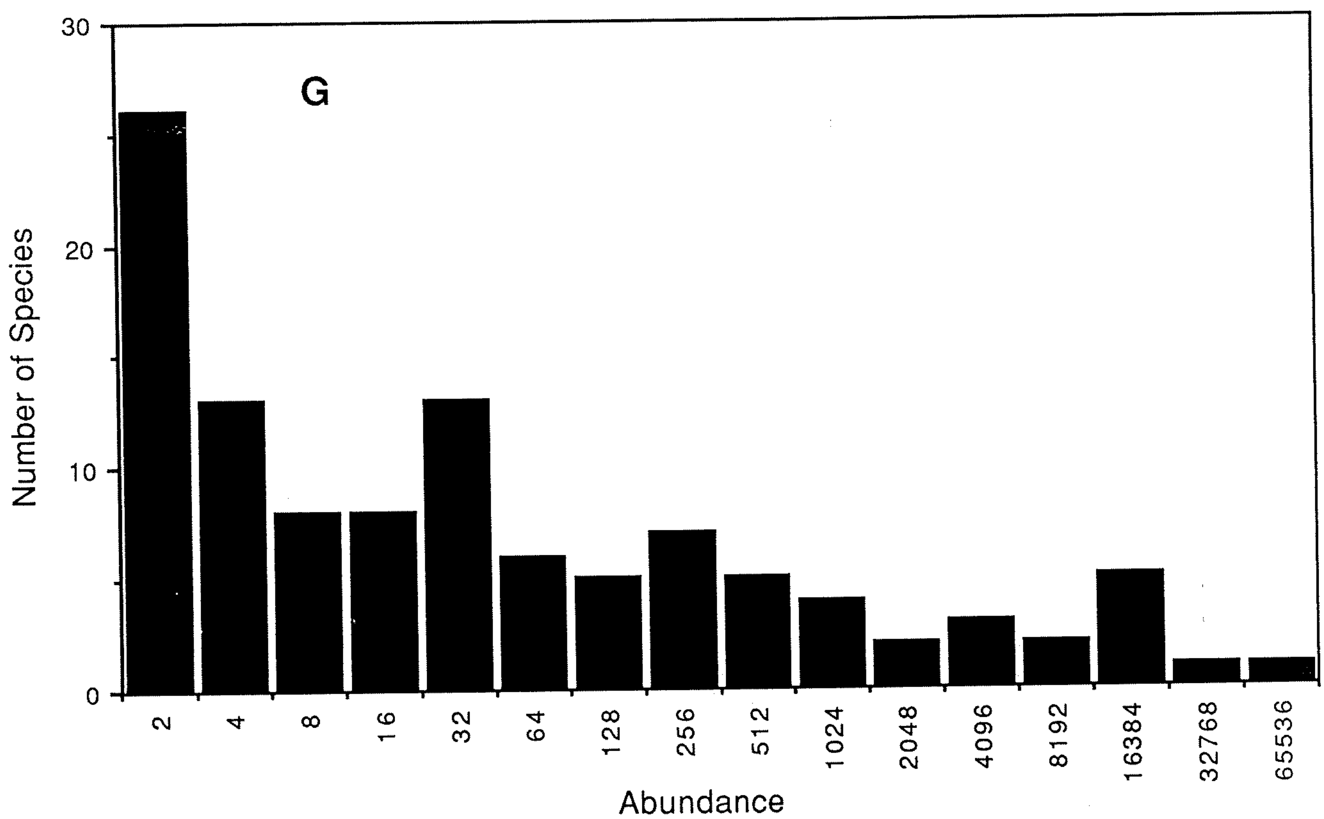
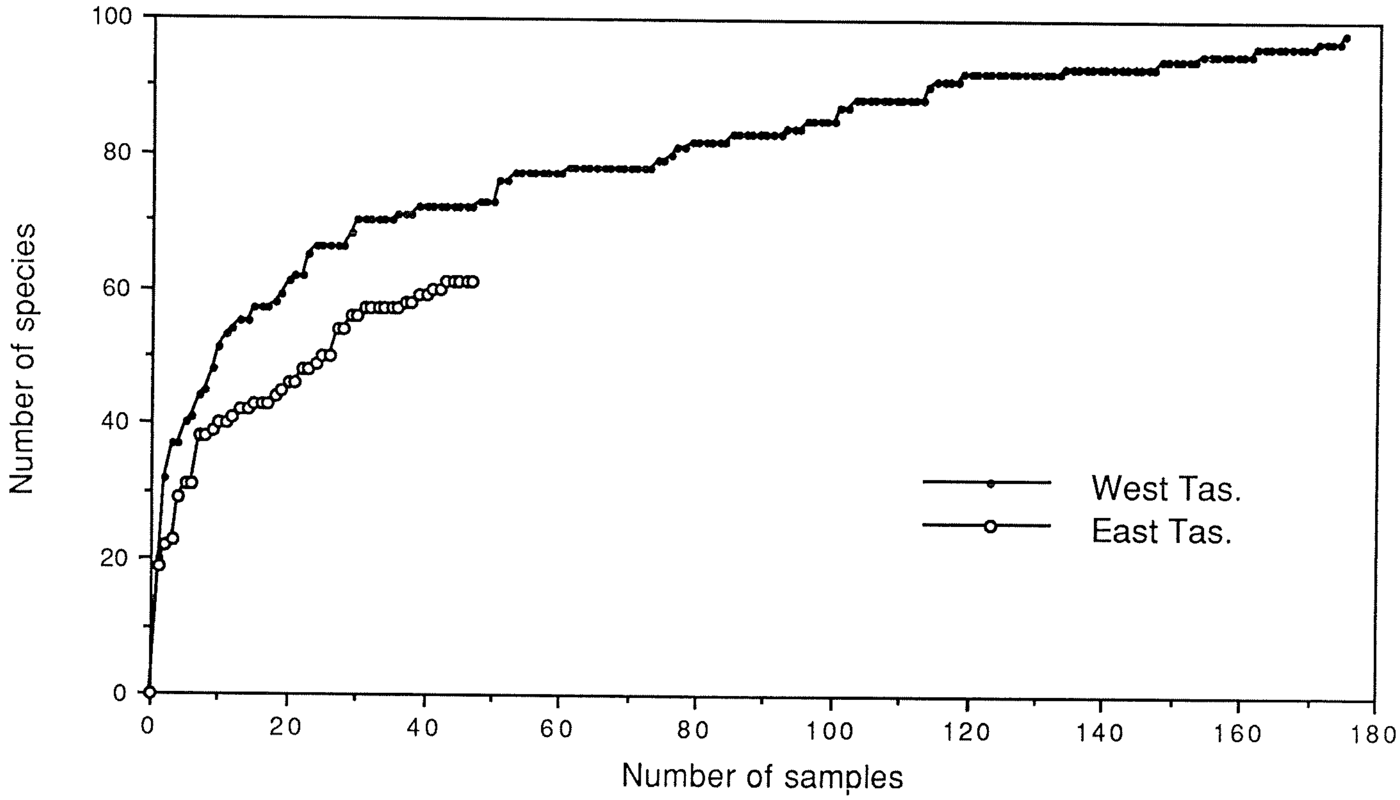
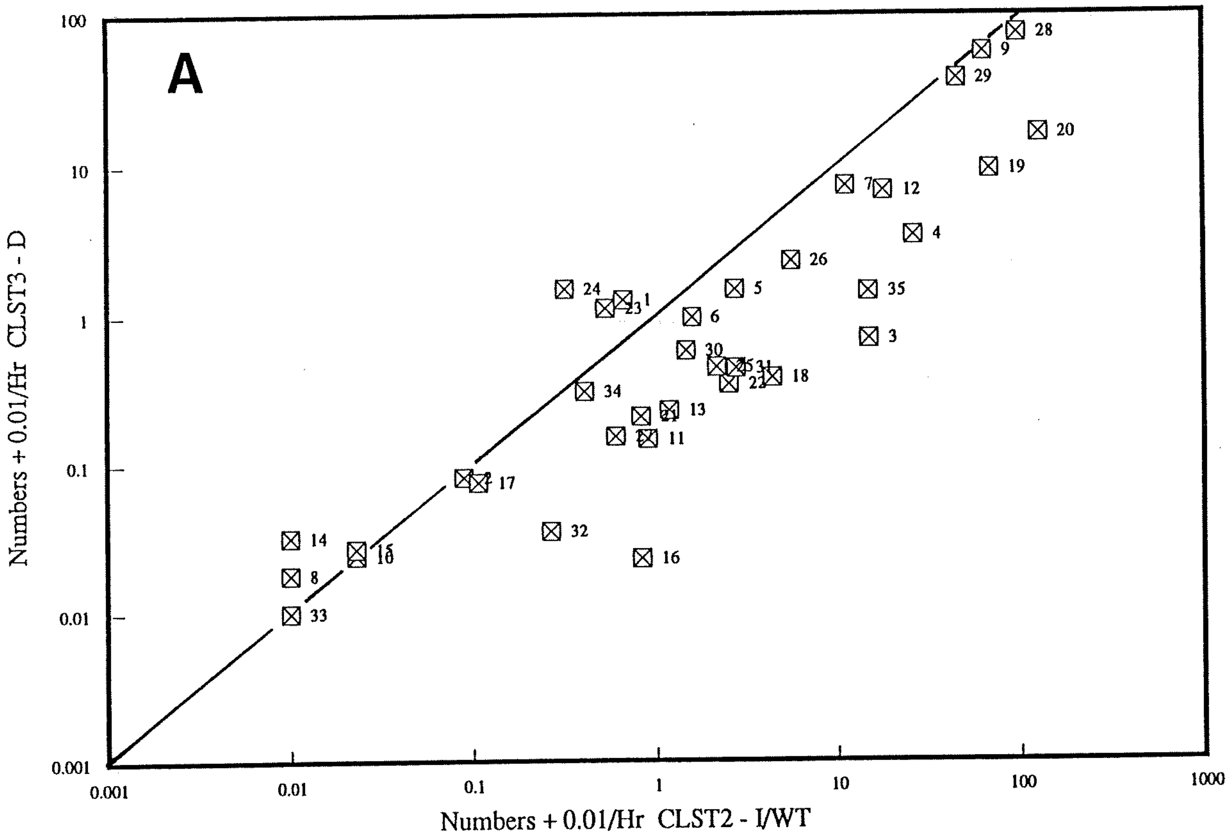

