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THE DEVELOPMENT POTENTIAL OF THE SOUTHERN CALAMARY SQUID (*Sepioteuthis australis*) FISHERY

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Abstract: Biological investigations suggest a 12 month life cycle from hatching to spawning. Growth rates of adult calamary are in the order of 1 cm/month for females and 1.5cm/month for males. There are two major broods in the population, a summer brood and a winter brood which are spatially and temporaly separated.

The calamary fishery in shallow coastal waters is based on the spawning population, juvenile populations are found in deeper waters. Total mortality per month is around 0.4. The Leslie model provided estimates of original population abundance similar to the total catch taken for that period. A method for determining target calamary fishermen has been developed.

INTRODUCTION

Stock assessment and management of a resource requires detailed knowledge of the biology of the species at all stages of the life cycle. It is necessary to understand the biology of a species in order to properly use and protect its potential.

The objectives of this study were:

- To determine the life history of the southern calamary (*Sepioteuthis australis*) in detail.
- To calculate population abundance and the yield-effort relationship for the species.
- To establish the export potential of the species.

In South Australia the major fishery is conducted by marine scale fishermen in the shallow coastal waters of both Gulf St. Vincent and Spencer Gulf (<50 metres depth). A variety of methods are used (handline, jigs, nets). Prawn trawlers operating in the deeper waters of the gulf system take incidental catches of small, immature calamary.

Catch and effort data relating to calamary has been extracted from marine scale fishermen's monthly returns for the years 1976/77 to 1981/82. These data were originally analysed by 15 separate areas (see progress report December 1980), however subsequent analyses of the data has shown that these areas can be combined into 8 regions (fig. 1) on the grounds of the seasonal abundance of calamary.

LIFE HISTORY

1.0 REPRODUCTIVE CYCLE

It was difficult to study the full reproductive cycle of individuals in a region for two reasons. Regular sampling of the juvenile population found in the deeper waters of both gulfs was not possible. Once individuals migrate to the shallow onshore waters where they are taken by marine scale fishermen, they are approaching sexual maturity (Fig. 2). Secondly, towards the end of a fishing season in a region, it is difficult to obtain sufficiently large samples for analyses.

Reproductive maturity was assessed by the criteria described in Appendix I. Approximately 80% of female calamary taken by marine scale fishermen are reproductively mature (Fig. 2). It appears that this fishery is based on the spawning populations. During this study, no individuals of either sex were observed in the spent condition.

The relationship between reproductive maturity and mantle length is shown in Fig. 3. The minimum size of female maturity is 16 cm. mangle length (M.L.), all females over 22 cm M.L. were reproductively mature.

To test the hypothesis that the fishery is based on the spawning population, regular S.C.U.B.A. diving surveys were carried out in the Marino area just South of Adelaide (Fig. 1). Spawning schools of calamary were observed in this area and numerous clusters of calamary eggs were present during the fishing season (December to April).

1.1 EGG-LAYING

Calamary (Sepioteuthis australis) form spawning aggregations consisting of both males and females. Movement of these groups appears co-ordinated, with individuals slowly moving backwards and forwards by undulating their large fins. The funnel is used for faster movements, when the animals are disturbed, or for travelling distances of more than a few metres. Each squid holds its short arms together, directly in front of the body, and the two longer arms are retracted.

Individuals approach the egg cluster using the fins only, with the body axis pointing obliquely head-down. When about 0.5 to 1 metre from the egg cluster, the animal folds the four lower short arms down and back. The four upper short arms remain together, pointing forward and forming a core with the apex towards the egg cluster. These arms enter the egg mass and are withdrawn after approximately 2 to 5 seconds as the animal reverses away, leaving a new capsule attached to the mass.

The capsules are finger-like in appearance and are attached to the gelatinous matrix by small stalks (Fig. 4). The capsules are jelly-like in consistency with a firm, translucent outer layer. There are 4-6 eggs in each capsule, arranged in a well-spaced single row and visible through the translucent gelatinous capsule. As in other cephalopods, the eggs are large and elongately oval. The tertiary egg membranes, including the outer capsule sheath, are supplied by the nidamental glands, which open into the mantle cavity. The siphon appears responsible for moulding the capsules as they pass through it to the arms which then fix the capsules to a suitable substrate. The elastic protein of the tunic toughens on contact with sea water.

Fertilization occurs during the process of extrusion and handling of the capsule before the membrane toughens precluding further entry of spermatozoa.

1.2 COPULATION

Spermatophores are transferred to the female by the hectocotylus, a ventral arm modified for reproductive function. Hectocolylisation is readily observed in some species of cephalopods (e.g. Ommastrephidae); however the structure is small and difficult to observe in Sepioteuthis australis.

In some cephalopod species, the male deposits spermatophores in the buccal region around the mouth and also inside the mantle cavity of the female. However in S. australis, spermatophores have only been observed around the buccal region of the female.

The male swims anterior to the female at time of copulation, and inserts the hectocotylised arm into the buccal region of the female, depositing the spermatophores.

1.3 COLLECTION AND MAINTENANCE OF EGG MASSES

Egg clusters were collected by S.C.U.B.A. diving. During initial trials, well developed egg clusters were removed to the laboratory, however it was found that the majority of eggs hatched during transportation due to mechanical stimulation. The survival rate of these prematurely hatched individuals was very low.

During subsequent trials, relatively undeveloped eggs (evident by their smaller size) were collected. It is important to ensure that the temperature of the water in which the eggs are kept during transportation, at all times approximates the temperature at collection. Relatively small changes in water temperature (1°C) can arrest embryological development.

After collection, eggs are transported in an esky with seawater and adequate aeration. The temperature is checked at frequent intervals, fresh sea water being added if the temperature begins to rise. Transportation to aquaria is conducted as quickly as possible, the maximum time being 4 hours after collection. Water in the aquaria is maintained at the same temperature as the natural environment of the eggs.

During initial trials on egg hatching, egg clusters were placed on the bottom of the aquarium; however it was found that only the eggs on the tips of the "fingers" hatched, eggs in the centre of the cluster failing to hatch. This was thought to be due to insufficient oxygen reaching these eggs, therefore subsequent egg masses were suspended in the water column, from polystyrene floats. This allows the "fingers" of eggs to fall apart, thereby assisting water and gaseous exchange. This method also reduced settlement of silt and debris on the eggs.

The lighting in the aquaria where eggs are maintained should be very dim to reduce growth of diatoms and green algae, which tend to adhere to the surface of the eggs, thus adversely affecting their development.

1.4 HATCHING

Just prior to hatching, the young calamary can be seen moving back and forth within the egg. Newly hatched calamary are 9-11 mm in total length. They are able to swim immediately, and progress with a rapid jerking movement produced by mantle contractions. They are also capable of rapid escape reactions using the funnel and can produce an ink cloud as soon as they hatch.

The yolk sac in some instances gets detached even prior to hatching, in others it falls off as the juvenile darts from the capsule, and in others the yolk sac is carried 1-2 hours after hatching. This may relate to postmature, mature and premature hatching respectively.

The newly hatched calamary can change colour rapidly, but is normally a translucent white. Chromatophores develop over the mantle, head, arms and the dorsal surface of the fins, and are easily seen with the naked eye. They range in colour from chocolate brown to yellow.

The fins are present at the posterior end as flaps (Fig. 5a); therefore the characteristic continuous fin bordering the entire mantle length of the Adult *S. australis* (Fig. 5b) must be attained with subsequent development. The arms are well-developed, five pairs in all, including tentacular arms which have not differentiated at this stage.

Through the mantle, the well-developed ctenidia, the rectum, ink gland and the pulsating branchial hearts are all clearly seen.

1.5 JUVENILE CALAMARY

Being continually active swimmers, calamary need oxygen levels near saturation, therefore good circulation of water within the aquaria is necessary. A serious problem in rearing small calamary hatchlings are air bubbles adhering to the integument, therefore air stones should not be placed in the rearing tank.

The aquarium design found most successful is shown in Figure 6. The pump inlet is separated from the main body of the aquaria so that calamary hatchlings cannot be taken up through the inlet pipe. Well-oxygenated water is then sprayed into the main body of the aquaria as a fine spray, therefore the presence of air bubbles in the aquaria is minimised. The aquaria is a closed system with under-gravel filter impregnated with nitrosoma bacteria to keep nitrate levels low.

Dim lighting should be present during the night to assist the juveniles to orientate in the unnatural surroundings.

1.6 FEEDING

One of the crucial problems in aquarium maintenance of cephalopods is the fact that they normally feed on live animals. The choice of food for newly-hatched calamary is important. If offered the proper food, normal fry will begin feeding about 10 to 15 hours after hatching, with the majority feeding after 17 hours. Lack of the proper food delays the feeding response. After about 30 to 33 hours without food, calamary begin to actively search for food and to investigate stimuli normally ignored.

In the continued absence of preferred foods, the calamary become less selective and begin attacking other food types; however these are generally insufficient to maintain life.

S. australis are very selective in their choice of food, only attacking actively moving animals of a limited size range. They would not eat dead, drifting or benthic organisms, and definitely preferred certain foods over others of similar size and activity. The most suitable feed for newly-hatched individuals was a species of mysid occurring in large concentrations in areas where calamary eggs are naturally found. Some calamary fed quite readily on these organisms, providing they were of suitable size (1/5th to 4/5ths total length of calamary). It is unfortunate that the handiest live feed, Artemia salina (brine shrimp) does not appear to be suitable as feed for this species.

Insufficient density of suitable food was the greatest difficulty encountered in this work, and led to high mortality of juveniles. To overcome this difficulty, hatchlings were placed in small compartments, screened off from the rest of the aquarium, this allows for a higher density of food items to be maintained, and also facilitates observation of individuals.

Death by starvation is a slow weakening process, with the calamary unable to remain swimming. They fall to the bottom of the aquarium where pumping of the mantle cavity is increasingly sporadic until eventually the animal dies.

2.0 TAGGING PROGRAM

In the initial stages of this programme, considerable effort was directed towards finding a suitable means of tagging calamary. Sites of tag location used are shown in Fig. 7. Location 1, although suitable for oceanic squids, is inappropriate for calamary due to the softness of the mantle tissue, and the proximity of the reproductive organs. Movement of the T-bar inside the mantle cavity caused irritation to the gonads, and tags were readily lost from this location.

Location 2 resulted in excessive circular movement of the tag during the swimming process, causing severe abrasion to the skin and mantle tissue. Location 3 appears suitable for tagging larger individuals of this species (>16cm M.L.). At this location there is a small cavity surrounded by cartilage, into which the T-bar can be inserted. Animals at liberty for 1-3 months with tags at this location have exhibited virtually no skin abrasion and no abrasion of mantle tissue. This location is not suitable for smaller calamary since the T-bar cannot fit inside the cavity.

Tagging details with respect to the regions in Fig. 1 are shown in Table 1.

	Region						Total
	1	2	3	4	6	7	
No. of tags released	197	35	373	315	31	658	1609
% Returns - Professional	3.0	0	3.2	3.2	5.0	5.0	3.9
% Returns - Recreational	1.0	8.6	0.3	0.6	0	0.2	0.6
TOTAL % Returned	4.1	8.6	3.5	3.8	3.2	5.2	4.5

Table 1. Tag return for Regions 1 to 7 (no tags released in Region 5 or Region 8).

Recreational effort is highest in region 2, this region being closest to Adelaide. Although the overall tag return rate is not particularly high (4.5%), this may be a result of a number of factors, low fishing mortality, high natural mortality, tag loss or tagging mortality. Whilst it is recognised that tag retention and tag mortality studies are important, they have not been carried out as yet due to the difficulties associated with maintaining adult calamary in aquaria, and the lack of suitable facilities.

There appears to be no trauma associated with the tagging process, since some tagged calamary have been caught up to three times immediately following initial release.

A possible explanation of the relatively low tag return rate may be natural mortality following spawning. It is difficult to tag sufficient numbers until the calamary have schooled and are reasonably abundant. By this time, the gonads of individuals are well developed and spawning is imminent (i.e. the fishery is based on the spawning population). Therefore, a large proportion of individuals are reproductively mature when released.

Tag Recapture	Time at Liberty (days)									Total
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	
% Males	24	27	14	7	3	2	2	1	1	81
% Females	5	11	2	-	-	-	-	-	1	19
Total %	29	38	16	7	3	2	2	1	2	100

Table 2. Days at liberty for tag recaptures.

The majority of tag recaptures occurred less than one month after release (Table 2), individuals probably having spawned in that time. The majority of tag recaptures were male, which achieve a greater size than females and may live longer than females. These results suggest a high natural mortality, particularly of female calamary following spawning. Further investigations will require a tagging programme on juveniles.

The majority of tag recaptures show virtually no migration (Table 3).

	Distance (km)					
	<1	1-5	6-10	11-20	21-50	51-100
No. of individuals	20	28	7	1	0	1

Table 3. Distance travelled by tagged calamary.

Although movements were generally less than 10 km, there was some pattern in some areas. All movements in the Second valley area were in a southwesterly direction (fig. 8). Movements in Pt. Wakefield area were both north and south (fig. 9), suggesting random dispersion. Movements in the Edithburgh area (fig. 10) were all southerly, as were movements in the area just south of Moonta (fig. 11). There was only one movement from tags released in the Port Broughton region (Fig. 12), but the tags released in the Whyalla area show the most interesting movement. Whereas the majority of the returns showed random dispersion from the tagging location, one calamary moved from Whyalla to Wallaroo.

3.0 LENGTH WEIGHT RELATIONSHIP

A length-weight relationship for this species was determined, initially for combined sexes and separately for males, females and unsexed juveniles (N = 4040). The regression for separate sexes was significantly different ($P < 0.05$) from the values for combined sexes, therefore the length-weight relationship is different for each group. A plot of the regression lines obtained against the observed data for each mantle length, showed some deviation from the line for mature males and females. Since it was possible that sexual maturity may have been influencing the length-weight relationship, both sexes were further divided into three groups based on observation of the onset of sexual maturity (Fig. 3). These groups were immature (<11 cm. mantle length), maturing (11-17 cm. mantle length) and mature (>17 cm. mantle length).

The regression lines obtained for each group were significantly different to the regression line obtained for all groups combined for both males and females, therefore the length-weight relationship obtained for the separate groups was used.

	Males		Females		Juveniles	
Immature	$W = 0.11\ ML^{2.613}$		$W = 0.103\ ML^{2.655}$		$W = 0.11\ ML^{2.633}$	
	$r^2 = 0.95^{***}$	N = 388	$r^2 = 0.91^{***}$	N = 299	$r^2 = 0.98^{***}$	N = 573
Maturing	$W = 0.09\ ML^{2.688}$		$W = 0.087\ ML^{2.719}$			
	$r^2 = 0.82^{***}$	N = 285	$r^2 = 0.90^{***}$	N = 282		
Mature	$W = 0.19\ ML^{2.417}$		$W = 0.131\ ML^{2.582}$			
	$r^2 = 0.93^{***}$	N = 1341	$r^2 = 0.87^{***}$	N = 873		

W = Body weight, ML = Mantle Length and N = No. of individuals

These regression lines for males and females are plotted in Fig. 13a. For a given mantle length, females are heavier than males. The line for juveniles plotted on the same scale was virtually the same as for males. The regression line for females is plotted along with the observed data (fig. 13b). There is still some deviation from the line for larger mantle lengths. Unfortunately there are few observations in this range since females this size are rarely taken. The fact that the observations are generally below the line could be due to one of two factors. Females of this size may have finished spawning and the reproductive organs contribute little to the total body weight, or it may be an indication of loss of body condition preceding senescence or die-off of larger individuals. This can only be determined by selective sampling of these larger individuals over a long period of time to obtain sufficiently large samples.

Dissection of individuals to determine relative proportions of the weight of body organs is underway, but the results have not yet been analysed.

4.0 GROWTH

Location of modes in the length frequency data was determined using Cassie's (1954) method and the resulting plot of model length against time for Gulf St. Vincent is shown in Fig. 14. Males achieve a greater size than females and there are more size groups in the male population than in the female population. These size groups are probably the result of spawning activity and their number and close proximity makes the calculation of growth rate from modal progression extremely difficult and possibly inaccurate. In some instances it appears that two modes can combine which will lead to an underestimate of growth rate from modal progression. Given these possible inaccuracies, the following estimates of growth rate were obtained from modal progression.

	Summer Brood	Winter Brood	Average
Males	1.08 cm/month	1.24 cm/month	1.13 cm/month
Females	-	0.88 cm/month	

Growth rate was also estimated from tag-recapture data and, given the problems associated with the analysis of modal progression, are likely to be a more realistic estimate.

	10-20 cm M.L.	20-30 cm M.L.	Average
Males	1.76cm. ML/month	1.08 cm ML/month	1.48 cm ML/month
Females	1.01cm. ML/month		

4.1 TRAWL CAUGHT CALAMARY

It was difficult to obtain a continuous time series of data on trawl caught calamary from a particular location since it was necessary to rely on opportunistic sampling of catches from commercial prawn trawlers. Length frequency data for trawl caught calamary (plotted with a running mean of 3) are shown in Fig. 15. These data are combined over both gulfs, and there was insufficient data from any one location, for determination of growth rates by model progression. There are few individuals over 20 cm. M.L. in the samples (fig. 15), the majority being less than 12 cm. M.L. The population in the deeper waters is composed of juvenile calamary which move into the shallow onshore areas from a size of 13 cm mantle length.

4.2 AGE-LENGTH KEY

The growth rates calculated from tag-recapture experiments were used to produce an age-length key (Fig. 16). For females greater than 20cm. M.L., a decrease in growth rate proportional to that observed for males, was presumed. Since there were no estimates of growth rate for juvenile animals (< 10 cm. M.L.) a growth rate of 2 cm. per month was used. This is not an unreasonable estimate given a growth rate of 1.76 cm per month for males 10 to 20 cm. M.L.

