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Orange Roughy Surveys, 1988 and 1989; Part A: Abundance Indices Part B: Biological Data

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Abstract

The continental slope (between 700 m and 1200 m) of southeastern Australia was surveyed in 1988 and 1989, using a depth-stratified random sample design, to determine the distribution and abundance of orange roughy *Hoplostethus atlanticus* Collett, and to obtain biological information on the species. The survey area (over 13 000 km^2) covered the eastern region of the Great Australian Bight, western Bass strait, west Tasmania, east Tasmania and eastern Bass Strait, and also southern New South Wales (random trawling in 1988). Three cruises were made each year to complete the surveys. In all, 135 survey trawls (51% of planned stations) were made in 1988 and 154 (62%) in 1989. Abundance indices were similar over the two years, but are considered conservative because of assumptions made in the survey design and the high proportion of the survey area that consisted of steep sloping or rough ground. Such ground did not allow a survey design requirement for a 15–30 minute tow within a specified 100 m depth stratum at each random station.

On the east coast of Tasmania, gonadal development was observed in fish from March and July 1988 and April 1989. The female: male ratio of 1:1.5 for this area differed from that for other regions, where the ratio was one. Length at maturity was 32 cm for females and 30 cm for males. An average of 35% of adult females were described as non-reproductive. A bimodal length-frequency distribution was found for orange roughy from all areas except New South Wales and eastern Bass Strait.

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Contents

Introduction

The deep water trawl fishery for orange roughy (*Hoplostethus atlanticus* Collett, 1889) in southeast Australia is relatively new. Rapid expansion and capitalization in this fishery followed the discovery of a major aggregation off western Tasmania (Sandy Cape) in late 1986. Landings of orange roughy increased from 400 tonnes per annum to around 9 000 tonnes for 1986/87 (Evans and Wilson, 1987).

There was an urgent need for basic information on the abundance and distribution of orange roughy in the South East Trawl (SET) Fishery, as estimates of neither the standing stock nor the potential yield were known. To address these problems, and to collect other biological information of use in the management of the fishery, CSIRO made a comprehensive survey of areas within the SET Fishery in early 1988 and again in early 1989 using the FRV *Soela*. The objectives of the survey were:

- to assess the abundance and distribution of orange roughy in the south-eastern waters of Australia,
- to obtain biological information for use in determining the stocks, the size (and age) composition and the reproductive strategies of orange roughy.

Survey design

Stratified random sampling is widely used to assess the distribution and abundance of fish stocks (Grosslein, 1969; Doubleday, 1981; Francis, 1984). It gives an unbiased 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 to high density strata will increase the precision of the estimates (Saville, 1977; Francis, 1981, 1984). Knowing what catch rates (i.e. fish densities) are likely to be achieved within an area makes it possible to allocate effort during the survey design (Robertson *et al.*, 1984); however, an adaptive strategy based on results from the first part of a two-phase survey design can be used when probable catch rates are not known (Francis, 1984).

Our survey was designed as a depth-stratified random sample survey, with allocation of effort per stratum proportional to the stratum area. Such allocation of effort assumes a uniform distribution of fish within the survey area, which was a valid assumption given that there was no information to suggest otherwise nor to allow the prediction of fish densities within a stratum. The survey was planned for the late summer/autumn months of the year to eliminate the risk of encountering either winter spawning aggregations or summer aggregations (e.g. Sandy Cape in late 1986) of fish. A two-phase survey design was logistically impractical given the extent of the survey area and ship-time available.

1988 Survey

The 1988 survey in south-east Australian waters extended from Kangaroo Island (137°E), around Tasmania and east to Gabo Island (150°E) (Fig. 1). The survey was made at depths between 700 m and 1200 m. Accurate charts of depth contours were obtained from the survey conducted by the Tasmanian Department of Sea Fisheries (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 21 sub-areas of approximately 600 km^2 (A to U, Fig. 1) and five 100 m depth intervals, giving a total of 105 strata. Random positions were generated at a density of 1 station per 43 km^2 for sub-areas A to F and 1 station per 53 km^2 for the other 15 sub-areas (Table 1), with stations within a depth stratum no less than 4 km apart. The change in density was due to time constraints for the survey.

Tows were aimed to be of 30 minutes duration (bottom time); any tows less than 15 minutes 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.

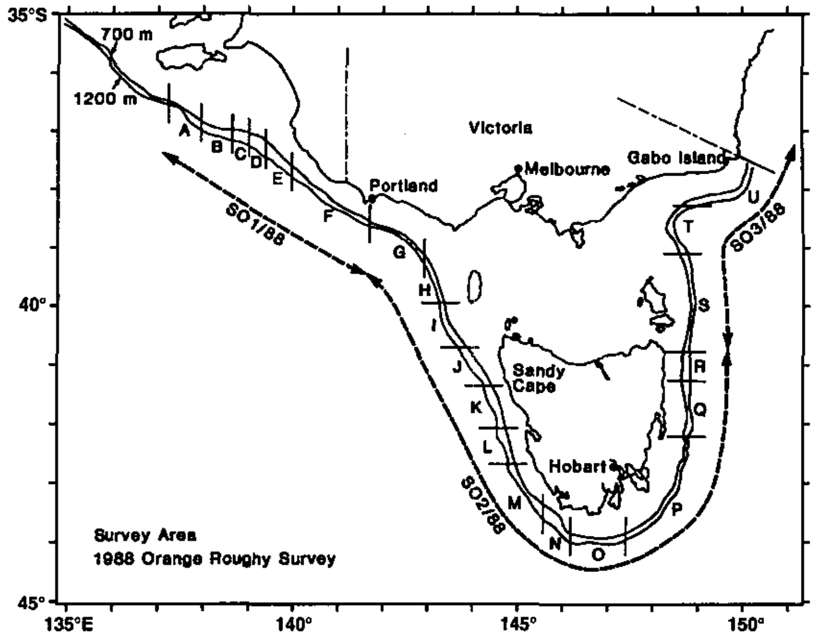

Figure 1: The area surveyed by the CSIRO FRV *Soela* in 1988 showing the 21 areas, each of which contained 5 depth strata from 700 to 1200 m.

1989 Survey

The sampling method for the 1989 survey was identical to that of the 1988 survey, apart from some changes to the sampling intensity and the 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. The survey was extended in the Kangaroo Island region (from 137°E to 136°E, Figure 2) but the total ground surveyed (7 165 km^2) was reduced because the previous survey indicated grounds unsuitable for survey tows in some areas. However, the number of planned stations was increased to 1 per 30 km^2 (Table 2).

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

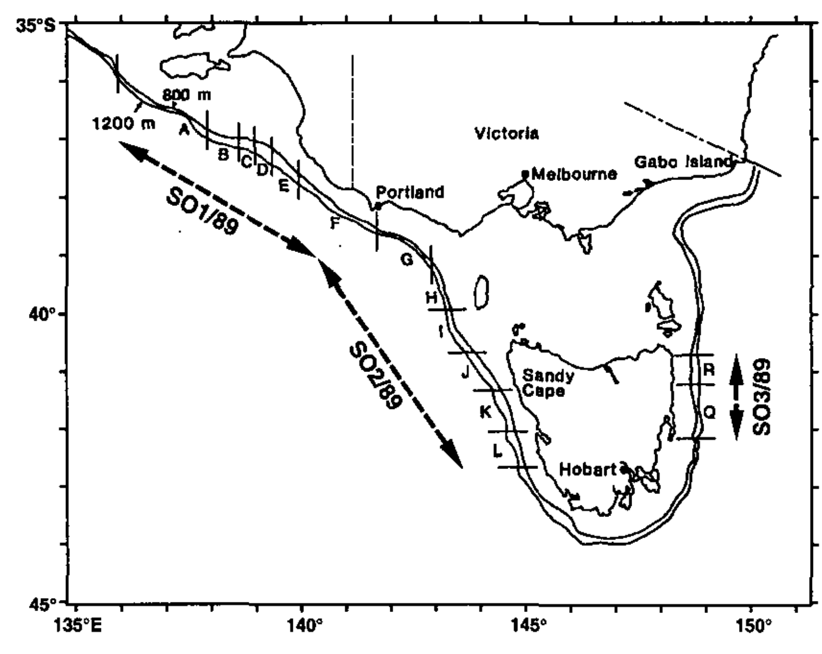

Figure 2: The 1989 survey area, with a reduced number of subareas and depth strata from 800 to 1200 m

Survey results

1988

Three cruises on FRV *Soela* 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 New South Wales.

Fewer stations were completed than planned (Table 1) because about 4 700 km^2 were deemed to be unsuitable for survey tows; either the ground appeared to be rough, or it seemed unlikely that the tow would remain within the predetermined 100 m depth range or be of at least 15 minutes bottom time duration. Small sections of ground within most subareas were also considered unsuitable, but they were an insignificant part of the total area. The areas where isolated shots were aborted (because the gear was hooked up within 15 minutes or was so badly damaged that the catch was not likely to be indicative of the fish population) were not included in the calculation of unsuitable survey ground. Thus, only relatively large areas of ground were estimated.

The largest area considered unsuitable (approximately 2 300 km^2) was the ground south of 43°S latitude (southern Tasmania), although a few isolated patches are suitable for survey trawling (e.g. off Port Davey, the Hippolytes). The east coast of Tasmania to Gabo Island was also unsuitable for survey tows (approximately 2 400 km^2) except for the grounds off St Patricks Head (north-east Tasmania), an area north-east of Flinders Island (about 39°S) and very small areas around both Maria and Gabo Islands. Several exploratory tows were made off the New South Wales coast north of the survey area but have not been included in the abundance estimates since they did not conform to the survey requirements.

The 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 (South Australia) area, which later became a commercial site (Fig. 3), one from the east coast of Tasmania (Fig. 6) and one north-east of Flinders Island (Fig. 7), which consisted almost entirely of fish smaller than 30 cm.

Table 1: Results of the 1988 CSIRO survey. (see Figure 1 for strata locations)

Stratum	from	to	Area (km^2)	Stations planned	Stations trawled	%
A	137°00' °E	137° 37' °E	559	10	8	80
B	137° 38' °E	138° 25' °E	610	15	4	27
C	138° 26' °E	138° 48' °E	570	16	15	94
D	138° 49' °E	139° 08' °E	583	15	13	87
E	139° 09' °E	139° 41' °E	627	15	6	40
F	139° 42' °E	141° 29' °E	823	16	13	81
G	141° 30' °E	142° 40' °E	675	12	8	67
H	142° 41' °E	40° 11' °S	639	12	4	33
I	40°12' °S	40° 53' °S	582	12	6	50
J	40° 54' °S	41° 32' °S	554	12	9	75
K	41° 33' °S	42° 15' °S	555	12	11	92
L	42° 16' °S	42° 56' °S	549	12	11	92
M	42° 57' °S	145° 36' °E	538	12	2	17
N	145° 37' °E	146° 08' °E	521	12	1	8
O	146° 09' °E	147° 29' °E	590	12	0	0
P	147° 30' °E	42° 24' °S	678	12	4	33
Q	42° 23' °S	41° 31' °S	622	12	6	50
R	41° 30' °S	41° 02' °S	582	12	4	33
S	41° 01' °S	39° 14' °S	774	12	3	25
T	39° 13' °S	38° 21' °S	749	12	4	33
U	38° 20' °S	37° 40' °S	840	12	3	25
Total			13 220	267	135	51

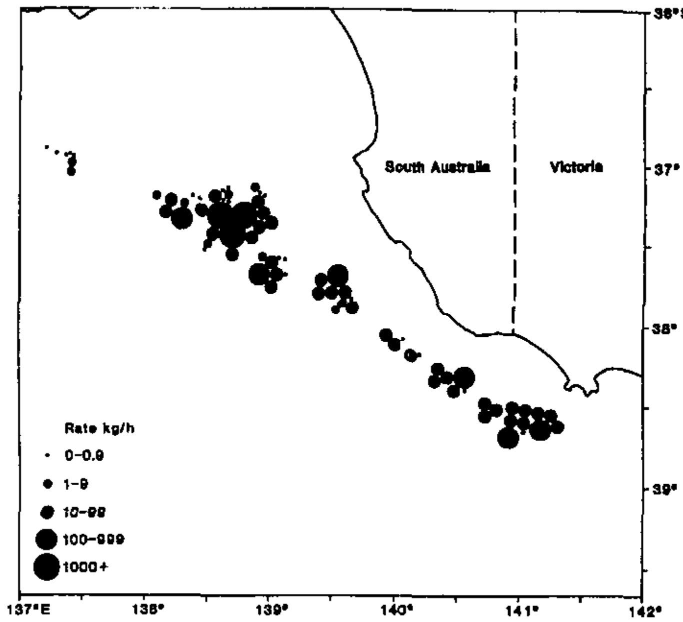

Figure 3: Catch rates of orange roughy (kg/h) from the Kangaroo Island to Portland area during SO1/88 (January–February), including tows from depths greater than 1200 m.