30
20
10
0
Number of Species
G
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
32768
65536
Abundance

Figure 2 G



100
80
60
40
20
0
Number of species
0
20
40
60
80
100
120
140
160
180
Number of samples
West Tas.
East Tas.

Figure 3


A
Numbers + 0.01/Hr CLST3 - D
Numbers + 0.01/Hr CLST2 - I/WT
100
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000

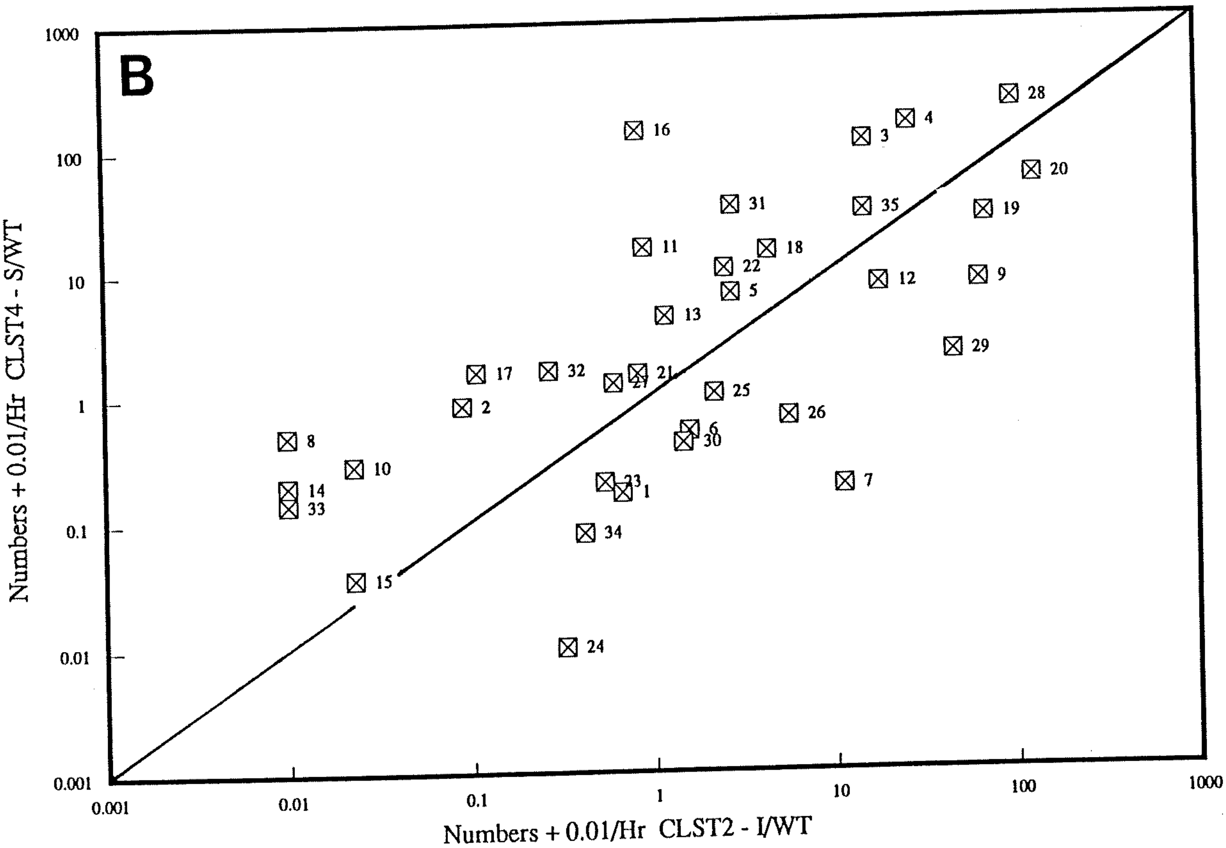
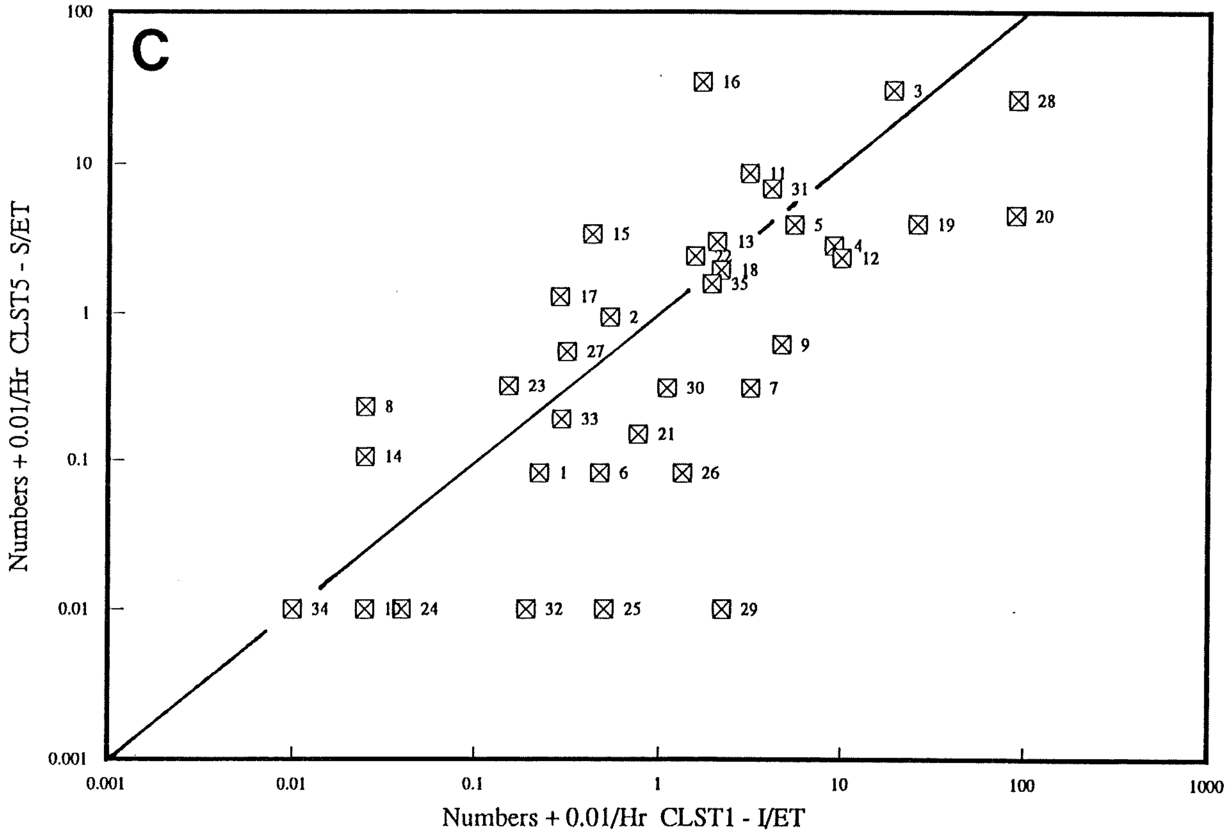