5.0 MALE-FEMALE RATIO

Table 4 shows the male:female ratio for the summer and winter brood over a twelve month period. For the summer brood, this ratio decreases during August-September to equal numbers of males and females and then the number of males increases. Similarly for the winter brood, the ratio initially decreases to less than 1:1 then increases to 2:1.

Males therefore migrate to the shallow onshore waters before the females which move in 1-2 months later. Females either die soon after spawning, or cease to be susceptible to the catching methods. The change in male:female ratio may be a combination of these two causes. The main method used in the summer fishing is handline and jigs (see Section 7), whereas the winter fishery mainly uses haul nets. If female calamary cease feeding around spawning time, then they would not be taken by handline and jigs, whereas they may be taken by haul nets. Therefore the male:female rates in the winter brood may be an indication of a higher mortality rate of males than females, whereas the male:female ratio in the summer brood may be an indication of mortality plus changes in catchability.

MONTH	SUMMER BROOD (M:F)	WINTER BROOD (M:F)
January		
February		
March		2.0 : 1
April		1.8 : 1
May		0.8 : 1
June		0.9 : 1
July		1.2 : 1
August	1.3 : 1	1.4 : 1
September	1.0 : 1	1.8 : 1
October	2.5 : 1	2.0 : 1
November	2.5 : 1	
December	2.8 : 1	
January	4.6 : 1	
February	3.7 : 1	

Table 4. Male Female ratio, summer and winter broods.

6.0 CONCLUSIONS

Based on the age length key and knowledge of spawning and reproduction, the proposed life history of calamary is shown in Fig. 17. There are two main broods, a summer brood and a winter brood. For the summer brood, although spawning appears to occur throughout October to April, there appears to be two peaks in spawning activity around November and February. A similar situation is proposed for the winter fishery, however this requires supporting data on the presence of calamary egg masses. These two major broods are separated both temporally and spatially, adults of the summer brood being present in the south-eastern areas of both gulfs and the winter brood being most abundant in the northern areas (see fig. 1).

This proposed life history is supported by the analysis of catch and effort data where there is evidence for both a summer and a winter fishery (fig. 22).

Length frequency data from Gulf St. Vincent (plotted with a running mean of 3) is shown in Fig. 18. There are very few female calamary over 30 cm. M.L. Females around this size would be approaching their second spawning season, therefore it appears as if the majority of females only live for one spawning season. There are considerably more males over 30 cm. M.L. and it appears as if some males may survive for a second spawning season. Another explanation for the existence of these large individuals may be that they result for eggs hatching late in the season. By the following season they are not reproductively mature. Therefore they survive until a further season.

A high natural mortality after spawning has been reported for other species of the family Loliginidae. Loligo opalescens (Reckseik 1978) has immediate mortality after spawning, the spawning grounds being littered with corpses. Loligo forbesi (Holme 1974) and S. sepiodea (Moynihan and Rodaniche 1982) also die after spawning, although this does not happen immediately as with L. opalescens.

No dead calamary have been seen in the vicinity of the spawning grounds, therefore there appears to be no immediate mortality after spawning as in L. opalescens, however there is considerable evidence to suggest a high, if not total, mortality of adults after spawning.

POPULATION DYNAMICS

1.0 CATCH AND EFFORT DATA - MARINE SCALE FISHERMEN

Catch and effort information relating to calamary from marine scale fishermen's returns were analysed for the years 1976/77 to 1981/82. All figures reported in this section relate to a monthly resolution since this was the lowest level of resolution available.

The number of man days was initially used as an index of effort; however, there was variation in the number of hours worked per fishing day by individual fishermen. An analysis was conducted of the number of hours worked for each fishing method each year (Table 5).

	1976/77		1977/78		1978/79		1979/80		1980/81	
	Av. No. Hours Per Day	Standard Deviation	Av. No. Hours Per Day	Standard Deviation	Av. No. Hours Per Day	Standard Deviation	Av. No. Hours Per Day	Standard Deviation	Av. No. Hours Per Day	Standard Deviation
Hauling	7.5	2.5	7.7	2.3	7.7	2.2	7.9	2.2	8.0	2.3
Set Nets	7.4	2.3	7.5	2.4	8.0	2.8	7.7	2.0	7.6	2.0
Handline & Jigs	6.9	1.6	7.0	1.7	7.3	1.6	7.3	2.1	7.1	2.1
Other	6.3	0.7	7.9	0.5	8.0	0	8.0	0	5.8	3.6
Average All Methods	7.2	2.2	7.4	2.1	7.7	2.2	7.6	2.1	7.6	2.2

Table 5. Average number of hours worked per fishing day for each method per year.

Analysis of variance showed that there was no significant difference ($P > 0.05$) in average hours worked per fishing day, between methods or years. Therefore it was decided to use a 7½ hour day (called an average man day) as the unit of effort.

Annual catch and effort trends over the six year period 1976/77 to 1981/82 are shown in Table 6.

	Total Catch (tonnes)	Av. Catch per unit effort	Av. Price ($/kg.)	Annual Value ($'000)
1976/77	56	6.2	1.70	96
1977/78	105	7.0	1.80	190
1978/79	148	7.5	2.20	326
1979/80	193	9.5	2.80	540
1980/81	114	6.5	3.30	376
1981/82	139	6.8	3.90	542

Table 6. Annual South Australian production and value of calamary caught by marine scale fishermen.

Total catch increased to a maximum in 1979/80 followed by a substantial decline in 1980/81, and a rise in 1981/82, with similar changes in catch per unit of effort. The price has increased each year to $3.90 in 1981/82.

2.0 PRAWN FISHERY

Production of calamary from prawn vessels had to be estimated since no reliable data were available. Catch rates were estimated from data obtained from the FRV "Joseph Verco" in 1979. The relative fishing power between this vessel and standard prawn vessels in both gulfs has been determined, and this factor was applied to estimate the monthly catch rate of a standard vessel in both gulfs. This multiplied by the number of hours per month fished by the prawn fleet, provides an estimate of calamary production by the prawn fleet for 1978/79. This data is presented in Table 7.

Spencer Gulf (tonnes)	Gulf St. Vincent (tonnes)	Total (tonnes)	Catch by Marine Scale Fishermen (tonnes)	Total Catch (tonnes)
103	31	134	148	282

Table 7. Estimated catch of calamary by prawn trawlers and total production for 1978/79.

In 1978/79, the prawn fleet took the equivalent of 90% of the catch taken by marine scale fishermen. Therefore the total catch of calamary in South Australia in any year would be approximately double that taken by marine scale fishermen. This potentially large catch by prawn vessels requires further attention, considering the fact that it is mainly juvenile calamary. Therefore in terms of catch in numbers, prawn vessels would probably take twice as many calamary as marine scale fishermen. It should be noted that not all calamary taken by prawn trawlers is retained for sale, however since it would not survive the trawling process it has effectively been removed from the population.

A new catch and effort system for the marine scale fishery is presently being developed which will provide statistics on calamary taken by prawn vessels, enabling this aspect of the calamary fishery to be investigated.

3.0 ANALYSIS OF REGIONS

Catch and effort data by regions (fig. 1) is shown in figs. 19 and 20. The single most important region in terms of catch and CPUE is Region 1, Cape Jervis. The season in this region is spring-summer. Region 2 is similarly a spring-summer region, the lower total catch in relation to Region 1 being a reflection on the smaller number of fishermen working this region than Region 1 (Fig. 21).

The rest of Gulf St. Vincent (Region 3) is not as productive, the season being basically autumn-winter. Very little calamary is caught in Region 4 with the season principally autumn-winter.

Region 5 is a small area around Moonta Bay, the season in this region being principally autumn with small catches being taken during other times of the year. Region 6, the area around Wallaroo although close to Moonta, has principally a summer season with occasional large catches at other times of the year.

Region 7, northern Spencer Gulf, is an autumn-winter season with large increases of catch for minimal increases in CPUE. This is a result of the high level of effort in the region (Fig. 21), and almost total lack of target fishing for calamary. The season in Region 8 is autumn-winter with small increases in catch rate during the season.

It is interesting to note the difference between Gulf St. Vincent and Spencer Gulf. The only region in Spencer Gulf showing a summer season is Wallaroo; however areas north and south of this region have an autumn-winter season. From Region 4 to Region 7 you can see the progression of autumn winter season (Region 4), to autumn season (Region 5) to summer season (Region 6) to autumn-winter season (Region 7). In Gulf St. Vincent there is a summer season in the South-East and an autumn-winter season throughout the rest of the gulf.

4.0 SUMMER AND WINTER FISHERIES

We can see from Figs. 19 and 20, that there is a summer fishery for calamary in Regions 1, 2 and 6 and a winter fishery in the other regions (Fig. 1). This relates to the data on the life history of the species where a summer and a winter brood are proposed.

The catch and CPUE for the summer and winter fisheries 1976/77 to 1980/81 are shown in Fig. 22. There are marked increases in CPUE in the summer fishery October to March with subsequent increases in catch. Although catch in the winter fishery increases March to September, there is little change in the CPUE over this time. There is little change in effort in the summer fishery, however effort in the winter fishery increases significantly during the season (fig. 23).

The basic difference between these two fisheries is that the summer fishery has a high proportion of fishermen targeting for calamary whereas the winter fishery is effectively a by-catch fishery with little target fishing.

5.0 FISHING METHODS BY REGIONS

There are differences in the principle fishing method used between regions (Fig. 24). The catch by method by region for the years 1977/78 to 1980/81 is shown in fig. 24(a). In Region 2, only handline and jigs are used because there is a total ban on netting on the Adelaide Metropolitan Coast. Handlining (including jigs) accounts for the majority of the catch in Regions 1 and 2. In Region 6 the relative proportion of the catch taken by handlining has declined to 50% of the catch in 1980/81. In all other regions (i.e. the winter fishery) netting accounts for the majority of the catch.

CPUE for handlining in Regions 1, 2 and 6 (the summer fishery) are high (fig. 24(b)). Catch rates in the winter fishery for all methods are generally much lower.

The percentage of total catch taken by each method for the Summer and Winter fisheries is shown in Table 8. Whereas handline fishing (including jigs) accounts for around 80% of the catch in the summer fishery in all years, it only accounts for 10-15% of the catch in the winter fishery where hauling is the major method and accounts for around 70% of the total catch.

	Summer Fishery			Winter Fishery		
	Hauling	Set Nets	Handline	Hauling	Set Nets	Handline
1977/78	17	5	78	71	19	10
1978/79	11	5	84	73	19	7
1979/80	16	3	81	65	20	15
1980/81	21	5	74	69	19	11
1981/82	15	4	78	69	16	15

Table 8. Percentage of catch taken by each method for the Summer and Winter fisheries 1977/78 to 1981/82.

6.0 EAST VERSUS WEST

Large catches of calamary are taken on the eastern side of both gulfs (fig. 22). An analysis of variance showed that there was a significant difference in catch and CPUE per fishing unit for the five years 1976/77 to 1980/81 and a significant difference in effort per fishing unit per month for 1976/77, 1979/80 and 1980/81 (see Appendix II) between locations 1 to 6 shown in Fig. 25.

A t-test was conducted between sets of data to investigate the nature of this difference. The results of the t-test are shown in Appendix II (Table II.2). There was significant difference between catch and CPUE per month between locations 1 and 2 and locations 3 and 4 each year. That is, average catch and CPUE per fishing unit per month is significantly higher on the eastern side of both gulfs compared to the western side. In most years, the effort is not significantly different between the eastern and western sides therefore it is proposed that the higher catch rate of calamary on the eastern sides of the gulfs is due to increased abundance of calamary.

Bullock (1974, 1975) has shown that the water circulation in the Gulfs is basically clockwise, i.e. water moves up the Western side and down the Eastern side. This circulation pattern is mainly due to differences in salinity. There is little variation in temperature throughout the gulfs. Salinity may be the cause of the summer and winter distribution of calamary. Salinities reach very high levels in the northern portions of the gulfs in summer, particularly Spencer Gulf where they can greatly exceed $40°/_{oo}$. When the juvenile calamary migrate from the deeper water to shallow onshore waters, they may be choosing areas of prefered salinity or temperature.

7.0 MORTALITY

Total mortality per month (Z) was calculated by regression of decline in catch per unit of effort after recruitment against time. The following figures were obtained (Table 9).

Region	Total Mortality (Z) per month	r^2
1 and 2	0.42	0.85 ***
3	0.53	0.87 ***
5	0.42	0.70 ***
6	0.43	0.86 ***
7	0.30	0.72 ***
8	0.44	0.64 ***

Table 9. Total mortality (Z) and correlation coefficient.

Total mortality is greatest in Region 3 and least in Region 7, for all other regions, the mortality is around 0.4, which corresponds to an annual mortality rate of 0.35.

8.0 LESLIE-DELURY MODEL

This model was used to estimate catchability and original population abundance. These methods are based on the decline in catch per unit of effort due to the removal of individuals from the exploited population. According to Ricker (1975), the predictive regression line in the DeLury method will underestimate catchability and consequently overestimate the original population abundance, whereas the Leslie method tends to underestimate original population abundance. The latter was considered preferable for the management decision process.

Braaton (1969) modified the Leslie method as described in Ricker (1975), so that instead of regressing CPUE at each time interval on the cumulative catch at the start of the time inverval, the modified method uses cumulative catch to the start of the interval plus half of that taken during the interval.

The equation for the linear regression is:-

$$\frac{Ct}{ft} = q\,N_o - qK_t \qquad \text{where}$$

$\frac{Ct}{ft}$ = catch per unit of effort (CPUE) during the interval t

q = catchability

k_t = cumulative catch

N_o = original population abundance.

The regression equation was estimated by the least squares procedure, and the Y-axis intercept is the absolute value of the regression coefficient (qN_o). The resulting regression equations for the years 1977/78 to 1981/82 by region are shown in Appendix III.

The value q, N_o and total catch by regions for 1979/80 to 1981/82 are shown in Table 10. It appears as if this model certainly underestimates the original population abundance (N_o) since this figure is less than the total catch in most years for Regions 1 and 2 and Region 3. There are wide fluctuations in catchability in regions over the three years. The DeLury method will be used on this data and the resulting estimates of original population abundance compared with those obtained by the Leslie method.

Regions	1979/80			1980/81			1981/82		
	q	No. (Tonnes)	Total Catch (Tonnes)	q	No. (Tonnes)	Total Catch (Tonnes)	q	No. (Tonnes)	Total Catch (Tonnes)
1 and 2	5×10^{-4}	83	76	6.5×10^{-3}	23	27	1.0×10^{-3}	31	31
3	2.3×10^{-3}	17	20	1.6×10^{-3}	16	19	7.0×10^{-4}	32	36
5	1.2×10^{-3}	29	23	1.4×10^{-3}	20	15	2.6×10^{-3}	14	13
6	2.6×10^{-3}	38	32	1.8×10^{-3}	20	17	3.8×10^{-3}	14	12
7	3.0×10^{-4}	95	75	1.4×10^{-3}	34	30	2.0×10^{-4}	51	33
8	2.6×10^{-3}	4	3	2.9×10^{-3}	6	5	7.6×10^{-3}	4	3

Table 10. Catchability (q), original population abundance (N_o) and total catch by region for 1979/80 to 1981/82.

A potential source of error in applying this model to the calamary fishery is the problem of determining a unit of effort. A large proportion of fishermen taking calamary are not targeting, therefore the effort expended is not necessarily required to take that quantity of calamary. In an effort to resolve this problem, it was attempted to isolate target fishermen for calamary.

9.0 TARGET FISHING FOR CALAMARY

There is no calamary fishery as such. Calamary is part of the multi-species marine scale fishery. The monthly catch and effort forms for the marine scale fishery do not request information on target species, therefore a method of determining target calamary fishermen was devised.

Three methods are used to take calamary, hauling, mesh or gill nets and handline or jigs. Only two of these methods are considered to be potential target methods based on the records of fishermen catching only calamary, these are hauling and handline or jigs.

A cluster analysis was run for records of each of these methods for each year using the variables catch, days fished, species caught and the percentage of calamary per fishing unit per month. The percentage of calamary was calculated as follows:-

$$\text{Percentage Calamary (CALPCT)} = \frac{\text{Catch of Calamary}}{\text{Total Catch (kg) of all species}} \times 100$$

Therefore if CALPCT is 100 then only calamary was caught. Whilst there were a number of fishermen using handlines who caught only calamary, there were fewer fishermen using haul nets who caught only calamary since it is more difficult to specifically target using this method.

The cluster analysis was run separately for each method. It separated the recores into two groups based on a vector obtained from the sum of all variables. One group contained all the records for which CALPCT = 100 and this group was designated target fishermen. The cut off point between these groups was CALPCT = 50 for hauling and CALPCT = 65 for handline and jigs. There was only minimal overlap between the groups and the analysis showed a significant difference ($P \leqq 0.05$) between clusters for all variables except for the year 1979/80. This year was thereby excluded from the analysis because calamary were extremely abundant during that year, and large catches were taken independently of targeting.

From this cluster analysis, fishermen using hauling with calpct ≧50 and fishermen using handline with CALPCT ≧65 were considered to be target fishing for calamary, therefore their total effort could be considered necessary to obtain their catch of calamary.

This gives a more realistic estimate of CPUE relating to the calamary component of the Marine Scale Fishery. For the rest of this report, references to CPUE and effort will be with respect to target fishermen as defined above.

