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Abstract

An area off Sandy Cape (western Tasmania) and another off St Patrick's Head (eastern Tasmania) were surveyed on five occasions in 1987 (April to August) to gather information on the life history of orange roughy *Hoplostethus atlanticus* Collett. Acoustic surveys and demersal and pelagic tows were made on each visit. No large aggregations of fish were detected in either area. Catch rates for orange roughy ranged from 0 to 10 161 kgh^{-1}, with most catch rates less than 100 kgh^{-1} and only four greater than 1000 kgh^{-1}. The main dietary item of adult orange roughy was fish. The length-frequency distribution of the orange roughy was bimodal. The major mode for males was 35-36 cm and for females was 38 cm. Length at first maturity was 30 cm for males and 32 cm for females. Spawning occurred off the eastern coast of Tasmania during late July, evidenced by approximately 80% of the adult fish from this area being spent by August. No evidence of spawning was detected in fish from the west coast.

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Bibliography.
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1. Orange roughy — Tasmania — Geographical distribution.
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I. Elliott, N. G. (Nicholas Grant), 1953-
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Contents

Introduction

In 1981 the Tasmanian Department of Sea Fisheries (then the Tasmanian Fisheries Development Authority) discovered orange roughy (*Hoplostethus atlanticus* Collett) in Tasmanian waters in quantities that promised to be commercially viable (Wilson, 1982a). An assessment of the potential of orange roughy as a deepwater fishery was then made during several exploratory surveys (Wilson, 1982b; Wilson and Evans, 1983, 1984; Wilson *et al.*, 1984; Evans and Pullen, 1986; Pullen *et al.*, 1986). The catch rates from these early fishing ventures were similar to those of the developmental stage of the New Zealand fishery (Williams, 1987).

Orange roughy is distributed widely in southeast Australian waters. They were found off New South Wales by *Kapala* in 1983, although the catches were predominantly of small fish (<30 cm) (Gorman and Graham, 1984). Roughy have also been caught in the Great Australian Bight, west of the Western and South Australia border (Wilson and Evans, 1983), and in Tasmanian waters on the Cascade Plateau (Pullen *et al.*, 1986) and the Tasman Rise (Kenchington and Dews, 1986; Bulman and Dews, unpubl. report). Exploratory surveys in 1000–1400 m depths off the west coast of Tasmania in mid-1986 also found orange roughy in reasonable quantities (Bulman and Dews, unpublished report).

The discovery of an aggregation, colloquially known as a "hot spot", west of Tasmania (Sandy Cape) in late 1986 was followed by a rapid expansion and capitalisation of the deepwater trawl fishery in the southeast region. Landings of orange roughy increased from 400 tonnes per annum to around 9000 tonnes in 1986/7 (Evans and Wilson, 1987). This rapid development of a highly profitable fishery raised the Australian fin-fish landings by 12% in 1986/87, with a 34% increase in value to $137m (Bureau of Agricultural Economics, 1987).

Despite recent work in Australia and New Zealand, many gaps existed in our knowledge of the life history, distribution and abundance of orange roughy in Australian waters. The discovery of the first aggregation at Sandy Cape, and the subsequent commercial interest in it, highlighted our lack of knowledge of the species, particularly of its aggregating behaviour and the biomass of fish, both within aggregations and in total. The consequences of overfishing on aggregations was beginning to be felt in the New Zealand fishery; the Australian fishery was therefore at an important stage in its initial development and management.

The objectives of the research described in the present report were to make acoustic and trawl assessments of the biomass of orange roughy on the Sandy Cape (41°07'S to 41°17'S; 143°56'E to 144°04'E), Cape Grim (40°36'S to 40°40'S; 143°22'E to 143°30'E) and St Patricks Head (41°10'S to 41°45'S; 148°35'E to 148°52'E) grounds (Fig. 1), and to gather more information on the life history of the fish. From April to August 1987, five cruises of the FRV*Soela* investigated the population of roughy on the grounds, conducted bathymetric surveys of the grounds and collected environmental data where appropriate. We were unable to estimate biomass from the data from these cruises; however bathymetric and biological data are reported here.

Materials and Methods

Vessel

FRV *Soela* :	stern trawler, built in 1963
L.O.A.:	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 3200 m of 24 mm trawl wire
Trawl doors:	Polyvalent, each door 800 kg + 200 kg

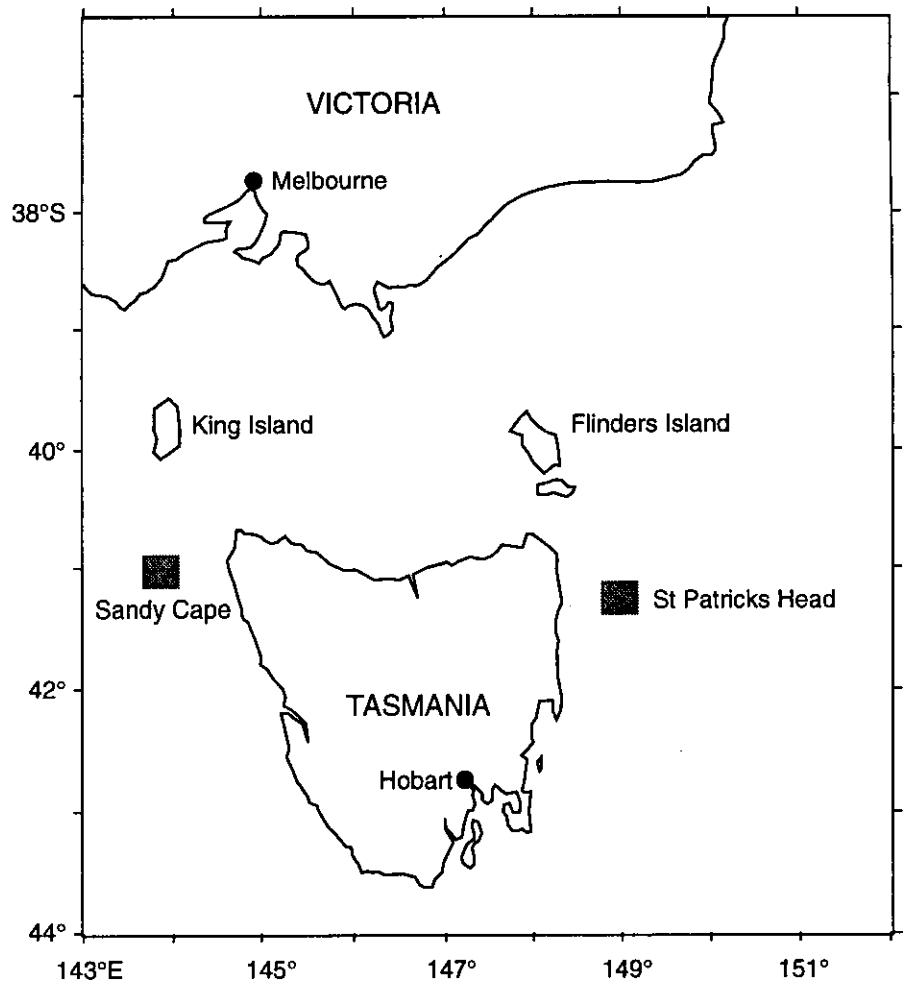

Fig. 1. Study areas at Sandy Cape and St Patricks Head during the 1987 study.

Equipment

Soela was equipped with a Trimble 10X Navigator global positioning system (GPS), in addition to a Magnavox MX 1105 satellite navigator. Using the GPS, position fixes accurate to within ±45 m, and detailed navigation data were available for about eight hours each day. A Taiyo TP–C10 colour course plotter, Taiyo TP–R14 data recorder and an Epson LX–86 printer were linked to the GPS system to provide an immediate plot of the ship's course, to store the course track and waypoints if needed, and to print position fixes and related data every 20 s.

A Simrad Skipper CS–119 38 kHz colour sounder on the bridge provided a system comparable to those used by the commercial fleet for detection of large fish schools. A Furuno 50kHz/75kHz net recorder was used on nearly all tows. It provided information on net opening, distance off the bottom of the headline, fish entering the net, water temperature and time on the bottom. The recorder could look up or down or in both directions simultaneously.

A Simrad EK 400 12 kHz echosounder was used for bathymetric and fish surveys, and an EK 50 kHz was used occasionally for comparison.

An Engel high-lift bottom trawl was used for demersal trawling, except on three tows when a Frank and Bryce trawl was used. An Engel 152 pelagic trawl was used in most midwater tows, while an Engel 308 pelagic trawl was used on a few occasions (Appendix 1).

Acoustic surveys

Bathymetric surveys

Over the five cruises, SO2/87 (April) to SO6/87 (August), the Sandy Cape (west) and St Patricks Head (east) grounds (Fig. 1) were surveyed with the Simrad EK400 echo sounder during periods when the GPS was operational. The Cape Grim ground was surveyed only during the first cruise. Bathymetric charts of the two major grounds were constructed from records of position, depth, speed and heading, and annotated echo sounder traces. Transects over the St Patricks Head ground are indicated in Figure 2.

Fish surveys

Echograms were annotated when marks suspected to be fish were seen. Attempts were made to identify the "schools" by target trawling.

Table 1. EK 400 sounder settings during surveys

Gain	3–4
Attenuation	0 dB
Mode	dynaline
Pulse duration	3 m s^{-1}
Subgain	0 or 3
Power	high
Time varied gain	20 dB
Reference depth	0
Sound velocity	1498 m s^{-1}
Expanded mode	bottom
Draft	3.5 m
Expanded range	10 m
Band width	0.33 kHz
Expanded readout	bottom contour/low
Transducer	4 (12 kHz)

Biological sampling

Catches from demersal tows were sorted; the species were identified and the dominant species, including orange roughy, were weighed. The actual weight of the total catch was recorded or, when catches were large, estimated. A maximum of 2 orange roughy per sex per cm size class were selected for measurements of standard length (SL), weight, gonad weight and maturation stage, stomach fullness and prey. Females ≥ 30 cm SL and males ≥ 28 cm SL were considered to be adults, based on the caudal fork length at first maturity (Evans and Wilson, 1987). Otoliths, gonad tissue for histology and fecundity, and liver or ovary for stock identification experiments (Zoology Dept, University of Tasmania) were also collected.

Length frequency

An additional maximum of 200 sexed fish from every tow were measured for length. The data were analysed separately for sexes by area (east and west), by 50 m depth strata and by area per month.

Length–weight relationships

Length–weight relationships were calculated for males and females in each area for each cruise. A multiple regression was indicated by the data and a natural log-transformation of the data was necessary.

Reproductive biology

Gonad staging was based on the criteria of Pankhurst *et al.* (1987) (Appendix 2). Length at maturity was determined by calculating the length at which 50% of fish caught from April to June were showing signs of maturation (i.e. females ≥ stage 3 and males ≥ stage 2). The gonosomatic index (GSI) was calculated for all fish

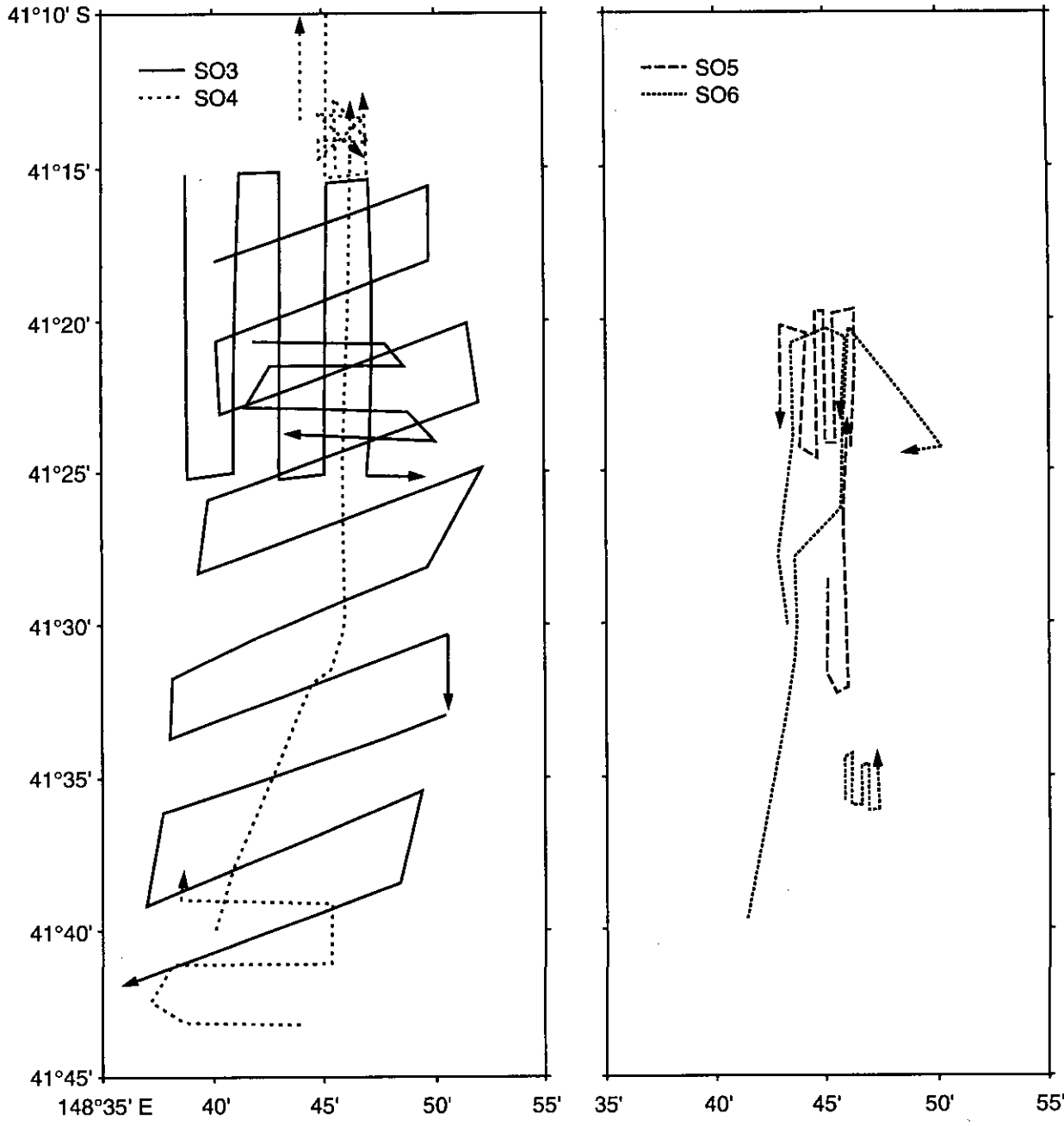

Fig. 2. Bathymetric transects over the St Patricks Head ground. (a) Transects during May (SO3) and June (SO4). (b) Transects during July (SO5) and August (SO6).

whose gonads had been weighed, using the formula:

$$\frac{\text{Gonad weight (g)} \times 100}{\text{Body weight (g)}}$$

GSIs were plotted against length (SL cm) for males and females in each area (east and west) for each cruise. The mean GSIs and standard errors (SE) were calculated for the adults (females ≥ 30 cm; males ≥ 28 cm) in each case and plotted against time.

Fecundity

The ovaries of sexually mature (stage 3) females were slit open and preserved in modified Gilson's fluid (Simpson, 1951). They were vigorously shaken during storage to free the eggs, but occasionally manual separation was also required.

