# THE BIOLOGY OF THE WESTERN KING PRAWN *Penaeus latisulcatus* KISHINOUYE AND ASPECTS OF THE FISHERY IN SOUTH AUSTRALIA

by

MICHAEL GORDON KING B.Sc

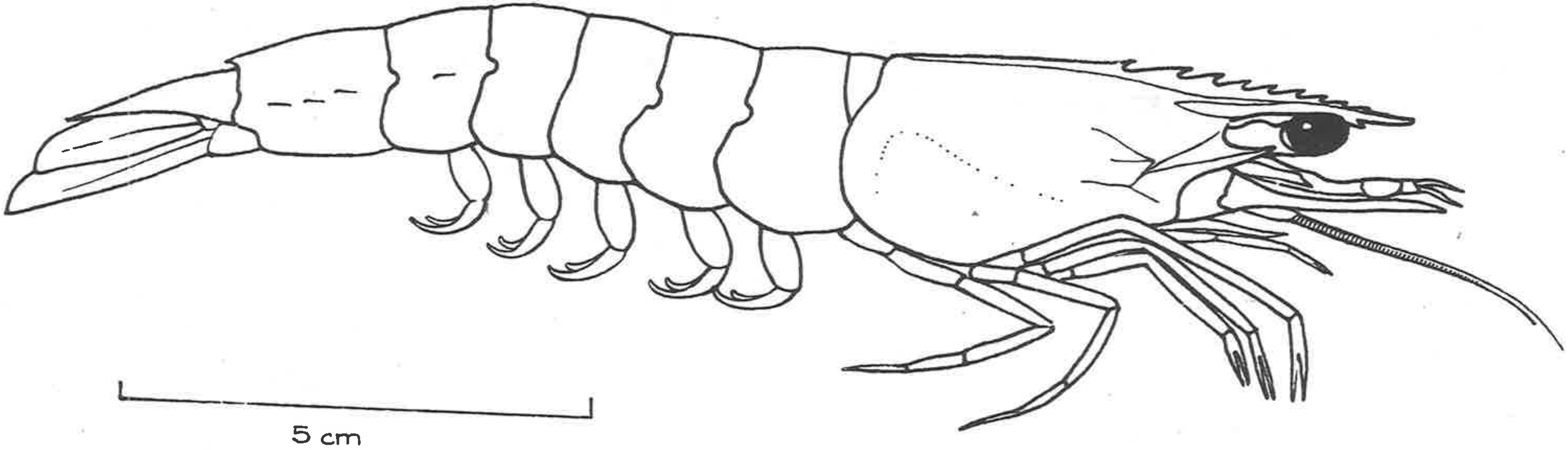
being a dissertation submitted in fulfilment of the requirements for the degree of Master of Science at the Department of Zoology, University of Adelaide, ~~October 1977~~. 1979

Awarded November 1980.

This thesis has not been submitted for the award of any degree/diploma at any other university and contains no material published or written by any other person without due reference in the text.

..................................

M.G. KING




The western king prawn Penaeus latisulcatus Kishinouye

# PREFACE

The prawn fishery in South Australia is unique on two accounts. Firstly it is based on a single species of penaeid prawn (*Penaeus latisulcatus*) and secondly, sensible management measures were taken at its very inception in 1968. These measures have served the fishery well in its development.

However, the fishery has now progressed beyond the developmental stage. Its very nature (involving a luxury food item and handsome profits shared amongst the 61 vessels in the limited licence fishery) has created an unfortunate amount of publicity, jealousy and greed. Management, under these conditions, continues to involve more socio-logical and economic issues than biological. Nevertheless, knowledge of the general biology and population dynamics of the species is basic to sound management.

There are several published accounts of studies on *P. latisulcatus* in Western Australian waters (Penn 1973, 1974, 1975, White 1973). In South Australia, work on the physiological aspects of the species is being carried out (P. Zed, 1977, University of Adelaide) but to date there has been no published work on the biology of *P. latisulcatus* in this State.