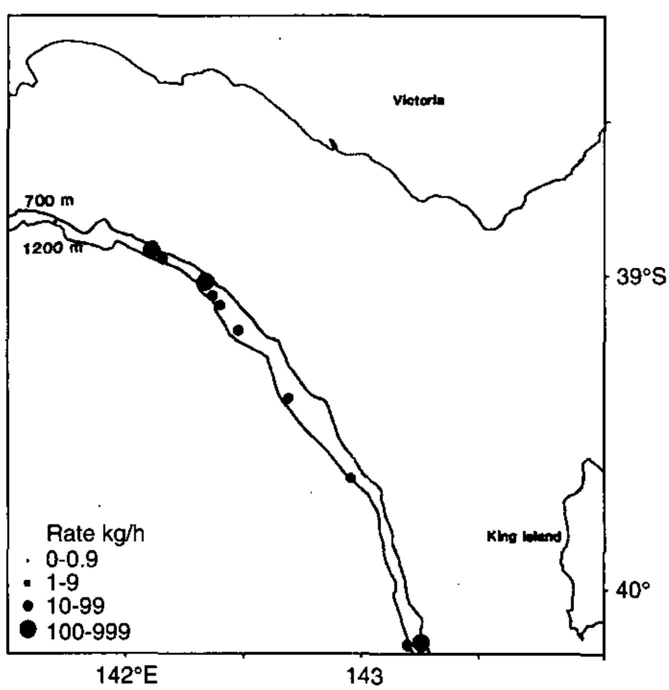

Figure 4: Catch rates of orange roughy (kg/h) from the western Bass Strait and King Island area during SO2/88 (March–April), including tows from depths greater than 1200 m.

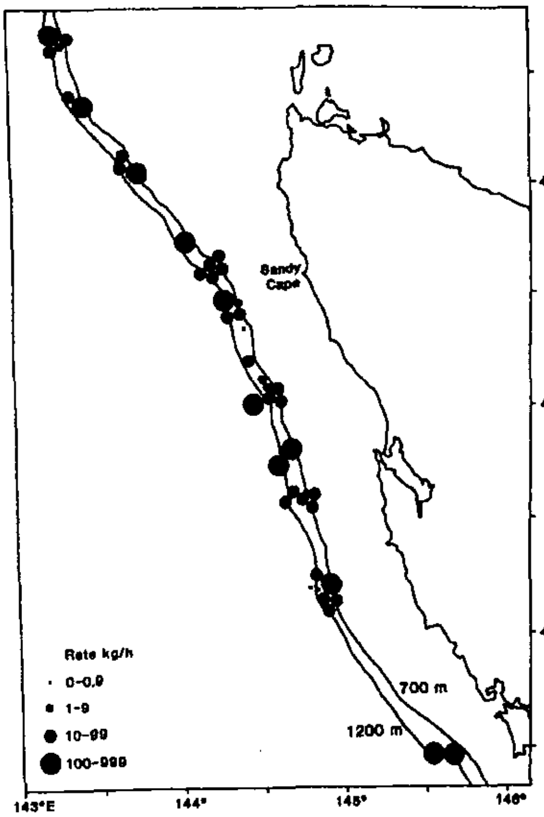

Figure 5: Catch rates of orange roughy (kg/h) from the west coast of Tasmania during SO2/88 (March–April), including tows from depths greater than 1200 m.

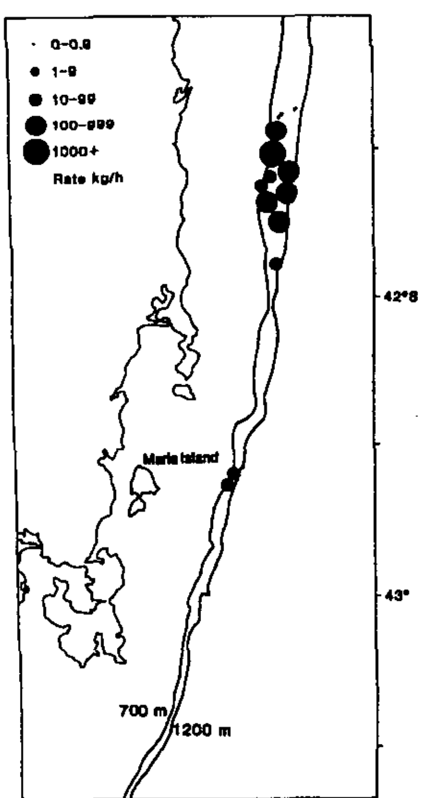

Figure 6: Catch rates of orange roughy (kg/h) from the east coast of Tasmania during SO2/88 (March–April), including tows from depths greater than 1200 m.

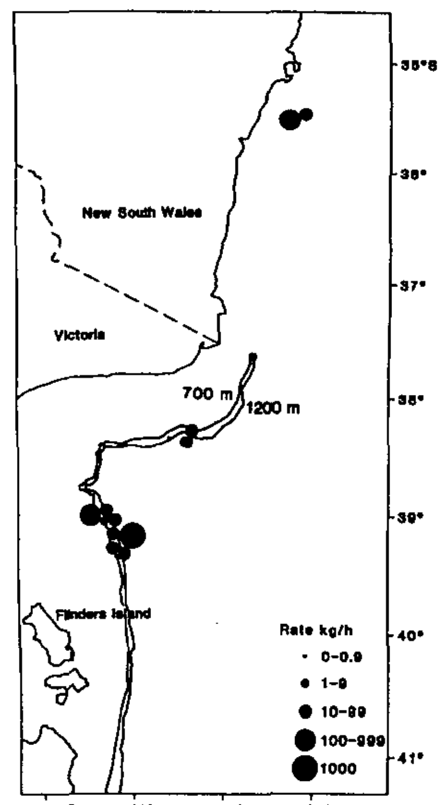

Figure 7: Catch rates of orange roughy (kg/h) from eastern Bass Strait and New South Wales during SO3/88 (May), including tows from depths greater than 1200 m.

1989

Three cruises were made in the 1989 survey: SO1/89 (January–February) Kangaroo Island to west of Portland; SO2/89 (March) west of Portland to Low Rocky Point (west Tasmania); and SO3/89 (April–May) east coast of Tasmania and north-east of Flinders Island (east Bass Strait). About the same proportion of stations were completed as in the 1988 survey (Table 2).

The catch rates were, again, generally under 100 kg/h (Figs 8–11). One large catch was taken from an area east of Bicheno (east coast of Tasmania, Fig. 11), which was later commercially exploited. FRV *Soela* made further tows through the aggregation (Elliott and Kloser 1993).

Table 2: *Results of the 1989 CSIRO survey. (see Figure 2 for strata locations)*

Stratum	from	to	Area (km^2)	Stations planned	Stations trawled	%
A	136° 00' °E	137° 37' °E	709	24	9	38
B	137° 38' °E	138° 25' °E	505	17	4	24
C	138° 26' °E	138° 48' °E	459	15	11	73
D	138° 49' °E	139° 08' °E	453	15	15	100
E	139° 09' °E	139° 41' °E	561	19	14	74
F	139° 42' °E	141° 29' °E	690	23	15	65
G	141° 30' °E	142° 40' °E	601	20	14	70
H	142° 41' °E	40° 11' °S	550	18	1	6
I	40° 12' °S	40° 53' °S	480	17	14	82
J	40° 54' °S	41° 32' °S	437	15	17	113
K	41° 33' °S	42° 15' °S	457	15	15	100
L	42° 16' °S	42° 56' °S	451	15	14	93
Q	42° 23' °S	41° 31' °S	552	18	9	50
R	41° 30' °S	41° 02' °S	494	16	2	13
Total			7 399	247	154	62

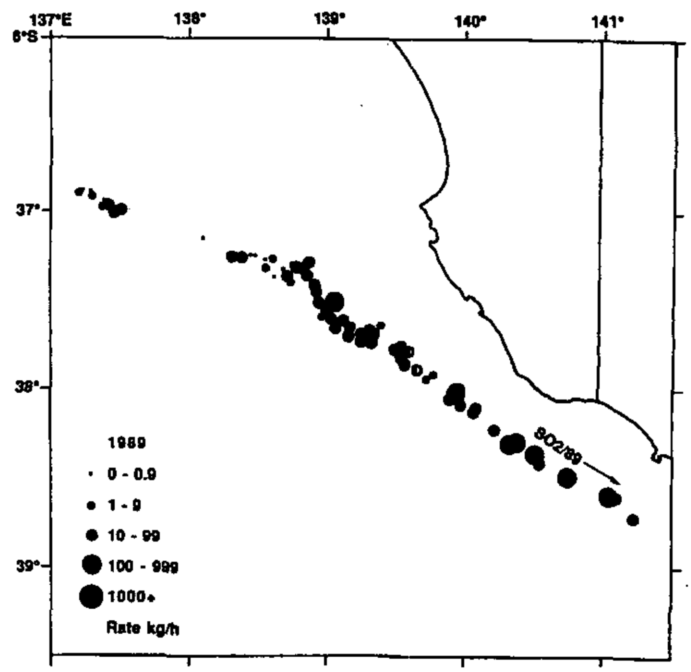

Figure 8: Catch rates of orange roughy (kg/h) from Kangaroo Island to Portland area during SO1/89 and SO2/89 (January–March).

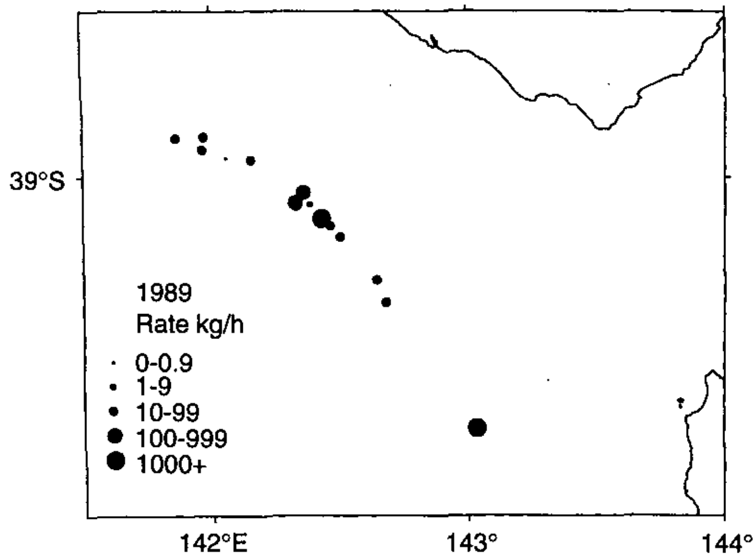

Figure 9: Catch rates of orange roughy (kg/h) from Portland to King Island during SO2/89 (March).

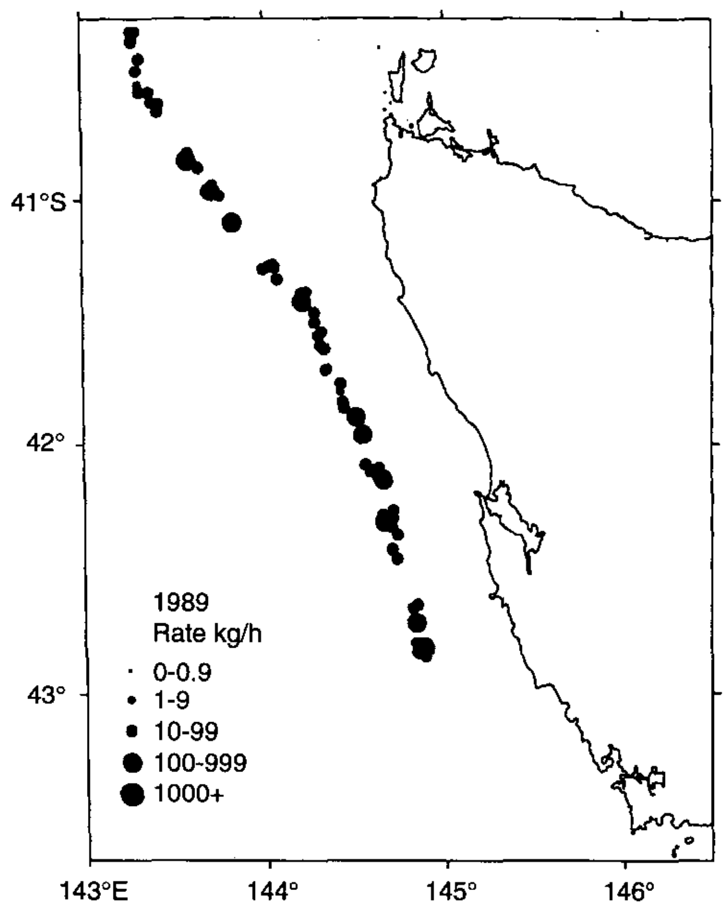

Figure 10: Catch rates of orange roughy (kg/h) from the west coast of Tasmania from King Island to Low Rocky Point during SO2/89 (March).

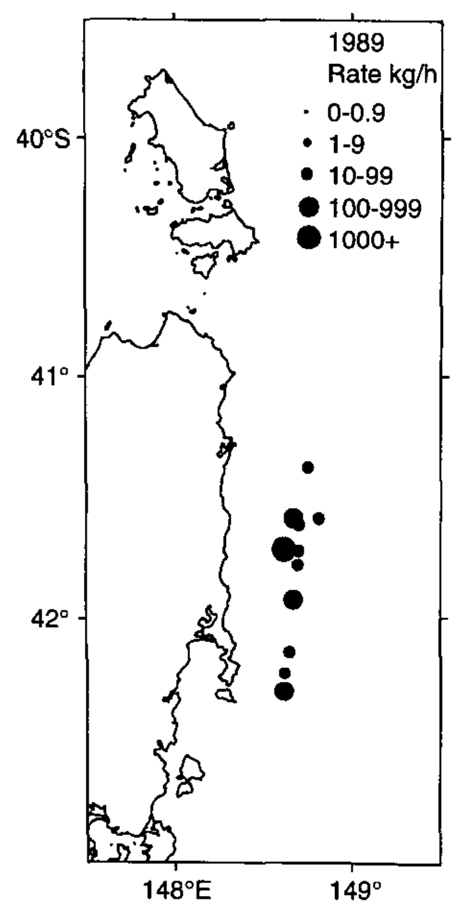

Figure 11: Catch rates of orange roughy (kg/h) from the east coast of Tasmania during SO3/89 (April–May).