The eggs were then washed, their excess water was removed and their total weight recorded. The number of vitellogenic yolky eggs in three subsamples of approximately 1 gram each were counted manually. The total fecundity for both ovaries was calculated from the average of these three counts. This procedure was similar to Pankhurst and Conroy's (1987) for New Zealand orange roughy, although they froze the ovaries after removal from the fish.

Dietary analyses

Dietary information—fullness, digestion stage of the stomach contents, identity and wet weight of prey—was recorded. Fullness was scored by the following scale: 0 = empty; 1 = 1–25% full, 2 = 26–50%; 3 = 51–75%; 4 = 76–100+%. Digestion was scored from Table 2, which is loosely based on Sainsbury and Whitelaw (in press) but modified to cater for differences in the effects of digestion on crustacea, fish and cephalopods.

Table 2. Degree of digestion, adapted from Sainsbury and Whitelaw (in press).

Scale	Degree of digestion
1	Little or no digestion; skin or carapace still intact; items can be identified to species
2	Partial digestion; skin mostly missing; carapace very soft or some missing; items may be identifiable only to genus
3	Advanced digestion; bones beginning to dissolve and flesh separating from skeleton; most of the exoskeleton dissolved or missing; items may be identifiable only to family
4	Almost complete digestion; very little left except eye lenses, otoliths or major bones and pieces of flesh; items may be identifiable only to phylum by colour and texture of flesh

Identification of stomach contents to species or genus was often possible on well-digested items (stages 3–4) because parts that do not deteriorate rapidly, such as otoliths and beaks of squid, could be specifically identified. As some animals were very occasional components of the diet, they were not identified below family level.

The percentage of the total prey weight and the frequency of occurrence in stomachs containing food were calculated for each prey category, in each area per cruise. The average stomach fullness (g/kg) per tow was calculated by :

$$\frac{\text{weight of prey items in stomachs examined per tow (g)}}{\text{weight of all fish examined per tow (kg)}}$$

Results

Details of all tows are given in Appendix 3.

Acoustic

Bathymetric surveys

A chart of the Sandy Cape ground was constructed from 822 depth soundings taken on the first three cruises (Fig. 3). The St Patricks Head chart was constructed from 541 depth soundings taken on the last four cruises (Fig. 4). No fish were found on the Cape Grim ground, so detailed bathymetry was not attempted.

Fish surveys

Orange roughy at the Sandy Cape ground had been caught by commercial fishermen in the 1986/7 summer over a steep southeast slope dropping into a 200 m deep canyon (Fig. 5). The aggregations reported were not found during our surveys; our catch rates were low and declined over the survey period. Better catches were found to the west, further down the slope in deeper water. Surveys detected only four possible fish schools, none of which could be confirmed as orange roughy.

Features closely resembling characteristic fish marks were observed during surveys of the St Patricks Head ground, but trawling and routine surveying showed that they were rocky outcrops (Fig. 6).

Biological

Length frequency

The major mode for the males from the west coast was 35 cm and from the east coast 36 cm, while for females from both areas it was 38 cm (Fig. 7). The frequency of adult females was nearly twice as high on the west coast as on the east coast, while the frequency of adult males was similar on both coasts. Juveniles were more frequent on the east coast, presenting a stronger pulse in the mid-20 cm range, than on the west coast.

The two smallest specimens of orange roughy to date (26 and 28 mm) were caught in a pelagic tow on the St Patricks Head ground, fishing at about 10 m off the bottom (bottom depth 400–1000 m).

Overall, the ratio of males to females was equal, but the ratios were different within each area (Table 3).

Table 3. Sex ratios

Sex	East	West
female	0.43	0.56
male	0.57	0.44

Length–frequency distributions for each cruise (month) are given in Appendix 4. These data represent all fish measured. Two catches were subsampled, but the data were not scaled up to account for this.

The proportion of adults on the east coast increased in July and August but on the west coast the proportion declined. The increase on the east coast was largely due to an increase in the proportion of adult males from about 35% of the total number caught in May and June to about 58.5% in July and August. The proportion of adult females declined by nearly half from an average of about 36% to 20% in June. The proportion of juveniles declined from 26% (May) and 42% (June) to an average of 4.5% in July and August. On the west coast, the proportion of adult males declined from about 51% in April and May to about 23% by August. On the other hand, the proportion of adult females increased in August from an average of 46% to 56%. The proportions of juveniles caught increased from below 10% to about 20% by July and August.

Length frequencies from all cruises were combined and then stratified by area (east or west) and by 50 m depth intervals (Appendix 5). On both coasts, the greatest number of fish (adults and juveniles) were from 900–1000 m depth. The 1050–1100 m depth on the east coast had the highest proportion of juveniles, where they were in roughly equal numbers to adults. On the west coast, the proportions of juveniles in the depth ranges below 950 m were greater than in the shallower ranges.

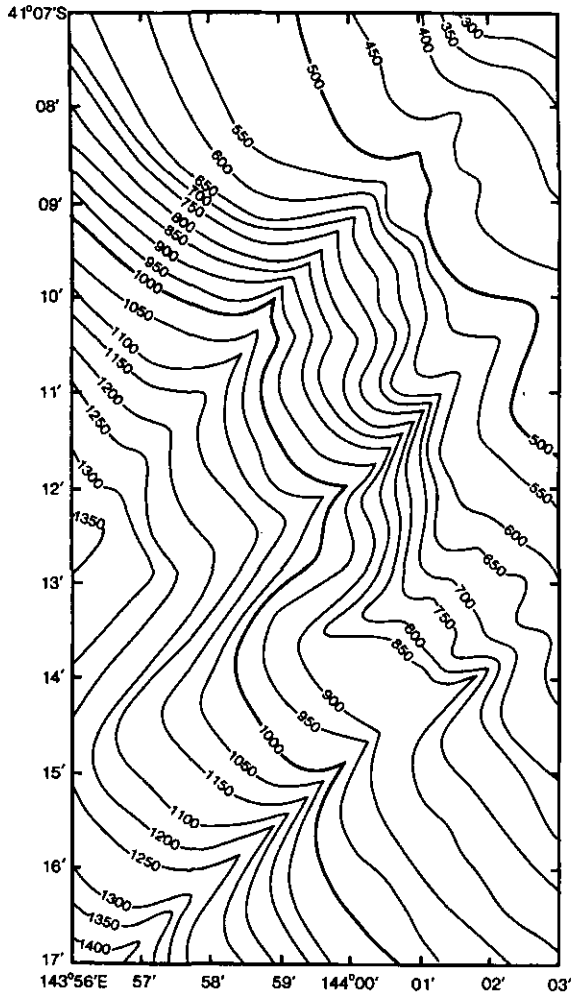

Fig. 3. Bathymetric chart of Sandy Cape.

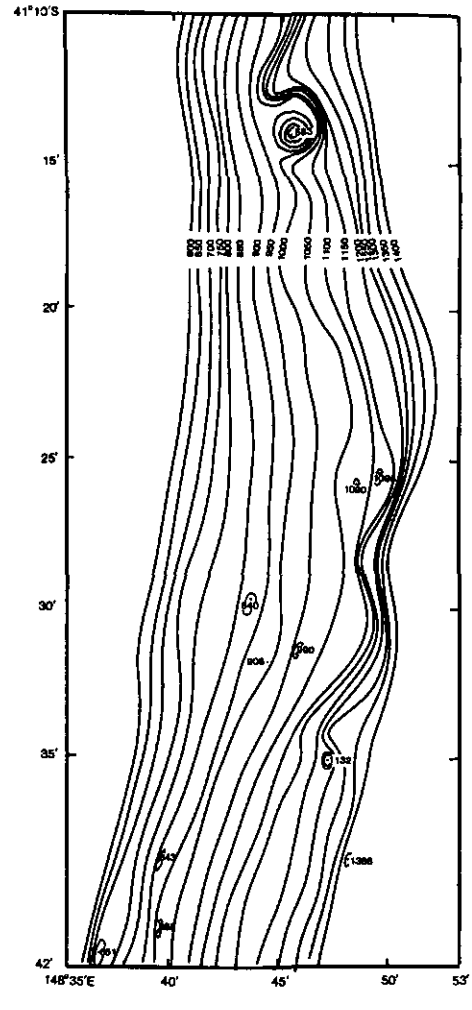

Fig. 4. Bathymetric chart of St Patricks Head.

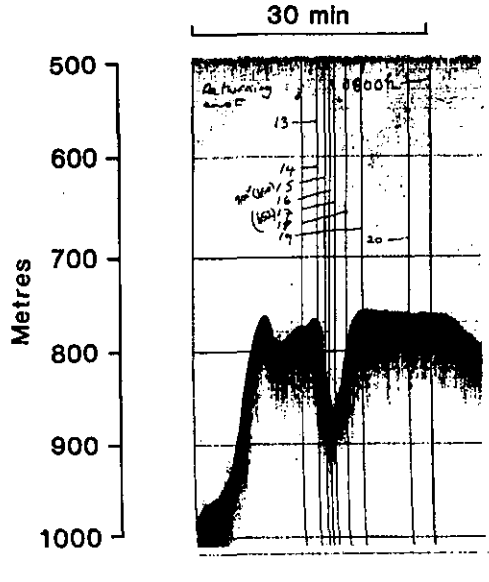

Fig. 5. Echogram of the Sandy Cape ground, which was the site of a large aggregation of orange roughy during the summer of 1986/7.

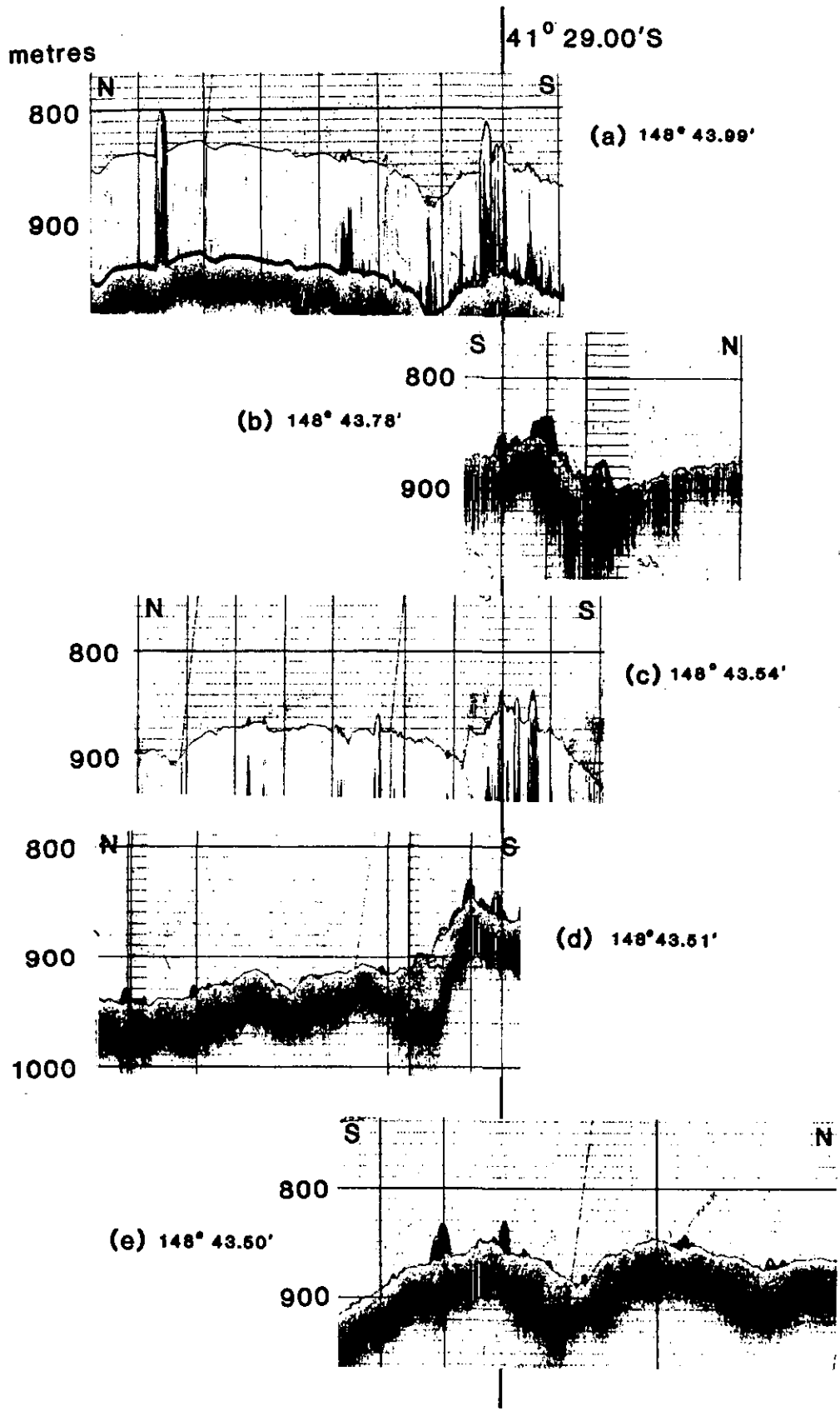

Fig. 6. Echograms of north–south transects on the St Patricks Head ground showing the consistent position of features at about 41 29.00'S. Each trace represents a transect along a longitude, moving from east to west, between 148 43.99' E and 148 43.50'E, during (a) and (c) April, (d) July and (b) and (e) August.

Length–weight relationships

The model fitted to the length–weight data was:

ln(Weight) = a + b ln(Length).

The curves for males and females were compared for each cruise using the "extra sum-of-squares" principle (Appendix 6). The slopes of the regressions for males and females were not significantly different but the values of the intercepts were (Table 4).

Table 4. Length–weight regression of all male and female orange roughy.

Sex	*n*	Equation	R^2
males	943	$W = 0.0782 \times L^{2.75}$	0·981
females	858	$W = 0.0802 \times L^{2.75}$	0·981

Overall, the slope of the west coast regression was significantly higher than that of the east ($F_{(1, 1803)} = 32.35$; $p < 0.01$) but the intercept was lower (Table 5).

Table 5. Length–weight relationship for orange roughy (sexes combined) off east and west Tasmania

Area	*n*	Equation	R^2
east	1233	W = 0.0840 x L 2.73	0.981
west	568	W = 0.0504 x L 2.88	0.981

Reproductive biology

The length at first maturity (i.e. the length at which 50% or more of fish in the length class were mature) was 32 cm for females and about 30 cm for males (Fig. 8). In the monthly plots of GSI against length, the lengths at which maturing fish (≥ stage 3 for females and ≥ stage 2 for males) exhibited an increase in GSI value corresponded well to these lengths (Appendix 7).

The mean GSIs for females ≥ 30 cm SL on the east coast were highest in July and had declined significantly by August (Fig. 9a), while the mean for females on the west coast peaked in June. The GSIs for males ≥ 28 cm SL on the east coast gradually declined from April, but on the west coast the GSIs declined sharply from May (Fig. 9b).

The results from macroscopic staging reflected the changes seen in the GSI data for east coast males and females (Figs 10 and 11). A high percentage of maturing males (95% ≥ stage 2) and females (84% ≥ stage 3) were caught off the east coast in July, but by August around 80% of males and females were spent. However, on the west coast spawning was not evident; by August only half of the females were spent and males were mostly immature. This situation on the west coast could have arisen if fish from the Sandy Cape ground moved out of the area to spawn or minor spawning had occurred off west Tasmania.