Generally, studies on the biology of marine species in South Australia have been few. The exceptions are mainly studies on commercially or recreationally important species such as the garfish (Ling 1956), the yellow-eye mullet (Harris 1968), the pilchard (Blackburn 1950), abalone (Shepherd, 1973 ) , Goolwa cockle (King, Ms.), Pacific oyster (King 1977), razorfish (Butler and Brewster, in prep.) and Rock Lobster (Lewis, in prep.).

This thesis reports the results of research begun in 1973 to study the biology and population parameters of the Western King Prawn in South Australian waters.

The following strategy has been used in the presentation of this thesis. The biology and life-cycle of penaeid prawns in general is discussed in the introduction. A formal literature survey is not included, but the work of others, where relevant, is quoted and discussed in the appropriate part of the thesis.

As the juveniles and adults exist in separate geographic areas (termed inshore and offshore for convenience) the biology of each is presented in separate sections. A short account of the history and management of the fishery is included at the beginning of the section on adults.

## CONTENTS

A. SUMMARY

The western king prawn, *Penaeus latisulcatus* has been fished commercially in South Australia since 1968. In 1973, the present study was initiated in Spencer Gulf and in mid 1976 research effort was transferred to the Gulf St. Vincent and Investigator Strait. This thesis reports the results of the research.

Juvenile prawns were found in many shallow water bays and tidal creeks. The waters of these nursery areas were hypersaline, had high summer temperatures and were invariably associated with seagrass communities (mainly *Posidonia australis*); many, but not all, were associated with stands of mangroves (*Avicennia marina*). In general, sheltered areas to the north of both Spencer and St. Vincent Gulfs were more favoured as nursery areas than southerly locations; however, large concentrations of juveniles were sometimes found in some isolated southerly areas (e.g. Spalding Cove near Port Lincoln).

Both juvenile and adult prawns were found to feed on a wide variety of material and are believed to be opportunistic feeders. Juvenile prawns were found to spend up to 12 months in the shallow water nursery areas. During this period the juveniles had a fast summer growth rate of up to 3 mm carapace length per month and estimates of instantaneous mortality varied from 0.007 per week at Chinaman's Creek (1976) to 0.026 per week at Barker's Inlet (1976). At about 23 mm carapace length juvenile prawns migrated to deeper waters to join the adult stocks. Behavioural mechanisms which are believed to be involved in this migration and recruitment to the fishable stocks are discussed.

After the time of the recruitment peak (December to February), high catch rates were evident in the fishery, especially in Spencer Gulf. The number of individuals recruited to the fishery varied from year to year.

Results of tagging experiments in Spencer Gulf indicated a general southerly migration of adults after recruitment. Growth rates were initially high (approximately 3 mm per month) but lower during the winter

months. Values of the von Bertallanfy growth parameters were calculated (K = 0.021 per week, L = 48 mm) but it is pointed out that there are limitations in the use of this growth model for *P. latisulcatus*.

A method of assessing the reproductive conditions of female *P. latisulcatus* was developed for use on board trawlers. Results showed that a peak in ovary development occurred around November in prawns in Spencer Gulf. At present levels of fishing, there appears to be no relationship between size of spawning stock in one year and recruitment in subsequent years. The recruitment or catch potential of a particular year is therefore likely to be related to the effect of environmental factors on the survival of the previous year's juveniles in the inshore nursery areas.

Present (1977) levels of instantaneous total mortality (Z) for Spencer Gulf were estimated to be 0.052 per week (approximately 5% per week). The average value of natural mortality (M) was 0.028 per week.

## B. INTRODUCTION

The exploited species of prawns in Australia belong to the genera *Penaeus* and *Metapenaeus*. Species of these genera are generally characterised by a short life cycle and correspondingly high mortality rates.

Three basic types of life cycle have been discribed (Kirkegaard 1973): ocean prawns, which spend both their larval and adult phases offshore; estuarine prawns which complete their life cycle in esturies or creeks and prawns which spend their juvenile phase inshore and their adult phase offshore in deeper water. Most exploited species belong to this third category which includes the eastern king prawn *Penaeus plebejus* (Racek 1959), the banana prawn *P. merguiensis* (Munro 1973), the tiger prawn *P. esculentus* (Racek 1959) and the school prawn *Metapenaeus macleayi* (Racek 1959).