Estimation of index of abundance

To obtain enough stations in each stratum to estimate variance, 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 were the same as in 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 Scanmar unit available could not monitor below 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, the 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 aij 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 (minutes bottom time) x 1/60 x 0.019 (wing spread in km).

The mean catch rate and standard error were 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 overall abundance index 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:

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

Although sub-areas were combined to obtain enough stations in each stratum, there were too few stations trawled at 800 m depth in Area 5. As there was no reason to assume that this 800 m depth stratum was different from any other 800 m stratum, or from the other strata in Area 5 except possibly the 700 m stratum, its mean and standard error were estimated from the catches at all the stations in the 800 m depth strata, and all stations from all depth strata in Area 5:

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

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, so the standard error was estimated from all other stations in the 700 m depth stratum of the entire survey. (The catch rates of the 700 m stations generally appeared to be different from the catch rates in deeper strata.) Similarly the standard error of the 1100 m stratum in the 1989 survey in Area 6 was estimated from all other stations in the 1100 m depth stratum of the survey, as well as all stations in the 900 m and 1000 m depth strata in Area 6. (The stations in the 800 m stratum were not used because of the presence of the one large catch.)

To make a conservative estimate of the abundance index we made the following assumptions:

1 The accessibility of the fish to the net was 100% (i.e., there were no fish above the headline and no fish moved in or out of the survey area or between depths during the survey).
2 The vulnerability of the fish was 100% (i.e., no fish escaped from or avoided the net and the effective path swept was equal to the measured wing spread).

The high catch rates from three tows off Beachport (South Australia) in 1988 produced high mean catch rates with large variances for the corresponding strata (Area 1, 900 m and 1000 m strata; see Tables 3 and 4). To reduce the variance, the area associated with the high density of orange roughy was treated as a separate stratum, effectively reducing the area to which a high mean catch rate of fish could be attributed. Two area sizes for the extra stratum were used; A. an area of 277.7 km^2, which was defined by the area of commercial exploitation during the weeks after *Soela's* find, and B. an area of 60 km^2, which was defined as the immediate vicinity of the *Soela* catches. The mean catch rates of orange roughy for Area 1 were recalculated using the two alternative areas for the aggregation (Table 5).

The overall abundance index for the area surveyed in 1988 was calculated using the original design strata and the two alternative treatments of the additional stratum in Area 1 for the Beachport aggregation (Table 6).

Table 3: Mean catch rates of orange roughy per stratum in the 1988 survey. (S.E. = standard error; catch rates in kg/km²)

Stratum	Depth (m)	Area (km²)	Number of stations	Catch rate Mean	Catch rate 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 in the 1989 survey and for the comparable areas in 1988. (S.E. = standard error; catch rates in kg/km^2).

		1988				1989		
Stratum	Depth (m)	Area (km^2)	Number of stations	Catch rate Mean	Catch rate S.E.	Number of stations	Catch rate Mean	Catch rate 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*	4	1932.0	778.9
	1100	254.7	2	2373.0	1115.8	1	954.9	665.2*
Total		7164.8	102			154		

* estimated from other stations

A high mean catch rate and large variance was produced in the 800 m depth stratum in Area 6 of the 1989 survey due to the one large catch from a relatively small aggregation of fish (Table 4). To refine these results the site of the aggregation was treated as an extra stratum. Only one survey tow was in this stratum but a mean catch rate and standard error for the stratum were calculated using the results of 5 additional tows by *Soela* through the aggregation of fish. The mean catch rates of orange roughy for Area 6 were recalculated using this extra stratum (Table 7).

The 1989 mean catch rates produce abundance indices for the area surveyed in 1989 similar to those of the previous year for the same area of ground (Table 8). The 1989 abundance index was calculated using both the original design strata and with the addition of the extra stratum in Area 6 for the site of the aggregation.

Table 5: Recalculated mean catch rates of orange roughy for Area 1 in the 1988 survey, following the allocation of the Beachport aggregation as a separate stratum. Alternative treatment of the aggregation stratum based on: A. the commercial exploitation area, and B. the *Soela* survey area. (S.E. = standard error; catch rates in kg/km^2)

Treatment	Stratum	Area (km^2)	Number of stations	Catch rate Mean	S.E.
A	700 m	301.4	5	0	0
	800 m	388.4	7	46.5	22.5
	900 m	233.3	3	357.2	287.3
	1000 m	248.4	4	43.3	30.1
	1100 m	289.3	3	167.6	128.5
	aggregation	277.7	8	22261.3	11774.2
B	700 m	301.4	5	0	0
	800 m	382.4	7	46.5	22.5
	900 m	364.6	6	681.2	389.1
	1000 m	346.8	5	59.0	28.1
	1100 m	283.3	3	167.6	128.5
	aggregation	60.0	4	43738.3	18414.7

Table 6: Abundance indices (tonnes) of orange roughy for the area surveyed in 1988, using the original strata and two alternative treatments of the extra stratum (as in Table 5) for the aggregation fished off Beachport (South Australia). (S.E. = standard error)

Treatment of strata	Abundance indices Mean	S.E.	95% confidence limit (%)
Original strata	23 833	6 764	55.6
A. Extra stratum - Commercial fishing area (278 km^2)	21 209	5 562	51.4
B. Extra stratum - *Soela* survey area (60 km^2)	17 825	4 635	51.0

Table 7: Recalculated mean catch rates of orange roughy for Area 6 in the 1989 survey, following the allocation of a separate stratum to the site of the one large catch. Mean and standard error for the aggregation stratum were calculated using the one survey tow and 5 additional tows through the aggregation. (S.E. = standard error; catch rates in kg/km^2)

Stratum	Area (km^2)	Number of stations	Catch rate Mean	S.E.
800 m	250.2	2	875.7	640.0
900 m	289.8	3	372.1	146.5
1000 m	243.8	4	1932.0	778.9
1100 m	254.7	1	954.9	665.2
aggregation	7.7	6	36648.2	18761.6

Table 8: Comparison of the 1988 and 1989 abundance indices (tonnes) of orange roughy from the area surveyed in 1989. Three treatments of the 1988 results are presented as in Tables 5 and 6 and two treatments of the 1989 results as in Table 7. (S.E. = standard error).

Year	Treatment	Abundance indices Mean	S.E.	95% confidence limit
1988	original strata	15 674	5131	64.2
1988	extra stratum - commercial area	13 049	3392	50.9
1988	extra stratum - *Soela* area	9 665	1 432	29.0
1989	original strata	11 127	4 742	83.5
1989	extra stratum - aggregation	7 406	2 559	67.7

Discussion

The abundance indices obtained from the trawl surveys are very conservative because of the assumptions made. The assumptions seemed justified, however, because so little is known about how a trawl net samples fish populations or how orange roughy behave. Obviously, fish can be expected to move in and out of the survey area, to be stacked above the net (particularly in aggregations) and to escape or avoid the net. Measurement of these factors was beyond the scope of these surveys, however some advances were made.

Experiments indicated there was little or no escapement, at least with the catch rates encountered during the surveys. A camera on the headline of the net provided us with good pictures of roughy in an aggregation, but whether the fish were avoiding the net was difficult to ascertain. How the net actually performs (the width of path it sweeps, how long it is on the bottom etc.) would affect estimates, although modern net monitoring devices now provide useful data. Measurements of wing spread, door spread and headline height gave us the best possible information on the trawl net's performance.

The confidence limits of the 1988 estimates at ±50% is probably fairly accurate, given the effect on sampling variability of densely clustered aggregations. The 1989 results, on the other hand, were disappointing because the 95% confidence limits were greater than those for 1988 despite the lack of any major aggregation being encountered during the survey.

Poor precision was a result of the variability in catch rates caused by a few large catches. In 1988, two large catches of fish were made, apart from the "Beachport" catches: one from the east coast of Tasmania 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". The latter catch comprised small fish (<30 cm), unlike the usual size composition of the 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 the one large catch east of Bicheno (Area 6, 800 m). As we could not estimate the area covered by these denser populations, the tows were retained in their original strata and not treated separately. Because of this, the mean catch rates of these strata may be overestimated, which would inflate the abundance indices. This situation highlights 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 1987 survey of the Challenger Plateau orange roughy fishery gave estimates with coefficients of variation between 18 and 47% (Clark and Tracey, 1988). The 95% confidence limits of these estimates are then ±35% and ±92% respectively, a range within which our confidence intervals fall. The 90% confidence limits obtained from a survey off the western United States of rockfish, which have similar patterns of distribution as roughy, were typically between ±30 and 150% (Gunderson and Sample, 1980).

Clark (1988) concluded that trawl surveys of fish such as orange roughy 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 estimates of overall biomass (Robertson, 1989); the Chatham Rise population is currently estimated at about 20% of the virgin biomass and is apparently decreasing.

The validity of extrapolating abundance values from areas suitable for conducting a trawl survey to those unsuitable was a major problem in our survey. It was highlighted by the discovery of a spawning aggregation of orange roughy off the Tasmanian east coast shortly after the 1989 survey. The fish aggregated about a pinnacle in an area which had been excluded from our survey because the nature of the bottom would render a tow invalid for the purposes of the survey. About 17 000 tonnes were caught over three months from the pinnacle; our abundance index of the east coast area for 1989 was between 1300 and 5000 tonnes, which was considerably less. Since the practice of extrapolation was questionable, the areas not surveyed were excluded from the calculations or comparisons of abundance. Another area we were unable to survey because of the nature of the bottom was off Maatsuyker Island and Pedra Branca (southern Tasmania), a centre of commercial activity since late 1989, which further highlights the impossibility of using a random trawl survey to accurately assess fish populations commonly found on rough or steep sloping ground.

Despite the obvious inadequacies of the trawl surveys, they provided an initial assessment of a major part of the Australian population of orange roughy. Future surveys will need to be refined and combined with other stock assessment techniques, such as acoustic assessments (Do and Coombs, 1989; Elliott and Kloser, 1993) and egg production assessments which are more suitable for aggregating stocks of fish. These methods should prove more beneficial for the expanding orange roughy fishery as commercial fishing effort is now targeting predominantly on the large aggregations of fish found around pinnacles and other bottom features rather than relying on long tows over relatively smooth trawlable grounds. With this maturity of the Australian orange roughy fishery the ability to provide prompt, reliable and accurate biomass assessments of these aggregations is of paramount importance. Whilst the use of such technology as deepwater acoustics will enable such assessments to be made, trawl surveys will still be required as a means of monitoring general trends in the population and of gathering information on stock parameters.

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Orange Roughy Surveys, 1988 and 1989;
Part B:
Biological Data

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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. Before 1988, stock size had not been estimated by 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 in the South East Trawl management area. We conducted a comprehensive survey of the area in 1988 and 1989 with the following objectives:

- to assess the abundance and distribution of orange roughy in the south-eastern waters of Australia
- to obtain biological information on orange roughy to help determine the stocks, their size (and age) composition and reproductive strategies.

This report summarises the biological data obtained during the surveys. Details of the survey design and the abundance indices are described in part A.

Methods

Survey design

The survey was of a random depth-stratified design (part A). 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 at 100 m intervals (Fig. 1). No prior knowledge of fish densities was assumed, so the number of stations allocated to a stratum was proportional to the area of the stratum.

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 and 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).

Standard survey tows were of 30 minutes' duration (bottom time) within specified 100 m depth stratum. 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, 1994). 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 of Tasmania 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.* (1992) 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.*, 1992; Bulman and Koslow, 1992).

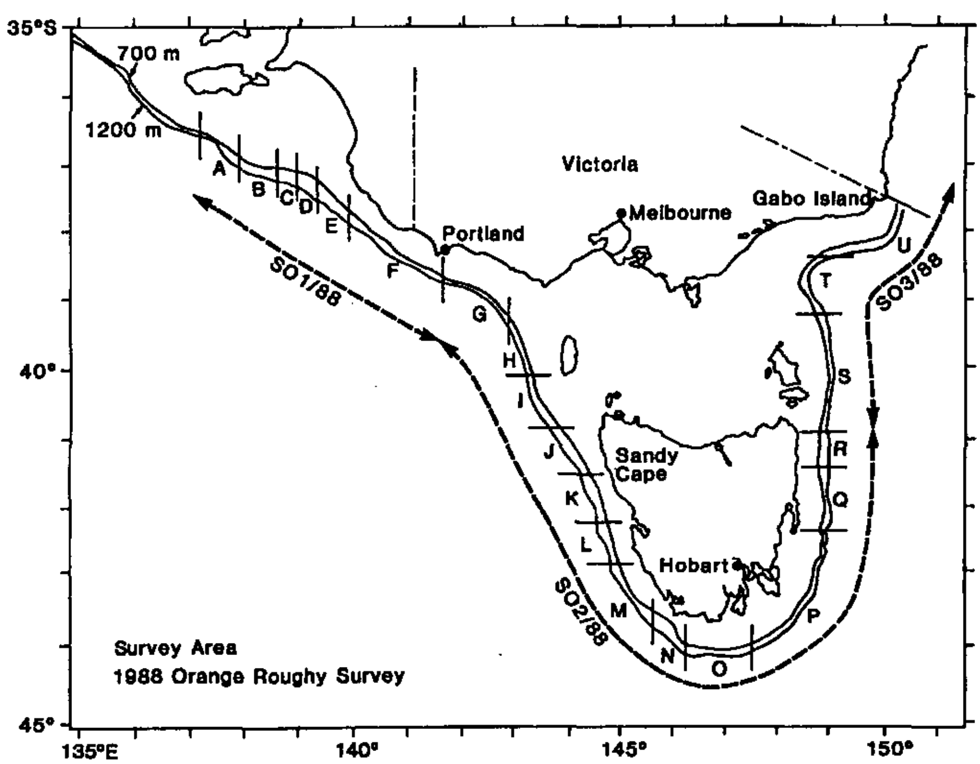

Fig: 1. Survey area.