Design of a new catch and effort system for the South Australian Marine Scale Fishery is underway, and will be introduced in June, 1983. Information gained during the course of this study has been useful in designing the new system with respect to calamary. The new system will be requesting information on target species, therefore the cluster analysis will be run on the first year's data to test how target fishermen extracted by this method relates to the information fishermen provide on target species.

There has been insufficient time to apply data from target fishermen to the Leslie or DeLury methods, however this will be done in the near future.

An indication of the general state of the fishery can be obtained from a plot of total catch against total effort. For the purposes of this plot, catch was plotted against effective effort which is calculated as follows.

Target fisherman:	Effective Effort	=	Effort
Non-target Fishermen:	Effective Effort	=	Catch/CPUE for target fishermen

This plot is shown in Fig. 26. There appears to be no trend for decreased catches with increased effort, therefore the fishery does not appear to be overexploited.

MARKETING

From Table 6, the price per kilogram for calamary has increased steadily over the years 1976/77 to 1981/82. Whilst this trend continues there is potential for development of the calamary fishery. However, the market for South Australian calamary has recently been affected by imports of frozen squid tubes (Ommastrephidae) from New Zealand. These frozen tubes are selling for around $4.00/kg. Given a 50% loss in weight with removal of head, tentacles and gutting, this brings the equivalent price of calamary tubes to around $8.00/kg, double the price of the New Zealand imports.

Restaurants are now buying the New Zealand squid in preference to the local product because of price and convenience. Prior to the New Zealand imports the Australian market had not reached saturation point for calamary, demand being in excess of supply. This development has occurred recently (May 1982) and the effect on calamary production and value will not be evident until the 1982/83 figures are available.

DEVELOPMENT POTENTIAL

A preliminary analysis of the overall fishery suggest that it is not overexploited, however some areas may be more heavily exploited than others.

Since the Leslie model does not seem applicable to the data it is ncessary to try and determine a suitable model to estimate population abundance and catchability.

Now that most aspects of the life history have been determined, an intensified tagging program is necessary to obtain estimates of fishing mortality, and seasonal estimates of growth rate. A tagging program of juvenile calamary is necessary to determine growth rates and migration.

In conclusion, although there are no indications that the calamary fishery is overexploited, it has not been possible to determine whether the fishery is close to the optimum level of exploitation. Given the fact that the major fishery is based on the spawning population, it seems advisable to err on the side of caution by instituting minimal increases in effort and observing the results.

There has been a substantial increase in hidden effort over the past 12 months in the form of the introduction of Japanese style jigs made to resemble prawns or fish. These are certainly more efficient than previous methods, and could result in a significant increase in effort in both the professional and recreational fisheries. It will be at least 12 months before the effects of this increased effort will become evident, therefore any further increases in effort in the form of additional licences, should be reviewed at that time.

CONCLUSIONS

Biological investigations of the Southern Calamary (*Sepioteuthis australis*) suggest a twelve month life cycle from hatching to spawning. Growth rates of adult calamary are in the order of 1.5 cm/month for males and around 1cm/month for females.

The calamary fishery in the shallow coastal areas is based on the spawning populations. Tag recapture rates are relatively low, possible explanations of this have been proposed. The majority of tag recaptures were within 1 month of release with a maximum period of recapture of 90 days. Most recaptures showed movements of less than 20 kilometers.

It appears as if reproductively mature calamary migrate to shallow coastal waters for spawning. There is virtually no migration from these fishing areas within three months.

There are two major broods, a summer brood and a winter brood which are spatially as well as temporaly separated. The summer fishery, based on the summer brood, is situated in the South-eastern portions of both gulfs whereas the winter fishery, based on the winter brood, is principally located in the northern portions of both gulfs.

The eastern side of both gulfs is more productive than the western side which may be due to water circulation currents.

Total mortality per month was estimated for the major fishing regions, and ranges from 0.3 to 0.53. The Leslie method of estimating catchability and original population abundance (N_o) provided estimates of N_o similar to the total catch taken for that period.

A method for determining target calamary fishermen has been developed and the results will be applied to the Leslie method to obtain more realistic estimates of original population abundance.

A plot of total catch against total effective effort suggests that the fishery is not overexploited, however it is not possible to determine whether the fishery is near the optimum level of exploitation.

There is evidence for a significant mortality or migration of adult squid at the conclusion of the fishing season, however a detailed study of the calamary population in deeper water is necessary to resolve some of the aspects of survival of adults.

SUGGESTIONS FOR FUTURE RESEARCH

A detailed study of the deep-water population of calamary (principally juveniles) to determine:

- growth rates of juvenile animals
- onset of sexual maturity
- migration of individuals to other areas
- presence of adult animals after spawning

A study of the larger male (>36cm M.L.) and female (>26cm M.L.) calamary to look for indications of senescence.

Presence of calamary egg masses throughout the gulf to determine spawning times in areas.

Intensive tagging program on both adults and juveniles to determine the relationship between the summer and winter broods.

ACKNOWLEDGEMENTS

This study was funded by the Fishing Industry Research Trust Account. I am indebted to Mr. Keith Evans, Technical Services Officer, employed under funds provided by the grant, who conducted the field collection of data, assisted with analysis of data and preparation of diagrams. I wish to thank the calamary fishermen of South Australia for their assistance with this program, and the technical staff of the Department of Fisheries for assistance with field work activities. Finally, I would like to thank the Principle Research Officer, Mr. R. Lewis, for guidance in the project and Dr. D. Arthur.

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APPENDIX I

FEMALE

Stage	Characteristics
Immature	Nidamental glands small, thin and transparent, small or invisible; ovaries small, clear and soft; oviduct small.
Maturing	Nidamental glands longer and thicker, whitening; ovaries whitening; oviduct glands small; oviduct small.
Mature	Nidamental glands large, thick and white; ovaries with visible, large eggs; oviduct glands large, orange in colour; oviduct white and obvious.

MALE

Stage	Characteristics
Immature	Vas deferens invisible; testes small, soft and clear.
Maturing	Vas deferens invisible or small; testes longer, firmer and less transparent; spermatophores small, usually visible.
Mature	Vas deferens white and ridged; testes large; Needham's sac full, with spermatophores obvious.

APPENDIX II

Statistical results of analysis of variance to test for differences between eastern and western sides of the gulfs.

	Catch per unit per month.	Effort per unit per month.	CPUE
1976/77	7.4 ***	10.2 ***	5.3 ***
1977/78	18.8 ***	18.9 ***	1.0 n.s.
1978/79	9.0 ***	12.4 ***	1.7 n.s.
1979/80	30.6 ***	33.5 ***	4.0 **
1980/81	13.1 ***	14.1 ***	3.7 **

TABLE II. Results of analysis of variance to test for difference between Locations 1 to 4 (Fig. 11).

Location	1976/77			1977/78			1978/79			1979/80			1980/81		
	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE
1	87.8	12.5	11.7	144.8	17.8	11.4	158.6	19.1	11.5	217.5	18.5	17.1	127.3	19.2	10.3
2	42.6	15.6	3.9	59.2	20.7	3.3	66.1	23.3	3.4	57.5	17.5	3.8	73.9	18.0	4.1
3	59.8	16.4	6.5	95.4	18.8	7.3	116.3	20.5	8.4	126.8	22.6	9.7	87.9	23.0	6.8
4	37.1	14.1	4.3	46.8	17.1	5.6	90.9	22.8	5.0	60.7	20.1	4.6	48.3	18.2	4.8

TABLE II.2(a) Mean values of Catch, Effort and CPUE per fishing unit per month for Locations 1 to 4 over the years 1976/77 to 1980/81.

Location	1976/77			1977/78			1978/79			1979/80			1980/81		
	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE
1,2	2.2*	-1.2	4.2***	3.9***	-1.0	8.3***	4.5***	-1.3	8.3***	7.9***	0.5	9.9***	2.9**	0.6	6.0***
3,4	3.8***	1.7*	2.3**	5.3***	1.1	2.0*	2.0*	-1.5	3.4***	5.6***	1.7	5.2***	4.8***	3.1**	2.1*
1,3	2.7**	-3.1**	2.9**	3.1**	-0.8	4.0***	2.7**	-1.1	2.5*	4.9***	-3.2**	5.0***	3.0**	-2.5*	3.2***
2,4	0.3n.s.	0.6	-0.4	0.7	1.1	-2.9**	-1.3	0.2	-2.4*	-0.2	1.2	-0.9	1.7[1]	-0.1	-0.8

TABLE II.2(b) Results of a t-test, t-values and significance between the locations shown in Fig. 11

APPENDIX III

Regions	1977/78	1978/79	1979/80	1980/81	1981/82
1 and 2	$CPUE = 570.91-0.0089k_t$ $r^2 = 0.995$***	$CPUE = 84.097-0.0009K_t$ $r^2 = 0.813$*	$CPUE = 115.47-0.005K_t$ $r^2 = 0.789$**	$CPUE = 433.2-0.0065K_t$ $r^2 = 0.61$ n.s.	$CPUE = 86.63-0.0010K_t$ $r^2 = 0.79$*
3	$CPUE = 36.45-0.0026K_t$ $r^2 = 0.882$*	$CPUE = 64.14-0.0014K_t$ $r^2 = 0.773$*	$CPUE = 121.0-0.0023K_t$ $r^2 = 0.932$**	$CPUE = 76.6-0.0016K_t$ $r^2 = 0.66$ n.s	$CPUE = 68.42-0.0007K_t$ $r^2 = 0.98$**
5	-	$CPUE = 61.57-0.0016K_t$ $r^2 = 0.87$ n.s.	$CPUE = 103.37-0.0012K_t$ $r^2 = 0.85$ n.s.	$CPUE = 79.33-0.0014K_t$ $r^2 = 0.35$ n.s.	$CPUE = 110.42-0.0026K_t$ $r^2 = 0.99$***
6	$CPUE = 143.13-0.0018K_t$ $r^2 = 0.886$*	$CPUE = 211.3-0.0041K_t$ $r^2 = 0.82$*	$CPUE = 299.68-0.0026K_t$ $r^2 = 0.915$***	$CPUE = 110.76-0.0018K_t$ $r^2 = 0.84$**	$CPUE = 167.24-0.0038K_t$ $r^2 = 0.907$*
7 to Pt. Lincoln	$CPUE = 27.20-0.0002K_t$ $r^2 = 0.412$ n.s.	$CPUE = 35.52-0.0003K_t$ $r^2 = 0.913$*	$CPUE = 74.66-0.0003K_t$ $r^2 = 0.93$**	$CPUE = 137.7-0.0014K_t$ $r^2 = 0.63$ n.s.	$CPUE = 35.08-0.0002K_t$ $r^2 = 0.977$**
West Coast	$CPUE = 21.1-0.0057K_t$ $r^2 = 0.9$ n.s.	$CPUE = 112.05-0.024K_t$ $r^2 = 0.563$ n.s.	$CPUE = 29.26-0.0026K_t$ $r^2 = 0.81$ n.s.	$CPUE = 47.00-0.0029K_t$ $r^2 = 0.91$*	$CPUE = 89.62-0.0076K_t$ $r^2 = 0.999$***

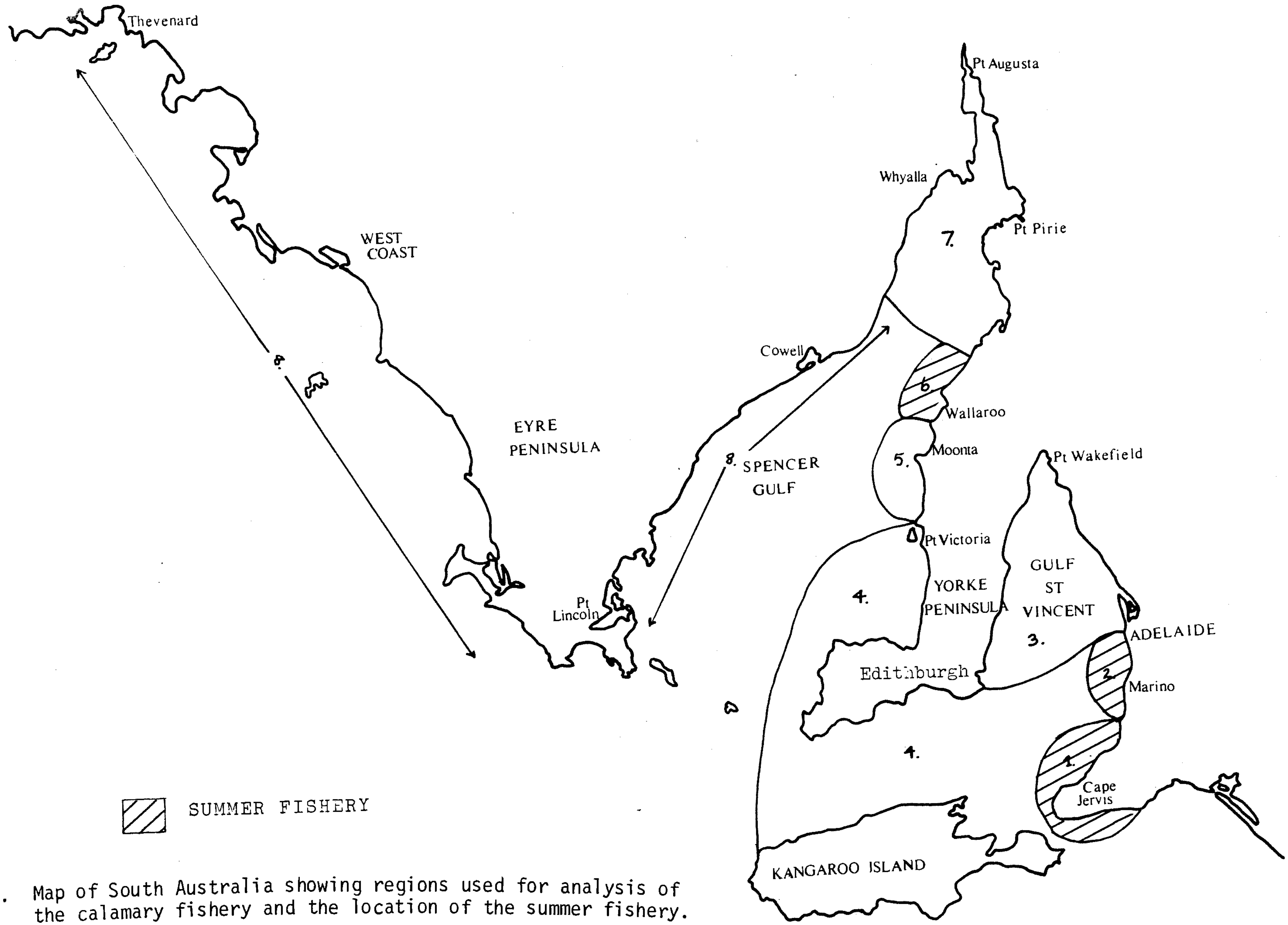

Fig. 1. Map of South Australia showing regions used for analysis of the calamary fishery and the location of the summer fishery.

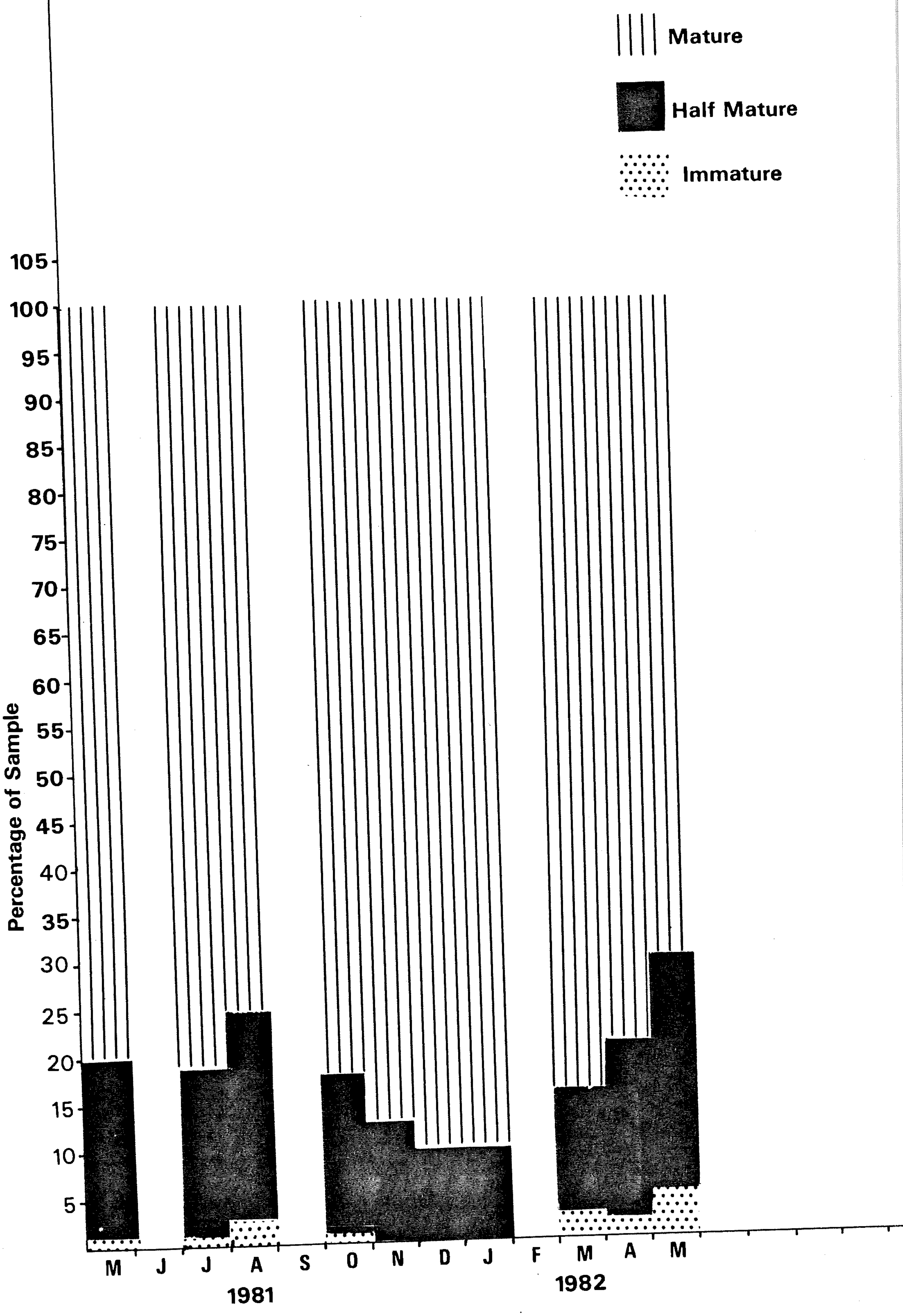

Fig. 2. Relative proportions of each stage of reproductive maturity in the total sample of female calamary.