In these species spawning takes place offshore. Fertilization is external and the eggs are shed near the sea bottom. Time taken to hatch into the first larval stage (nauplius) ranges from about 1 hour in *P. merguiensis* (Munro 1968) to 13 or 14 hours in *P. japonicus* (Hudinaga 1963) but temperatures for these hatching times were not given by these authors. The time taken for the eggs of *P. latisulcatus* to hatch in indoor tanks is approximately 15 hours at 27°C (K. Yasuda, 1977, pers. comm.).

Following the nauplius, protozoae and mysis larval stages, the post larvae reach and settle in shallow "nursery" areas on the coast. Here, the juveniles grow to subadults before migrating offshore to join the adult stock. Penaeid fisheries are therefore based on 'annual crops' of newly recruited prawns. The fishing and natural mortality in most prawn fisheries is generally thought to be high enough to allow only a small number of individuals to reach their second year offshore.

The western king prawn, *Penaeus latisulcatus* in Shark Bay, Western Australia is known to be unusual in that the larval stages migrate inshore to waters that are of greater salinity than the offshore areas where the adults live (Penn, pers. comm.). Only a few other penaeids are known to have juveniles which exist in high salinity areas - *P. californiensis* and *P. brevirostris* (Edwards and Bowers, 1974).

As with other penaeids in Australia, *P. latisulcatus* probably originated in tropical regions where it is widespread (Racek & Dall, 1965); the species is caught by trawlers operating in the coastal waters of several countries (Table B-1). Its distribution in cooler regions is limited and there is no evidence that the species has reached Australia from other temperate regions. Outside of Australia, *P. latisulcatus* has been recorded as far south as Durban Bay in South Africa (Joubert 1965).

TABLE B-1

Prawn fisheries outside Australia where some or all of the landed catch consists of *Penaeus latisulcatus*

| Location | Reference |
|---|---|
| Saudi Arabia, Arabian Gulf | Lewis *et al* (1973) |
| Africa, Mozambique coast | Ivanov & Hassan (1976) |
| Sri Lanka, North coast | De Bruin (1970) |
| New Guinea | Rapson & McIntosh (1971) |

Within Australian waters *P. latisulcatus* is found from South Australia around through west and tropical Australia (Figure B-1). The species has a scattered distribution down the east coast and has been reported as far south as Ocean Grove Beach at the entrance to Port Philip Bay (Winstanley 1975). The major fisheries for *P. latisulcatus* are in Spencer Gulf in South Australia and Shark Bay in Western Australia. In Shark Bay, however, a second species of penaeid prawn, *P. esculentus*, is also caught. Table B-2 shows the 1976 landings of Australian commercial fisheries.

TABLE B-2

1976 landings (tonnes) of *Penaeus latisulcatus* from Australian fisheries

| | | |
|---|---|---|
| Western Australia | Shark Bay | 1 511 |
| | Exmouth Gulf | 232 |
| | Onslow | 1 |
| South Australia | Spencer Gulf | 2 130 |
| | Gulf St. Vincent | 511 |
| | Investigator Strait | 147 |
| | West Coast | 51 |