B
Numbers + 0.01/Hr CLST4 - S/WT
Numbers + 0.01/Hr CLST2 - I/WT
1000
100
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000

Figure 4 A-B


C
Numbers + 0.01/Hr CLST5 - S/ET
Numbers + 0.01/Hr CLST1 - I/ET
0.001
0.01
0.1
1
10
100
1000

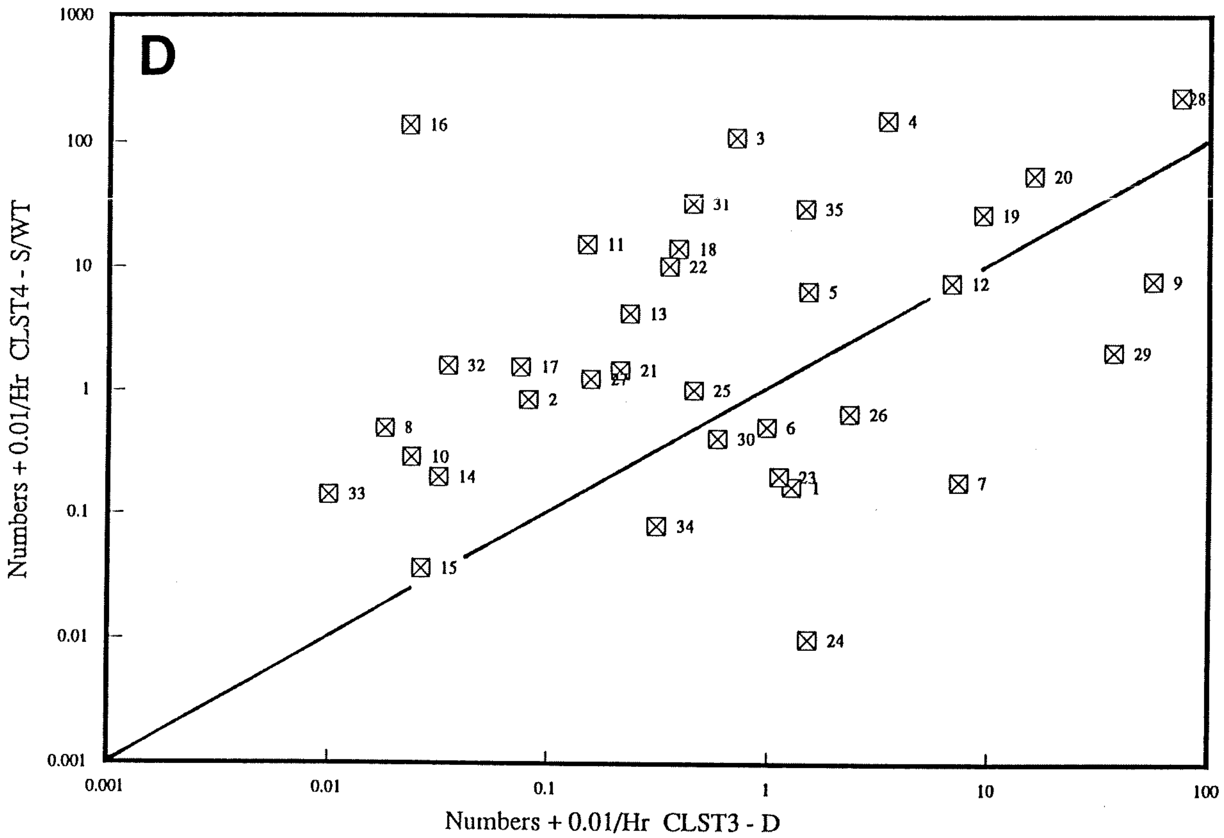
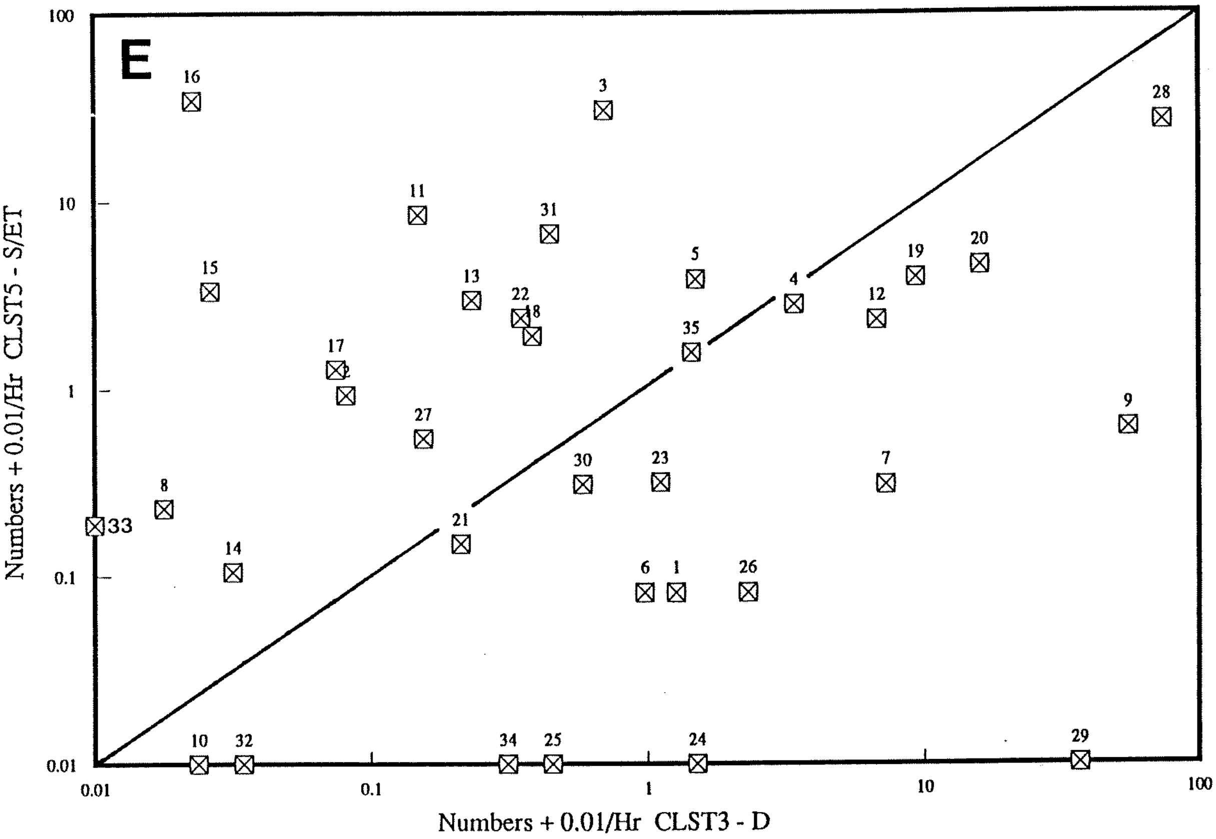

D
Numbers + 0.01/Hr CLST4 - S/WT
Numbers + 0.01/Hr CLST3 - D
0.001
0.01
0.1
1
10
100
1000