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 northeast coast Tasmania; and SO3/88 (May) east coast Tasmania to Gabo Island (NSW) and southern NSW. In all 169 stations were completed: 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. 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 northeast of Flinders Island. Of the 168 tows, data from 167 tows were used. The survey results and abundance estimates are reported in Part A.

Results

A total of 6964 fish were caught in the two years; 4462 from 1988 and 2502 from 1989.

Reproductive biology

The sex ratio in most areas was 1:1; however, on the east coast of Tasmania 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, advanced gonadal development was not widespread at the time of sampling. The west Tasmanian fish were sampled in March and were maturing at 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 matured at 32 cm (Fig. 3a) and the males 30 cm (Fig. 3b), as in 1987 (Bulman and Elliott, 1994). Sample sizes in the east Bass Strait and New South Wales areas were too small to make reliable estimates.

Gonosomatic indices (GSI) are plotted against length 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 GSIs of mature males and females were calculated for 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 main spawning period for orange roughy in Australia and New Zealand (Australian Fisheries, 1982; Evans and Wilson, 1987; Bell *et al.*, 1992; 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.

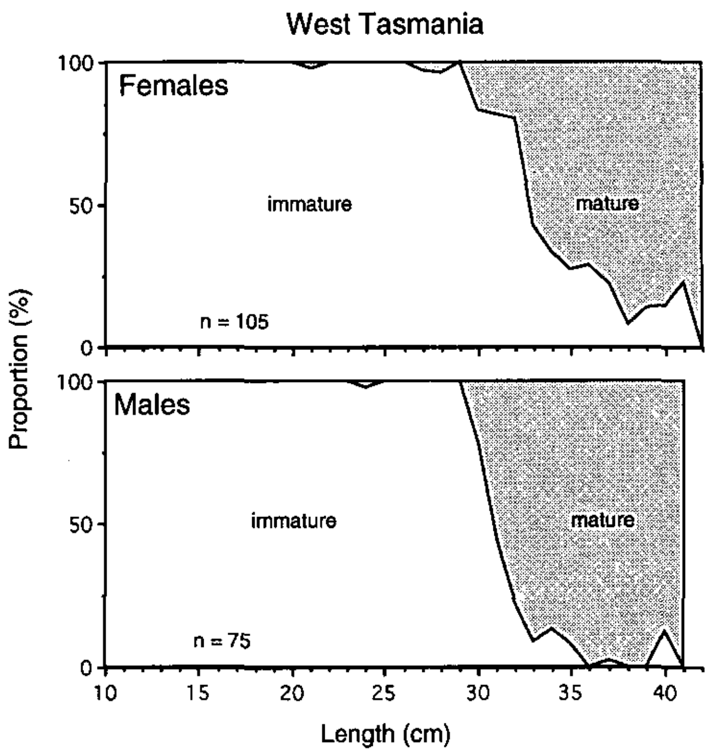

Fig. 2. Proportion of mature vs. immature fish for (a) female and (b) male orange roughy from west Tasmania over 1988 and 1989.

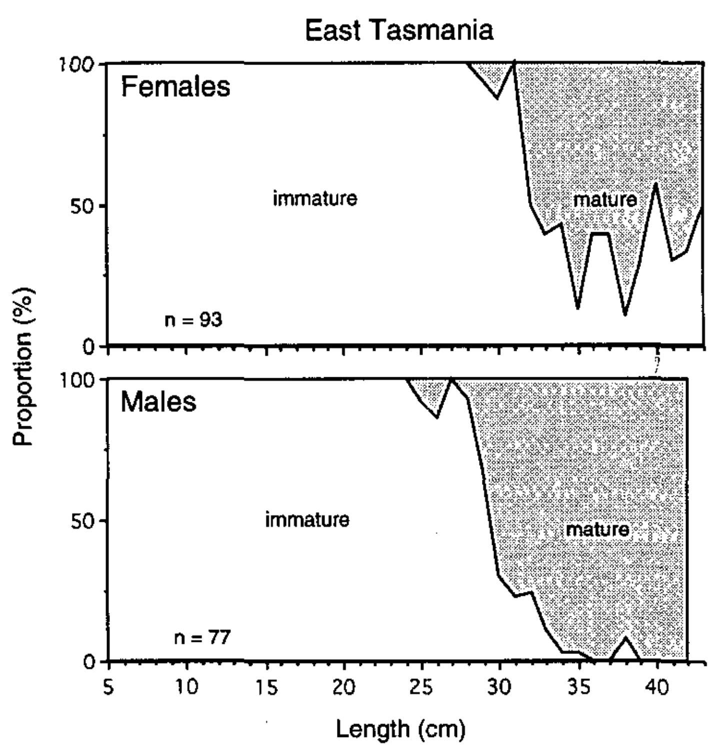

Fig. 3. Proportion of mature vs. immature fish for (a) female and (b) male orange roughy from east Tasmania over 1988 and 1989.

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 & western Bass Strait (GAB)						
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
Western Tasmania (WTas)						
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
Eastern Tasmania (ETas)						
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 (EBass) 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 proportions of maturing adult females (≥ 32 cm and ≥ stage 3) varied according to area and sampling month. In the GAB region in January and March, slightly more than half the females were in spawning condition in both years (Table 3). The proportion in western Tasmania was higher; 88.4% in late March 1988 and 67.3% in early March 1989. In eastern Tasmania, the proportions were similar to those of the western Tasmanian fish although sample sizes were small; 73.8% in early April 1988 and 57.9% in late April 1989. More advanced maturation was found in the July 1988 sample from the east coast; only 21% of females were at stage 3 but 68% were stage 4. No running ripe (stage 5) females were found — the spawning aggregation off St Helens had not yet been discovered. Only a quarter of NSW and eastern Bass Strait females caught in May 1988 were maturing.

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 GAB was about half in both years (Table 4). A large proportion of males from western Tasmania were at stage 2 in both years (88.6% and 89.4%). A slightly greater proportion of males from eastern 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). In contrast to the eastern Tasmanian fish, 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	-	6.2	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 also dominated by juveniles. However, the sample sizes in 1989 were less than 10% of those in 1988 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).

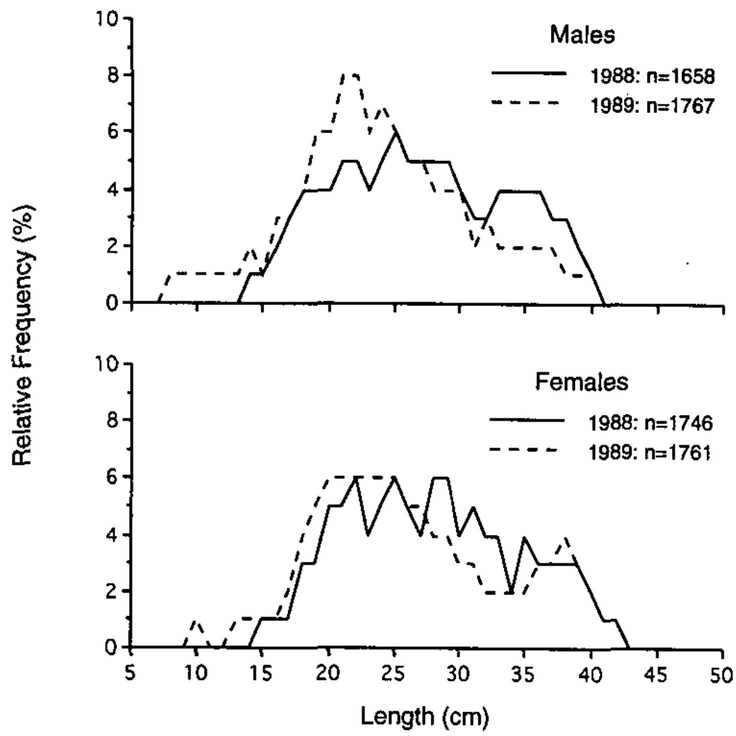

Fig: 4. Length frequency distribution of (a) male and (b) female orange roughy from the Great Australian Bight and west Bass Strait during 1988 and 1989.

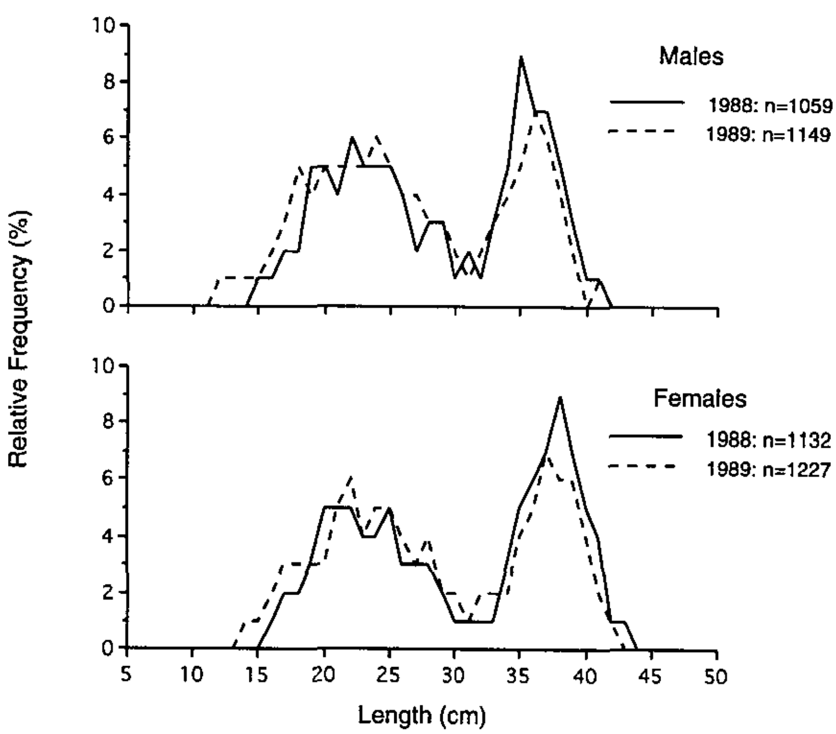

Fig: 5. Length frequency distribution of (a) male and (b) female orange roughy from the west Tasmania during 1988 and 1989.

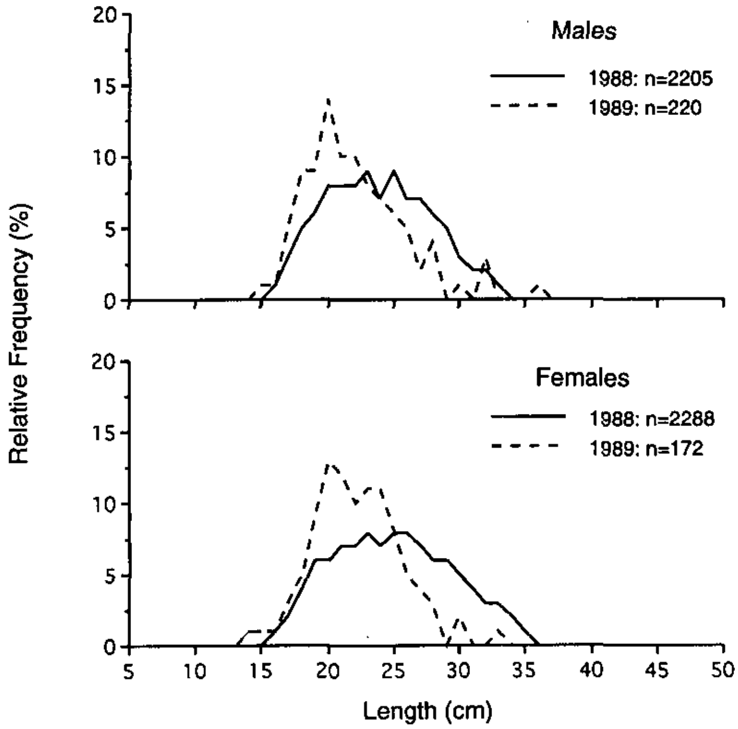

Fig: 6. Length frequency distribution of (a) male and (b) female orange roughy from the New South Wales and east Bass Strait during 1988 and 1989.

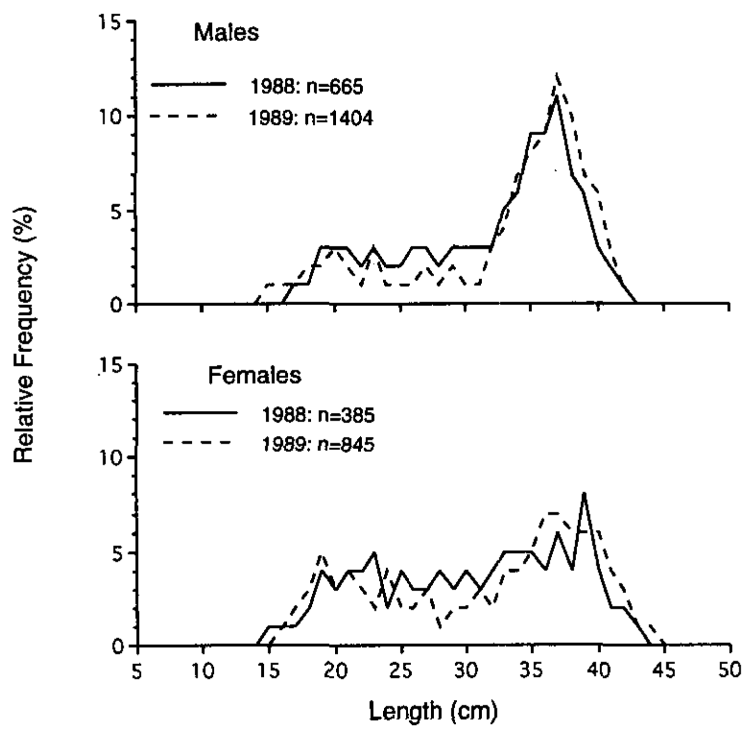

Fig: 7. Length frequency distribution of (a) male and (b) female orange roughy from the east Tasmania during 1988 and 1989.