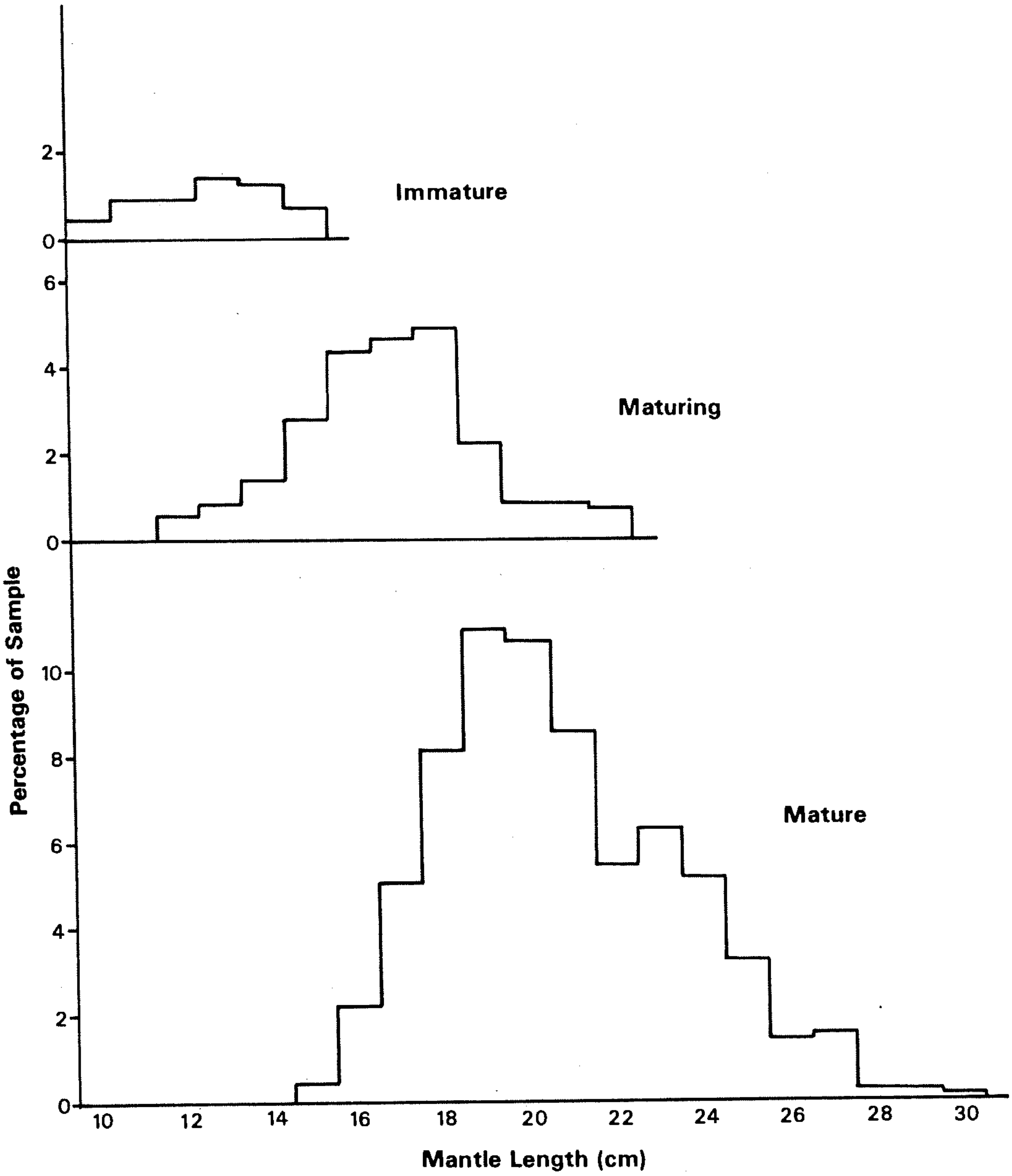

Fig. 3. Reproductive maturity of female calamary with mantle length.

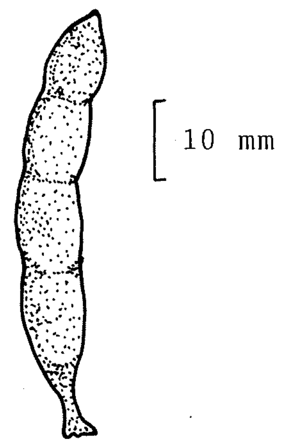

Fig. 4. Egg capsule (finger).

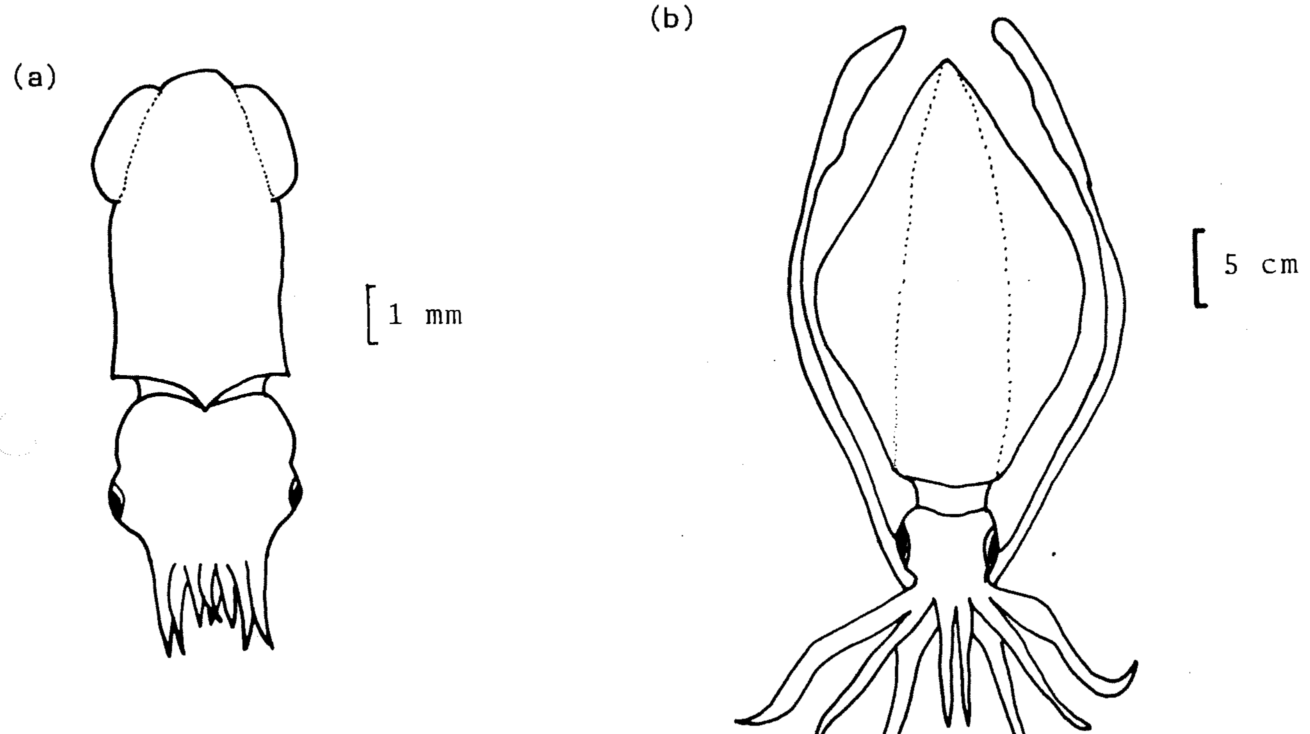

Fig. 5.

(a) Newly hatched juvenile S. australis
(b) Adult S. australis

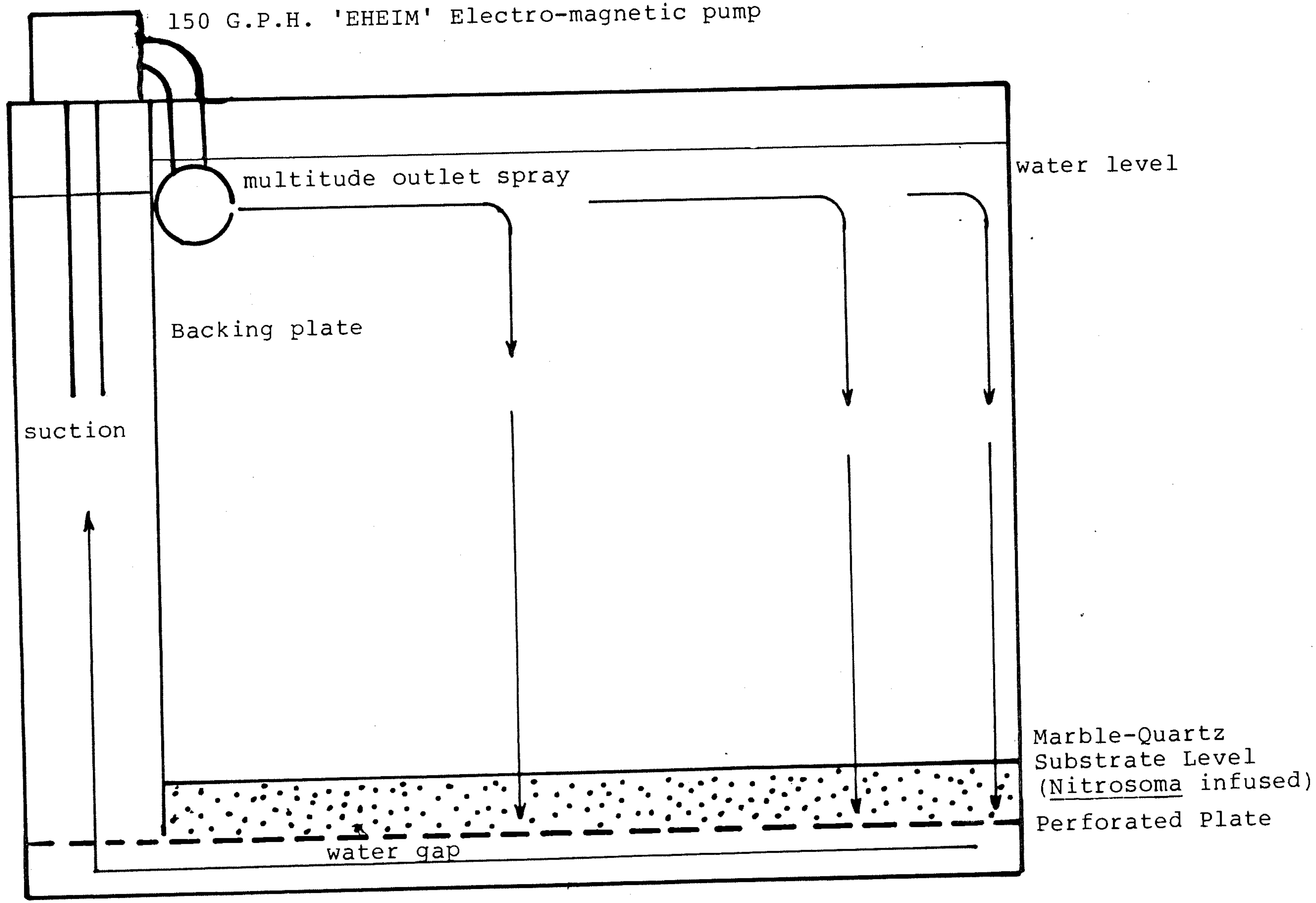

Fig. 6. Diagrammatic end elevation of aquarium design.

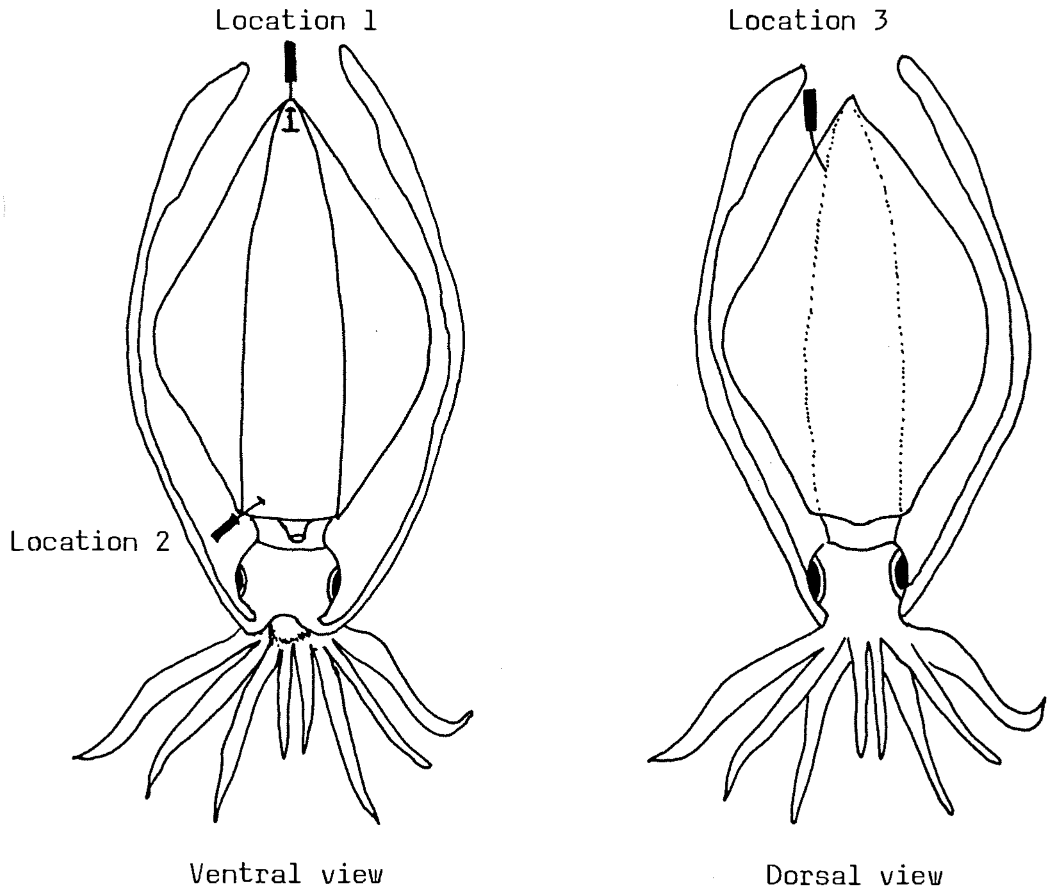

Fig. 7. Tag sites used during tagging programme.

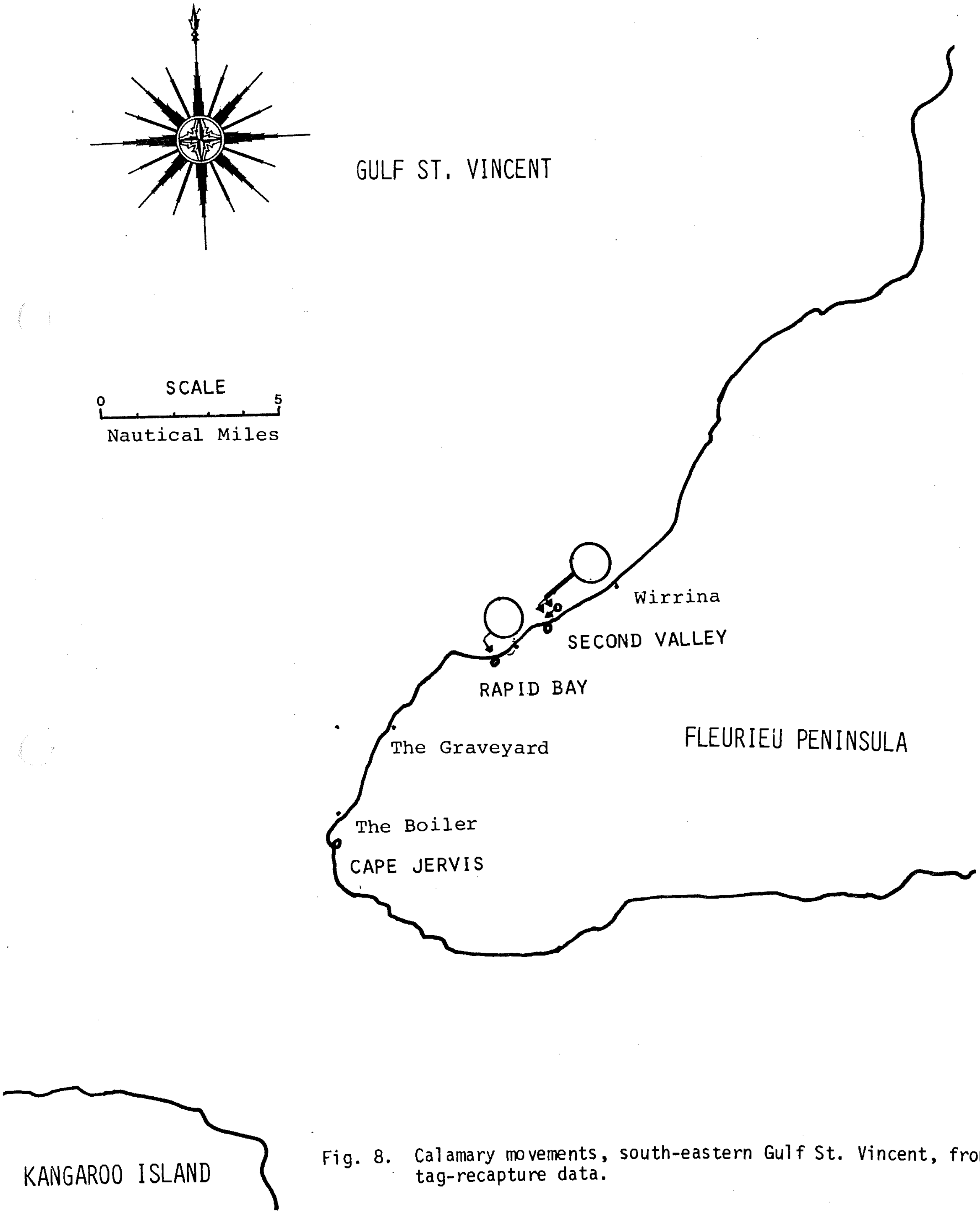

Fig. 8. Calamary movements, south-eastern Gulf St. Vincent, from tag-recapture data.