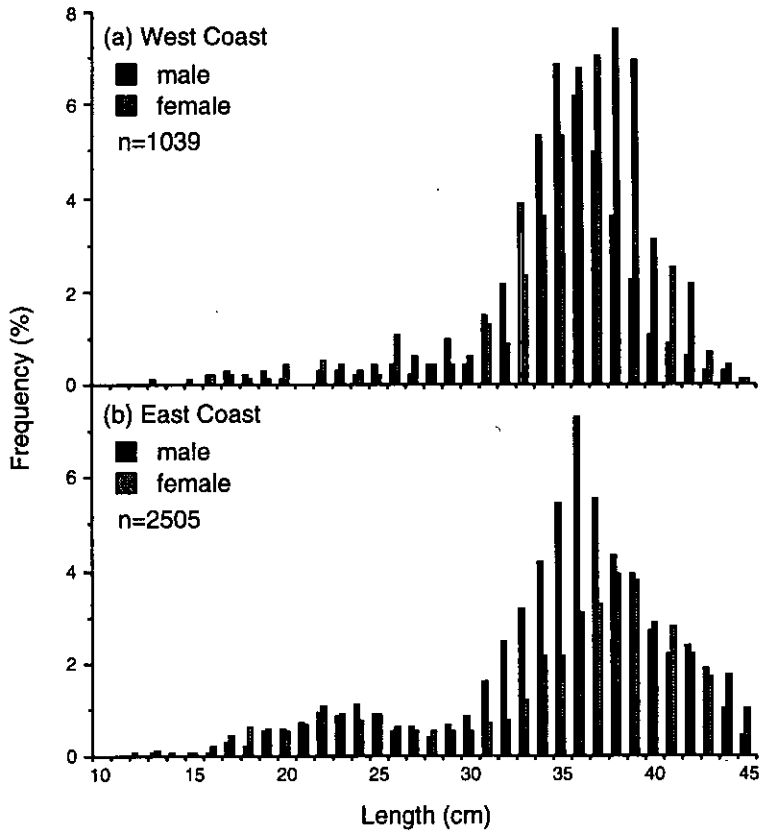

Fig. 7. Overall length frequency of orange roughy caught during the 1987 study off the (a) west coast (Sandy Cape) and (b) east coast (St Patricks Head) of Tasmania.

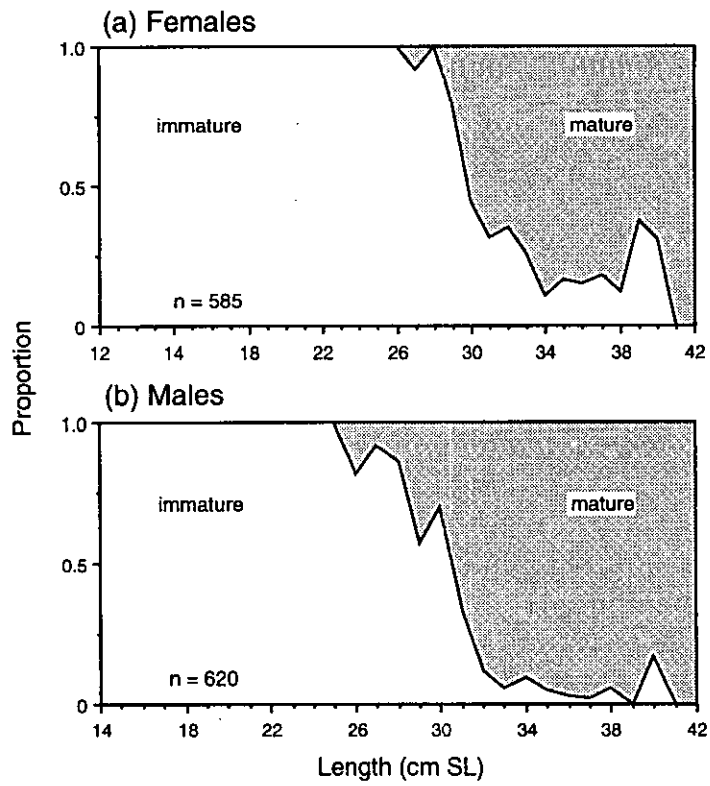

Fig. 8. Proportion of immature and mature fish per length class from April through June 1987, indicating length at maturity for (a) females and (b) males.

Fecundity

Fecundity estimates were made from the ovaries of 96 maturing (stage 3) females (46 from the east coast and 50 from the west coast of Tasmania). The size-frequency distribution of oocyte diameters (n = 500) from a representative subsample of one ovary is shown in Fig. 12. The larger vitellogenic (yolky) oocyte class (diameter 1.0 to 1.3 mm) is clearly distinguishable from the smaller previtellogenic oocyte class (diameter <0.5 mm).

The mean total fecundities (number of eggs per fish) of the east coast fish (37 650 ± 2193 (SE)) and the west coast fish (42 425 ± 1514 (SE)) were not significantly different. The range of fecundities from the east coast was 10 422 to 72 209 eggs per fish, and from the west coast 19 406 to 68 192 eggs per fish.

Fecundity and weight in west coast orange roughy were poorly correlated (r = 0.296, p = 0.048), and fecundity and length showed no correlation. In contrast, both of these relationships were highly correlated in east coast orange roughy (r = 0.564 for length, r = 0.578 for weight) (Figs 13 and 14).

These relationships can be expressed as:

fecundity = 2801(length) – 66 602 (SE of slope ± 168)

fecundity = 21 959 (body weight) – 979 (SE of slope ± 4677).

Relative fecundity (number of eggs per kg body weight) was calculated for each fish. No correlation was found between relative fecundity and body weight. However, the relative fecundities of fish from the two sites were significantly different (p = 0.003). East coast fish had a lower average relative fecundity of 21 354 ± 996 eggs per kg body weight than those from the west coast (25 849 ± 1062 eggs per kg body weight).

Dietary analyses

(a) Adults

In both areas, the main part of the diet of adult orange roughy was fish (Tables 6 and 7). In the diet of east coast roughy, fish comprised between 55-95% by weight: in May and June the fish contribution peaked at over 94% by weight (%W). The frequency of occurrence of fish was lowest in July and August (48.7% and 50.0%). On the west coast, the fish contribution to roughy diet was lower (45-64% by weight) than on the east. Also in contrast to the east coast, the frequency of occurrence of fish was highest during July and August (Table 7). The most commonly occurring prey fish were *Chauliodus sloani* and *Gymnoscopelus* sp.

In east coast roughy diets, the contribution of crustaceans was lowest in May and June (3% and 4% by weight); in west coast diets it was lowest in July (13% by weight). On both coasts, the frequency of occurrence of crustaceans followed a similar trend to the proportions by weight. Seasonal trends in prey consumption were apparent on both coasts, the occurrence of *Sergestes* spp. decreased. In diets of the west coast fish, the dominant crustaeceans were *Acanthephyra* spp.

In the diet of both east and west coast fish, cephalopods were highest by weight in July.

Although samples were small, the data indicated that on the east coast, the proportion of roughy stomachs with food present decreased from an average of 27% in May and June to an average of 12% in July and August (Table 6).

The average stomach fullness of the east coast fish was very low in July and August, but in the west coast fish it increased from June through August.

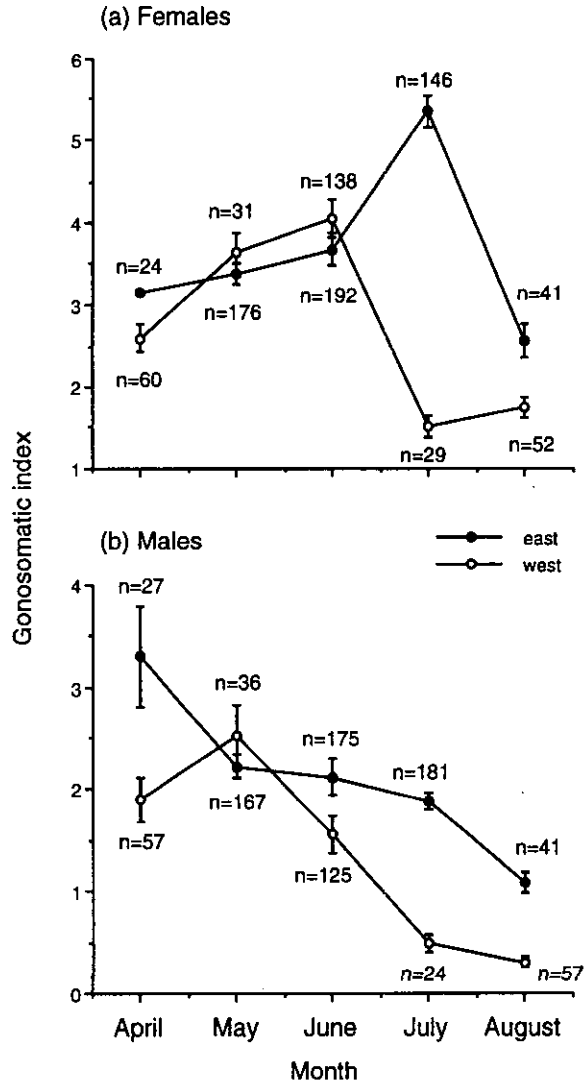

Fig. 9. Mean gonosomatic indices (± S. E.) of (a) female and (b) male orange roughy from April to August 1987.

(b) Juveniles

Diets of juveniles off the east coast were dominated by crustaceans (Table 8) except in May and June, when fish comprised slightly more than half of the diet by weight. Fishes did not occur in any other month. As in adult diets, *Sergestes* spp were the dominant crustaceans.

The numbers of west coast juveniles examined were generally too low for trends to be evident (Table 9). However fish dominated the diet in April, June and August. In April gonostomatids were dominant; in June and August *Chauliodus sloani* was dominant.

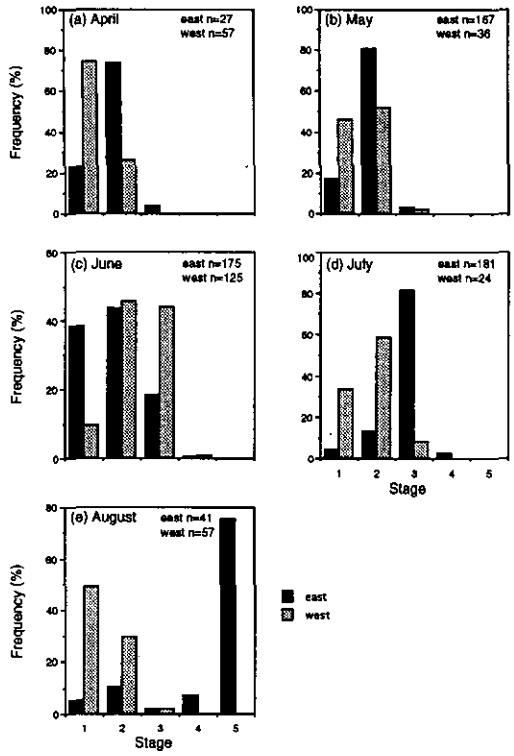

Fig. 10. Gonad stages of male orange roughy caught from (a) April to (e) August.

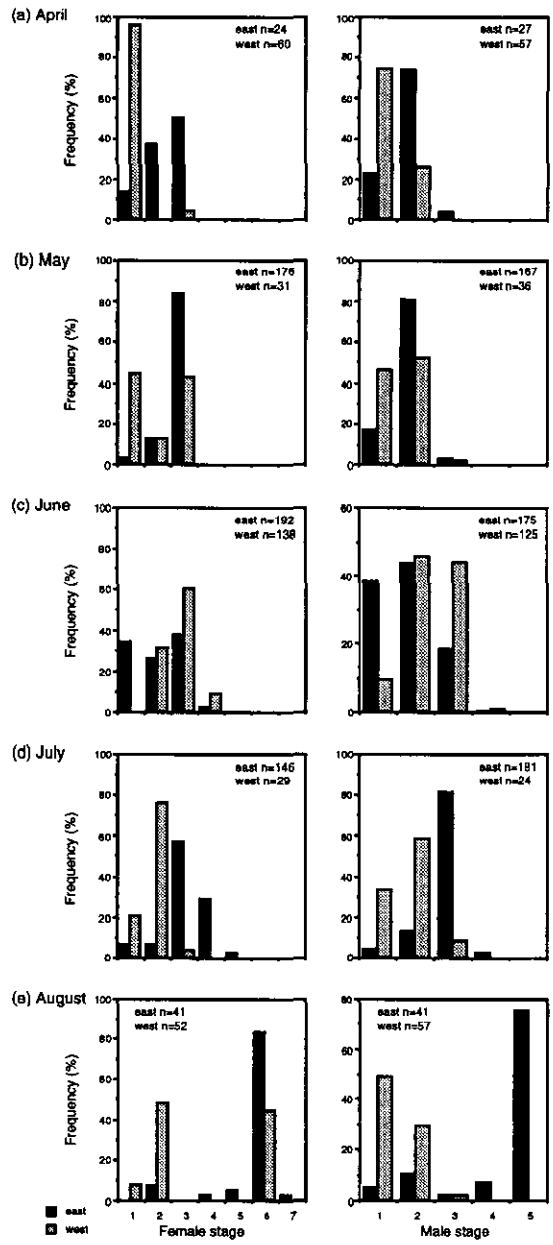

Fig. 11. Gonad stages of female orange roughy caught from (a) April to (e) August.

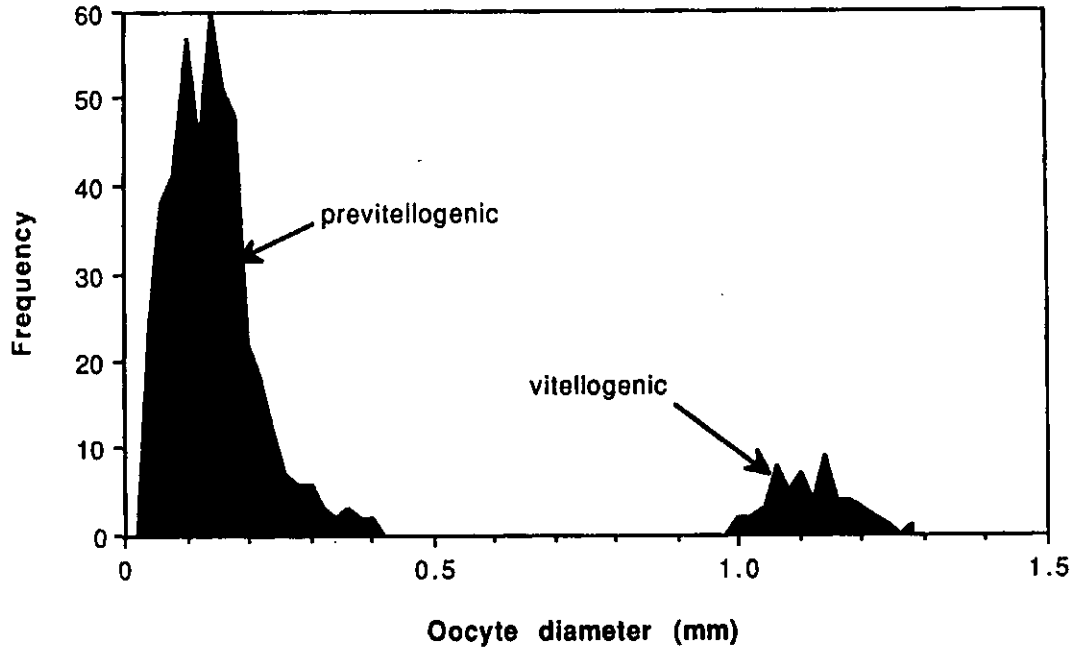

Fig. 12. Size–frequency distribution of oocytes.