Discussion

An interesting feature of the reproductive data was the proportion of adult females that had not progressed beyond stage 2 (stage 3 being the level of maturation beyond which spawning is presumed to definitely occur). 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 showed gonadal development.

The high proportion of non-reproductive females may be due to under-representation 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 not have been able to sample them. However, the Tasmanian Department of Sea Fisheries found that there were not large aggregations on the hill during March and May 1990 and that, 40-46% of the females they examined from the hill, showed no evidence of gonadal development. In July 1988 the proportion of non-reproductive fish had dropped to 10% 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 suggest that not all females reproduce every year. This was also supported by histological examination of gonad material collected from "non-reproductive" females (Lyle *et al.*, 1990; Bell *et al.*, 1992). Our data indicate 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. Surveys on the St Helens Hill conducted in March and May 1990 by Tasmanian Department of Sea Fisheries also found that males outnumbered females (Lyle *et al.*, 1990). As with the proportion of non-reproductive females, this inequality in sex ratios might also be a result of the unavailability of mature females during our sampling period. In contrast, other areas we surveyed showed little difference in length distribution between males and females and the sex ratio was about equal.

The length-frequency distribution exhibited by orange roughy was bimodal in all areas except the New South Wales and the eastern Bass Strait area. The Great Australian Bight length frequencies were dominated by juvenile fish. The modes of juveniles and adults in western Tasmanian distributions were nearly equal. The east Tasmanian distributions were bimodal but with the greatest proportion being adult males. Since seasonal data were not obtained for each area, we could not determine the extent to which regional differences were influenced by seasonal movements of fish stocks for spawning or feeding purposes. A 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 this species grows exceptionally slowly (Mace *et al.*, 1990) and may live over 50-70 years (Mace *et al.*, 1990; Fenton *et al.*, 1991), thus implying low natural mortality and low productivity (Mace *et al.*, 1990).

Variability in the proportion of females in reproductive condition might result in significant annual variation in the biomass of the now known spawning aggregation. Biomass estimations based on acoustic and egg production methods require an estimate of the proportion of non-reproductive fish (Saville, 1964). This proportion must be determined annually along with sex ratio and fecundity (Bell *et al.*, 1992). 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 that spawns on the east coast, management will need to be conservative to prevent overfishing.

Acknowledgments

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Appendix 1

GSI againt length (SL, cm) for male and female Orange Roughy for each cruise and/or area.Numbers represent gonad maturity stage (1-immature to 5-spent)

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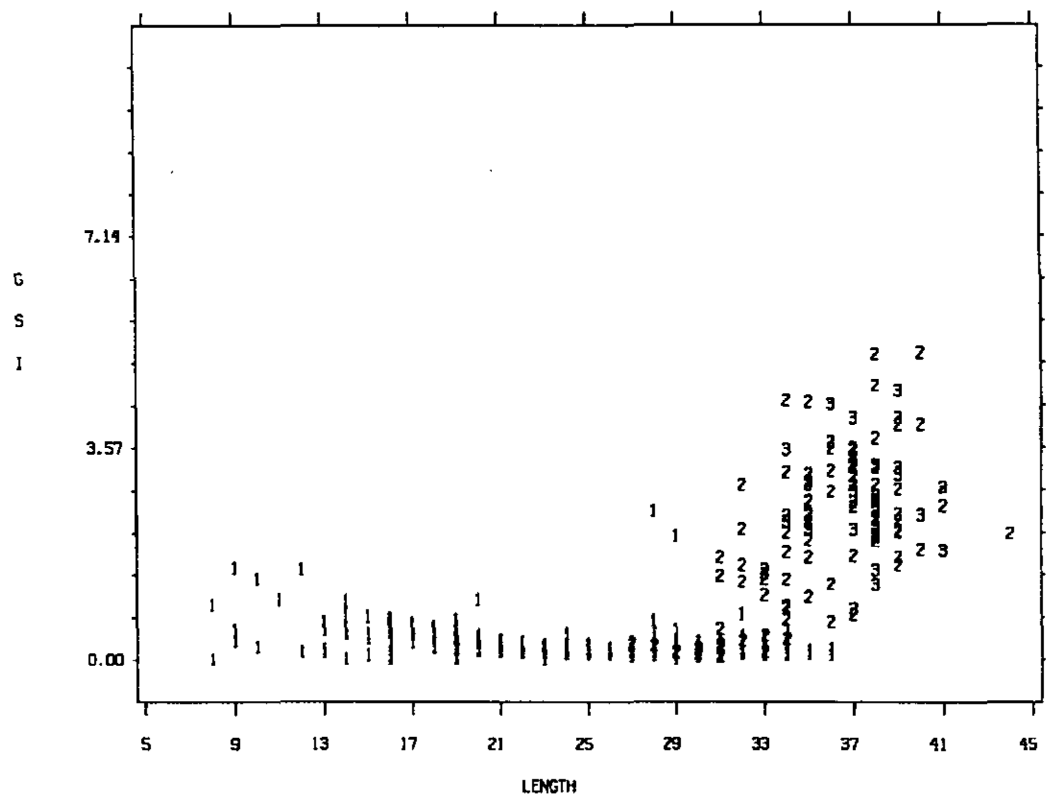

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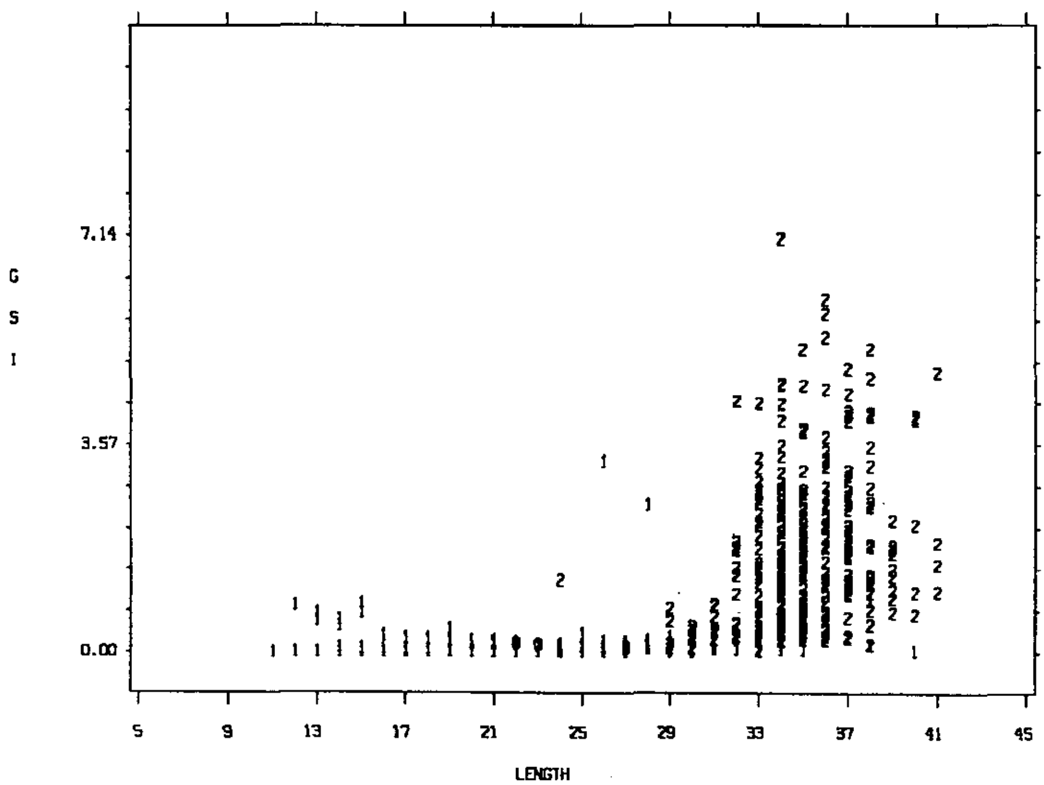

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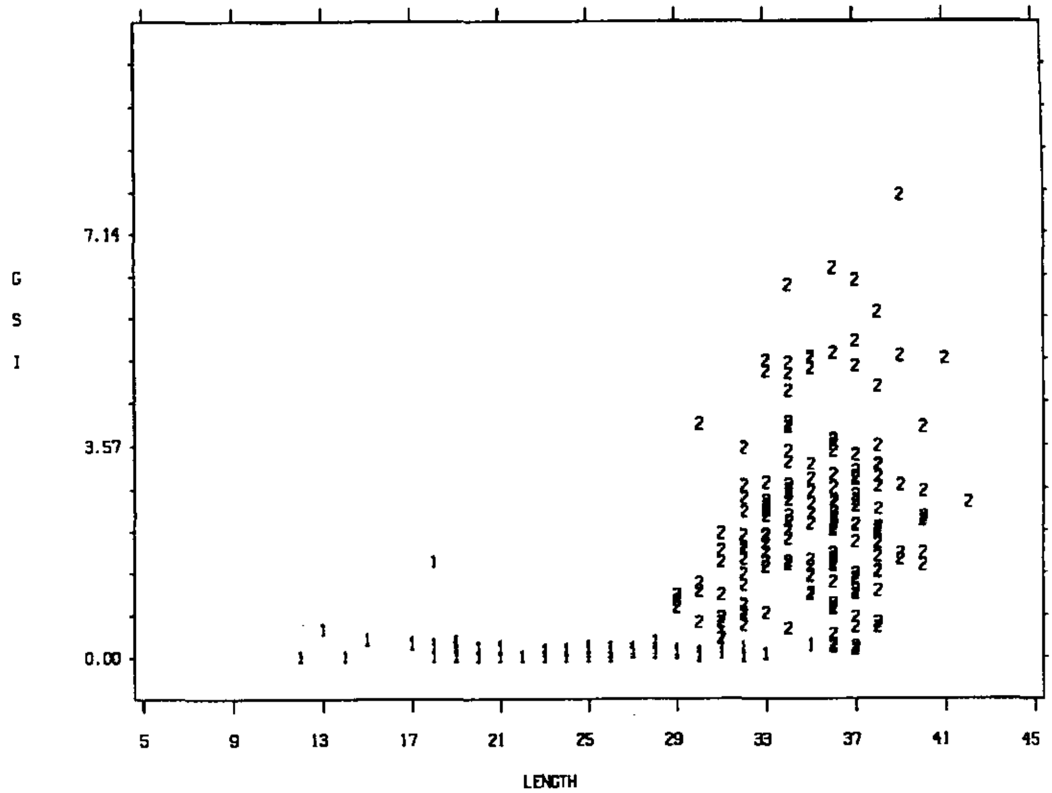

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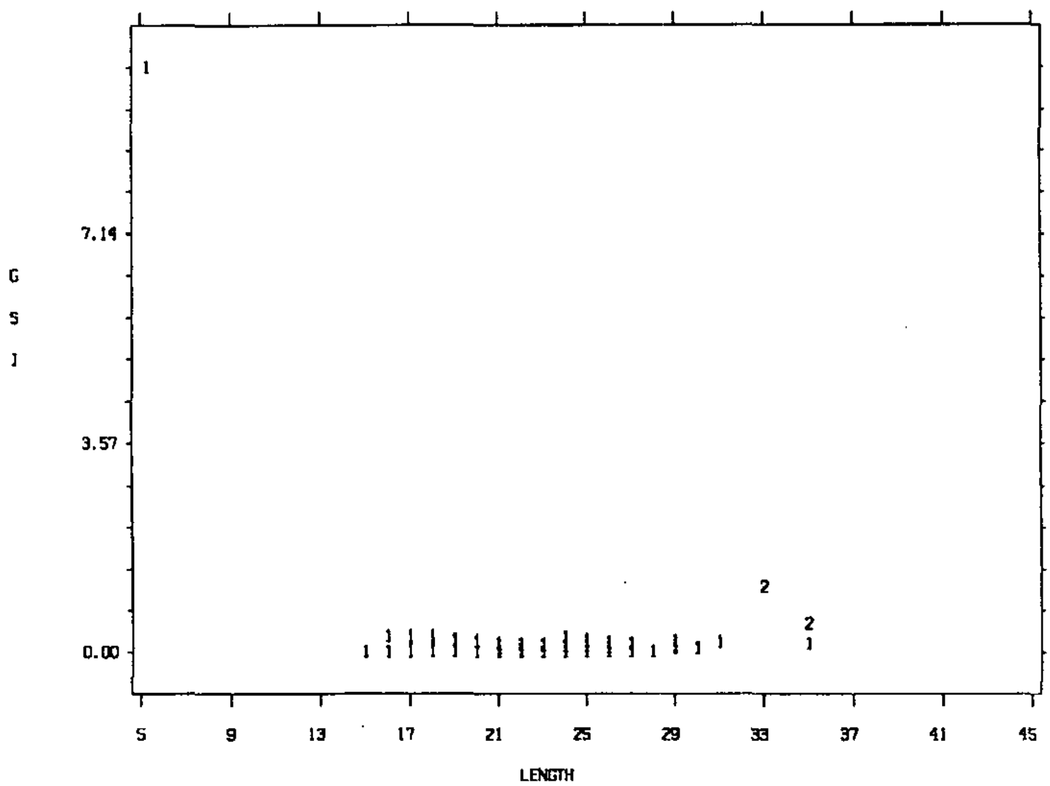