Figure 4 C-D


E
Numbers + 0.01/Hr CLST5 - S/ET
Numbers + 0.01/Hr CLST3 - D
100
10
1
0.1
0.01
0.01
0.1
1
10
100

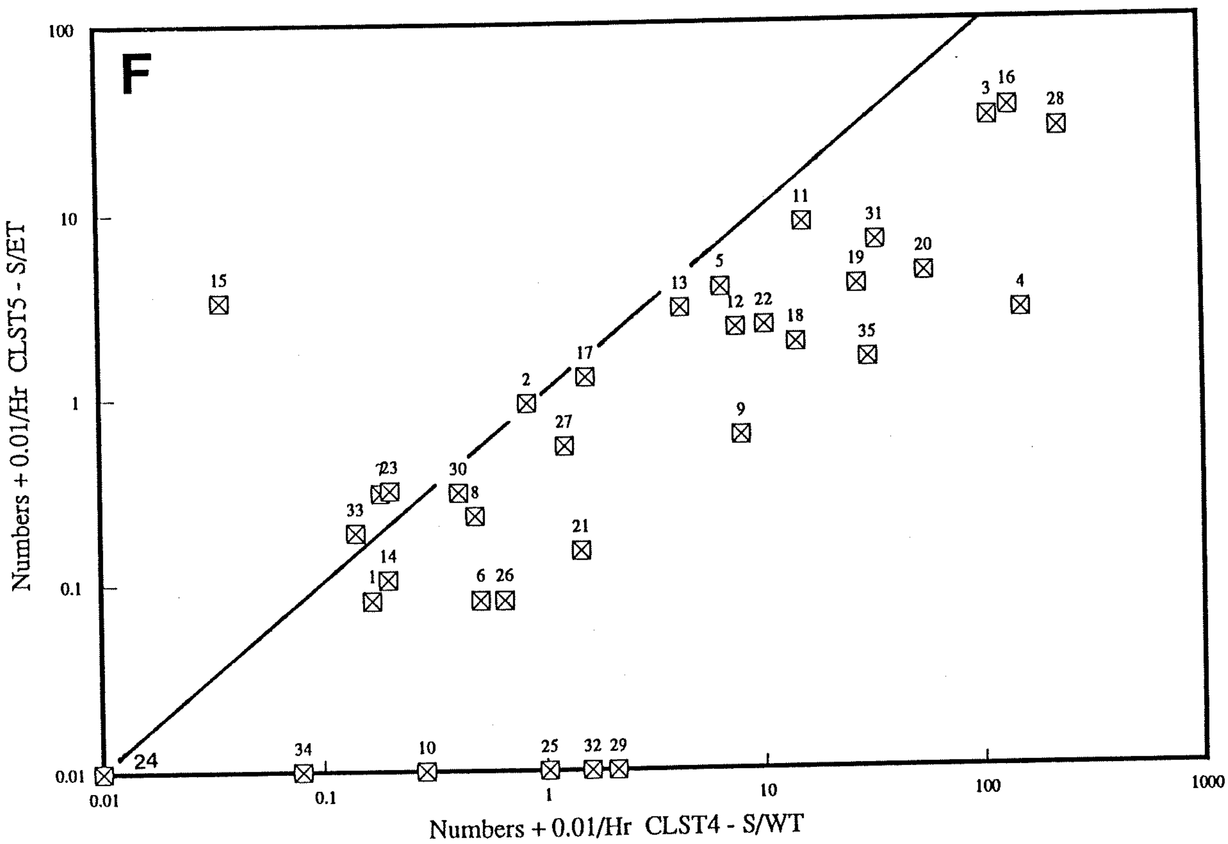

F
Numbers + 0.01/Hr CLST5 - S/ET
Numbers + 0.01/Hr CLST4 - S/WT
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000

Figure 4 E-F

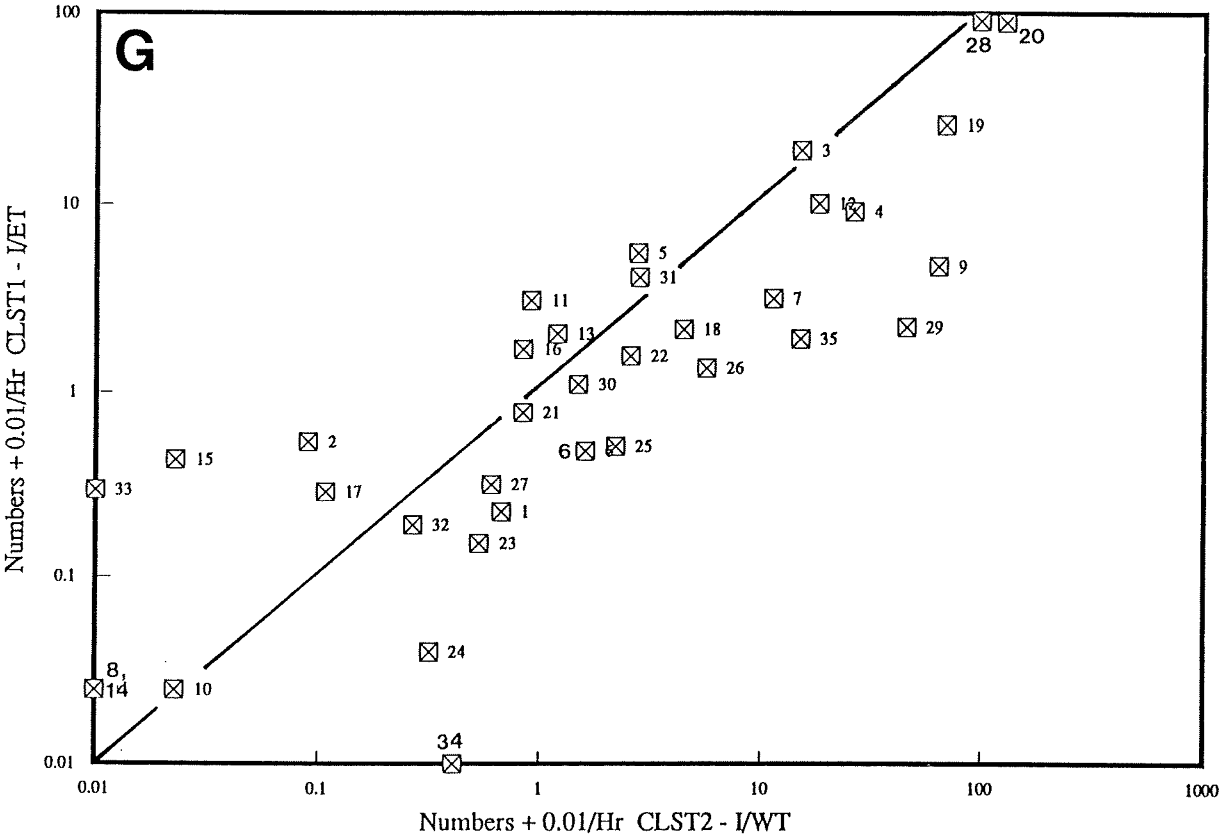

G
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
Numbers + 0.01/Hr CLST1 - I/ET
Numbers + 0.01/Hr CLST2 - I/WT
28
20
19
3
12
4
5
31
9
11
7
13
16
18
35
29
22
26
30
21
2
15
6
25
33
17
27
1
32
23
24
8,
14
10
34

Figure 4 G

F. APPENDIX

Original grant applications

F. APPENDIX

DETAILS OF ORIGINAL GRANT APPLICATION

FISHING INDUSTRY RESEARCH TRUST ACCOUNT
APPLICATION FOR GRANT 1987/88

1. Title of proposal

The abundance, distribution, movements and population dynamics of orange roughy (*Hoplostethus atlanticus*) in south east Australian waters.

2. Name of applicant

CSIRO

3. Division

Fisheries Research

4. Proposal

Orange roughy are fished on a number of grounds in south east Australian waters. There is an urgent need to estimate the abundance of the fish with error limits acceptable for management decisions. It is also essential to add to our understanding of the biology of the orange roughy so as to be able to describe, in its fullest sense, the population dynamics of the species. To this end it is proposed to make the F.R.V. *"Soela"* - or its replacement - available for seven 14d cruises (say 100 d) in south eastern Australian waters during the months of January to July inclusive for three years in the first instance. This application is for funds to contribute towards the operating costs of the research vessel, the cost of acoustic and electronic equipment essential for the exercise, and the salaries and operating costs of extra staff to carry out the work.