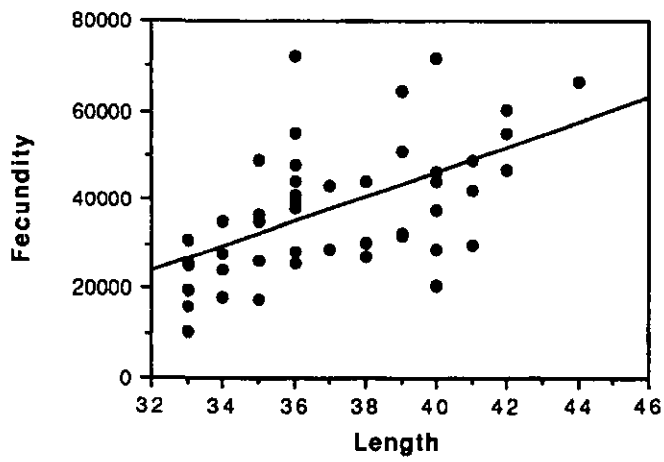

Fig. 13. Fecundity (no. eggs per fish) and length (SL, cm) relationship of female orange roughy caught on the east coast.

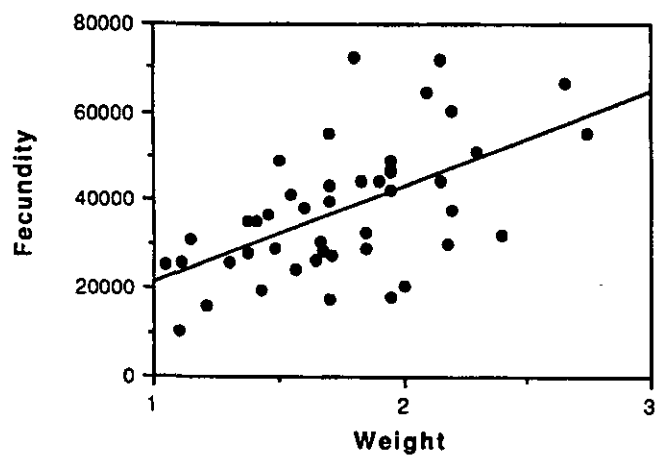

Fig. 14. Fecundity (no. eggs per fish) and weight (kg) relationship of female orange roughy caught on the east coast.

Table 6. Diets of adult orange roughy (females ≥30 cm; males ≥28 cm) off the east coast of Tasmania. Prey is expressed as proportion of diet by weight (%W) and by frequency of occurrence (%F).

Prey species	April		May		June		July		August	
	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F
Polychaeta	**0**	**0**	**<0.1**	**2.0**	**0**	**0**	**0**	**0**	**0**	**0**
Gnathophausia sp.	14.1	20.0	1.8	6.0	0.8	2.9	2.9	4.9	0	0
Unidentified mysids	0	0	0	0	0.4	8.6	1.5	4.9	8.1	40.0
Amphipoda	0	0	0.1	6.0	0.4	8.6	1.4	9.8	9.8	20.0
Gennadas gilchristi	0	0	0	0	0	0	0.6	2.4	0	0
Sergestes (Sergestes) arcticus	1.1	20.0	0.2	10.0	0.3	5.7	1.3	4.9	0	0
Pasiphae sp.	10.9	20.0	0	0	0	0	0.8	2.4	1.7	10.0
Acanthephyra pelagica	0	0	0	0	0	0	2.4	4.9	0	0
A. quadrispinosa	18.5	20.0	0	0	0	0	0	0	0	0
Oplophorus novaezealandiae	0	0	0	0	0.7	2.9	0	0	0	0
Unidentified caridae	0	0	0	0	1.0	5.7	0	0	0	0
Unidentified crustacea	0	0	0.5	18.0	0.2	2.9	1.4	9.8	0	0
Total crustacea	**44.6**	**80.0**	**2.6**	**40.0**	**3.8**	**37.3**	**12.3**	**44.0**	**19.6**	**70.0**
Gonostomatidae	0	0	2.2	2.0	0	0	1.2	2.4	0	0
Chauliodus sloani	0	0	6.1	4.0	44.9	22.9	0	0	44.3	10.0
Gymnoscopelus sp.	0	0	74.6	22.0	0	0	0	0	0	0
Lampanyctus spp.	0	0	1.0	2.0	19.6	11.4	1.2	2.4	0	0
Unidentified myctophidae	0	0	0.5	2.0	3.0	5.7	0	0	0	0
Lestidiops pacifica	0	0	0	0	5.7	2.9	0	0	0	0
Lepidorhynchus denticulatus	0	0	0	0	0	0	24.0	4.9	0	0
Coryphaenoides spp.	0	0	0.5	2.0	0	0	0	0	0	0
Unidentified fish	55.4	60.0	9.9	32.0	21.0	28.6	52.1	39.0	36.2	40.0
Total fish	**55.4**	**60.0**	**94.8**	**66.0**	**94.2**	**71.5**	**78.5**	**48.7**	**80.5**	**50.0**
Cephalopoda	**0**	**0**	**2.5**	**6.0**	**2.2**	**5.7**	**9.2**	**4.9**	**0**	**0**
Total weight of prey (g)	**27.6**		**1644.2**		**558.2**		**323.2**		**117.5**	
No. stomachs examined	8		193		125		310		91	
No. stomachs with food (%)	5 (62.5)		50 (25.9)		35 (28.0)		41 (13.2)		10 (11.0)	
Mean av. stomach fullness per tow (g/kg)	2.27		6.37 ± 4.42		2.56 ± 1.82		0.66 ± 0.92		0.62 ± 0.93	
No. tows	1		9		8		9		5	

Table 7. Diets of adult orange roughy (females ≥ 30 cm; males ≥ 28 cm) off the west coast of Tasmania. Prey is expressed as proportion of diet by weight (%W) and by frequency of occurrence (%F).

Prey species	April		May		June		July		August	
	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F
Polychaeta	**0.1**	**1.6**	**0**	**0**	**1.1**	**1.5**	**0**	**0**	**0**	**0**
Gnathophausia sp.	0	0	1.7	2.7	1.2	1.5	0	0	2.5	2.9
Unidentified mysids	1.3	19.3	0	0	0	0	0	0	0	0
Amphipoda	0	0	0.2	5.4	0.7	7.5	0.2	6.1	0.3	2.9
Euphausiidae	0	0	0.1	2.7	0	0	0	0	0	0
Plesiopenaeus edwardsianus	0	0	2.7	2.7	0	0	0	0	0	0
Gennadas gilchristi	0	0	0.6	2.7	1.6	10.4	0	0	0	0
Sergestes (Sergestes) arcticus	5.8	38.7	3.3	40.5	3.1	16.4	0.2	3.0	0.2	2.9
Unidentified penaiedae	0.5	1.6	0	0	0.1	1.5	0	0	0	0
Pasiphae sp.	0	0	0	0	0	0	7.2	21.2	1.4	2.9
Acanthephyra pelagica	5.3	8.1	1.1	2.7	0	0	5.1	21.2	18.1	40.0
A. quadrispinosa	17.5	16.1	30.4	35.1	15.7	32.8	0	0	0	0
Oplophorus novaezealandiae	0	0	0	0	1.1	3.0	0	0	0	0
Unidentified caridae	1.7	9.7	3.4	2.7	2.1	3.0	0	0	0	0
Unidentified crustacea	0.6	9.7	8.2	13.5	2.0	10.4	0	0	2.0	14.3
Total Crustacea	**32.7**	**103.2**	**51.7**	**110.7**	**27.6**	**86.5**	**12.7**	**51.5**	**24.5**	**65.9**
Gonostomatidae	2.9	1.6	0.6	5.4	0	0	5.5	6.1	0	0
Chauliodus sloani	0	0	0	0	20.2	9.0	22.4	21.2	28.7	11.4
Symbolophorus barnardi	8.9	1.6	0	0	0	0	0	0	0	0
Lampanyctus spp.	6.9	1.6	0	0	2.8	3.0	0	0	0	0
Lampichthys spp.	0	0	0	0	1.5	1.5	0	0	0	0
Unidentified myctophidae	0	0	0	0	0.9	1.5	2.6	6.1	1.7	5.7
Lepidorhynchus denticulatus	13.3	1.6	0	0	0	0	0	0	5.4	2.9
Coryphaenoides spp.	3.3	1.6	0	0	0	0	0	0	0	0
Epigonus lenimen	0	0	0	0	0	0	10.7	3.0	0	0
Unidentified fish	27.4	17.7	43.1	27.0	37.0	19.4	16.8	27.3	28.2	34.3
Total fish	**62.7**	**25.7**	**43.7**	**32.4**	**62.4**	**34.4**	**58.0**	**63.7**	**64.0**	**54.3**
Cephalopoda	**4.4**	**11.3**	**4.8**	**5.4**	**8.8**	**9.0**	**29.3**	**33.3**	**11.4**	**11.4**
Total weight of prey (g)	**359.8**		**252.7**		**894.4**		**605.9**		**699.5**	
No. stomachs examined	99		64		109		40		54	
No. stomachs with food (%)	62 (62.6)		37 (57.8)		67 (61.5)		33 (82.5)		35 (64.8)	
Mean av. stomach fullness per tow (g/kg)	2.69 ± 1.61		2.41 ± 0.33		4.95 ± 4.01		6.96 ± 4.29		7.06 ± 5.82	
No. of tows	8		3		6		3		3	

Table 8. Diets of juvenile orange roughy (females <30 cm; males <28 cm) off the east coast of Tasmania. Prey is expressed as proportion of diet by weight (%W) and by frequency of occurrence (%F).

Prey species	April		May		June		July		August	
	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F
Copepoda	0.1	3.1	0	0	0.1	2.3	21.9	16.7	0	0
Gnathophausia sp.	0	0	10.6	3.6	0	0	0	0	0	0
Unidentified mysids	0.6	6.3	8.7	7.3	10.8	27.9	0	0	0	0
Amphipoda	0	0	0.5	3.6	0.3	2.3	0	0	0	0
Plesiopenaeus edwardsianus	10.1	3.1	0	0	0	0	0	0	0	0
Sergestes (Sergestes) arcticus	2.7	18.8	5.2	21.8	9.5	16.3	0	0	0	0
Pasiphae sp.	12.6	3.1	4.2	1.8	3.3	2.3	0	0	0	0
Acanthephyra pelagica	7.0	3.1	0	0	0	0	0	0	85.5	50.0
A. quadrispinosus	2.0	3.1	0	0	0.4	2.3	0	0	0	0
Pontophilus sp.	0	0	0	0	1.5	2.3	0	0	0	0
Unidentified caridae	11.1	9.4	0	0	9.9	4.7	0	0	0	0
Unidentified crustacea	26.1	50.0	12.1	50.9	7.3	18.6	78.1	66.7	14.5	50.0
Total Crustacea	**72.3**	**100.0**	**41.3**	**89.0**	**43.1**	**79.0**	**100.0**	**83.4**	**100.0**	**100.0**
Gymnoscopelus sp.	0	0	42.9	3.6	0	0	0	0	0	0
Lampanyctus spp.	0	0	0	0	3.1	2.4	0	0	0	0
Unidentified myctophidae	0	0	0	0	0.9	2.3	0	0	0	0
Hemiramphis sp.	0	0	0	0	16.6	2.3	0	0	0	0
Unidentified fish	0	0	15.6	14.5	35.1	23.3	0	0	0	0
Total Fish	**0**	**0**	**58.5**	**18.1**	**55.7**	**30.3**	**0**	**0**	**0**	**0**
Cephalopoda	**27.7**	**3.1**	**0.3**	**1.8**	**1.4**	**55.8**	**0**	**0**	**0**	**0**
Total weight of prey	**7.12**		**192.2**		**108.7**		**3.2**		**11.7**	
No. stomachs examined	43		90		111		20		7	
No. stomachs with food (%)	32 (74.4)		55 (61.1)		43 (38.7)		6 (30.0)		2 (28.6)	
Mean average stomach fullness per tow (g/kg)	3.63 ± 2.13		3.16 ± 4.50		2.23 ± 1.15		0.17 ± 0.34		2.09 ± 4.18	
No. of tows	3		8		8		6		4	

Table 9. Diets of juvenile orange roughy (females <30 cm; males <28 cm) off the west coast of Tasmania. Prey is expressed as proportion of diet by weight (%W) and by frequency of occurrence (%F).

Prey species	**April**		**May**		**June**		**July**		**August**	
	%W	**%F**	**%W**	**%F**	**%W**	**%F**	**%W**	**%F**	**%W**	**%F**
Unidentified mysids	4.5	37.5	0	0	0	0	0	0	0	0
Gennadas gilchristi	0	0	0	0	1.0	12.5	0	0	0	0
Sergestes (Sergestes) arcticus	0	0	0	0	0	0	100.0	100.0	0	0
Pasiphae sp.	0	0	0	0	0	0	0	0	5.1	11.1
Acanthephyra pelagica	0.6	12.5	0	0	0	0	0	0	19.5	27.8
A. quadrispinosa	0	0	100.0	100.0	19.2	25.0	0	0	0	0
Unidentified crustacea	1.8	25.0	0	0	0.5	12.5	0	0	8.7	38.9
Total crustacea	**6.9**	**75.0**	**100.0**	**100.0**	**20.7**	**50.0**	**100.0**	**100.0**	**33.3**	**77.8**
Gonostomatidae	65.3	12.5	0	0	0	0	0	0	0	0
Chauliodus sloani	0	0	0	0	69.6	25.0	0	0	48.9	11.1
Unidentified myctophidae	0	0	0	0	0	0	0	0	6.3	5.6
Unidentified fish	27.7	62.5	0	0	3.1	37.5	0	0	11.5	11.1
Total fish	**93.0**	**85.0**	**0**	**0**	**72.7**	**62.5**	**0**	**0**	**66.7**	**27.8**
Cephalopoda	**0**	**0**	**0**	**0**	**6.6**	**12.5**	**0**	**0**	**0**	**0**
Total weight of prey	**50.5**		**3.0**		**121.1**		**5.3**		**126.8**	
No. stomachs examined	14		1		10		12		30	
No. stomachs with food (%)	8 (57.1)		1 (100.0)		8 (80.0)		3 (25.0)		18 (60.0)	
Mean average stomach fullness per tow (g/kg)	25.43 ± 45.97		3.90		19.92 ± 23.95		0.59 ± 0.83		6.49 ± 5.15	
No. of tows	4		1		5		2		3	

Discussion

In the depths where orange roughy are found, the limitations of our acoustic equipment in detecting fish schools were evident from the results of the bathymetric/fish surveys. Comparison of our sounder traces with those of typical New Zealand marks (Tracey *et al.*, 1987; Do *et al.*, 1987; Clark and Tracey, 1988), and the considerably greater catch rates from the New Zealand fish schools indicate the fish abundances were much less in our survey areas, and were therefore less likely to be detected. However, on the two occasions when relatively large catches were taken the echograms showed nothing.