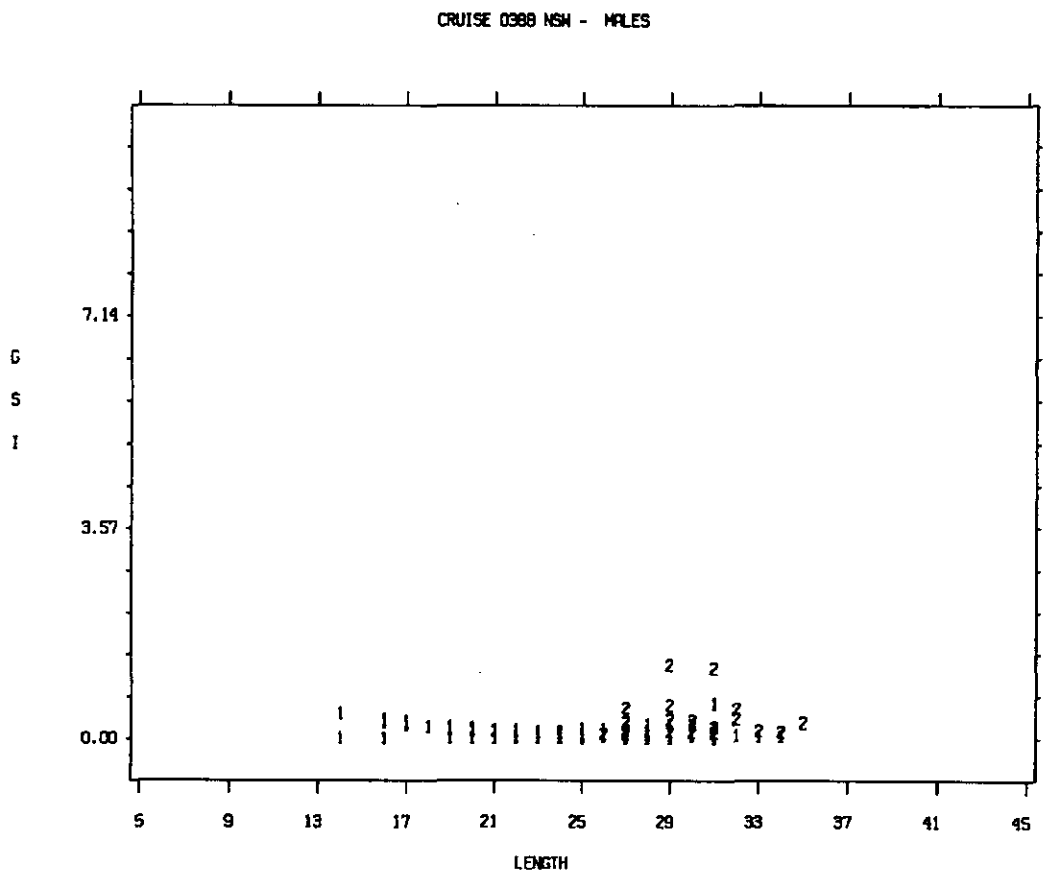
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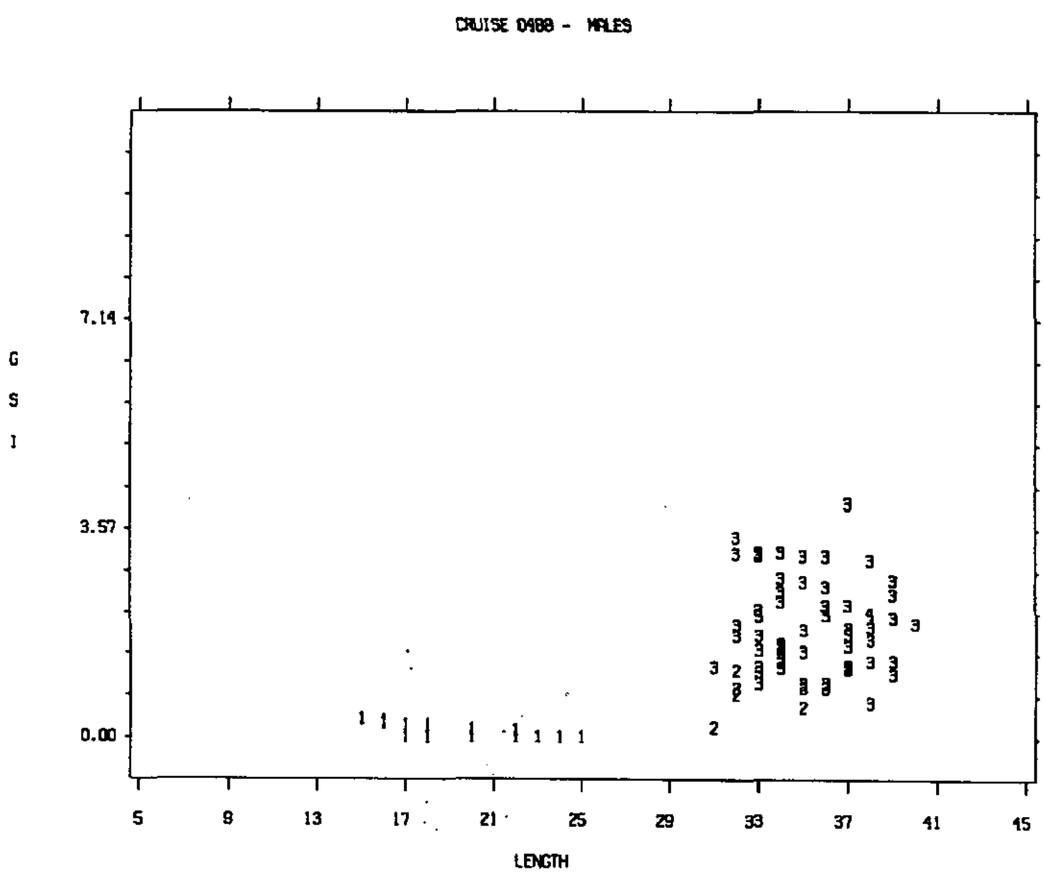
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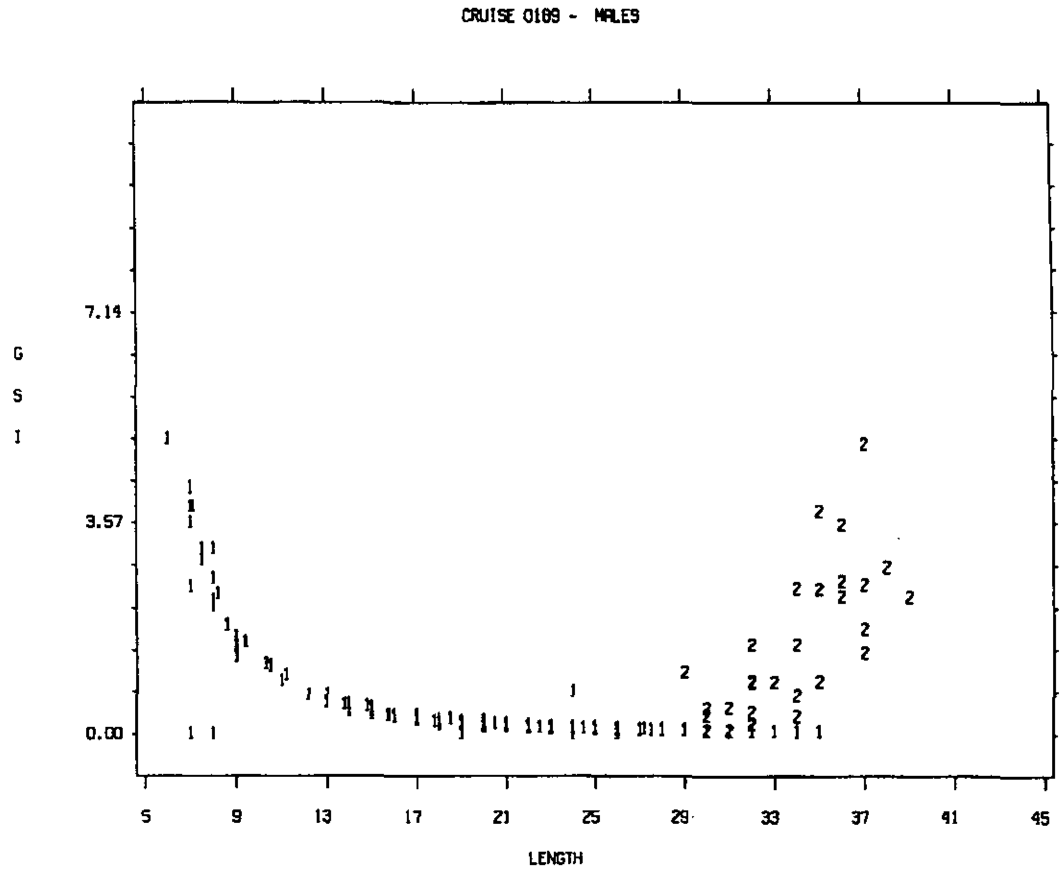
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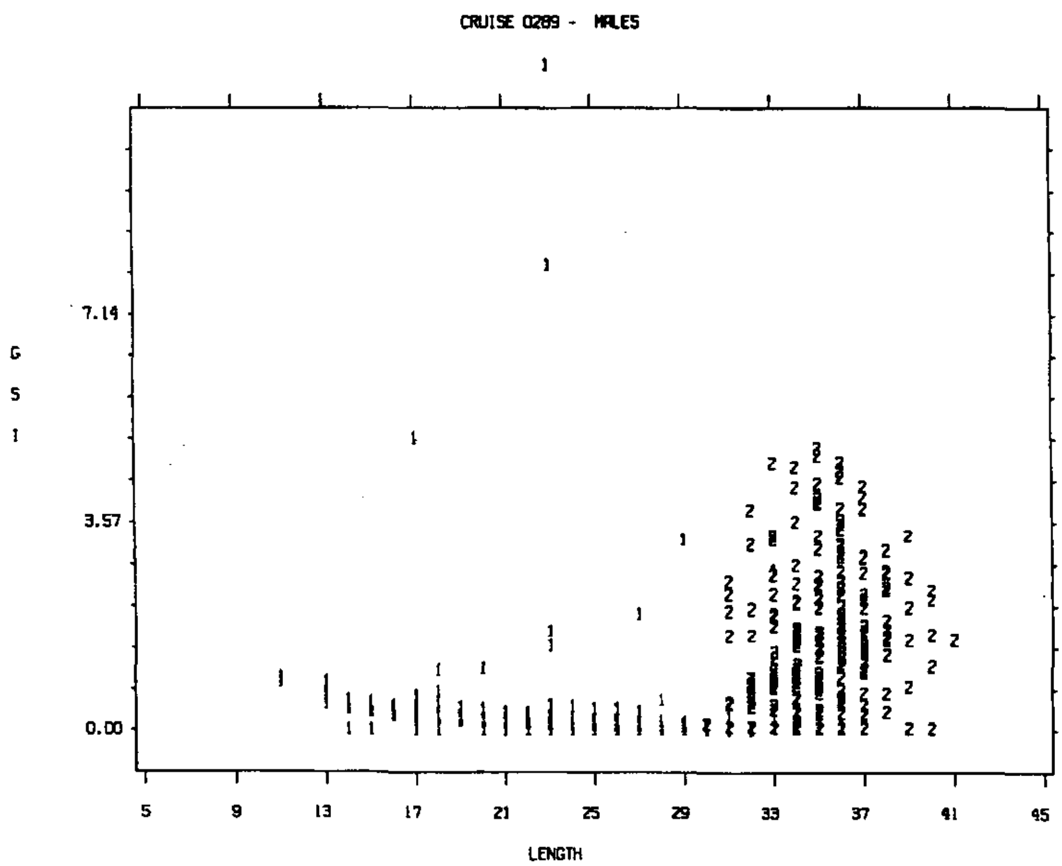
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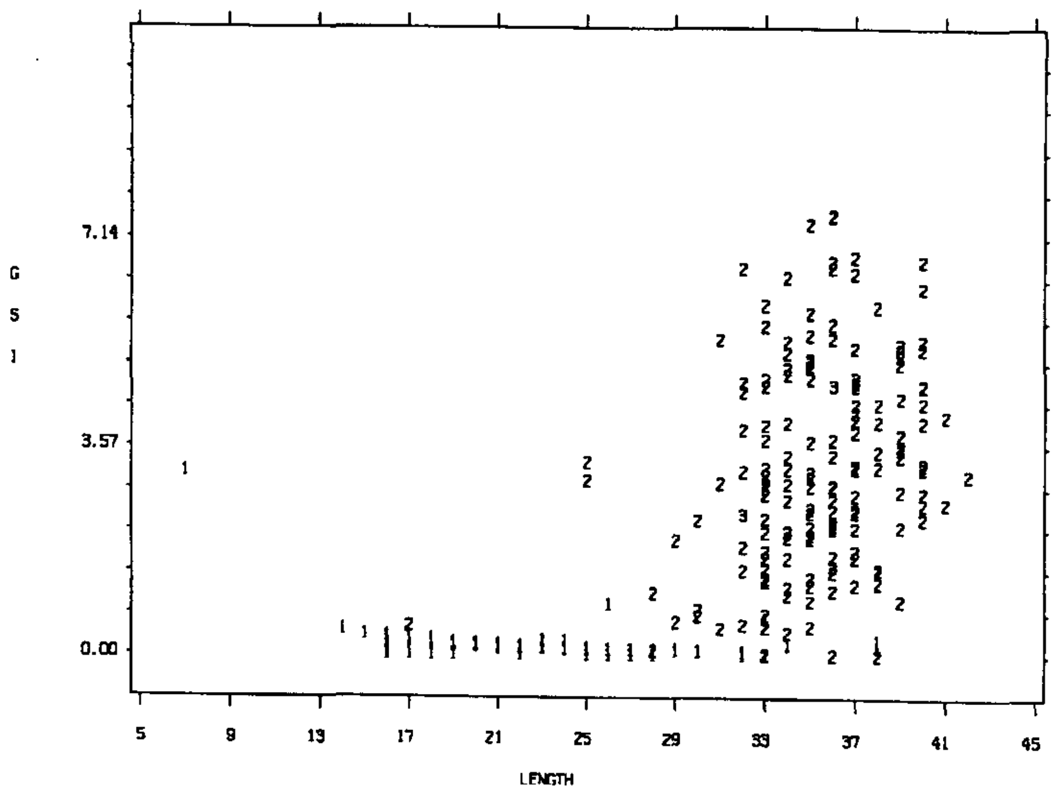