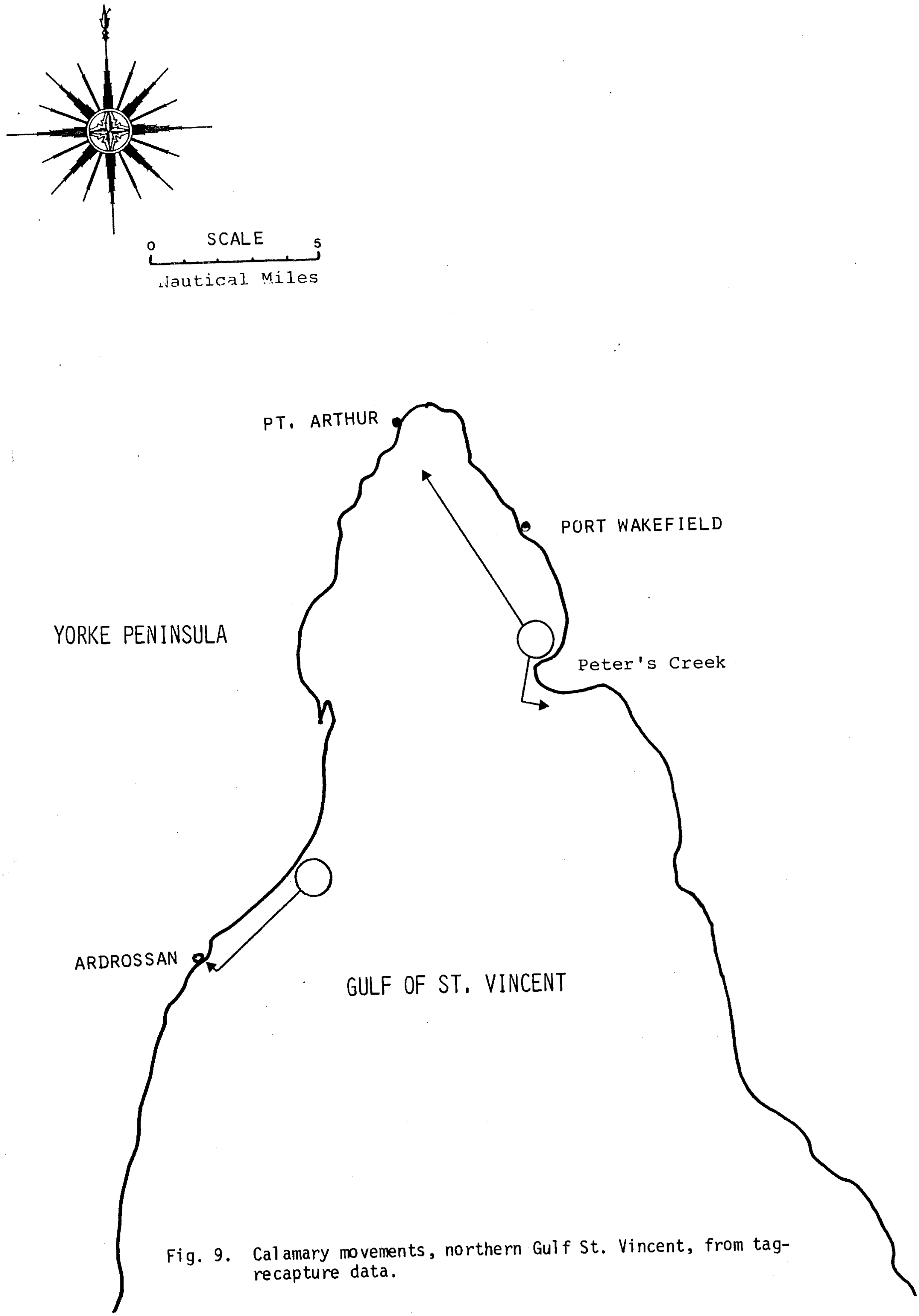

Fig. 9. Calamary movements, northern Gulf St. Vincent, from tag-recapture data.

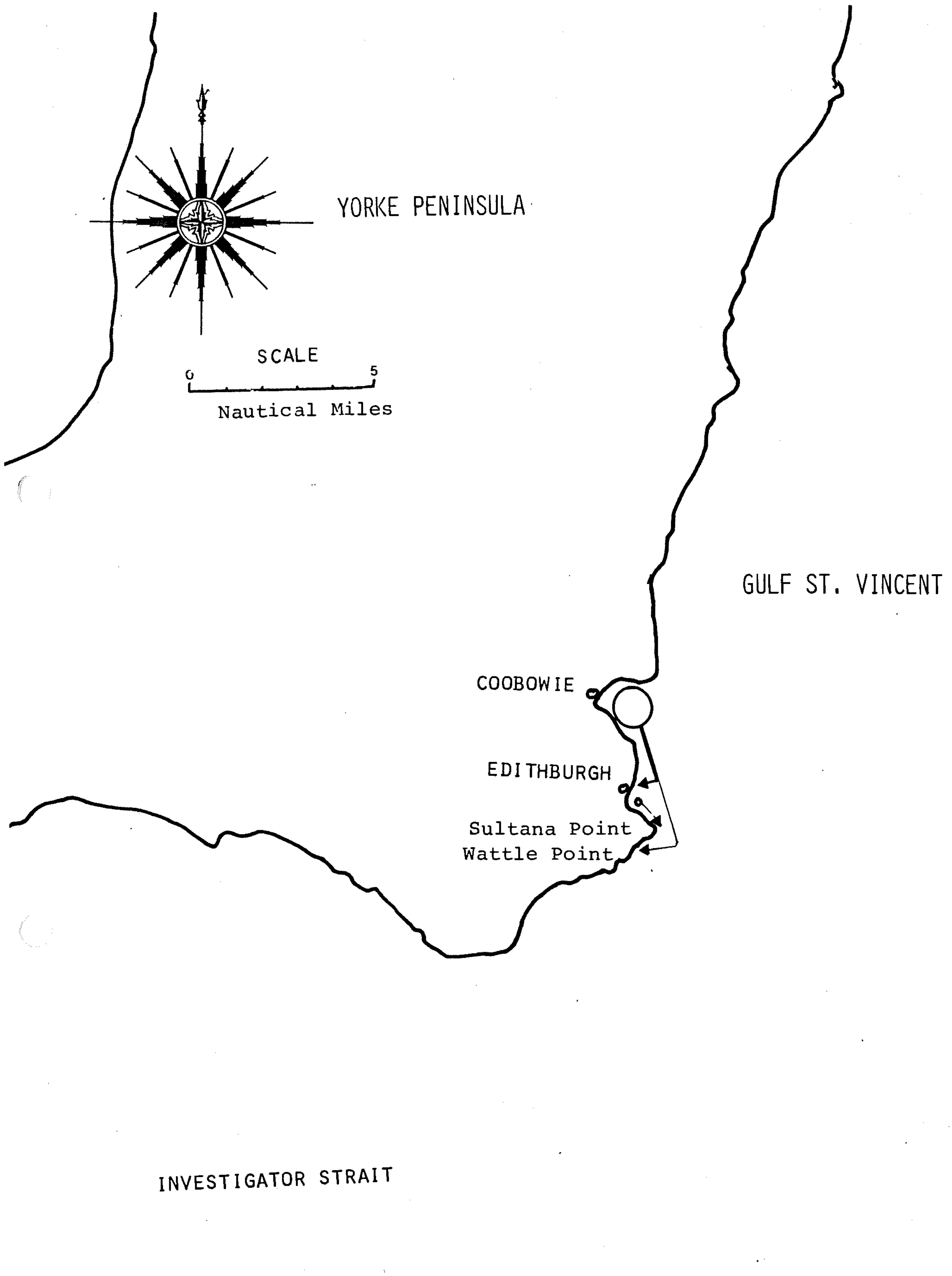

Fig. 10. Calamary movements, south-western Gulf St. Vincent, from tag-recapture data.

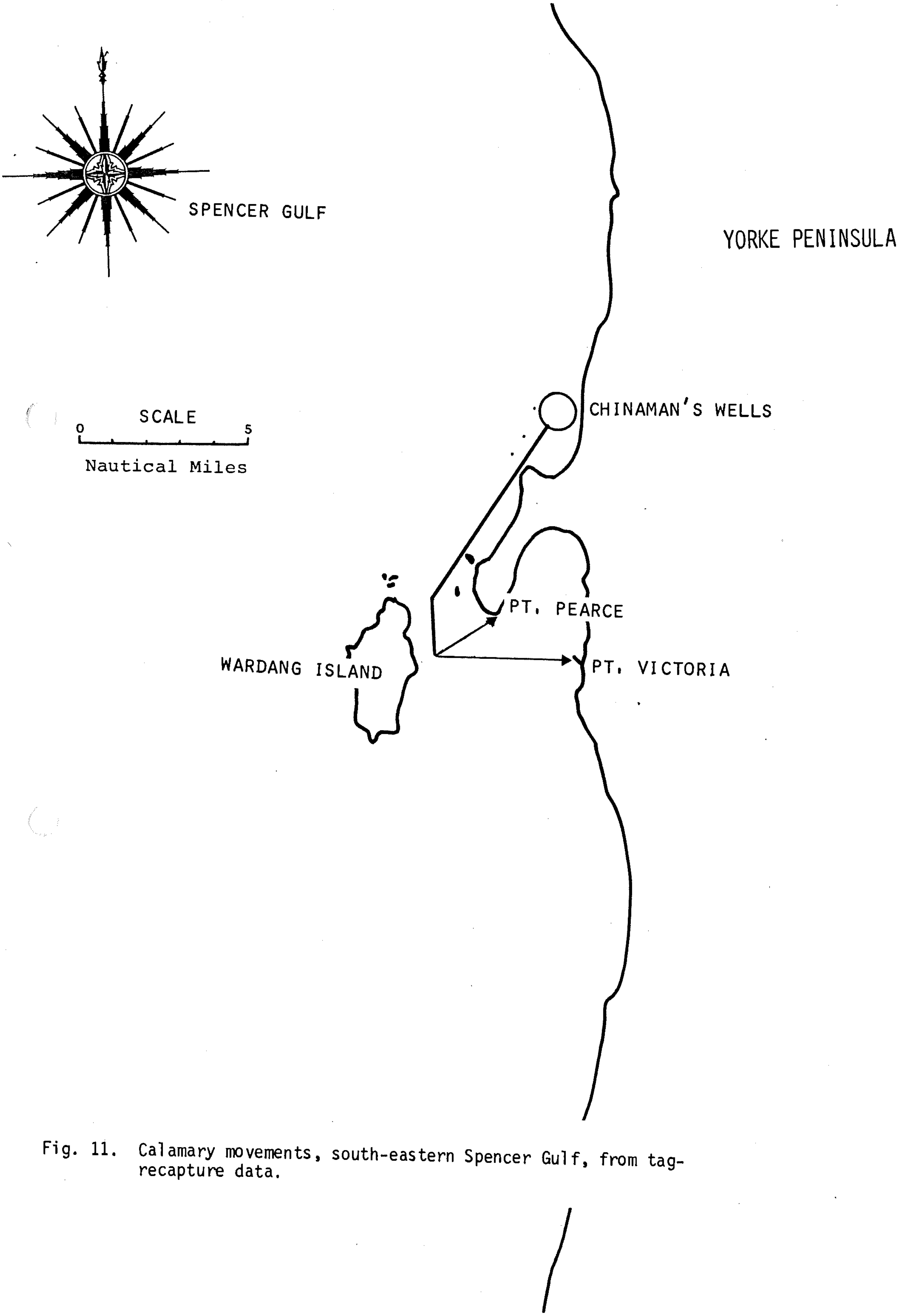

Fig. 11. Calamary movements, south-eastern Spencer Gulf, from tag-recapture data.

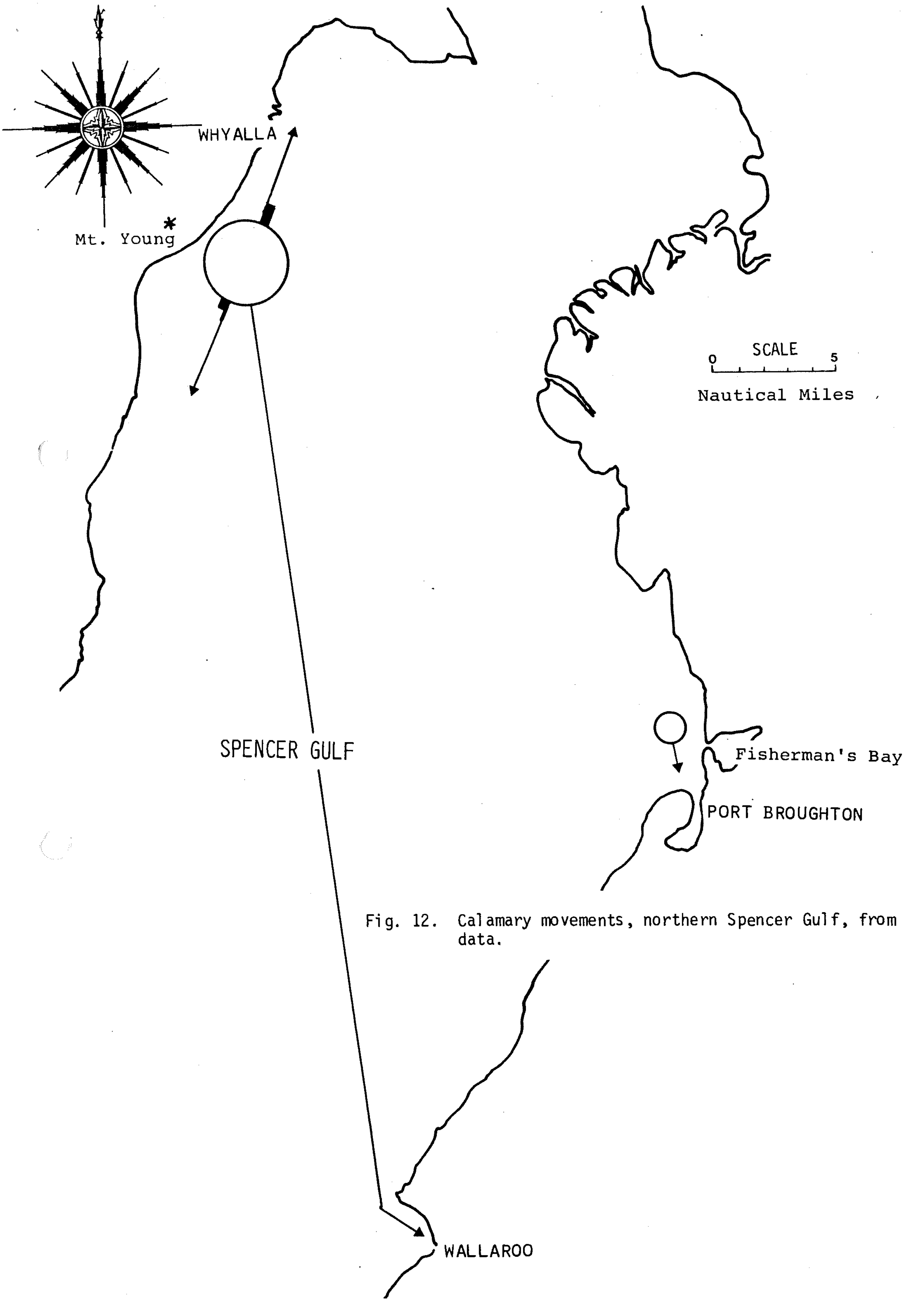

Fig. 12. Calamary movements, northern Spencer Gulf, from tag-recapture data.