In both the east and west populations, the length-frequency distribution of orange roughy was bimodal. This pattern is clearly seen in data previously collected in Tasmanian waters (Evans and Wilson, 1987) and the modes correspond well with our data. The 1982 Chatham Rise survey produced very similar patterns, although the first mode was markedly reduced when the results were weighted to account for subsampling (Robertson *et al.*, 1984). The west coast fishery of New Zealand's South Island produced length-frequency distributions with a large mode in the adult sizes during 1983 and 1985 (Armstrong and Tracey, 1986; 1987), a result of targeting large aggregations of adult fish. Length–frequency distributions from the Challenger Plateau surveys in 1986 and 1987 were also similar (Clark and Tracey, 1988; Tracey *et al.*, 1987).

The relative fecundity of orange roughy caught on the east coast of Tasmania (21 354 eggs per kg body weight) is close to specimens caught from the east coast of South Island of New Zealand (22 000; Pankhurst and Conroy, 1987). Yet in Tasmania the relative fecundity of east coast fish was significantly lower than west coast fish. This difference could reflect differences in age, diet or environmental conditions.

Reports of absolute fecundities of specimens in the same ranges of size and body weight differ. New Zealand specimens are reported to have between 26 000 and 90 000 eggs per fish (Pankhurst and Conroy, 1987); the Tasmanian specimens we measured had between 10 000 and 72 000 eggs per fish; and specimens caught off the Western Australian ridge in 1979 had between 19 400 and 203 400 eggs per fish (Kotlyar and Lisovenko, 1982).

The greater number of juveniles on the east coast than on the west coast suggests that the east may be an important spawning or nursery area. Other findings support this possibility:

- the condition of gonads of fish caught during July were advanced and the proportion of spent fish caught in August was high
- the two smallest specimens of *H. atlanticus* (26 mm and 28 mm SL) were collected off the east coast in a pelagic tow 10 m off the bottom
- feeding activity in the east coast population declined during July and August; in New Zealand populations this happens during spawning (e.g. 70% empty stomachs off the Chatham Rise in 1982; Robertson *et al.*, 1984).

Indeed, a spawning aggregation was found off the east coast at St Helens in winter 1989. On the west coast, there has been no evidence of major spawning activity from this study or previous work (Evans and Wilson, 1987); it is improbable that orange roughy would travel the distance from western Tasmania to the east coast spawning ground within the contracted spawning period of about a month. However, a small spawning event occurred in the Great Australian Bight in 1990 (Newton *et al.*, 1990), which suggests other minor or major spawning aggregations may exist. Until commercial activity focuses on the more sparsely explored rough ground, such as off southern Tasmania, they have yet to be discovered.

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References

Armstrong, J. H. and Tracey, D. M. (1986). History of the west coast South Island orange roughy fishery. *New Zealand Fisheries Research Division Internal Report* **42**, 68 pp.

Armstrong, J. H. and Tracey. D. M. (1987). *Arrow* orange roughy charter-for-quota cruise, west coast South Island, July–August 1986. *New Zealand Fisheries Research Division Internal Report* **58**, 31 pp.

Bureau of Agricultural Economics (1987). Fisheries Products. *Quarterly Review of the Rural Economy* **9**, pp. 158–159.

Bulman, C. and Dews, G. (in prep). A report on the experimental and exploratory fishing investigations around Tasmania, April–July, 1986. *CSIRO Marine Laboratories Report.*

Clark, M. R. and Tracey, D. M. (1988). Report of an orange roughy trawl survey on Challenger Plateau, June–July 1987. *New Zealand Fisheries Research Centre Internal Report* **86**, 87 pp.

Do, M. A., Coombs, R.F., Surti, A.M. and Hopkins, M. (1987). A deepwater acoustic survey of the population of orange roughy (*Hoplostethus atlanticus*) on the northern Chatham Rise, New Zealand. *New Zealand Fisheries Research Division Internal Report* **63**, 44 pp.

Evans, K. and Wilson, M. A. (1987). A summary of orange roughy biological information, 1981–1985. Report to Demersal and Pelagic Fisheries Research Group **24** from Department of Sea Fisheries, Hobart, 57 pp.

Evans, K.R. and Pullen. G. (1986). Great Australian Bight trawl survey results disappointing. *Australian Fisheries* **45**(7), 2–7.

Gorman, T. B. and Graham, K. J. (1984). *Kapala* finds orange roughy, oreos off NSW. *Australian Fisheries* **43**(1), 20–24.

Kenchington, T. J. and Dews, G. (1986). Report on an exploratory fishing cruise to the South Tasman Rise. Report to Demersal and Pelagic Fisheries Research Group, Queenscliff, 1986 from CSIRO Division of Fisheries Research.

Kotlyar, A.N. and Lisovenko, L.A. (1982). On the reproduction of the Atlantic bighead (*Hoplostethus atlanticus* Collett) and the Mediterranean bighead (*H. mediterraneus* Cuvier) (Trachichthyidae, Beryciformes) in the Indian Ocean, pp. 55-61 in: *Unsufficiently (sic) Studied Fishes of the Open Ocean. Academy of Sciences of the USSR,* Moscow.

Newton, G, Turner, D and Riley, S (1990). Spawning roughy in the GAB—a new find. *Australian Fisheries* **49** (10), 24–26.

Pankhurst, N.W. and Conroy, A.M. (1987). Size–fecundity relationships in orange roughy, *Hoplostethus atlanticus. New Zealand Journal of Marine and Freshwater Research* **21**, 295–300.

Pankhurst, N W., McMillan, P. J. and Tracey, D. M. (1987). Seasonal reproductive cycles in three commercially exploited fishes from the slope waters off New Zealand. *Journal of Fish Biology* **30**, 193–211.

Pullen, G., Evans, K. R., Cartwright, I. and Boyes, J. (1986). Target trawl survey on the Cascade Plateau. *Australian Fisheries* **45**(6), 2–7.

Robertson, D. A., Grimes, P. J. and McMillan, P. J. (1984). Orange roughy on the Chatham Rise; results of a trawl survey, August–September 1982. *New Zealand Fisheries Research Division Occasional Publication* **46**, 27 pp.

Sainsbury, K. J. and Whitelaw, A. W. (in press). Daily food consumption of the lizardfish, *Saurida undosquamosus*, on the north-west shelf of Australia. *Journal of Fish Biology.*

Simpson, A.C. (1951). The fecundity of the plaice. *Fishery Investigations, London, Series 2*, **17**(5), 27 pp.

Tracey, D. M., Armstrong, J. H. and Doonan, I. J. (1987). *Arrow* orange roughy charter-for-quota cruise, Challenger Plateau, July 1986. *New Zealand Fisheries Research Division Internal Report* **65**, 41 pp.

Wilson, M. A. (1982a). *Challenger* reveals potentially important roughy resource off Tasmania. *Australian Fisheries* **41**(5), 2–3.

Wilson M. A. (1982b). Tasmanian survey finds spawning orange roughy. *Australian Fisheries* **41**(11), 2–5.

Wilson, M A. and Evans, K. R. (1983). Bight survey finds orange roughy few and far between. *Australian Fisheries* **42**(11), 14–20.

Wilson, M. A. and Evans, K. R. (1984). Good catches of orange roughy in spring survey off Tasmania. *Australian Fisheries* **43**(8), 30–33.

Wilson, M. A., Evans, K. R. and Cameron, M. R. (1984). *A ground survey of the upper and mid-continental slope of southern Australia.* Tasmanian Fisheries Development Authority, Hobart. 275 pp.

Williams, M. (1987). Biological research on orange roughy steps up. *Australian Fisheries* **46**(6), 2–5.

Appendix 1.

Net specifications

Engel high-lift bottom trawl

Headline:	35.5 m
Footrope:	50 m 16 m chain on each wing, bosom with rubber bobbins
Wings:	rigged flying; mesh only attached to the 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:	approx. 19 m
Net opening:	approx. 6 m

Frank and Bryce bottom trawl

Headline:	26 m
Footrope:	32 m; 320 meshes at the mouth
Mesh size:	15 cm at mouth
Codend mesh size:	liner mesh 40 mm
Bridles:	50 m

Engel 152 pelagic trawl

Dimensions:	152 meshes and 1800 mm circumference stretched mesh
Headline:	49.3 m
Footrope:	58.3 m
Bridles:	4 x 50 m wire
Length:	approx. 114.5 m
Weights:	250 kg suppression weights each side
Codend mesh size:	main liner 40 mm 210/78 double twine extra liner 9 mm 210/9 knotted twine cover 12 mm (stretched) 6 mm diameter heavy twine

Engel 308 midwater trawl

Dimensions:	308 meshes x 800 mm at mouth
Headline:	42 m
Footrope:	42 m
Wings:	4 x 50 m
Length:	approx 100 m
Bridles:	50 m
Codend mesh size:	80 mm main liner 10 mm extra liner

Appendix 2.

Staging criteria from Pankhurst *et al.* (1987).

Stage	Gonad conditions
Females	
1	Immature or resting, ovary clear or pink. No oocytes visible; GSI < 2.0
2	Ovary pink or clear, small oocytes visible; GSI 2.0–3.0 (endogenous vitellogenesis)
3	Orange yolk-filled oocytes present; GSI 3.0–8.0 (exogenous vitellogenesis)
4	Hyaline oocytes present; GSI 8.0–9.0 (final maturation)
5	Ovulated eggs flow freely with light pressure on abdomen; GSI 8.0–10.0
6	Spent; ovary flaccid and bloody; residual eggs sometimes in oviduct
7	Atretic; ovary black or brown; degenerating or resorbing eggs present
Males	
1	Immature or resting; testes small and threadlike; GSI < 3.0
2	Maturing; testes larger but no milk expressible; GSI 0.5–3.0
3	Spermiated; viscous milk expressible ; GSI > 3.0
4	Spermiated; hydrated, freely flowing milk; GSI > 3.0
5	Spent; testes "bloody"; no milk expressible

Appendix 3. Location of demersal tows and catch rates for orange roughy during cruises SO2/87 (April) to SO6/87 (August).

Location of demersal tows and catch rates for orange roughy on Soela cruises

Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S02/87	01	3/4	41° 16.80' S 144° 00.80' E	41° 15.00' S 143° 59.00' E	320	51	935-980	12	
	02	4/4	41° 07.20' S 144° 00.80' E	41° 06.20' S 143° 59.60E	317	22	400-440	0	
	04	5/4	41° 11.40' S 143° 59.10' E	41° 11.20' S 144° 01.20E	60	50	860-570	13	major damage to net
	05	5/4	41° 14.50' S 144° 01.70' E	41° 12.70' S 143° 59.60' E	330	51	810-1000	432	
	06	6/4	41° 16.00' S 144° 02.50' E	41° 12.80' S 143° 57.90' E	318	71	830-1230	0	
	07	6/4	41° 13.80' S 144° 03.20' E	14° 13.00' S 144° 00.00' E	320	67	730-800	0	
	08	7/4	41° 09.40' S 143° 59.70' E	41° 08.30' S 143° 57.90' E	336	34	720-580	26	wing damage -rough ground
	09	9/4	41° 15.00' S 144° 02.10' E	41° 13.50' S 144° 01.10' E	312	34	760-770	26	aborted due to position error after sat. update
	10	"	41° 14.00' S 144° 01.00' E	41° 13.00' S 144° 00.70' E	320	22	670-670	82	
	11	"	41° 16.40' S 144° 02.60' E	41° 15.00' S 144° 00.80' E	285	45	780-670	0	

Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S02/87	12	10/4	41° 14.00' S 144° 01.00' E	41° 13.00' S 144° 00.00' E	335	35	810-770	0	
	13	"	41° 14.60' S 144° 01.70' E	41° 13.20' S 144° 00.80' E	335	35	770-770	22	
	14	10/4	41° 01.00' S 143° 52.90' E	41° 00.50' S 143° 52.30' E	335	33	490-475	0	
	15	13/4	41° 23.50' S 148° 43.30' E	41° 22.50' S 148° 43.00' E	340	25	842-822	0	
	16	"	41° 24.00' S 148° 43.40' E	41° 23.90' S 148° 43.40' E	340	6	850-850	140	came fast
	17	"	41° 23.60' S 148° 42.30' E	41° 22.70' S 148° 44.10' E	30	34	832-949	14	
S03/87	01	30/4	41° 50.50' S 144° 22.30' E	41° 48.30' S 144° 21.80' E	345	64	1350-1320	2	
	02	2/5	41° 15.10' S 144° 02.10' E	41° 13.50' S 144° 00.00' E	320	60	760-840	78	
	03	2/5	41° 15. 90 ' S 144° 02.60' E	41° 13.80' S 144° 00.90' E	320	81	680-820	31	
	04	4/5	41° 24.70' S 148° 45.70' E	41° 23.40' S 148° 46.20' E	0	11	970-980	1369	aborted
	05	"	41° 27.60' S 148° 45.50' E	41° 29.00' S 148° 45.50'	190	20	980-970	51	came fast

Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S03/87	06	5/5	41° 20.10' S 148° 47.90' E	41° 19.40' S 148° 49.40' E	30	31	1150-1320	7146	
	07	6/5	41° 21.10' S 148° 47.90' E	41° 21.00' S 148° 48.40' E	66	12	1070-1130	0	came fast
	08	"	41° 39.20' S 148° 41.90' E	41° 34.70' S 148° 45.70' E	35	120	1010-1120	77	
	09	7/5	41° 23.80' S 148° 46.10' E	41° 24.70' S 148° 47.10' E	136	30	990-1070	0	
	10	7/5	41° 24.30' S 148° 46.50' E	41° 25.50' S 148° 46.20' E	183	14	1010-1070	0	came fast transducer cable snapped
	11	8/5	41° 32.00' S 148° 47.00' E	41° 32.00' S 148° 46.90' E	170	10	1080-1080	0	came fast
	12	"	41° 30.80' S 148° 46.80' E	41° 31.20' S 148° 46.90' E	166	12	1080-1140	0	came fast
	13	9/5	41° 21.20' S 148° 48.90' E	41° 20.20' S 148° 50.50' E	30	41	1060-1260	19	
	14	"	41° 32.50' S 148° 47.90' E	41° 32.50' S 148° 47.90' E	132	0		0	aborted before net fishing very rough ground
	15	"	41° 34.80' S 148° 45.20' E	41° 34.00' S 148° 47.80' E	23	44	1160-1320	59	
	16	"	41° 34.70' S 148° 44.60' E	41° 33.40' S 148° 46.60' E	15	42	1090-1150	61	came fast