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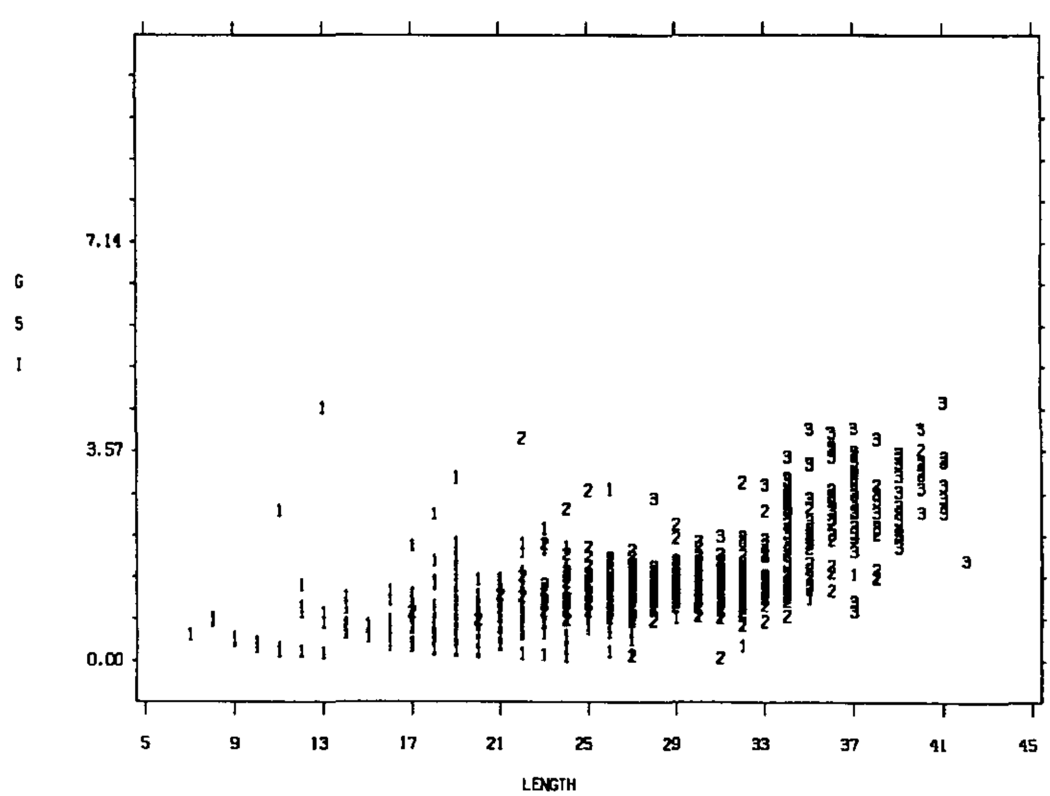

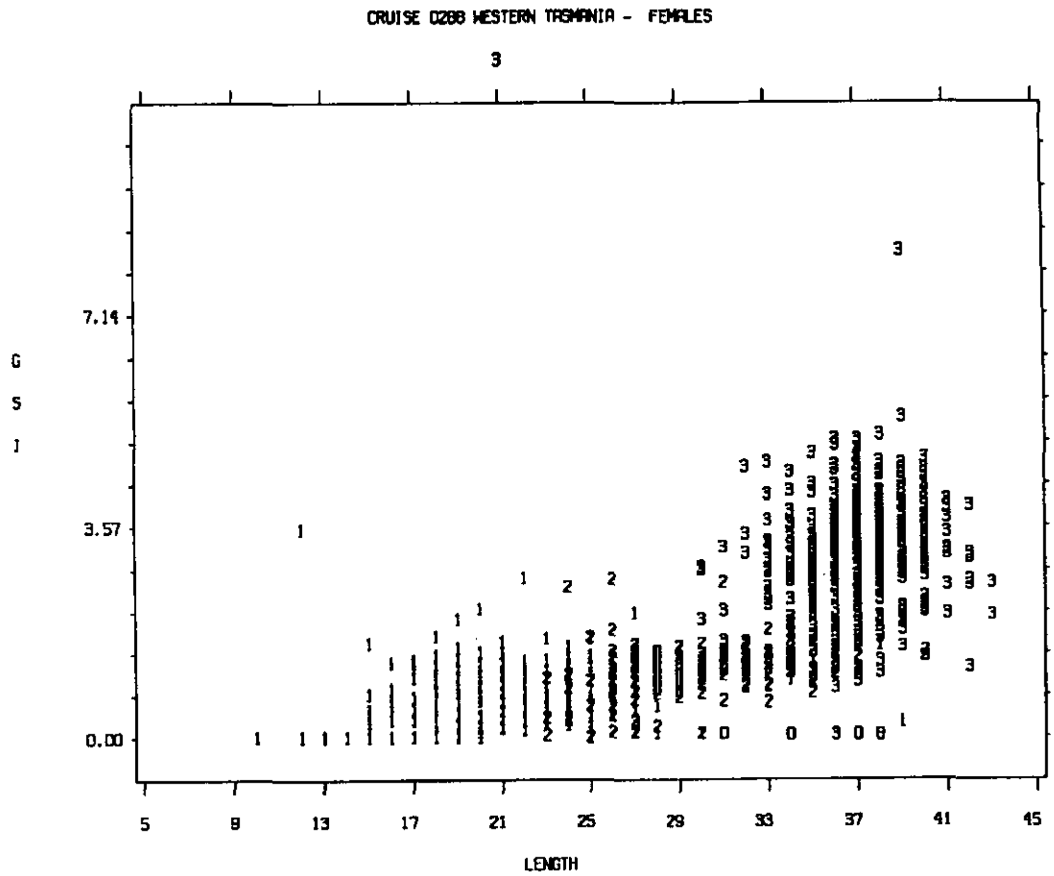
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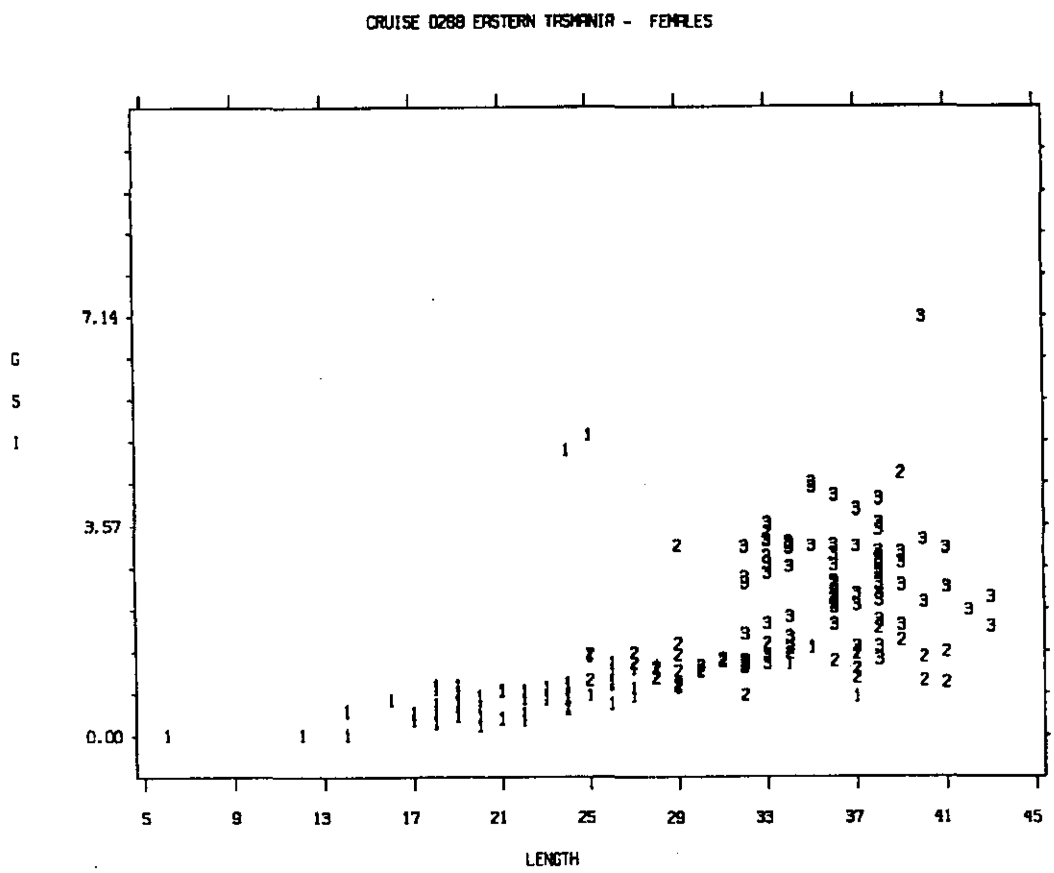
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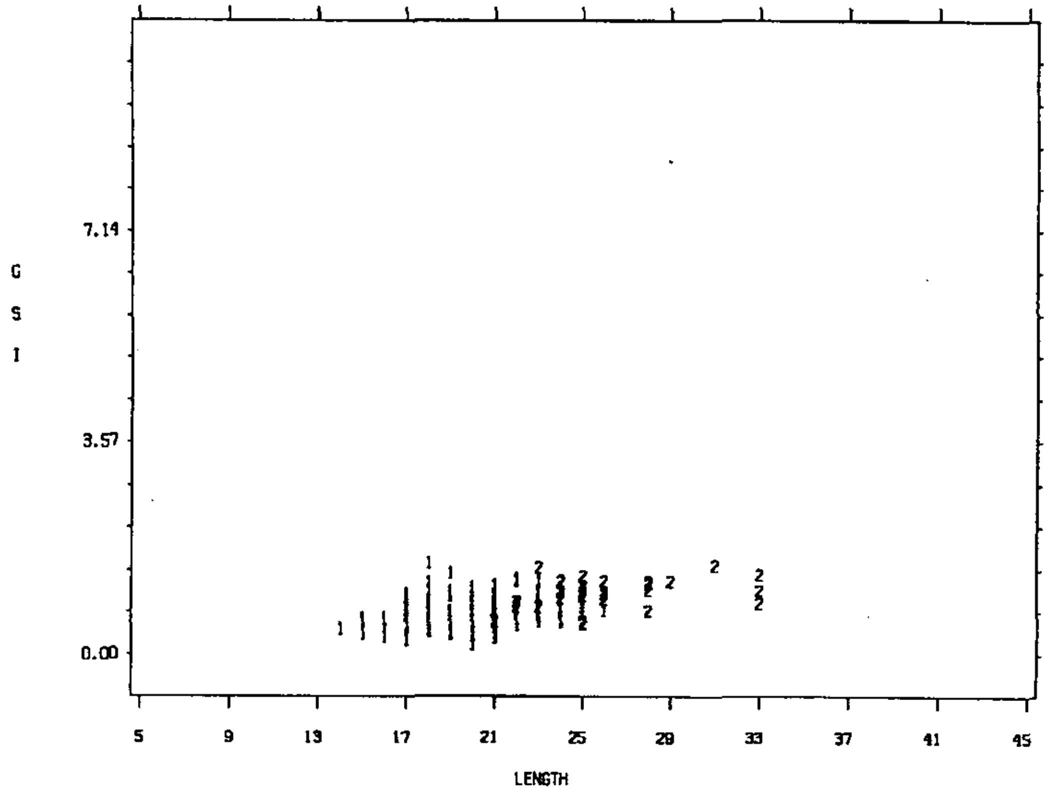