5. Name of person responsible for programme

Dr F.R. Harden Jones,
Chief,
CSIRO Division of Fisheries Research,
GPO Box 1538,
HOBART, TASMANIA, 7001
Phone (002) 206 222

Telex AA 57182

6. Qualifications of staff to be employed on the programme

		% time on project
Dr F.R. Harden Jones, PhD	Chief	15
Dr N.G. Elliott, PhD	SSOF 3	50
Dr C.A. Stanley, PhD	ES 3	30
Miss S.E. Wayte	ES	20
Mr R. Kloser	ES 1	30
Electronics Technician	TOF 1 or 2	30
Mr C. Liron	STOF 1	75
Mr O. Augustine	TOF 2	15
Senior Research Scientist	)	
Experimental Scientist 3	) To be appointed	
Experimental Scientist 2	)	
Technical Officer 2)		

7. Objectives

1. To estimate the abundance of orange roughy in southeast Australian waters, with particular reference to the Sandy Cape, Cape Grim and St Patrick's Head Grounds in the first instance.

2. To add to our knowledge and understanding of the life history of the orange roughy.

3. To present the results in a manner which can be used by Advisory and Management agencies for the benefit of the fishery, and by Industry to reduce the cost of capture and increase the value of the catch.

8. Justification

While the presence of orange roughy in Australian waters has been known for several years - the pioneering work being that of Marc Wilson and the Tasmanian Department of Sea Fisheries - the abundance, distribution, movements, life history and population dynamics of the species is virtually unknown. There is a wide consensus of opinion that studies directed towards filling these gaps should have a high priority. Such information is necessary for the management of the fishery whose annual value to Australia could be in excess of $100 million (50 000 t at a first sale value of $2.0/kg).

9. Location(s) of operation

F.R.V. *"Soela"* will be based in Hobart, and the work at sea will be carried out in southeast Australian waters. Laboratory studies will be carried out in the Division of Fisheries Research, CSIRO Marine Laboratories, Hobart.

10. Proposal in detail

1. Plan of operation

i) Methods of operation

a. Estimates of abundance

Orange roughy form large shoals but it is not known what proportion of the mature population is bound up in shoals at any one time of the year. In the first instance it will be assumed that the greater part of the population is in shoals in a restricted area rather than being dispersed over a much wider area. Estimates of abundance will therefore be made, in the first instance, by a combination of acoustic surveys and trawl hauls. The method is conceptually simple. A preliminary acoustic survey will be made of the area of interest, which is then partitioned or stratified into two parts: that with and that without fish shoals. A further survey will then be made within the area of fish shoals to determine the total volume of water occupied by fish.

If the shoals can then be identified by fishing, and the length frequency distribution and average weight of the fish determined, a knowledge of the packing density of the fish - that is the number of fish per cubic metre - will allow an estimate to be made of the weight or numbers of fish on the ground. The packing density can be estimated by

1, the volume swept clear method;

2, direct acoustic measurements; and

3, underwater television or photography, or direct observation from a manned submersible.

We would use, in the first instance, the volume-swept-clear method. Particular shoals, positioned by reference to a Global Positioning System, will be attacked and the fish density determined on the basis of the catch. For the method to succeed it is necessary to know the effective catching area of the net and when fish encounter it, and to have an estimate of the efficiency of the gear (this may be taken as 1.0, and will give an under-, rather than an over-estimate of abundance). The equipment needed will include echo sounders of appropriate frequency and acoustic output, a GPS, and a headline transducer to determine the time when the net strikes the shoal.

A second approach to an estimate of abundance would be to use acoustic methods directly to determine fish density (n/m^3) or biomass (kg/m^3) within the shoals (which must still be surveyed for volume and identified by fishing). For this approach to succeed, a valid measurement of the target strength of orange roughy is required (orange roughy do not have an air-filled swimbladder, and an airfree fish of 42 cm length has a TS of -59.2 dB at 12 kHz).

If special studies and equipment (viz, a dual beam transducer towed behind the research vessel) are required to determine the target strength of orange roughy, the costs of the work would be sought in a separate application. There are several ways in which the existing Simrad echo sounders on F.R.V. *"Soela"* could be modified for making quantitative measurements.

Work on acoustic methods of estimating the abundance of pelagic or demersal fish has not progressed in Australia. The advice of an overseas consultant will be sought to introduce the technology (at the present State of the Art) into Australia, and the transfer will be made to an appropriately qualified experimental scientist who will become responsible for this work in the southeastern fisheries. Independent resource surveys are likely to be required on an annual and continuing basis for several years (5 to 10). The roughy, which forms substantial single species shoals, could prove to be one of the few demersal species for which direct acoustic estimates of abundance may be applicable.

The third approach to packing density would be the use of cameras or TV equipment. The method is practical and has been used successfully outside Australia. The immediate costs for either approach would be an appropriate pressure housing for the equipment and conducting cable if TV pictures were to be viewed "on line". No costings are presently available for this approach, but the matter is being pursued.

The Tasmanian Department of Sea Fisheries has requested the use of the USA NOAA submersible facility, for orange roughy work in 1988 (Marc Wilson, personal communication). We should await the outcome of this application before proceeding further along these lines.

b. Population dynamics

At sea, every effort will be made to collect both the biological and environmental data required to add to our knowledge of the life history of the roughy. The biological requirements will include, for example, data on length-frequencies, length-at-age, sex ratios, age-at-first-maturity, gonad maturation stages, fecundity, feeding and condition factors. It is particularly important to establish baselines for many of these factors in the early stages of the fishery: the situation is almost unique and the opportunity should not be passed by.

There will be a considerable amount of data to collect at sea, and to work up and process in the laboratory. Standard methods in fisheries research will be applied in such studies, and if these prove inadequate, new methods will have to be devised.

Environmental data to be collected will include normal hydrographic data and bottom sediment samples in and out of the areas in which orange roughy occur.

ii) Justification of staff required.

The studies proposed in this application are seen as part of a continuing sub-programme in which both Commonwealth and State Agencies would be participating. We believe that an experienced and numerate fisheries biologist should assume responsibilities for the work outlined in this application and it may be desirable, in due course, for this officer to assume a wider responsibility for orange roughy work, supported by Commonwealth and Rural Industry funds. The Division does not have such an officer available to head a new subprogramme on orange roughy. An appointment at the CSIRO RS/SRS level would seem appropriate but it may not be possible to fill the post within Australia: the United Kingdom, Canada, or Norway might provide suitable candidates. There would be difficulties in recruiting a suitable officer for a one year appointment, and a period appointment for three years on CSIRO's normal T & C's would seem justified.

Support staff must be provided for the work, and while the Division of Fisheries Research intends to deploy a proportion of its existing staff into orange roughy work, three new posts are sought. The biological studies will require specialist knowledge in relation to stomach contents and here an Experimental Scientist position is sought for a named officer (Ms Cathy Bulman), presently engaged in the current CSIRO orange roughy programme. Further support will be required from a technical officer to help with less special but nevertheless essential routine work.

The new and more sophisticated electronic navigational and acoustic equipment to be used on F.R.V. *"Soela"* make it essential that an electronics officer is on board for each cruise. The Division presently has two electronics officers (one ES and one TO) to meet all its needs and cannot sustain the support required from present resources: a new post is sought.

The officer appointed will be responsible for the acoustic aspect of survey work and should become the Australian expert in this field. Some development work will be involved in applying northern hemisphere techniques to Australian conditions and an appointment at the ES 2/3 level would be appropriate. It is important that we receive the best advice, training and instruction in applying acoustic survey techniques to the orange roughy. An International Symposium on Fisheries Acoustics is being held in Seattle, USA from 22 to 26 June 1987. Dr Harden Jones, who is a member of the Symposium Steering Committee, will be attending the meeting and will take advantage of the opportunity to obtain advice from friends and colleagues. The most cost-effective way to proceed could be to bring out a suitable expert from the United Kingdom or Canada for two 4 to 6 week periods (one visit in the year 1987-88, and a back-up visit in 1988-89, should this be desirable). Support for the consultant's visit is also sought in this application. Extra equipment will be required for our echosounders (see previously), but an estimate cannot be made until advice is received. Consequently costs are not included in this application.

iii) Facilities available.