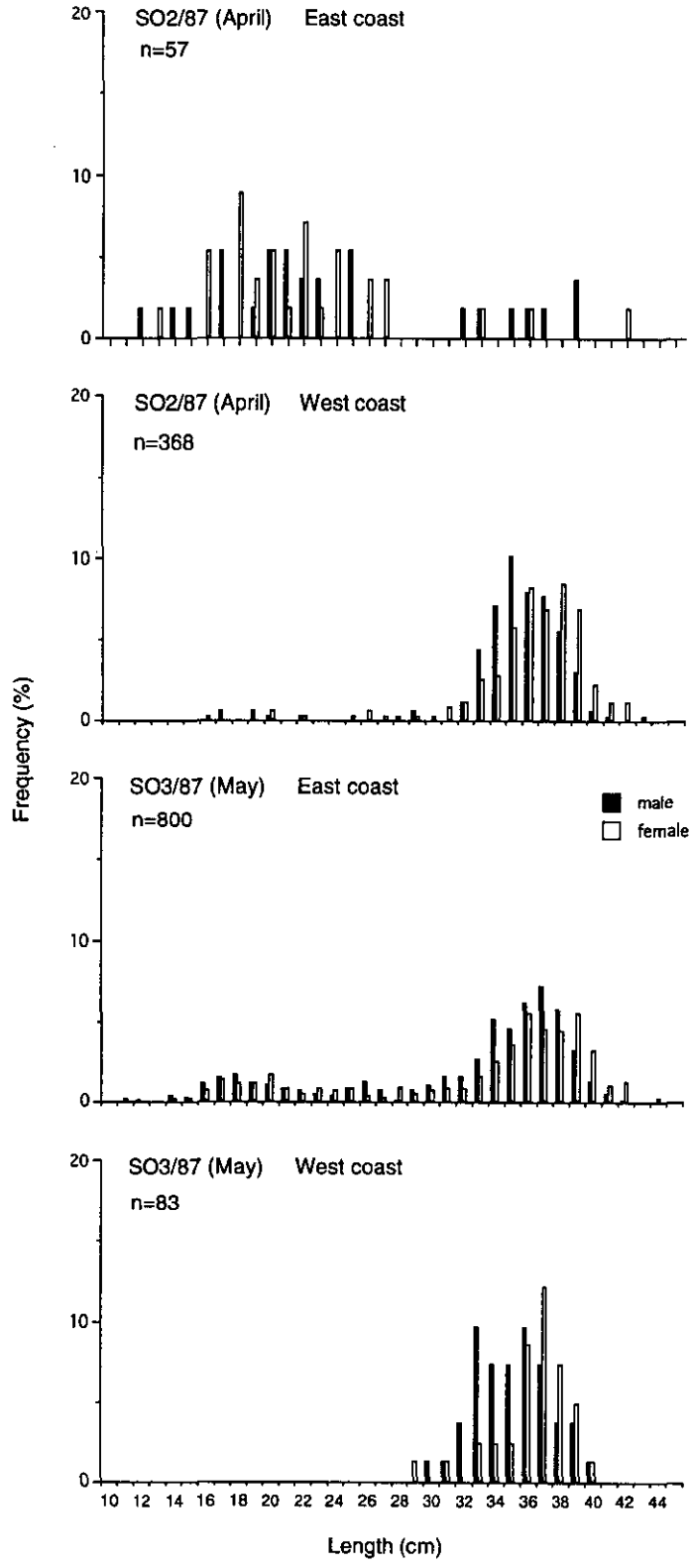
Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S03/87	17	10/5	41° 36.30' S 148° 43.50' E	41° 34.70' S 148° 45.00' E	7	39	1020-1060	34	came fast
	24	11/5	41° 22.40' S 148° 46.90' E	41° 20.89' S 148° 47.60' E	16	8	1020-1050	0	came fast net sonde failure
	25	"	41° 22.23' S 148° 46.77' E	41° 20.60' S 148° 47.80' E	40	18	1010-1040	7	aborted due to net sonde failure
S04/87	03	5/6	41° 22.40' S 148° 43.30' E	41° 20.80' S 148° 43.20' E	356	23	840-830	0	
	04	"	41° 26.90' S 148° 43.60' E	41° 22.40' S 148° 42.70' E	10	69	850-860	89	
	05	"	41° 19.40' S 148° 43.60' E	41° 17.00' S 148° 44.00' E	30	11	950-975	65	
	06	5/6	41° 24.00' S 148° 43.00' E	41° 22.50' S 148° 47.40' E	96	71	820-1065	199	
	07	6/6	41° 21.20' S 148° 44.60' E	41° 21.30' S 148° 46.80' E	95	25	934-1020	50	
	08	"	41° 21.30' S 148° 43.60' E	41° 20.50' S 148° 47.30' E	94	49	840-1060	102	
	09	"	41° 24.30' S 148° 43.70' E	41° 22.80' S 148° 48.70' E	95	57	890-1052	31	came fast
	12	9/6	41° 17.15' S 144° 04.54' E	41° 13.40' S 144° 00.80' E	335	43	808-940	75	

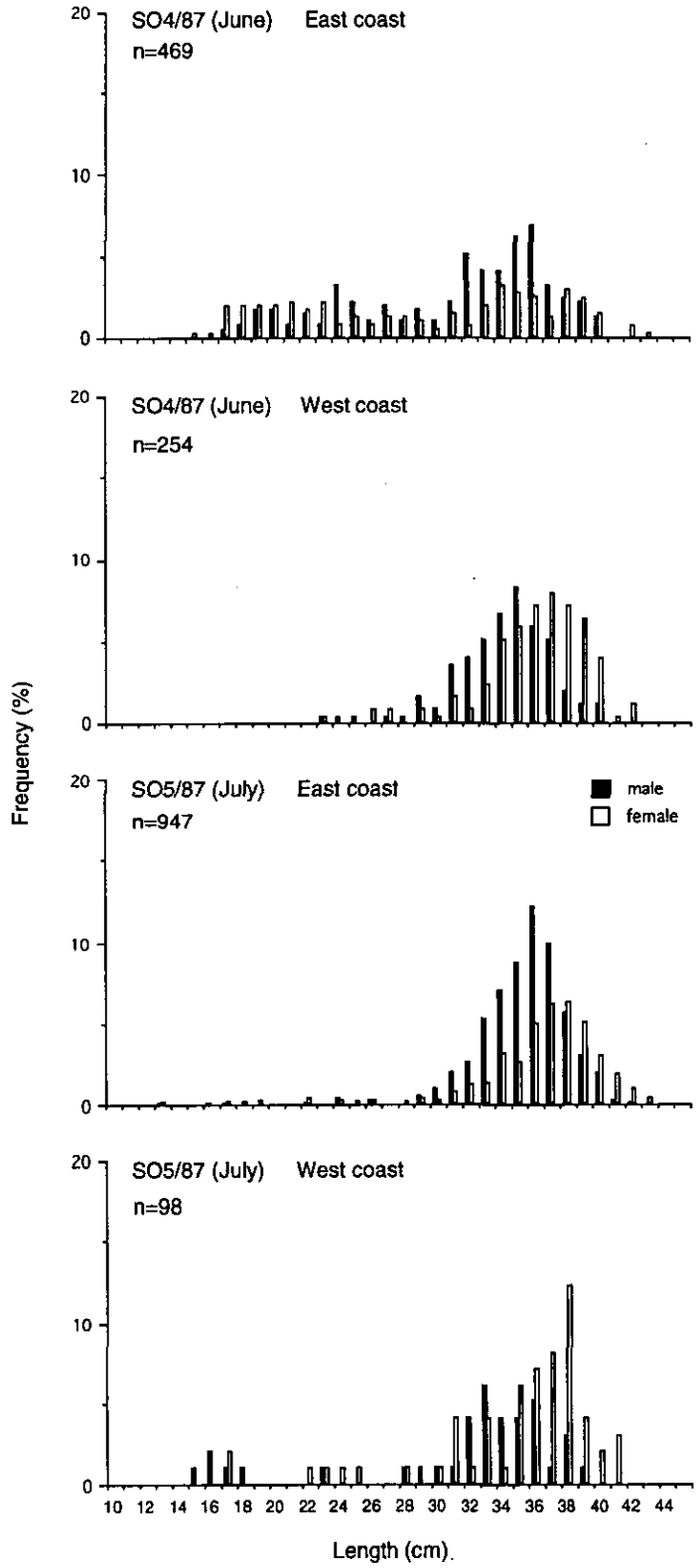
Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S04/87	13	"	41° 15.40' S 144° 01.70' E	41° 13.60' S 144° 01.60' E	330	36	830-750	107	
	17	10/6	41° 50.90' S 144° 23.60' E	41° 47.30' S 144° 22.60' E	334	67	1280-1230	8	net sonde failure
	18	10/6	41° 15.00' S 144° 02.00' E	41° 12.64' S 143° 58.85' E	325	65	780-1100	83	
	19	"	41° 14.60' S 144° 02.10' E	41° 12.40' S 144° 00.60' E	328	48	820-890	81	
	20	12/6	41° 14.40' S 144° 01.90' E	41° 12.45' S 143° 58.79' E	320	41	810-1040	272	
	21	"	41° 15.40' S 144° 03.00' E	41° 11.00' S 143° 57.20	325	47	720-880	1	
	22	"	41° 14.10' S 144° 01.60' E	41° 13.10' S 143° 58.70' E	300	77	836-1250	52	
	29	15/6	41° 21.40' S 148° 45.10' E	41° 22.30' S 148° 45.60' E	165	13	964-950	58	
	30	15/6	41° 22.40' S 148° 45.40' E	41° 23.30' S 148° 45.50' E	187	19	950-940	0	
	31	"	41° 20.60' S 148° 45.20' E	41° 22.40' S 148° 45.80' E	166	39	940-980	5	
	32	"	41° 20.10' S 148° 45.10' E	41° 21.90' S 148° 45.90' E	164	44	980-1010	61	

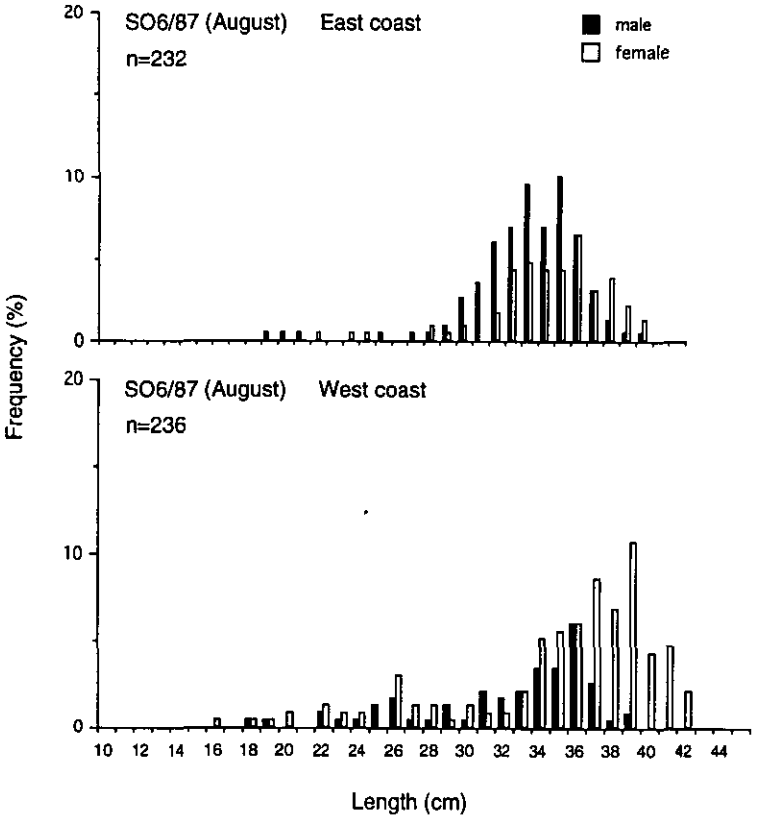
Cruise No	Station No	Date	Position		Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
			Start	Finish					
S05/87	04	10/7	41° 39.80' S 148° 40.00' E	41° 38.20' S 148° 41.80' E	358	10	930-940	1440	came fast
	05	"	41° 21.79' S 148° 44.50' E	41° 17.40' S 148° 44.60' E	353	45	965-970	128	
	06	11/7	41° 37.50' S 148° 41.40' E	41° 39.80' S 148° 40.50' E	196	45	940-990	329	
	07	12/7	41° 26.40' S 148° 45.90' E	41° 22.70' S 148° 45.90' E	0	40	970-1000	63	
	08	"	41° 36.40' S 148° 42.20' E	41° 39.60' S 148° 41.10' E	208	52	1008-980	293	
	09	"	41° 39.50' S 148° 41.50' E	41° 32.90' S 148° 43.40' E	20	82	960-910	49	
	12	17/7	41° 29.50' S 148° 43.30' E	41° 28.80' S 148° 43.50' E	10	19	860-920	14	came fast - lost transducer signal
	13	"	41° 37.20' S 148° 41.80' E	41° 34.60' S 148° 42.60' E	357	26	1000-950	609	came fast
	14	"	41° 39.20' S 148° 38.60' E	41° 37.30' S 148° 39.30' E	20	51	790-770	119	came fast
	15	17/7	41° 39.60' S 148° 43.80' E	41° 34.80' S 148° 46.40' E	22	59	1110-1170	9	came fast on hauling
	18	20/7	41° 14.80' S 144° 01.30' E	41° 13.10' S 143° 59.70"E	307	71	745-850	2	net sonde failure

Cruise No	Station No	Date	Position Start	Position Finish	Tow direction (° T)	Duration (min)	Bottom depth range (m)	Catch rate orange roughy (kg/hr)	Comments
S05/87	19	20/7	41° 15.00' S 144° 02.80' E	41° 12.10' S 143° 59.40' E	310	73	705-1090	7	
	20	"	41° 15.30' S 144° 00.70' E	41° 13.30' S 144° 00.20' E	320	50	875-825	8	net sonde failure
	21	"	41° 19.70' S 144° 04.00' E	41° 21.40' S 144° 08.50' E	120	82	1050-995	86	
S06/87	03	6/8	41° 34.56' S 148° 48.79' E	41° 35.83' S 148° 41.21' E	190	25	900-930	10	came fast-minor damage to net
	04	"	41° 37.91' S 148° 41.44' E	41° 30.80' S 148° 45.27' E	53	120	740-960	14	came fast on hauling major damage to net
	05	7/8	41° 40.33' S 148° 41.44' E	41° 37.72' S 148° 42.37' E	10	60	1020-980	104	net sonde failure
	06	"	41° 39.36' S 148° 40.58' E	41° 36.92' S 148° 41.08' E	0	72	964-880	5	
	07	"	41° 38.06' S 148° 43.06' E	41° 34.37' S 148° 47.05' E	10	62	1090-1150	10161	lost net sonde signal
	14	10/8	41° 49.74' S 144° 22.31' E	41° 45.60' S 144° 21.40' E	350	60	1296-1290	7	
	16	"	41° 14.52 ' S 144° 01.54' E	41° 12.97 ' S 143° 59.45' E	324	46	825-1010	39	
	17	"	41° 16.05' S 143° 58.00' E	41° 11.94' S 143° 55.98'	330	108	1190-1110	143	