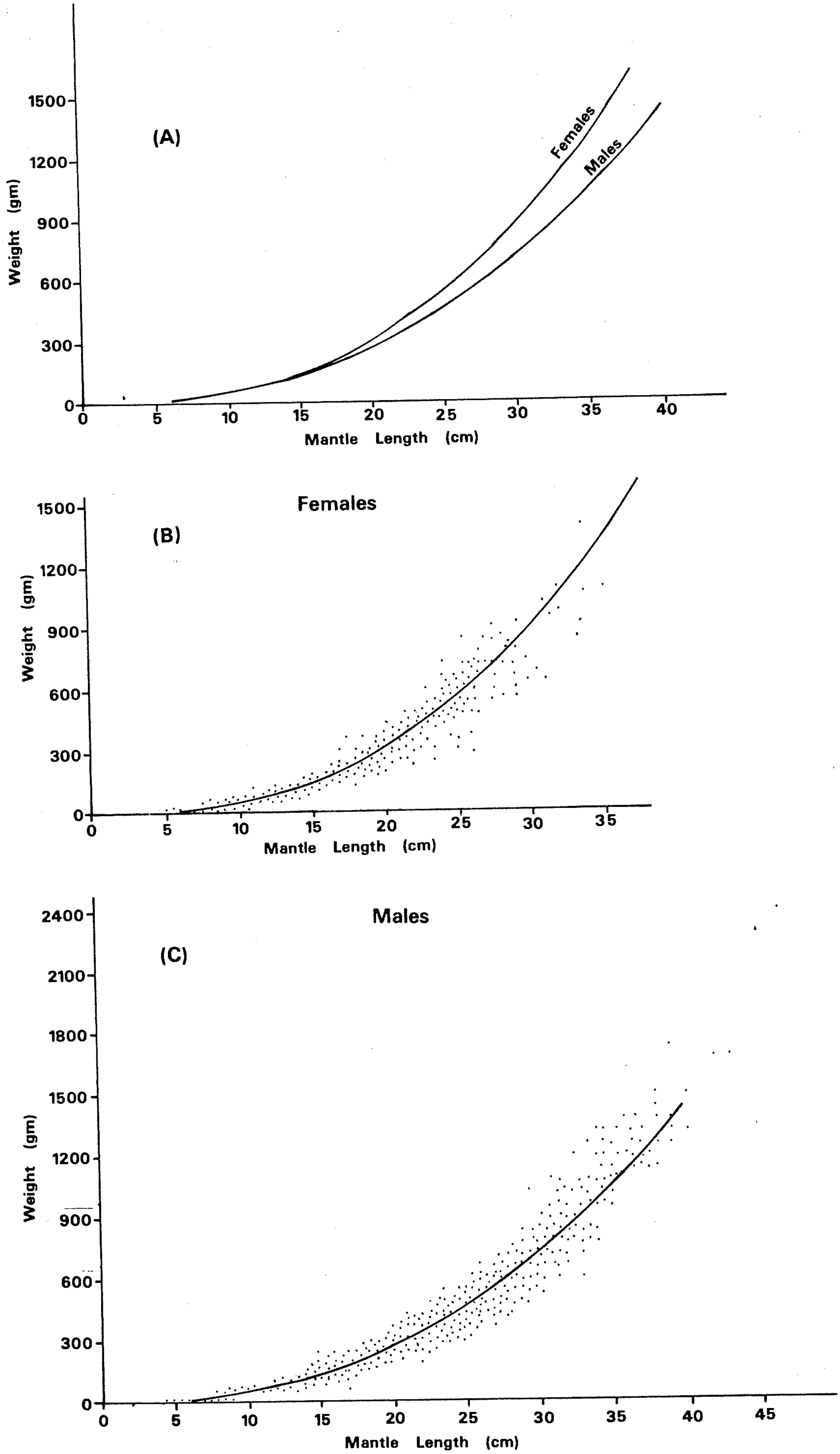

Fig. 13. Length-weight relationship for S. australis

(a) Male and female length-weight relationship.
(b) Observed values plotted against regression line-females.
(c) " " " " " " -males.

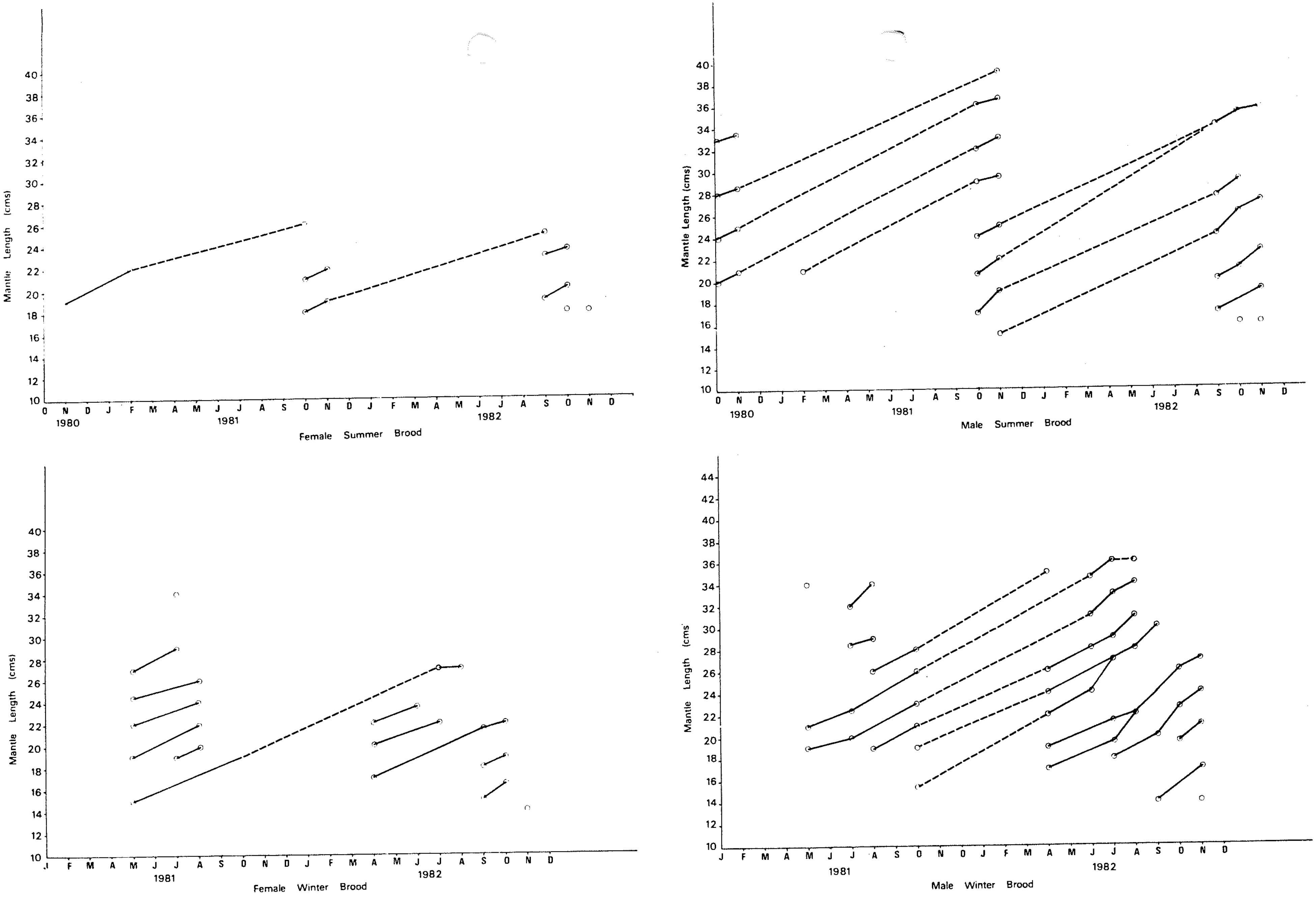

Fig. 14. Modal progression from length-frequency data for both the summer and winter brood (males and females separate).

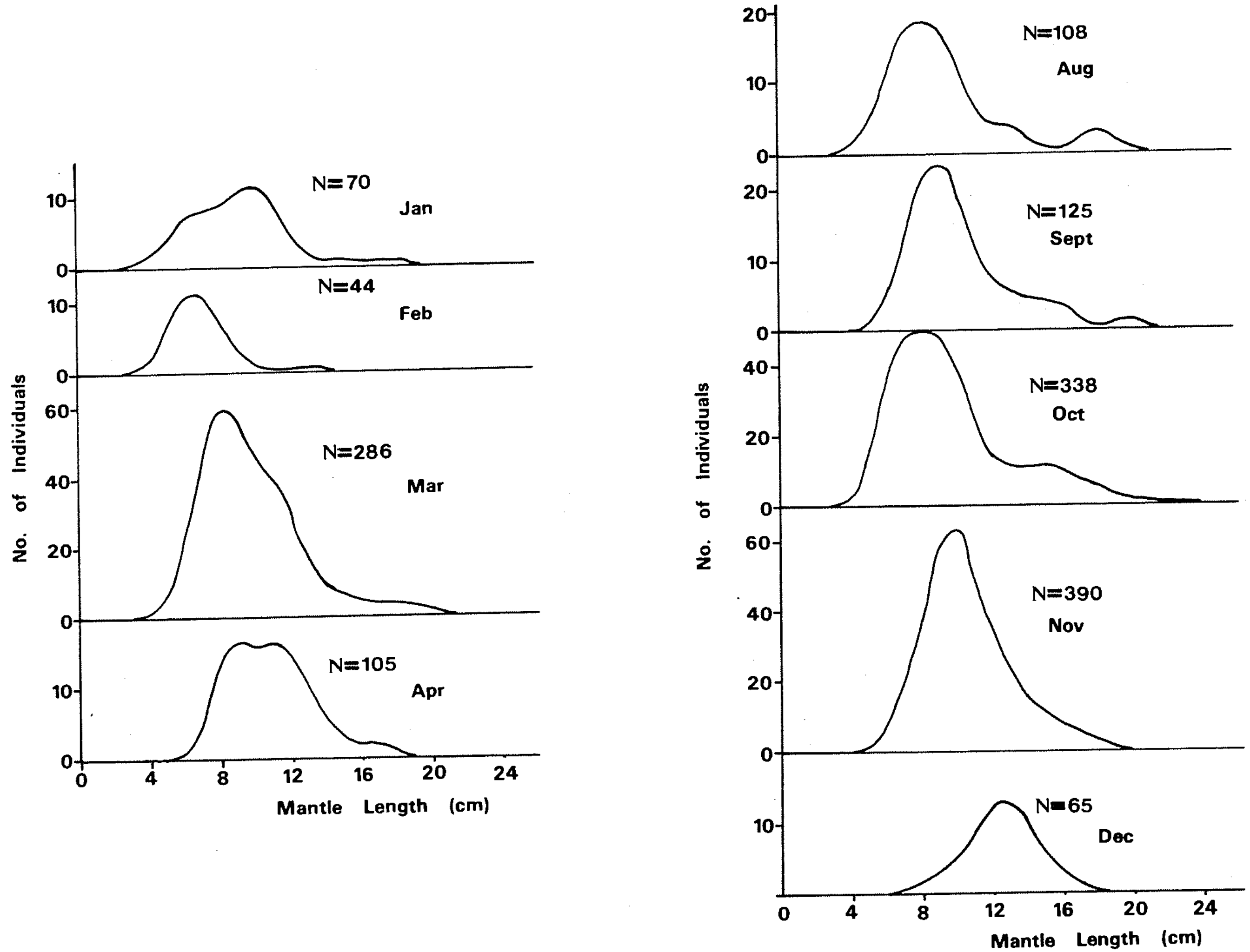

Fig. 15. Length-frequency of trawl caught calamary.

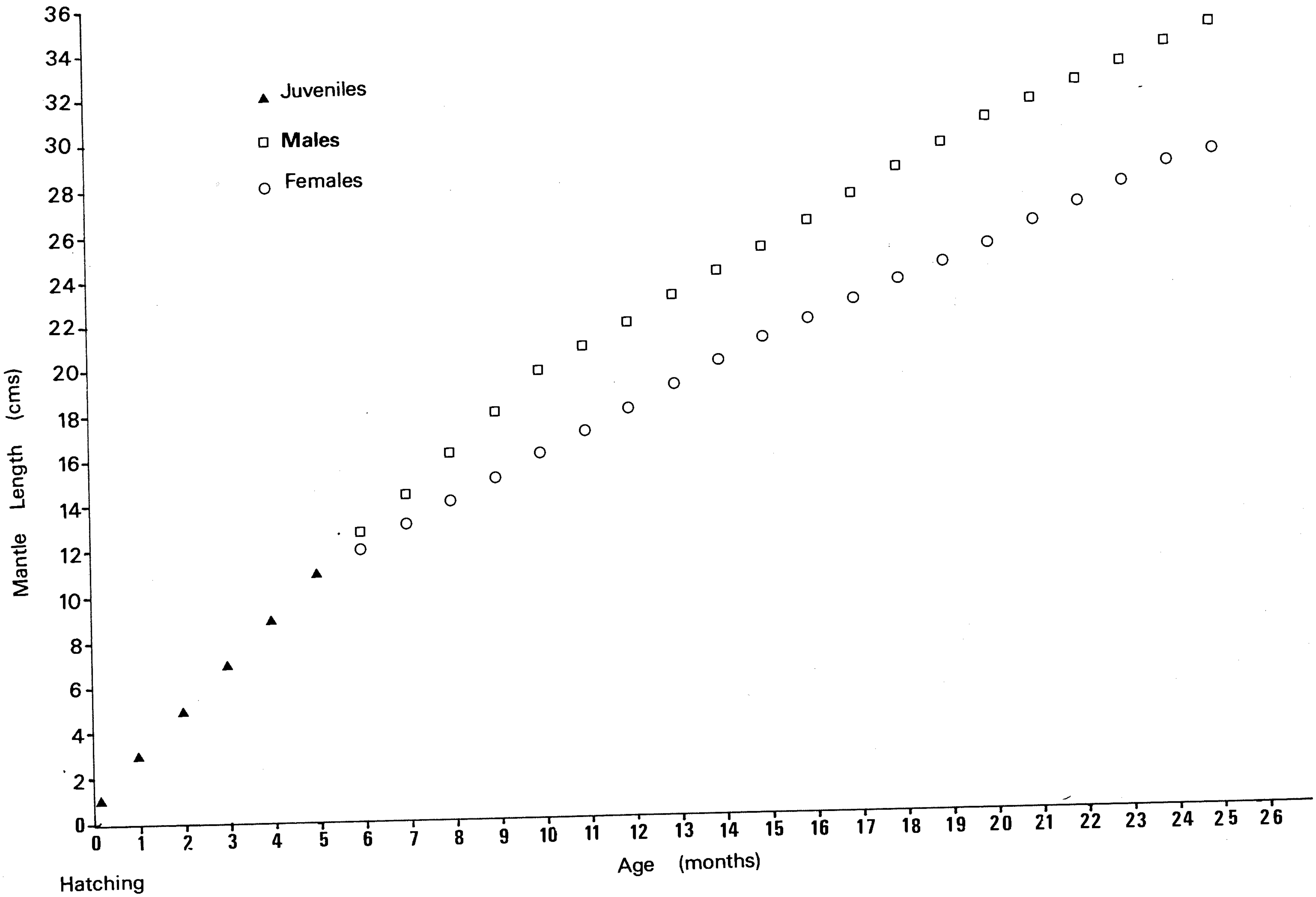

Fig. 16. Age-length key for *S. australis*.

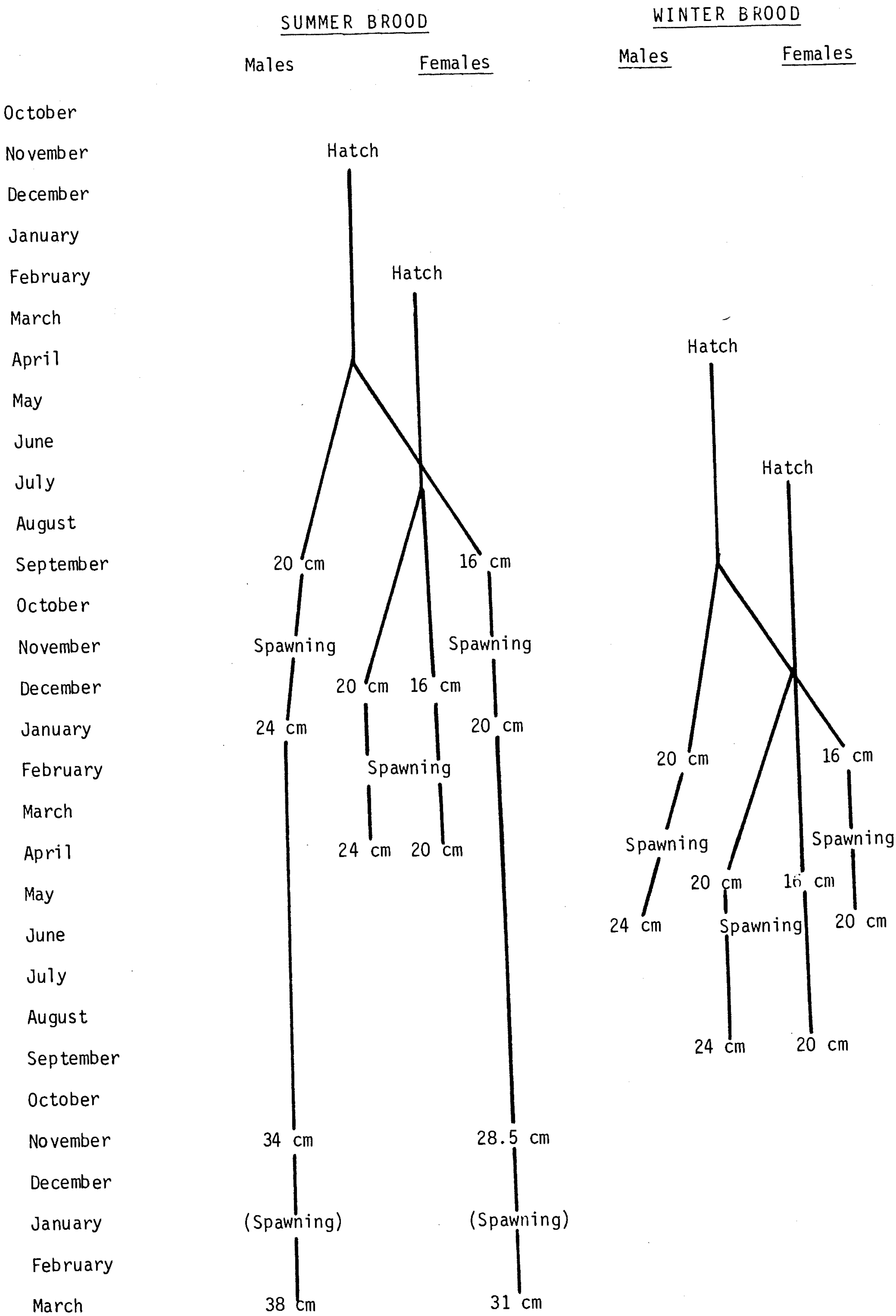

Fig. 17. Proposed life history of *S. australis*.