F.R.V. *"Soela"* has been equipped with new acoustic equipment and a Global Positioning System for this work. The Division has no funds to pay for the new equipment - which is essential for the work - and it is not clear if CSIRO HQ will provide funds to pay the bills. If no CSIRO support is forthcoming, an application will be made to FIRTA to meet the cost of the equipment and details have been included in the present budget. In all other respects, F.R.V. *"Soela"* can be regarded as-"well-found", and the full facilities of the CSIRO Marine Laboratories will be available to support the programme.

2. Supporting Data

The Division, with support from FIRTA Grant 1985/84, has carried out exploratory fishing cruises in Tasmanian waters in 1986, and has taken roughy on both the west and east costs. The Division is currently carrying out, at short notice, a series of 4 or 5 cruises to estimate the abundance of roughy on the Sandy Cape, Cape Grim, and St Patrick's Head Grounds. This work is supported, in part, by the Department of Primary Industry by a grant from the Fisheries Development Trust Fund.

11. Proposed date of commencement and anticipated completion date

The proposed commencement date of the present programme would be 1 July 1987 and should be completed by 30 June 1990.

12. Funds requested

	Year 1	Year 2	Year 3
a. Total salaries	268566	268566	291600
b. Total operating	214566	240291	181616
c. Total travel	21300	8800	5800
d. Total capital	95519	?	?
Gross total cost	$599951	$517657	$479016
Estimated net income	Nil	Nil	Nil

13. Funds to be provided by Applicant or sought from other sources

a. Salaries of CSIRO staff employed on the program

	% time spent on project	
Dr F.R. Harden Jones	15	12 557
Dr C. Stanley	30	13 063
Miss S. Wayte	20	7 510
Mr R. Kloser	30	7 452
Electronics Technician	30	8 890
Mr C. Liron	75	26 018
Mr 0. Augustine	15	3 561

b. Full charter cost for F.R.V. *"Soela"* including 100% of charter for 1O0d at sea, port & harbour dues, normal crew air fares, and 50% of fuel costs	1 452 857
c. Laboratory facilities, research support and overheads	63 240
d. Vessel facilities, equipment and fishing gear	+
Total funds provided by Applicant	$1 595 148 +

14 Co-operating agencies

Commonwealth Department of Primary Industry, and the Fisheries Departments of New South Wales, Victoria, South Australia ana .asmania. Full and complete co-operation between all management agencies and industry is seen as essential for the success of this work and it is recognized that it will be very important to keep all interested parties informed of the progress.

15. Similar work being-undertaken in Australia

Work on orange roughy is being carried out by the Fisheries Departments in New South Wales, Victoria, South Australia and Tasmania.

FIRTA 1987/88. An application entitled "Western Bass Strait Trawl Fishery Assessment (1986/39)" from the Department of Conservation, Forests and Lands, Victoria, is currently being considered by FIRC.

FIRTA 1987/65. An application entitled "An assessment of the orange roughy resources off the coast around Tasmania" from the Tasmanian Department of Sea

Fisheries, is currently being considered by FIRC.

FIRTA 1987/94. An application entitled "Investigation of two techniques for ageing marine animals" by Dr David Ritz, University of Tasmania, is currently being considered by FIRC.

FIRTA 1987/92. An application entitled "The assessment of restriction enzyme analysis mitochondrial DNA for the identification of stocks of commercially important marine species and for detection of genetic markers for use in salmonoid husbandry" by Dr White, University of Tasmania, has been approved by FIRC.

16. Plans for reporting or publishing results

In Australian Fisheries, scientific journals and technical reports, as appropriate.

Appendix 1

Details of funds requested

a. Salaries and wages

Dr N. Elliott, SSOF 3 1, 50%	16 559	16 559	16 559
Senior Research Scientist M	41 859	41 859	41 859
Experimental Scientist 3 M	36 657	36 657	36 657
Experimental Scientist 2 M	31 686	31 686	31 686
Technical Officer 2 M	26 805	26 805	26 805
Employers Superannuation, 20.5%	31 481	31 481	31 481
15% salary on cost for accrued leave and leave loading on conclusion of project	-	-	23 034
Marine Survey Allowance 14.5 sea weeks @ $720/w x 6 staff	62 640	62 640	62 640
Overtime 14.5 sea weeks @ $720/w x 2 staff	20 880	20 880	20 880
Total salaries & wages	$268 566	$268 566	$291 600

b. Operating expenses

i) Additional vessel operating costs

a) Fuel 30 days fuel @ 4.5 ton/day x $350/ton	-	47 250	-
50% of fuel usage @ 4.5 ton x 100 days (70 1988/89) x $350/ton	78 750	55 125	78 750
b) Crew air fares 209 additional fares Perth-Hobart based on 2-week sea program	87 362	87 362	87 362

c) Victualling 50% of cost of victualling @ $18.76/day x 100 days x 8 staff	7 504	7 504	7 504
ii) Other operating costs			
a) Advertising costs for new positions	4 400	-	-
b) Fishing gear:			
Bongo net & frame	3 500	-	-
Engel trawl x 2	16 000	16 000	-
Ropes, shackles, floats & miscellaneous fishing gear	3 000	3 000	-
c) Acoustics consultancy 2 x visits by UK consultant	11 050	11 050	-
d) Laboratory supplies, chemicals consumables	3 000	3 000	3 000
e) Electronics supplies for acoustics development	-	10 000	5 000
Total operating expenses	$214 566	$240 291	$181 616

c. Travel allowances and appointment expenses

Appointment costs for new staff to be recruited	15 500	3 000	-
Local travel expenses i) fares ii) allowances	-	-	-
Incidentals for staff at sea @ $7.25/d x 100 days x 8 staff	5 800	5 800	5 800
Total appointment & travel expenses	$ 21 300	$ 8 800	$ 5 800

d. Capital items

For F.R.V. *"Soela"*

Global Positioning System	49 052	-	-
Colour Echo Sounder	19 908	-	-
Trawl Net Recorder	26 559	=	=
Total Capital Items	$ 95 519	=	=
Gross Total Cost	**$599 951**	**$517 657**	**$479 016**
Estimated net income		**NIL**	

Appendix 2

Budget explanatory notes

Salaries and wages

Funds for salaries plus directly associated costs will be required for the staff to be appointed as identified under item 10 ii), of the application. Dr N. Elliott has been specifically deployed from other work to give 50% of his time for fecundity studies, for which he is qualified by ability and interest. Funds are required to employ an officer, on a temporary and casual basis, to carry on with the work which he has given up.

Marine survey allowance and overtime

Funds are required to meet the sea-going allowances payable to staff for duty at sea Costs are based on the standard rate being applied to all staff,.irrespective of classification, for the sea days involved.

Operating expenses

F.R.V. *"Soela"* additional costs

CSIRO currently meets the full cost of chartering F.R.V. *"Soela"* for fisheries research activities. As part of CSIRO's commitment to research in support of the AFZ, CSIRO is obliged to provide 50% of the charter and associated costs for these activities. Current charter funds provide for the vessel to be at sea for 182 days per year. Operations are based on *"Soela"* being at sea for 4 weeks followed by 4 weeks in port throughout the year. Therefore, to undertake this project, funds are needed to meet the additional expenses for operating the vessel over and above CSIRO's current commitment level.
They are:

Fuel

Because of the Divisional operating fund shortages and to achieve fuel savings, we had proposed to use *"Soela"* at sea for 132 days only in 1987/88 and 152 days only in 1988/89. For *"Soela"* to undertake this project, the vessel will need to be at sea for the full 183 days each year. The fuel costs for a full year's operation must therefore be provided. For 1978/88 the additional 50 days of fuel are to be provided from a DPI grant. However, for 1988/89, the 30 days' fuel costs that would not have been incurred must be provided for in this grant. In addition and based on present arrangements, the 50% of fuel costs over and above CSIRO's commitment to research in support of the AFZ must also be provided from the grant.