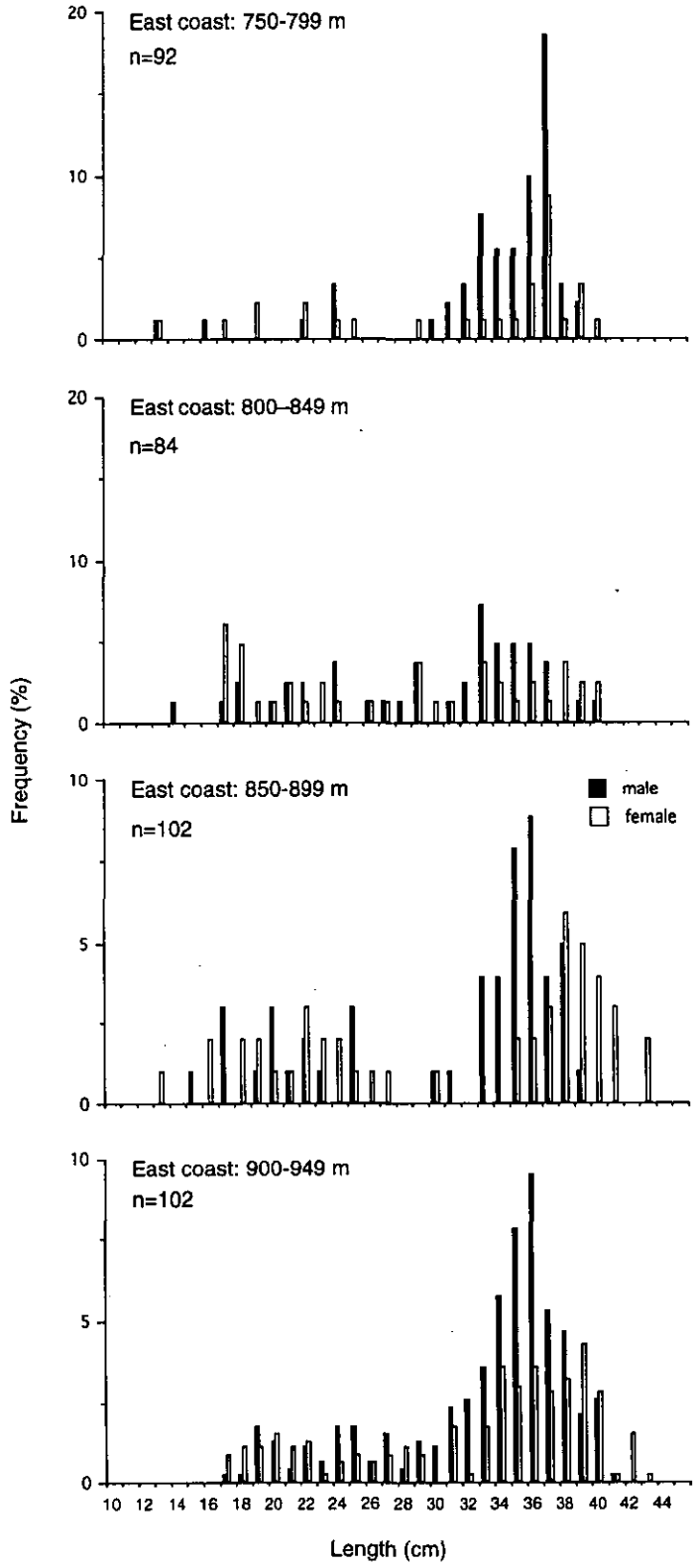
Appendix 4. Length frequencies of orange roughy off the east and west coasts of Tasmania sampled during each cruise (data have not been weighted).

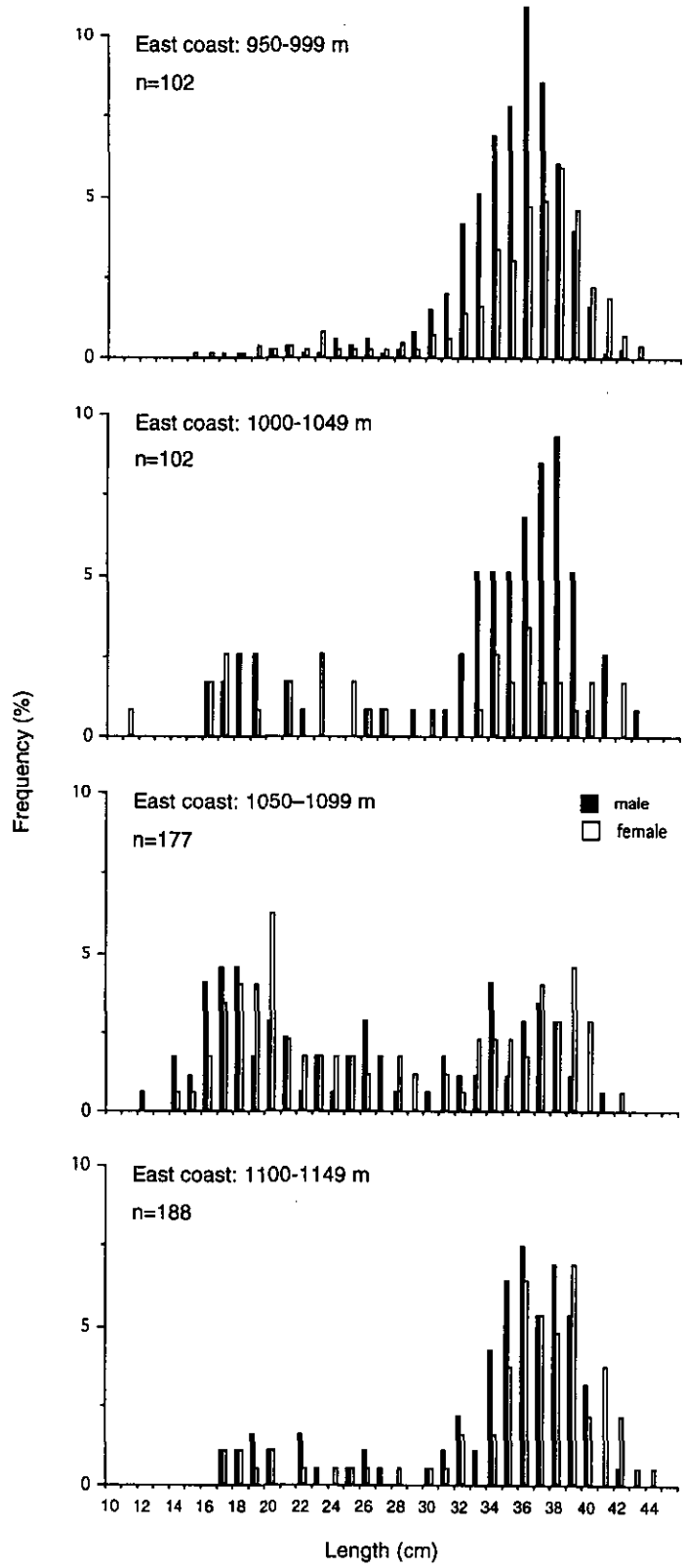


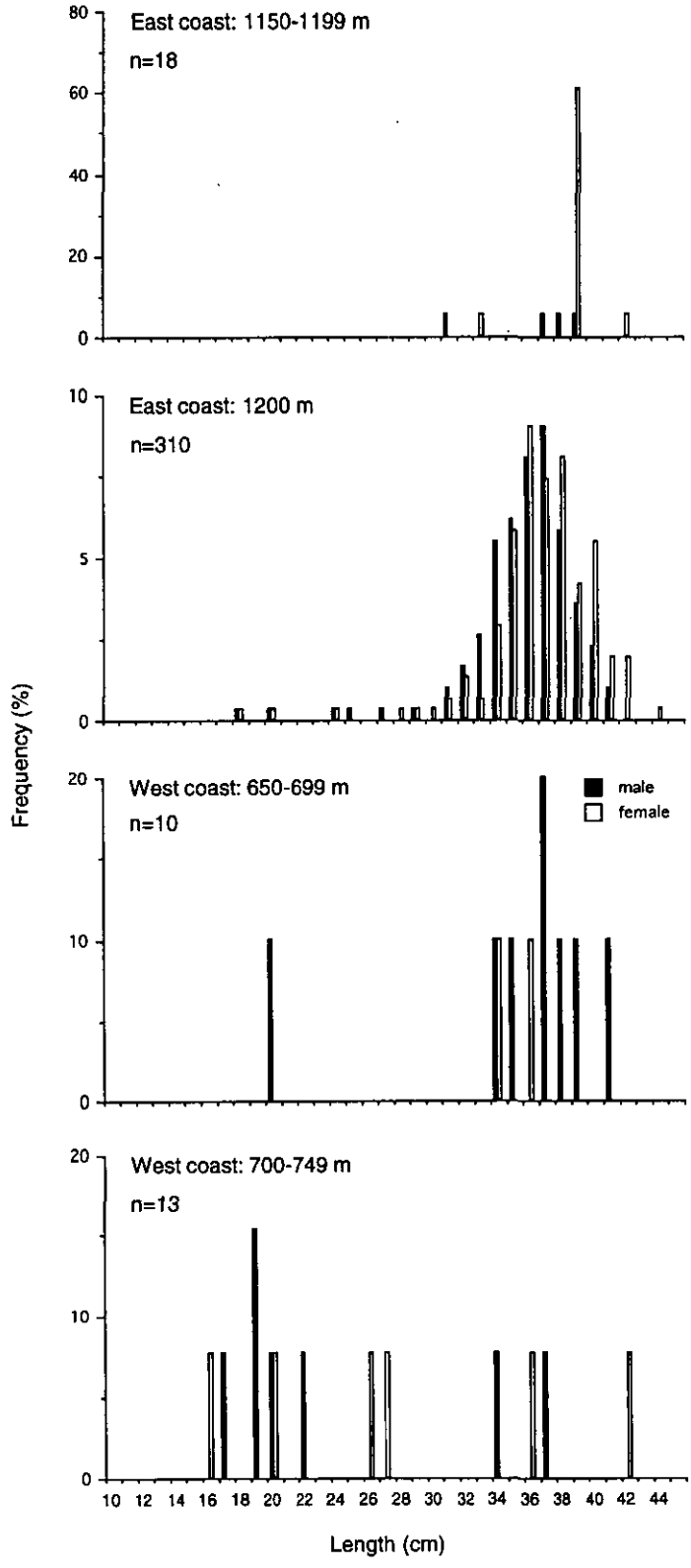

SO4/87 (June) East coast
n=469
SO4/87 (June) West coast
n=254
SO5/87 (July) East coast
n=947
male
female
SO5/87 (July) West coast
n=98
Frequency (%)
0
10
20
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
Length (cm)

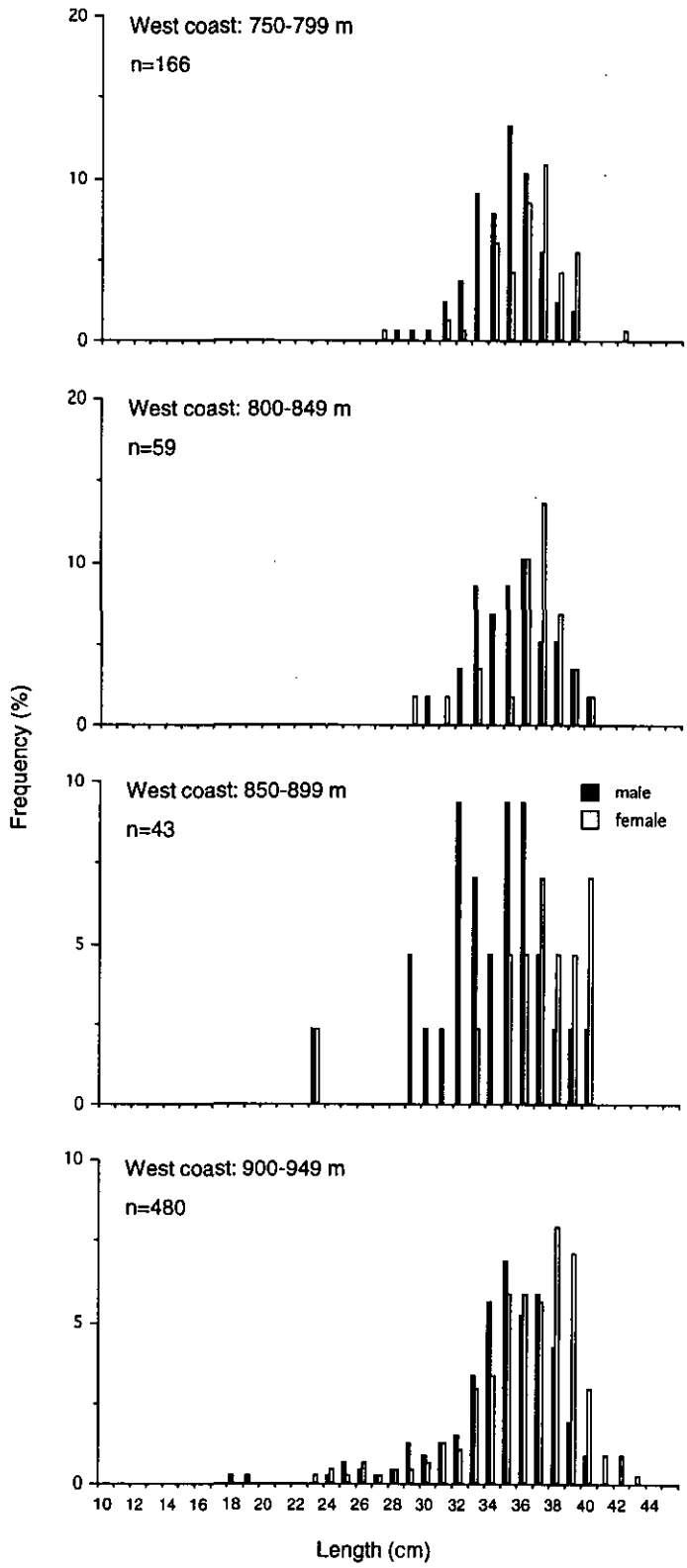

SO6/87 (August) East coast
n=232
male
female
SO6/87 (August) West coast
n=236
Frequency (%)
Length (cm)
0
10
20
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

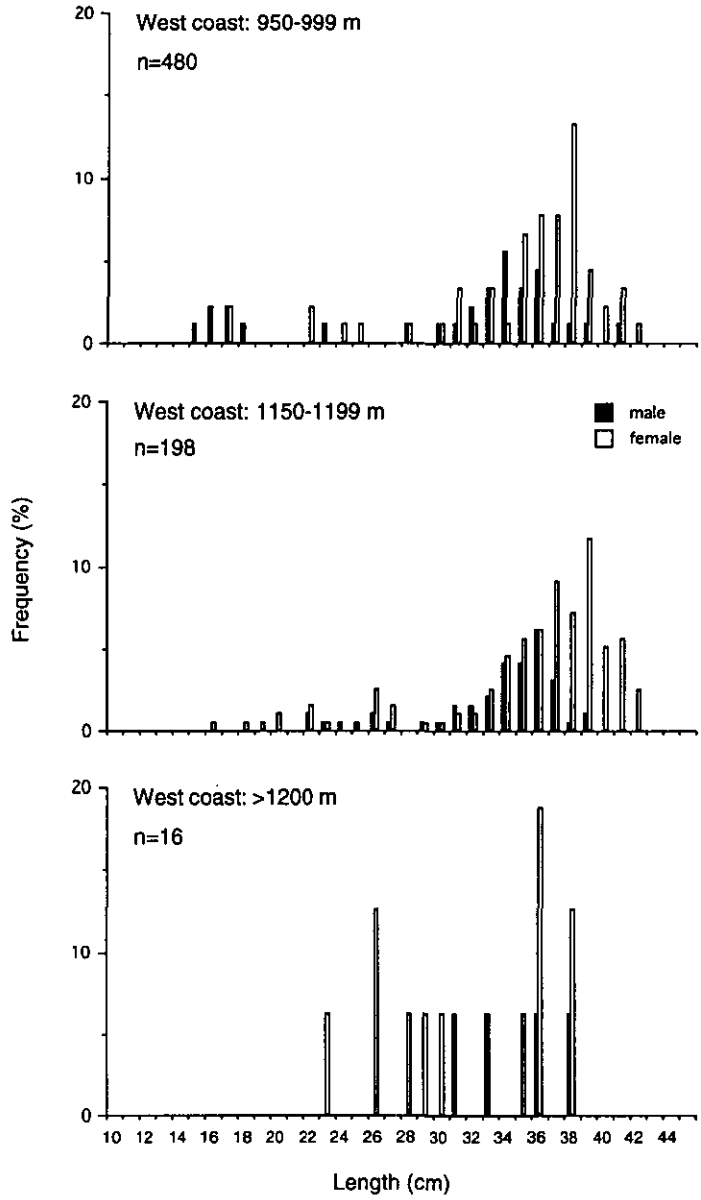
Appendix 5. Depth-stratified length frequencies of orange roughy off the east and west coasts of Tasmania (unadjusted).