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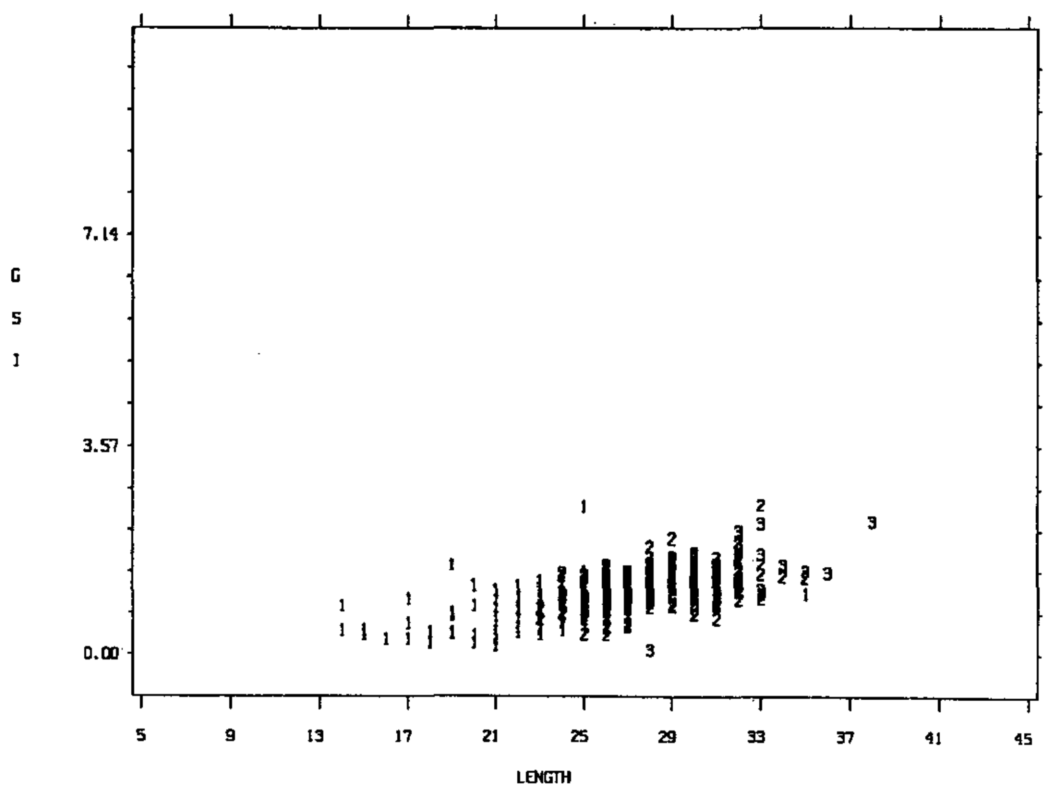

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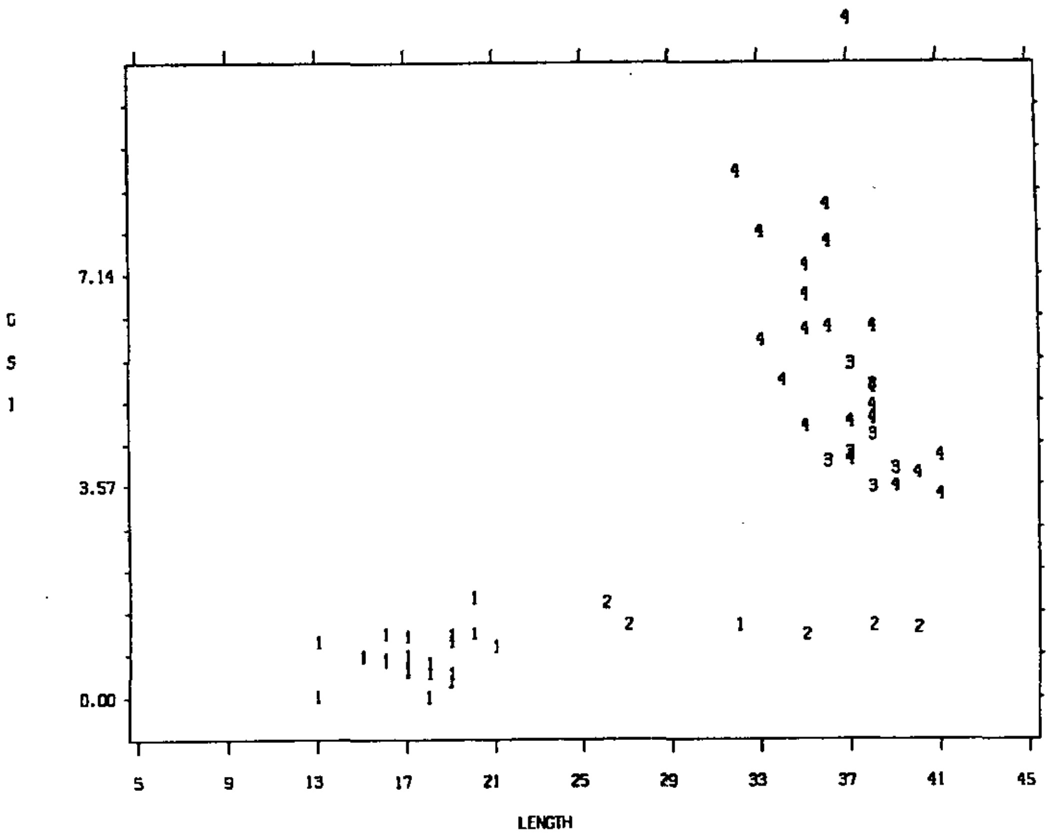

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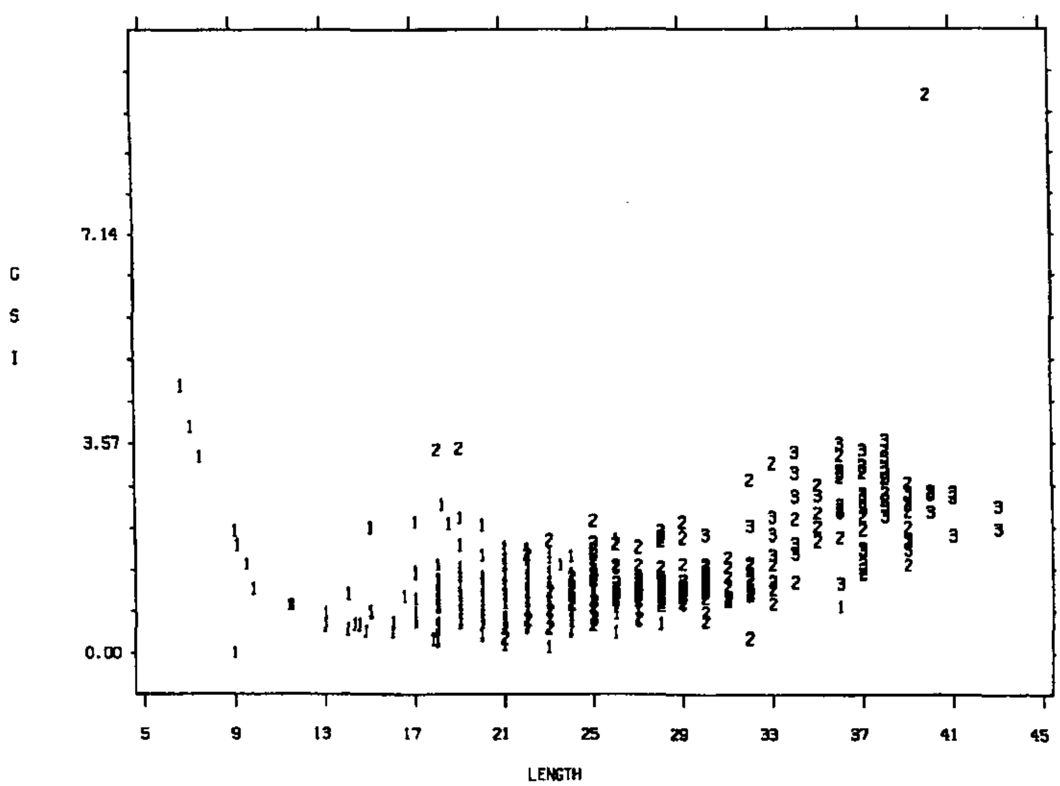

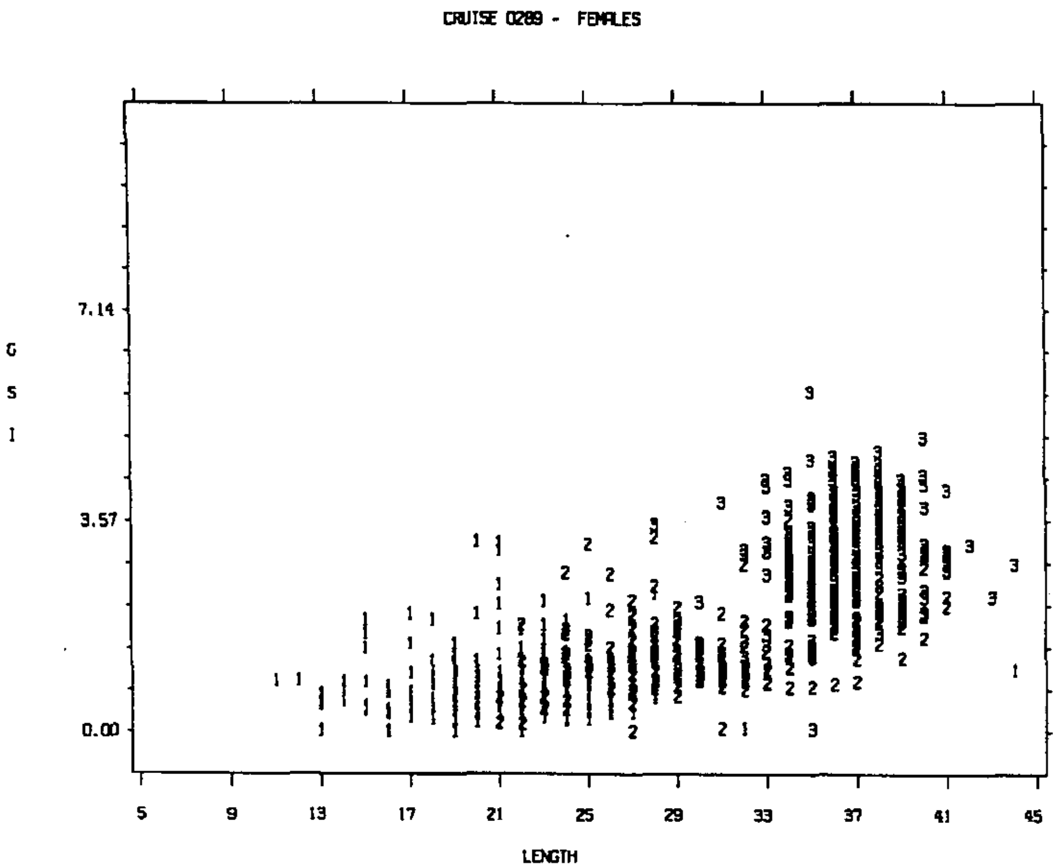
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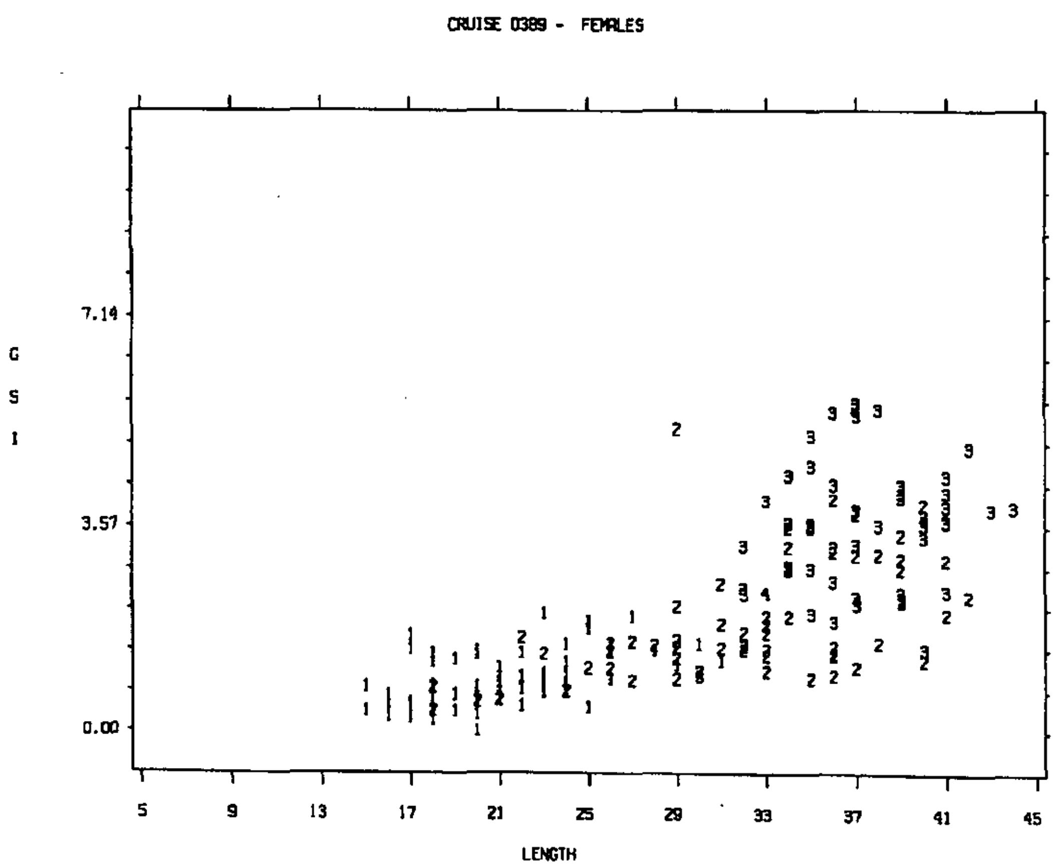
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