Crew air fares

Under the charter agreement, CSIRO is obliged to meet the crew air fare costs to return crew members to their home port (Fremantle, WA) after each tour of duty. Current operating procedure calls for a complete crew change each month. This project is based on operating *"Soela"* on a two week instead of monthly turn around (i.e. 2 weeks at sea followed by 2 weeks in port) for the duration of the project. This necessitates a complete crew change, sea crew for port crew, every two weeks, thus incurring additional costs. For 100 sea days on this project the cost of an additional 209 air fares will be incurred.

Victualling

For each day spent at sea by each person, a charge of $18.76 is levied for accommodation and meals provided by the vessel owners, These costs are debited against the research projects for which the vessel is used,

Other operating costs

Advertising

To recruit the staff needed for the project, CSIRO will need to advertise. Costs are based on international advertisements for the Senior Research Scientist and national advertisements for the Experimental Scientists at present day rates.

Fishing gear

In order to catch the orange roughy, there is a need for additional trawl nets to be provided to supplement the Division's existing net supply, which is inadequate for this project. In addition, miscellaneous items such as floats, ropes, shackles will also be required

Acoustics consultancy

Work on acoustic methods of estimating the abundance of pelagic or demersal fish has not progressed in Australia. The advice of an overseas consultant is required to introduce the technology (at the present State of the Art) into Australia, and the transfer will be made to an appropriately qualified experimental scientist who will become responsible for this work in the southeastern fisheries. Independent resource surveys are likely to be required on an annual and continuing basis for several years (5 to 10). The roughy, which forms substantial single species shoals, could prove to be one of the few demersal species for which direct acoustic estimates of abundance may be applicable.

Laboratory supplies, chemicals, consumables

Minimum funds are required for laboratory supplies to undertake laboratory based analyses such as fecundity studies. Existing resources will be utilized where possible, however additional supplies are necessary.

Electronics supplies

Funding of electronic supplies for the acoustics developmental work will be necessary. This will not occur until year 2 and specific details will be provided following the consultant's initial visit.

Travel expenses

Appointment costs

Funds have been allowed for the travel and accommodation costs on appointment for the staff identified. It is stressed that should an overseas appointment of the Senior Research Scientist be made, the amount requested will be the minimum necessary.

Local travel

Funds are required to pay travel allowance to staff for work at sea.

Capital items

F.R.V. "*Soela*" has been equipped with new acoustic equipment and a Global Positioning System for this work. The Division has no funds to pay for the new equipment - which is essential for the work - and it is not clear if CSIRO HQ will provide funds to pay the bills. If no CSIRO support is forthcoming, an application will be made to FIRTA to meet the cost of the equipment and details have been included in the present budget. In all other respects, F.R.V. "*Soela*" can be regarded as "well-found", and the full facilities of the CSIRO Marine Laboratories will be available to support the programme.

Fishing Industry Research Trust Account
Supplementary application to continuing grant 1987/129

1. Title of proposal

The abundance, distribution, movements and population dynamics of orange roughy (*Hoplostethus atlanticus*) in south east Australian waters.

2. Name of applicant

CSIRO

3. Division

CSIRO Division of Fisheries

4. Proposal

Funds are sought for the purchase and construction of acoustic equipment to be used in the acoustic estimates of the abundance of marine fishery resources, and in particular orange roughy. In both the original and continuing applications it was indicated that when the appropriate acoustic equipment had been identified, a supplementary application would be made for support. The present application follows from a visit by Dr Harden Jones in 1987 to Seattle to attend the International Symposium on Fisheries Acoustics; and from visits in 1988 to the USA by Mr Rudy Kloser (the acoustics ES employed on this project) and Dr Harden Jones.

5. Name of person responsible for programme

Dr F.R. Harden Jones,
Chief, CSIRO Division of Fisheries,
CSIRO Marine Laboratories,
GPO Box 1538,
Hobart, Tasmania 7001
Phone: (002) 20 6264
Telex: AA 57182
Fax: (002) 23 7125

6. Qualifications of staff employed on that part of the programme, relevant to this application

F.R. Harden Jones, PhD	CRS 3	10%
R. Kloser, BE	ES 1	100%

N.G. Elliott, BSc, PhD SSO 3 20%

7. Objectives

The objective of the work is to apply acoustic methods of estimating fish abundance to the deep water fishery resources - here orange roughy in the Australian Fishing Zone.

8. Justification

Estimates of the abundance (in terms of biomass) of orange roughy and other shelf, slope and deepwater species in the AFZ are unlikely to be obtained with confidence levels suitable for management purposes from the results of random stratified trawl surveys alone. Other methods must be developed to supplement the research vessel or commercial catch data. Three obvious approaches are to use acoustic methods (as argued in this application), tagging, and egg and larval surveys combined with fecundity studies.

Three methods which could be used to estimate the abundance of orange roughy will be considered under the following headings:

1, Random stratified trawl surveys;

2, Echo integration and trawl surveys; and

3, Echo integration, target strength measurements and trawl surveys.

1. Random stratified trawl surveys. The method was the basis for the 1988 work and a draft report has been prepared (Bulman, Wayte and Elliott, 1988). A limitation of the method is that the survey provides no information between trawl stations or for areas of rough bottom deemed to be unsuitable for trawling. Estimates of the biomass of orange roughy have been made assuming that 1, the gear catches all the fish in the path of the net (when the catchability coefficient $q = 1.0$); and 2, that all the fish are below the height of the headline (that is within 4 m of the bottom). It is most unlikely that these two assumptions are correct, and the surveys must underestimate the biomass on or over the fishing ground. The extent of the underestimate cannot be quantified with an acceptable level of accuracy. Kenchington's (paper submitted) calculations suggest that to assume that $q = 1.0$ for orange roughy taken in an Engel High Rise demersal trawl could underestimate the biomass by a factor of two. The forepart of the net has large meshes and the codend might only retain half the weight of fish that originally passed below the headline. New Zealand work (Do et al, 1987) shows that orange roughy extend from 20 m to 60 m above the bottom, and the assumption that the fish are restricted to only 4 m above the bottom could therefore underestimate the biomass by factors ranging from 5 to 15 times. The total range of the underestimate could therefore be from 10 to 30 times. There is clearly a need to improve the precision of the method and the accuracy of the estimates of the biomass.

2. Echo integration and trawl surveys. Echo integration, supported by trawl hauls at selected stations to identify the scatterers and the proportion of the species of interest, may

provide data on the abundance and thus the biomass of roughy between trawl stations and on grounds unsuitable for trawling. The method depends on being able to establish a correlation between the echo integration levels and the catch. Good correlations have been obtained by this method (Stromme and Saetersdal, 1982).
But this approach will not correct for the bias introduced by assuming that the gear retains all the fish in the path of the net. But a correction could be made for the bias (that is the underestimate) which must follow if a significant proportion of the fish are above the headline. Their vertical distribution can be determined by:

1, increasing the resolution of the acoustic system (transducer closer to the bottom, transmit at a higher frequency, shorter pulse length - 0.200 ms - and with a narrower beam);

2, the use of single frame underwater flash photography at known heights above the bottom. Photographs would be synchronized to echos returned by targets on the acoustic axis of a suitable high frequency echo sounder mounted alongside the underwater camera;

3, stratified hauls with a midwater trawl over grounds where roughy have been taken by a bottom trawl.

The acoustic system will provide the resolution required using items 1, 2, 13, 6, 7 and 8, and this equipment could also provide the acoustic component of the photographic system (the underwater camera is available).

3. Echo integration surveys whose signal levels are converted to biomass from the relationship between the acoustic target strength and the weight of the species of interest. The composition of the trawl catches provides the basis for assigning the biomass between species. The method has been developed and applied by Do et al (1987) to orange roughy on the Chatham Rise ground.