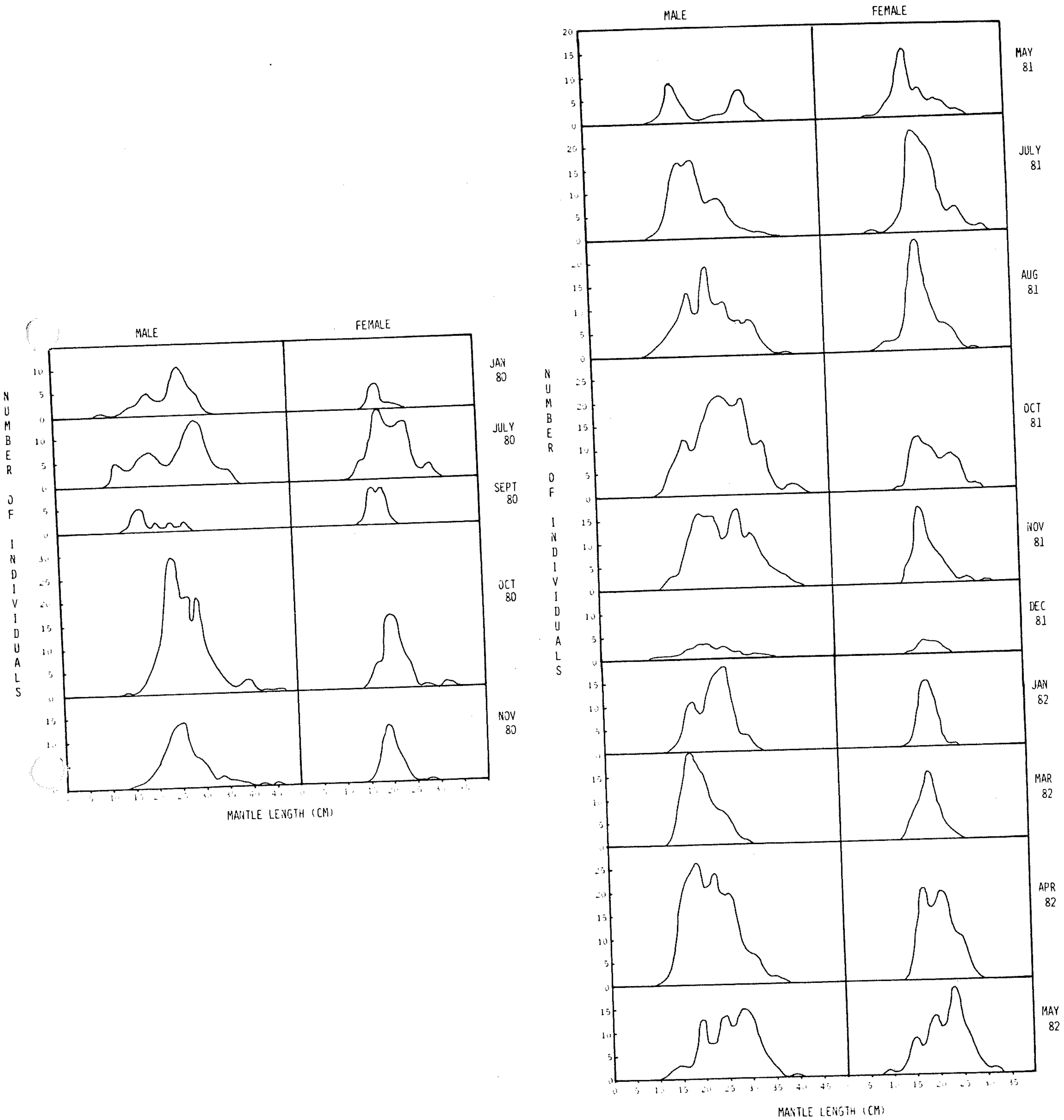

Fig. 18. Length-frequency data for Gulf St. Vincent.

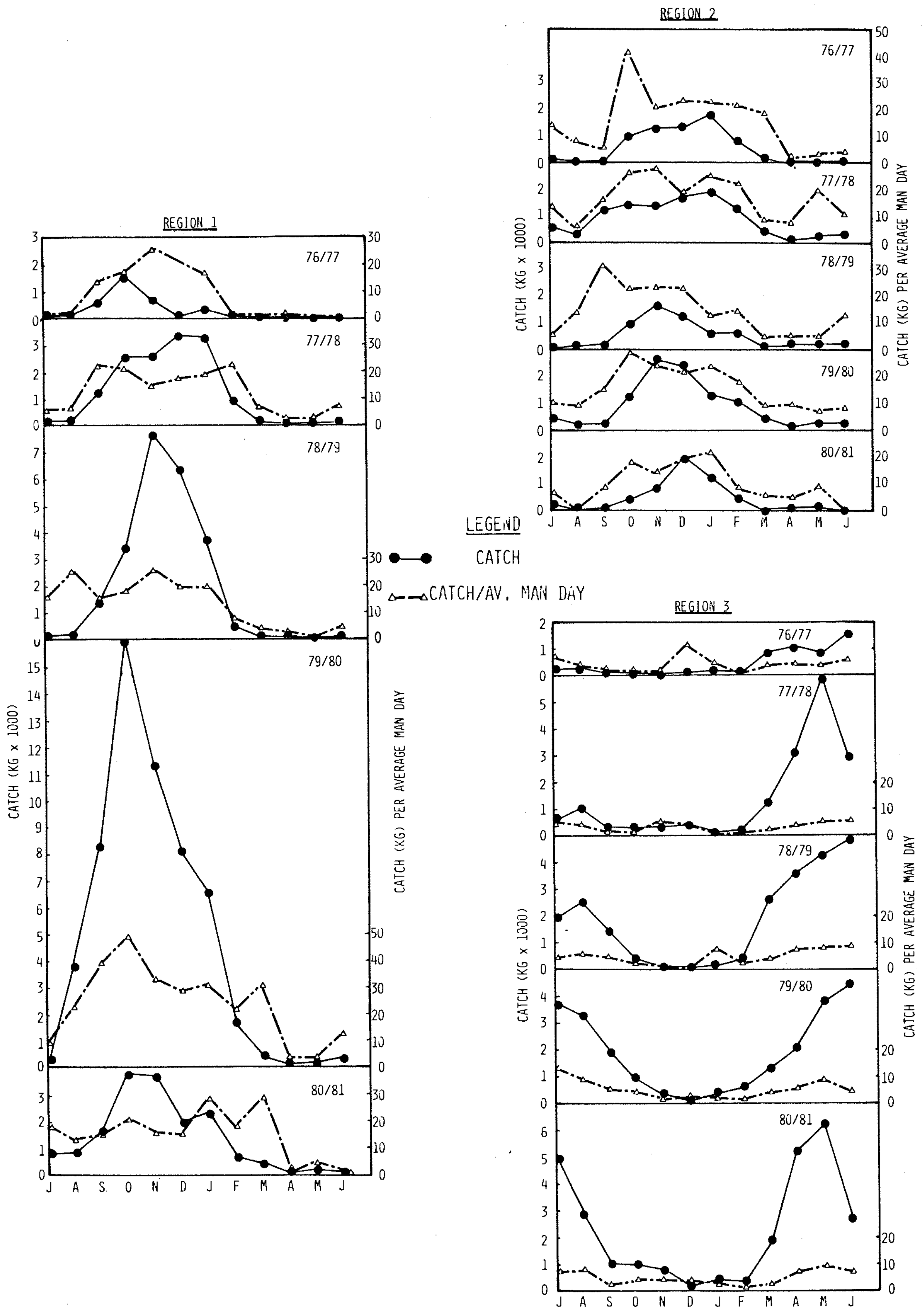

Fig. 19. Catch and CPUE for regions 1 to 3, 1976/77 to 1980/81.

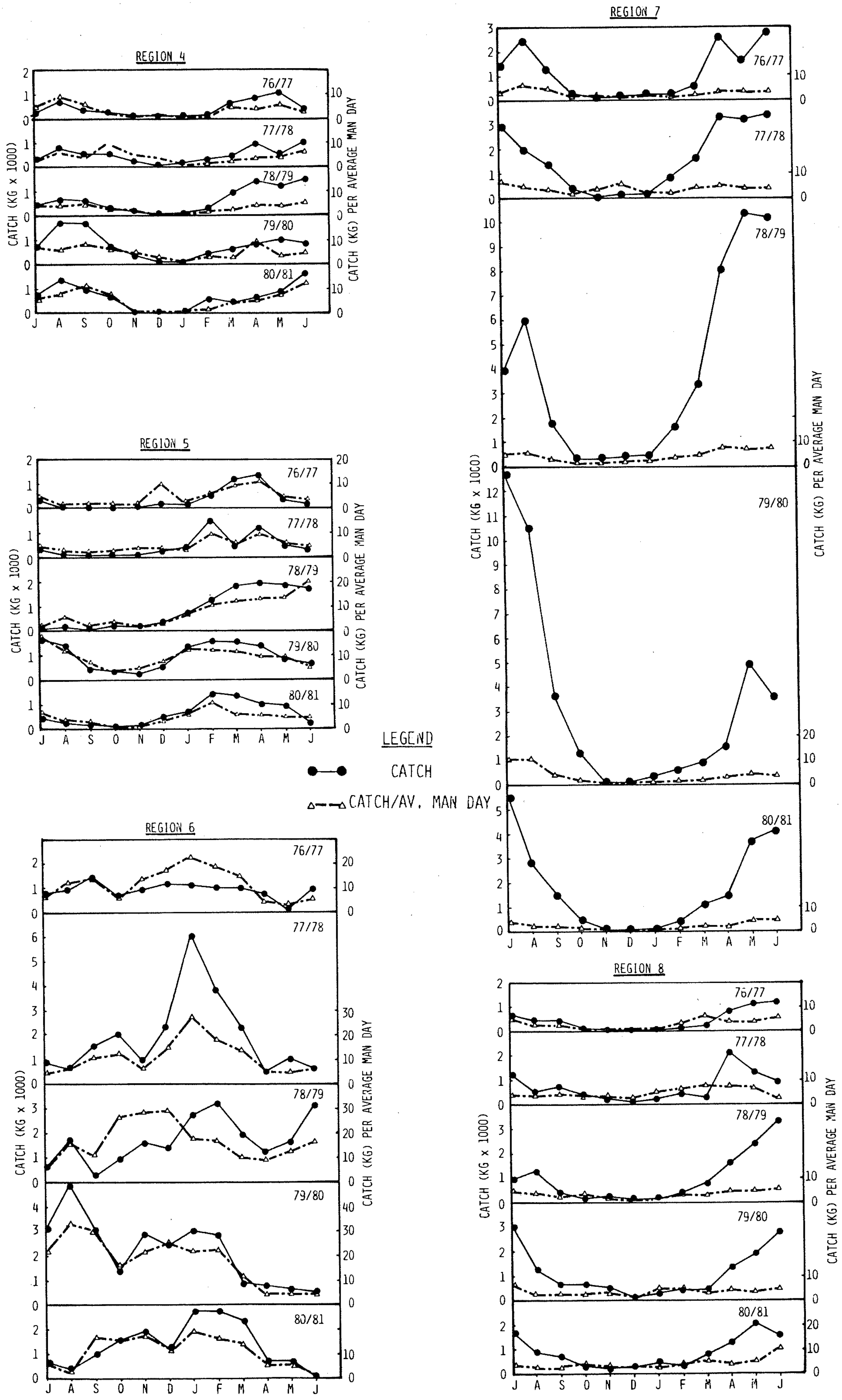

Fig. 20. Catch and CPUE for regions 4 to 8, 1976/77 to 1980/81.

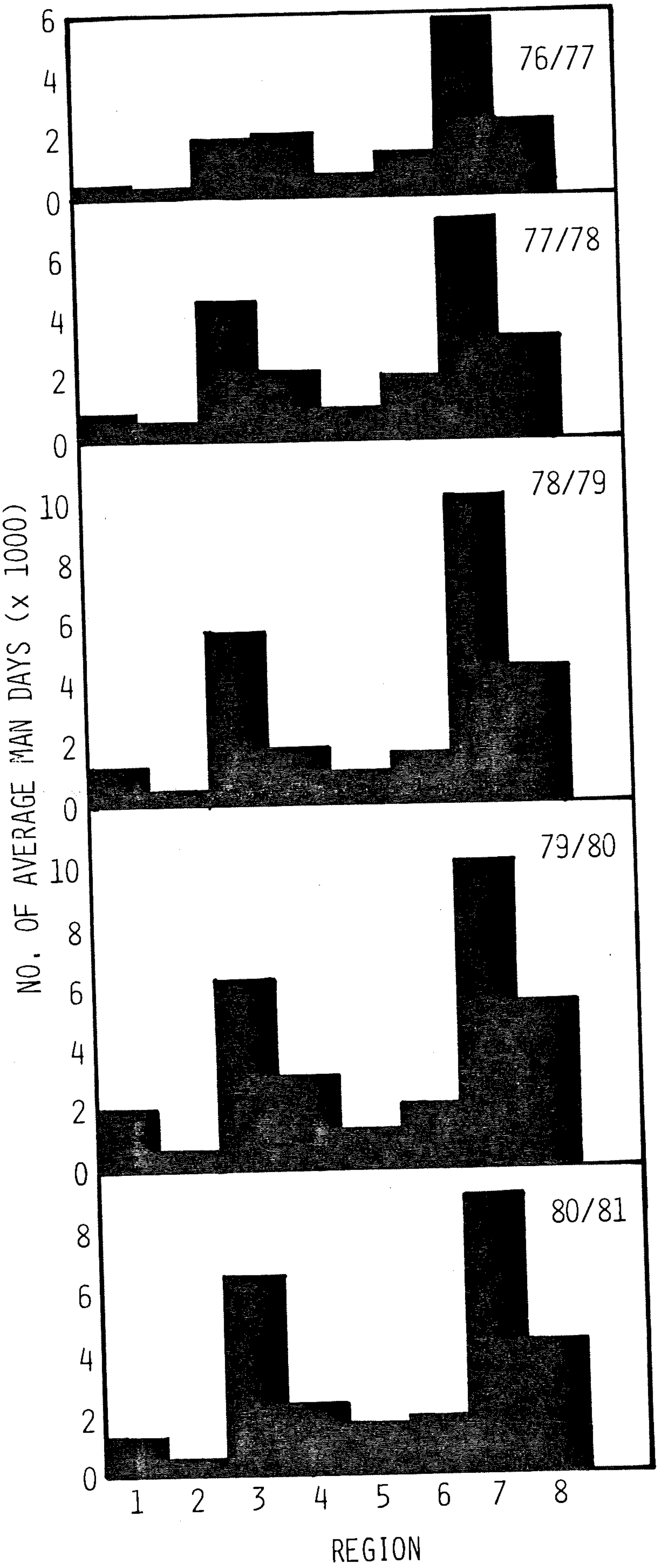

Fig. 21. Total effort (man-days) for all regions, 1976/77 to 1980/81.