East coast: 950-999 m
n=102
East coast: 1000-1049 m
n=102
East coast: 1050–1099 m
n=177
male
female
East coast: 1100-1149 m
n=188
Frequency (%)
Length (cm)
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44


East coast: 1150-1199 m
n=18
East coast: 1200 m
n=310
West coast: 650-699 m
n=10
male
female
West coast: 700-749 m
n=13
Frequency (%)
Length (cm)


West coast: 750-799 m
n=166
West coast: 800-849 m
n=59
West coast: 850-899 m
n=43
male
female
West coast: 900-949 m
n=480
Frequency (%)
Length (cm)
0
5
10
20
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44


West coast: 950-999 m
n=480
West coast: 1150-1199 m
n=198
male
female
West coast: >1200 m
n=16
Frequency (%)
Length (cm)
0
10
20
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

Appendix 6. Length-weight relationships of orange roughy.

Cruise	Area	Sex	Equation	*n*	Probability
2/87	east	m	$W=0.0646 \times L^{2.82}$	27	$F_{(1,47)}= 12.47$
		f	$W=0.1600 \times L^{2.53}$	24	$p<0.01$
	west	m	$W=0.0620 \times L^{2.81}$	116	n.s.
		f			
3/87	east	m	$W=0.0851 \times L^{2.72}$	191	$F_{(1,373)}= 11.05$
		f	$W=0.0876 \times L^{2.72}$	185	$p<0.01$
	west	m	$W=0.1080 \times L^{2.66}$	46	$F_{(1,79)}= 8.07$
		f	$W=0.1140 \times L^{2.66}$	36	$p<0.01$
4/87	east	m	$W=0.0700 \times L^{2.79}$	380	n.s.
		f			
	west	m	$W=0.0380 \times L^{2.95}$	108	$F_{(1,221)}= 8.78$
		f	$W=0.0400 \times L^{2.95}$	116	$p<0.01$
5/87	east	m	$W=0.1105 \times L^{2.65}$	181	$F_{(1,323)}= 18.39$
		f	$W=0.0455 \times L^{2.91}$	146	$p<0.01$
	west	m	$W=0.0510 \times L^{2.88}$	52	n.s.
		f			
6/87	east	m	$W=0.0811 \times L^{2.72}$	99	n.s.
		f			
	west	m	$W=0.0610 \times L^{2.82}$	94	n.s.
		f			

Appendix 7. Gonosomatic indices against standard length of orange roughy.

KEY

△ stage 1

▲ stage 2

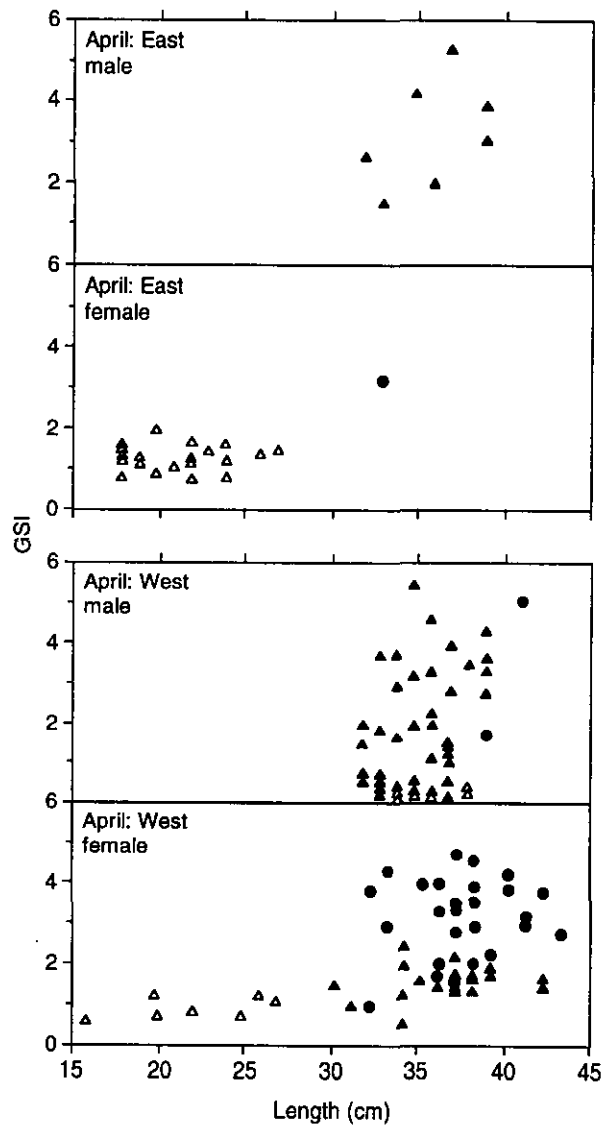
● stage 3

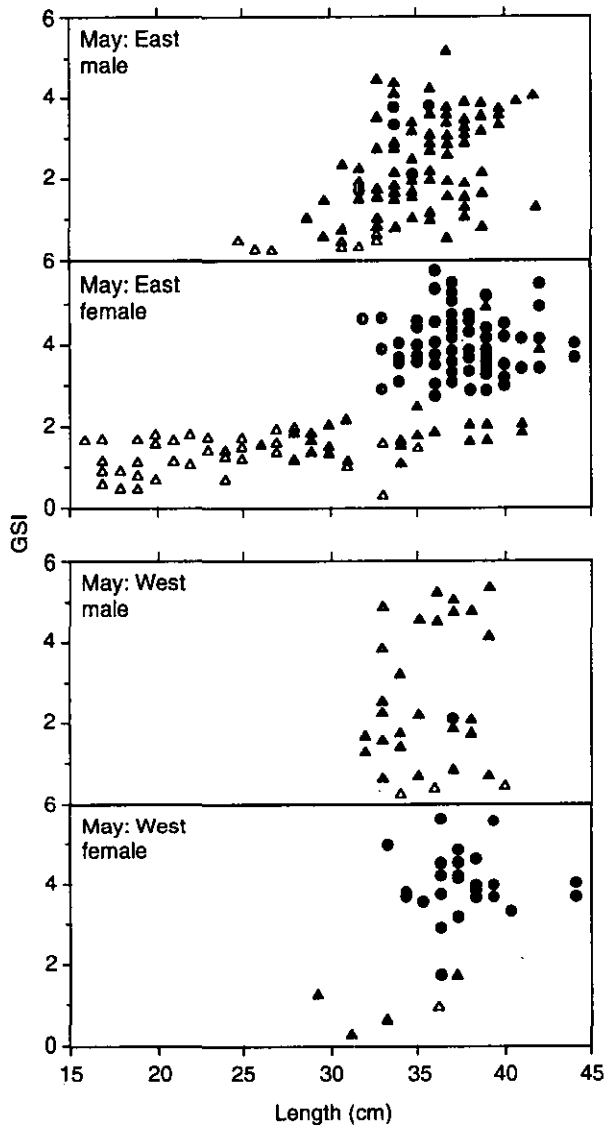
○ stage 4

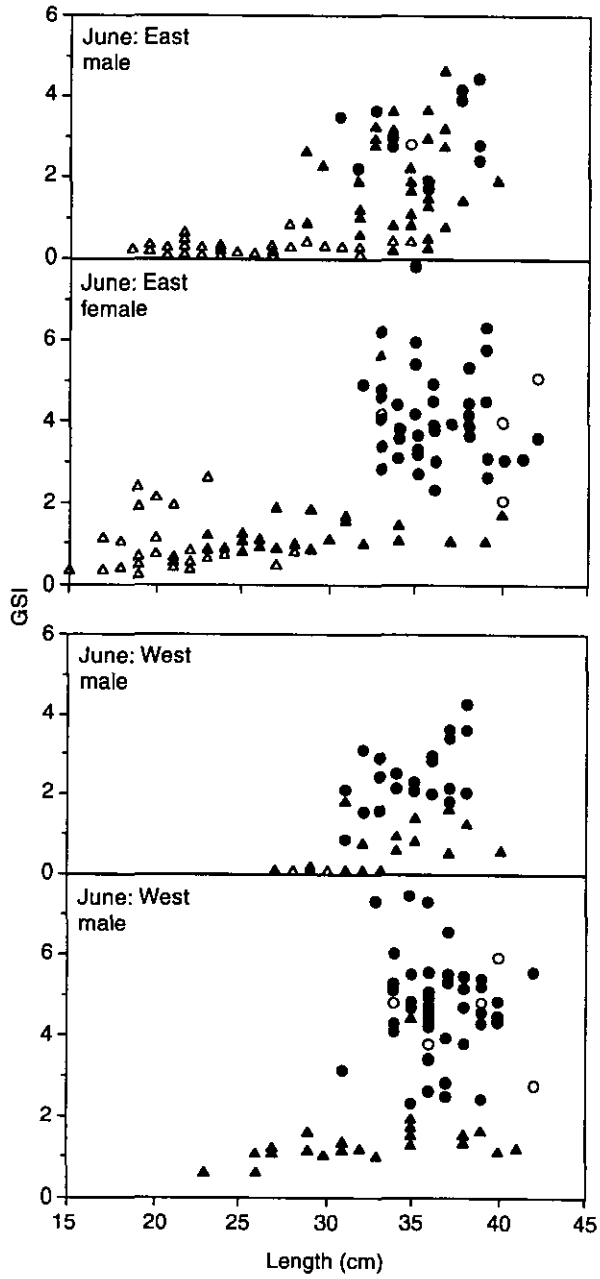
□ stage 5

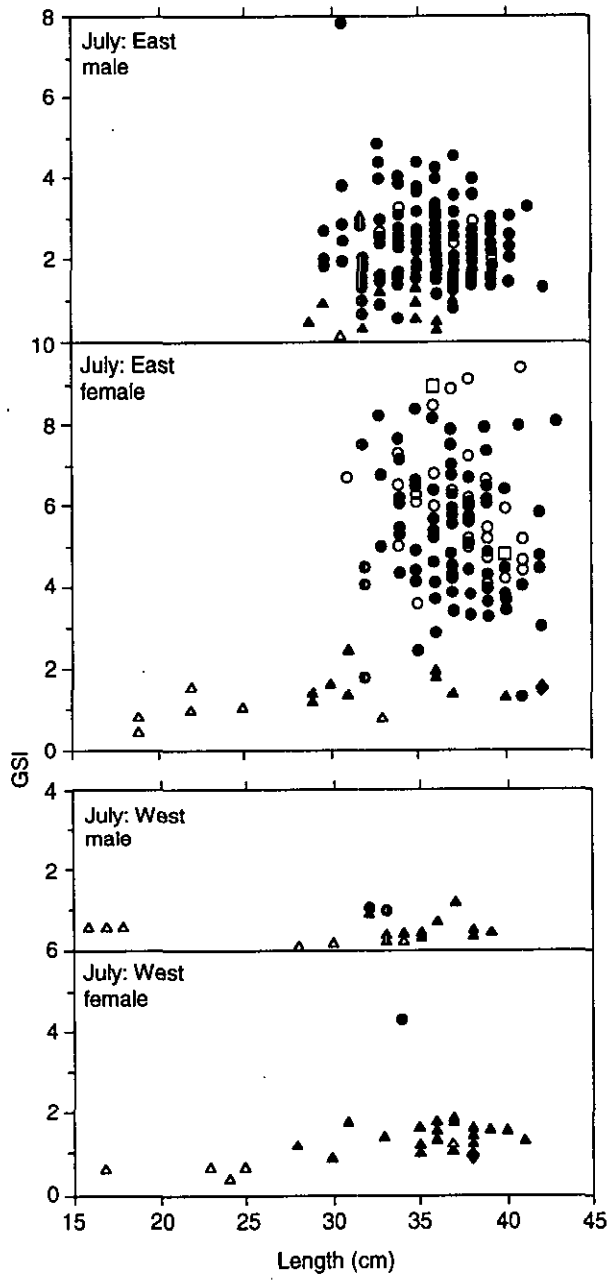
◆ stage 6

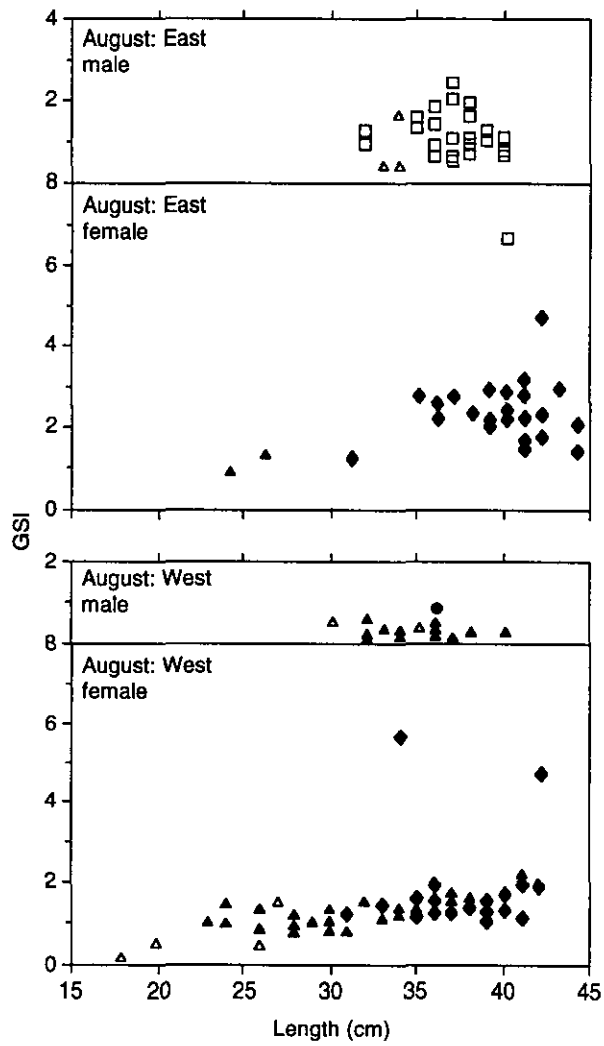
■ stage 7


April: East
male
April: East
female
April: West
male
April: West
female
GSI
Length (cm)
0
2
4
6
15
20
25
30
35
40
45


May: East
male
May: East
female
May: West
male
May: West
female
GSI
Length (cm)
0
2
4
6
15
20
25
30
35
40
45


June: East
male
June: East
female
June: West
male
June: West
male
GSI
Length (cm)
0
2
4
6
15
20
25
30
35
40
45


July: East
male
July: East
female
July: West
male
July: West
female
GSI
Length (cm)
0
2
4
6
8
10
15
20
25
30
35
40
45


August: East
male
August: East
female
August: West
male
August: West
female
GSI
Length (cm)
0
2
4
6
8
15
20
25
30
35
40
45

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