This method provides an estimate of biomass which is, in the first instance, independent of the trawl catch: biomass is determined as the quotient obtained by dividing the integrated echo signal by a derived value for the signal strength of 1 kg biomass. This value is calculated from acoustic target strength measurements of single or groups of fish, measurements being made in tanks or cages with alive or recently killed fish, or on single free swimming fish at sea or in freshwater (so called in-situ measurements). The advantage of in-situ measurements of target strength is that the measurements would be made on individuals from the population whose abundance is being estimated; and the variations in target strength attributable to the behaviour of fish on the fishing ground are included in the target strength measurements. Do et al (1987) made target strength measurements in tanks rather than at sea because they were unable to get the transducer to within 100-200 m of the bottom. The consensus of opinion - as expressed at the International Symposium on acoustical methods for measuring the abundance of fish, held at Seattle in 1987 - is that in-situ measurements are very much better than tank measurements with dead fish, and for fish with gas filled swimbladders. While the orange roughy does not have a gas filled swimbladder, we accept that there are considerable arguments for in-situ measurements and this work is necessary at this stage. Items 4, 5, 9, and 10 are required for the in-situ target strength measurements.

A note on a bias and an error associated with echo integration

An important source of bias and an important source of error cannot be ignored.

1. A bias due to noise. The echo signals are multiplied by a Time Varied Gain (20 log R) to correct for the spreading loss which increases with depth. The echo signals include single and multiple echos from fish and other targets collectively known as reverberation, to which is added noise. Noise is always present in the sea, and for a particular weather state, is constant at the transducer face. But as echo signals received at the transducer are subjected to a TVG, the last train of signals to be received and processed from a single outgoing pulse include a very much higher noise component (x 20 log R) than the first signals to be received. So an echo survey in which signals are integrated as the vessel steams from, for example, 800 m to 1200 m, will overestimate the abundance of fish in deeper water. Until recently this has been an intractable source of bias in the technique, but recently BioSonics have produced a means to overcome this problem which is incorporated in a new signal processing board (item 6).

2. An error due to targets which contribute to the integrated echosignal but are not retained in the net. This could be a serious error and will lead to an increase in the variance of the relation between integrated signal and trawl catch, and an overestimate of the biomass. In effect, echos from many small and unwanted targets within one pulse sampling volume could add to form a substantial echo which would exceed the lower threshold value for acceptance. Yet the targets could avoid the gear or escape through the meshes, to be represented in the catch far below the level to which they contribute to the integrated echo. The only precaution against this 'open-ended error' is vigilance and the wise use of codend liners, fine-meshed nets on or within the gear, and ancillary sampling equipment (for example, underwater cameras).

To carry out the work as outlined in this proposal requires an acoustic sampling system with the capabilities to:

1, detect low densities of fish close to the sea bed in a depth range of 700 to 1200 metres;

2, perform echo integration surveys at speeds of 5 to 10 knots; and

3, obtain in-situ target strength measurements (for biomass estimations) on individual fish, at a speed of 2 knots in water depths to 1200 metres.

The requirements of such a system dictate some general design principles. One, caused by the depth involved, is to reduce the significant attenuation of the sound beam due to its spherical spreading and absorption, and secondly, to overcome the significant attenuation caused by surface bubbles due to wind and wave actions. These are achieved by towing a transducer behind the vessel at a depth of 200-400 metres for echo integration work and down to 1000 metres for target strength work. This design will also reduce the sampled volume and enable a shorter pulse length (l ms) to be used, thereby providing a better vertical resolution and reducing the on-axis bottom dead zone (Figure 1).

In-situ target strength work requires a special transducer, and a scientific echo sounder of known stable output power that will receive in the dual or split beam mode . The target strength of individual fish is used in determining the abundance of particular species. The split beam method in theory gives a better signal to noise ratio, but requires more specialized cabling and hardware to implement than the dual beam method. So in this proposal we have chosen the dual beam option which costs less (use existing cables and winches), but may be upgraded to split beam if required in future years.

The operating frequency selected for this system will be 38 kHz. The size of a transducer radiating face is inversely related to the operating frequency, for equivalent beam angles. Therefore a 38 kHz transducer would be smaller in size than a 12 kHz transducer, and as such would require a smaller sized towed body for deployment. If this frequency is used, direct comparison can be made with the New Zealand data.

References

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Stromme, T., and Saetersdal, G., 1982. A comparison of abundance estimates of semi-demersal and demersal fish from trawl surveys and acoustic surveys. Symposium on Fisheries Acoustics, Bergen, Norway, 21-24 June 1982. Paper 45 (Mimeo).

9. Location of operation

Trials with some components of the equipment will be carried out on F.R.V. *"Soela"* in 1989, and on F.R.V. *"Southern Surveyor"* in 1989-1990.

10. Proposal in detail, including procedures

The work will be incorporated into the programme described in the continuing application 1987/129.

11. Proposed commencement date and anticipated completion date

October 1989 to July 1990

12. Details of equipment and funds requested

To make the recommendation on the equipment four companies were consulted, those being Simrad (Norway), BioSonics (USA), Instruments Inc. (USA), and EDO Western Co. (USA). Simrad was the only company who could provide a complete system using the split beam method for obtaining in-situ target strength. The time delay for the manufacture of the transducer and towed body was [illegible] months, which was not suitable for the work in 1989. Also the cable required to implement the split beam method was large in diameter and expensive ($140,000), this would have necessitated purchasing an additional winch and cable for the new research vessel.

The prices listed are quoted prices from the above companies as of August 1988, and are given as budgetary costs, and are subject to exchange fluctuations.

Item No.		$
1. Transducer. A specifically designed 38 kHz dual/split beam transducer, rated to 1000 m, with transmit/receive switches and preamplifier from EDO Corp., USA	Budgetary cost	46,000

2. Towed body. A suitable dead weight towed body to house the large EDO western transducer is available either for purchase ($50,000 plus at least 6 months time delay) or manufactured in house. Materials and contract labour for manufacture locally, under in- house supervision, by January 1989.

	Budgetary cost	20,000

3. Fairing for cable. Fairing is required to reduce flow induced noise and drag as the cable is towed through the water. The first 200 m of the cable needs to be faired to achieve any significant effect.

	Budgetary cost	2,000

4. Echo sounder transmitter. The transmitter sends a stable voltage to the transducer, via a long cable.The long lossy cable dictates that a high powered transmitter be used.

	Budgetary cost	27,000

5. Echo sounder receiver. The receiver filters and amplifies the returned echos with the appropriate time varied gain. For echo integration work, one 20 log R amplifier is required. For dual beam target strength work two 40 log R amplifiers are required.

	Budgetary cost	40,000

6. Echo integrator/target strength analyser. Provides a depth stratified amplitude record of the received echos. For orange roughy the integrator will need to work in the bottom referenced mode with compensation for the noise variation with depth.

	Budgetary cost	25,000

7. Simrad time varied gain (TVG) amplifier. The existing ship board sounder (Simrad) using a hull mounted transducer requires an extended TVG amplifier for echo integration work.

	Budgetary cost	2,500

8. Processing and archiving data, and running echo integrator requires a high speed dedicated processing computer with printer, plotter, software and back-up facilities.

	Budgetary cost	20,000

9. Chart recorder and display monitor to function off the scientific sounder and integrator.

	Budgetary cost	30,000

10. Equipment for transducer and system calibrating and testing.
    Function generator
    Universal counter
    Towed body manipulation equipment
    Test software for computer

Budgetary cost	20,000
Total budgetary cost	232,500

All prices quoted in the budget are FOB from the factory and do not cover import duty. A rough guesstimate of the additional costs provided are:

Air Freight (10 kg pack, 0.5 m x 0.5 m x 0.25 m)	$400
Import Duty	5-10% of purchase price

The above additional costs, when applied to items 1, 4, 5, 6 and 9 in the proposal, which have a total purchase price of $168,000,are:

Air freight	2,000
Import Duty	16,800
Total	$20,800

The grand total is therefore $232,500 + 20,800 = **$253,300**

13. Funds to be provided by the Applicant or sought from other sources

The equipment to be provided on F.R.V. *"Southern Surveyor"* and laboratory test equipment are relevant to this application

Winch for FRV	120,000
Cable for FRV	50,000
Test equipment	
oscilloscope	10,000
hydrophones	2,000
standard targets	1,000
dynamic analyser	20,000

203,000

14. Co-operating agencies and their functions

As the work develops, advice, and if necessary assistance, will be sought from appropriate Government agencies in NZ, USA and UK, CSIRO Division of Applied Physics, the Antarctic Division and RANRL.

15. Is similar work being undertaken in Australia

Not to our knowledge

16. Publication of results

Australian Fisheries, scientific journals.