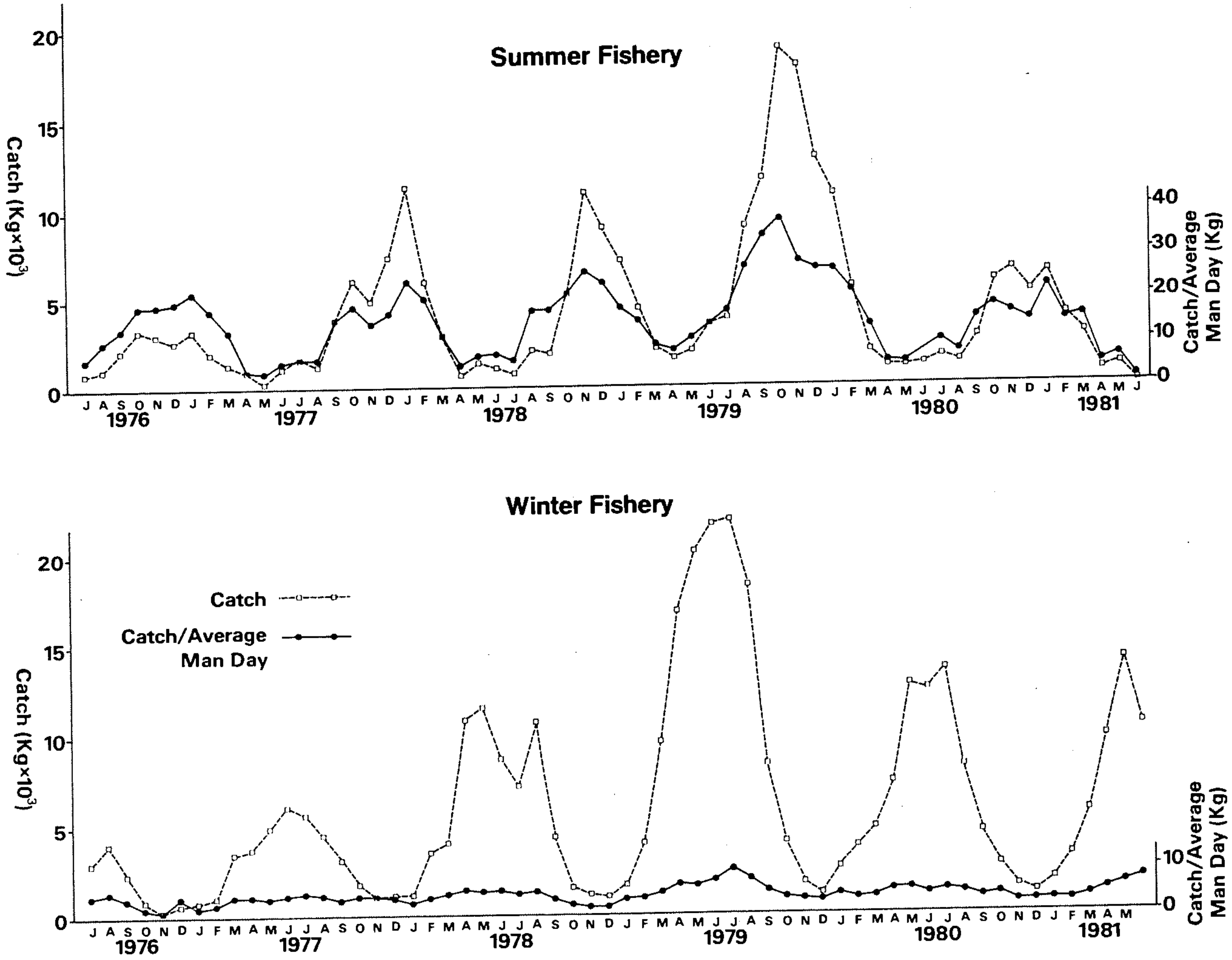

Fig. 22. Catch and CPUE for the summer and winter fisheries 1976/77 to 1980/81.

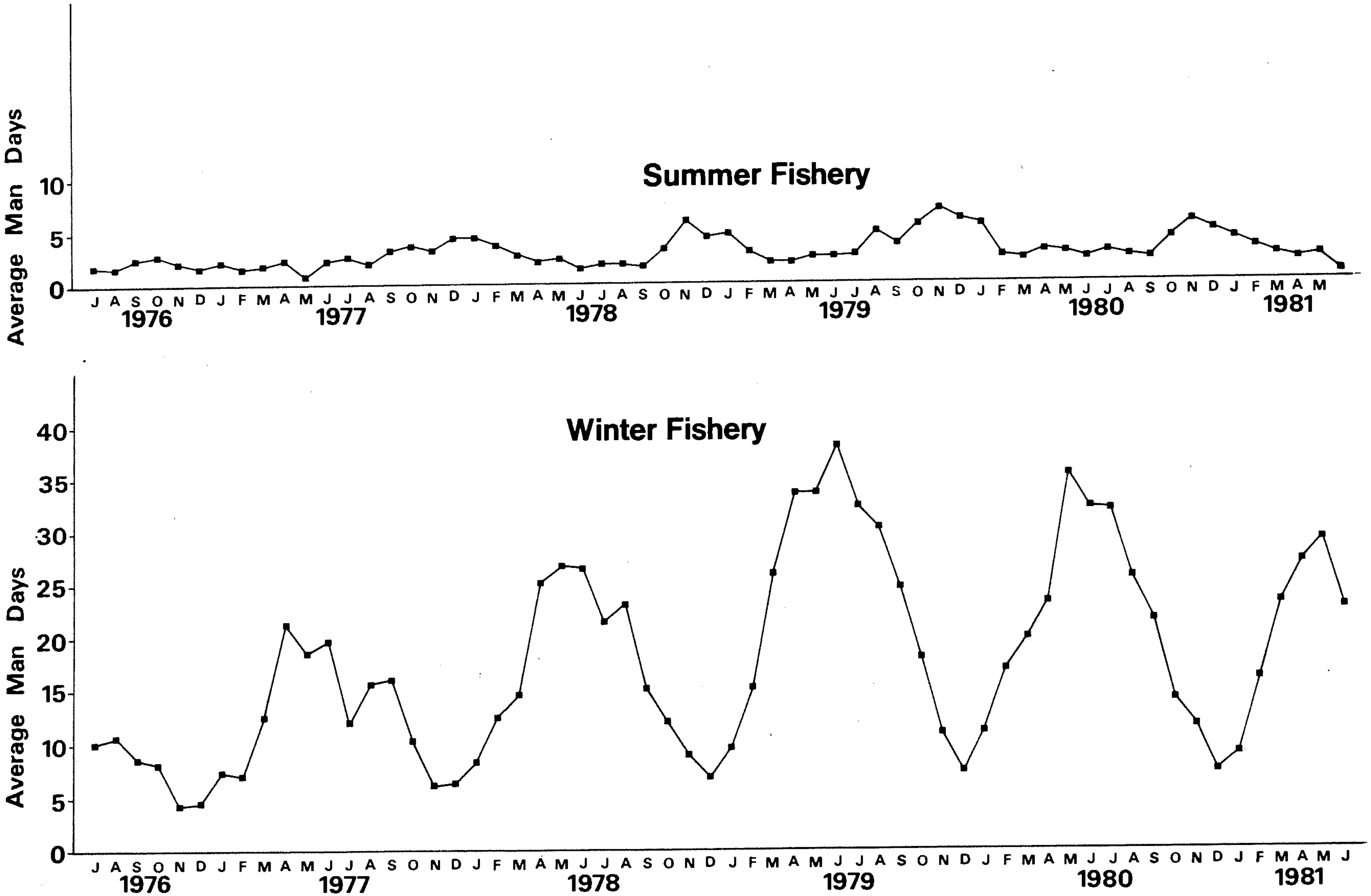

Fig. 23. Effort for the summer and winter fisheries, 1976/77 to 1980/81.

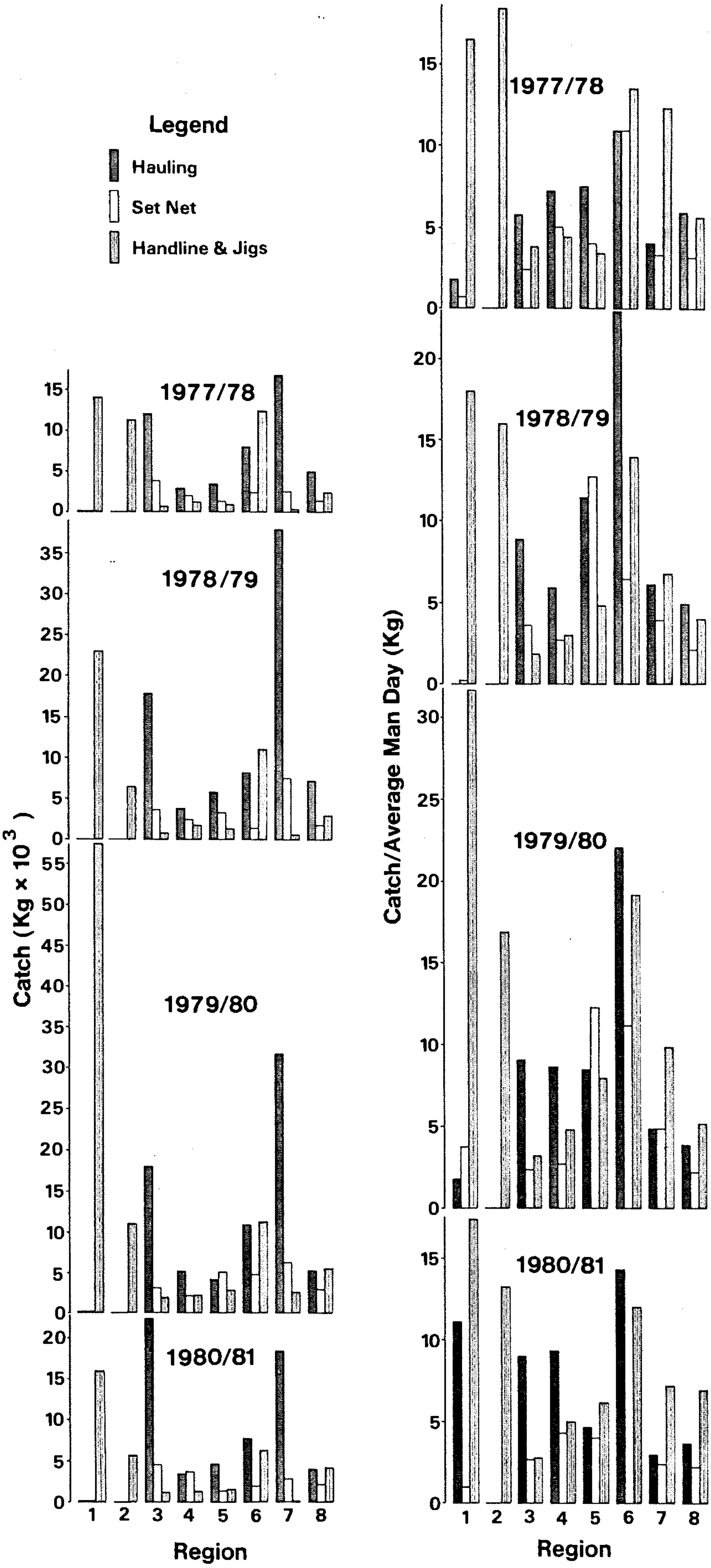

Fig. 24.

(a) Catch by method for regions 1 to 8, 1977/78 to 1980/81
(b) CPUE by method for regions 1 to 8, 1977/78 to 1980/81

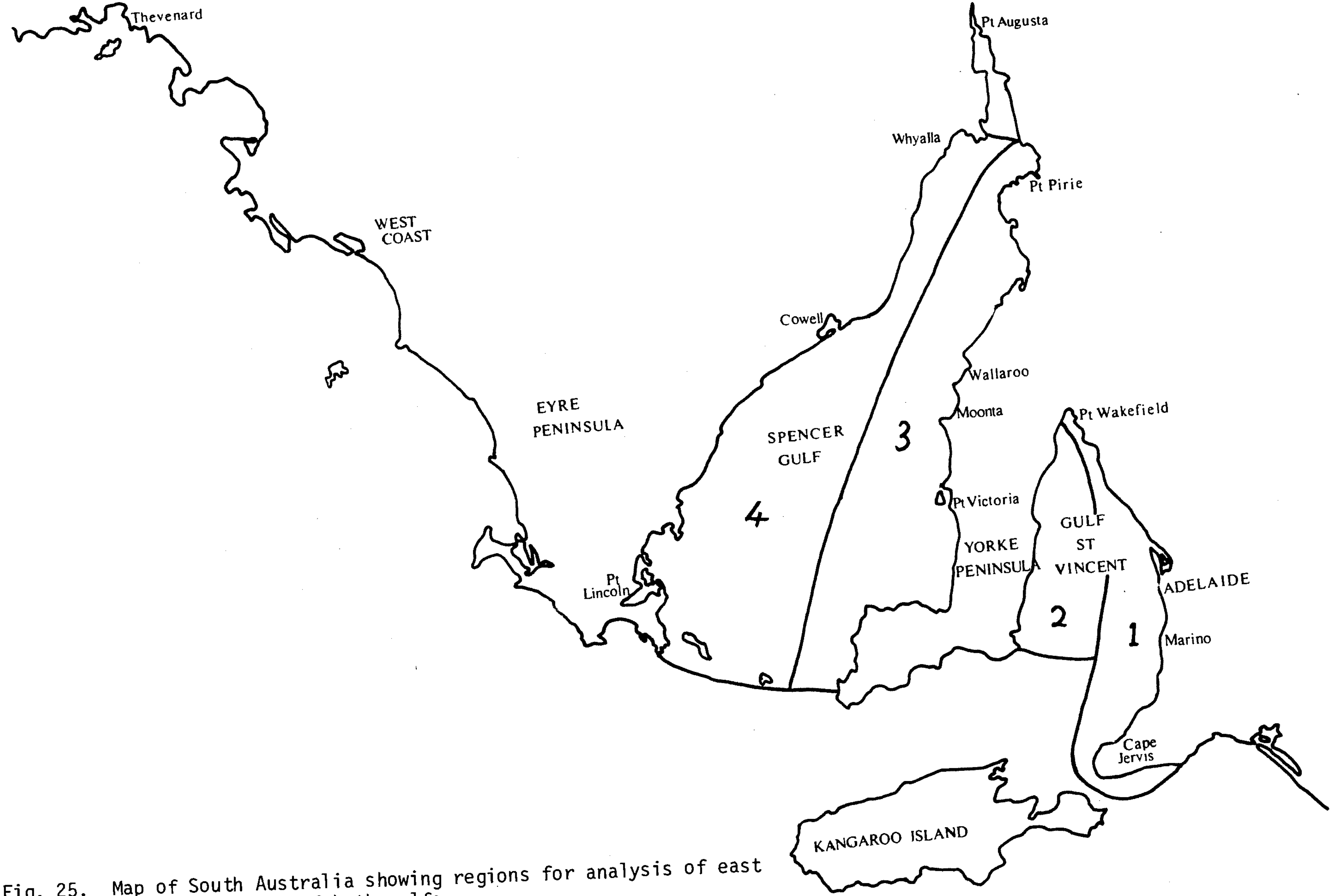

Fig. 25. Map of South Australia showing regions for analysis of east versus west side of both gulfs.

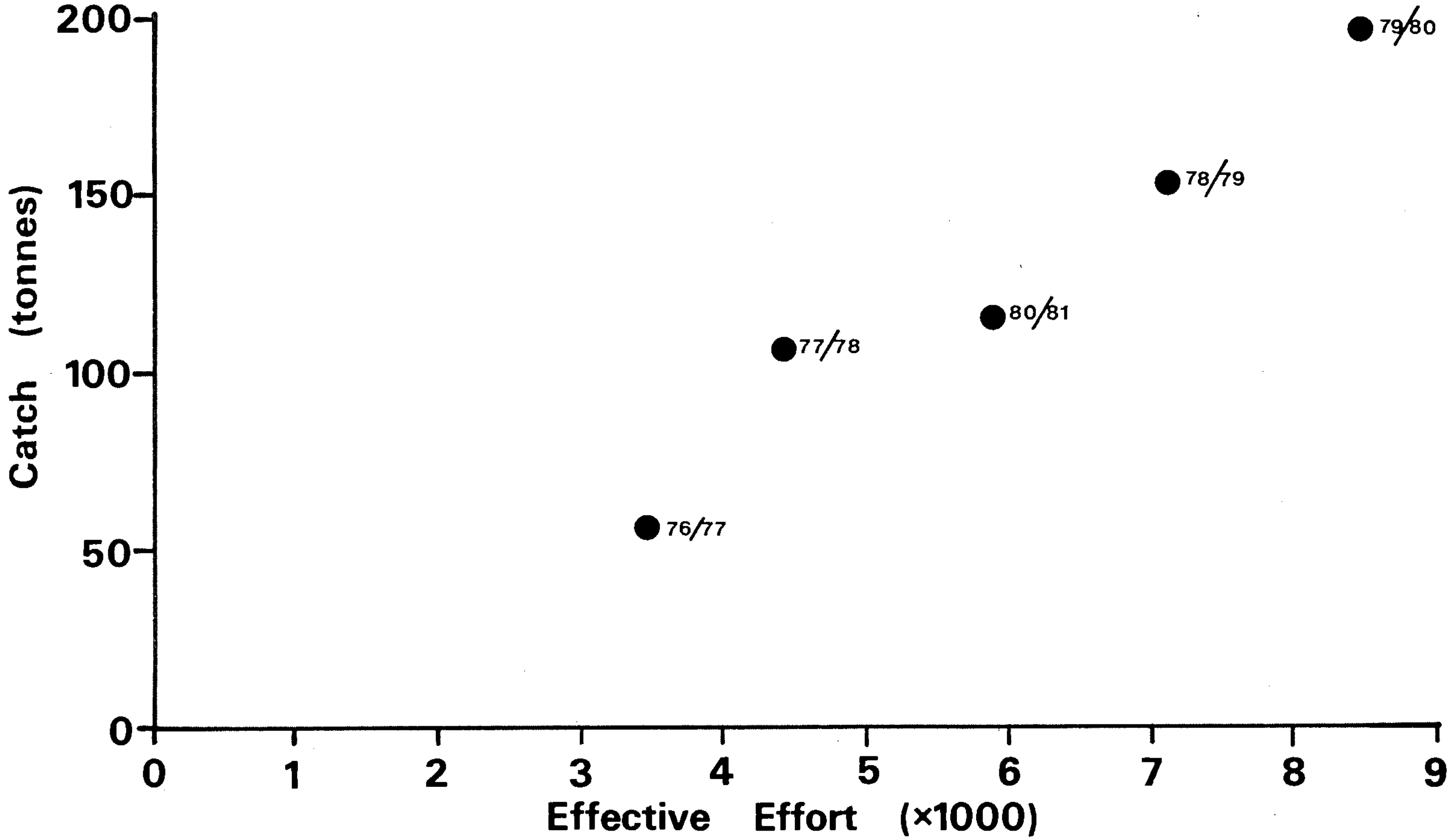

Fig. 26. Plot of catch versus effective effort for the calamary fishery, 1977/78 to 1981/82.