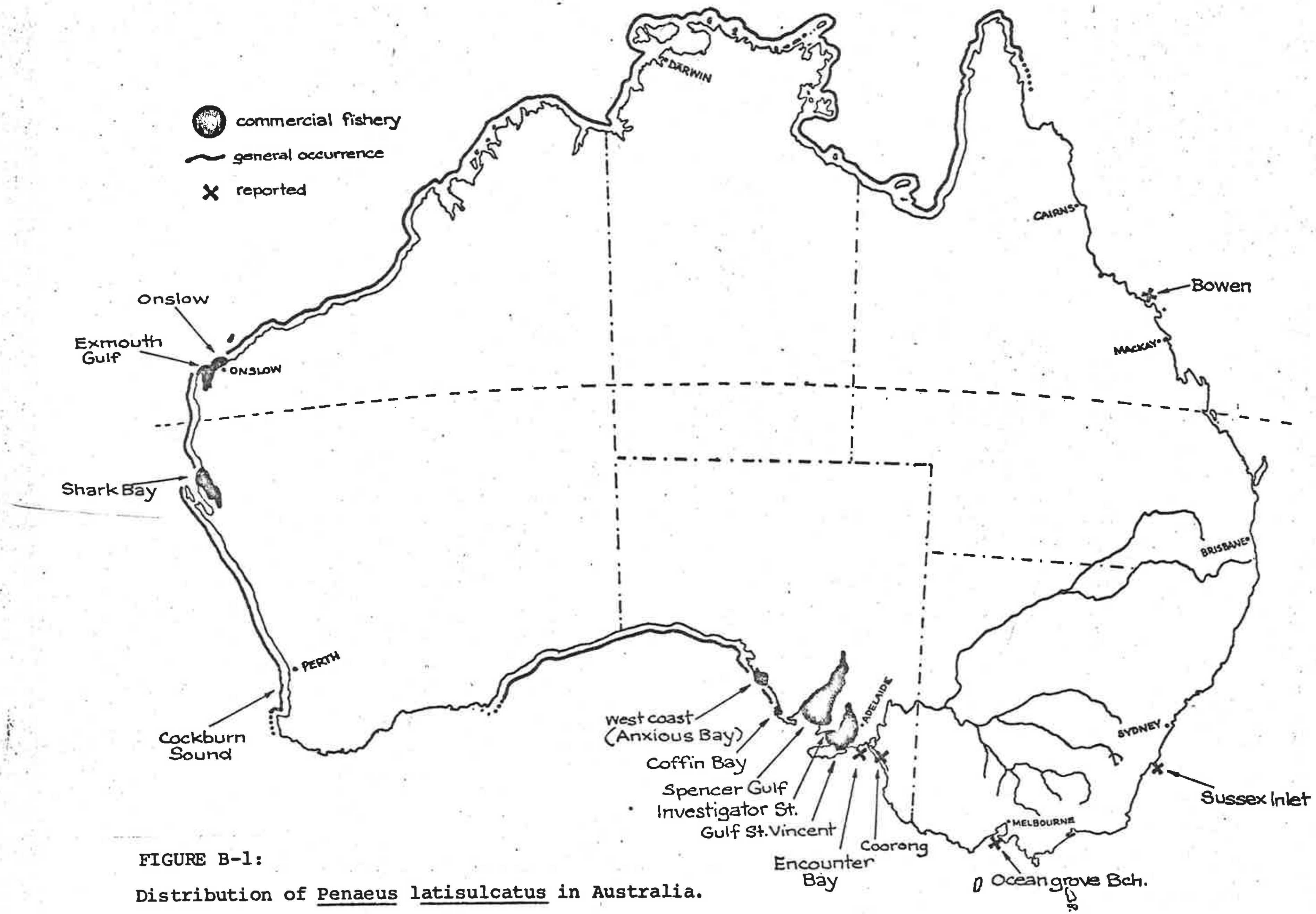



FIGURE B-1:

Distribution of <u>Penaeus</u> <u>latisulcatus</u> in Australia.

## C. METHODS

A field programme was designed to obtain and study both juvenile and adult *Penaeus latisulcatus* in Investigator Strait, the Gulf St. Vincent and especially the area which constitutes the major fishery, Spencer Gulf.

### 1. SAMPLING

Since the activity of other penaeid prawns is known to be related to the lunar cycle (White 1973, Munro 1973) all regular stations were sampled at the same period of the lunar month.

#### a. Juveniles

Juvenile prawns were sampled using a beam trawl, the design of which was adapted from similar shrimp nets used in Holland, where the size of shrimp in the commercial catch is similar to juvenile *P. latisulcatus*. Dimensions of the frame are given in Figure C-1 and the net is of ½" (12.7 mm) mesh (stretched between knots). A 5mm diameter 'tickler' chain was fitted and the action of the net was checked by SCUBA diving.

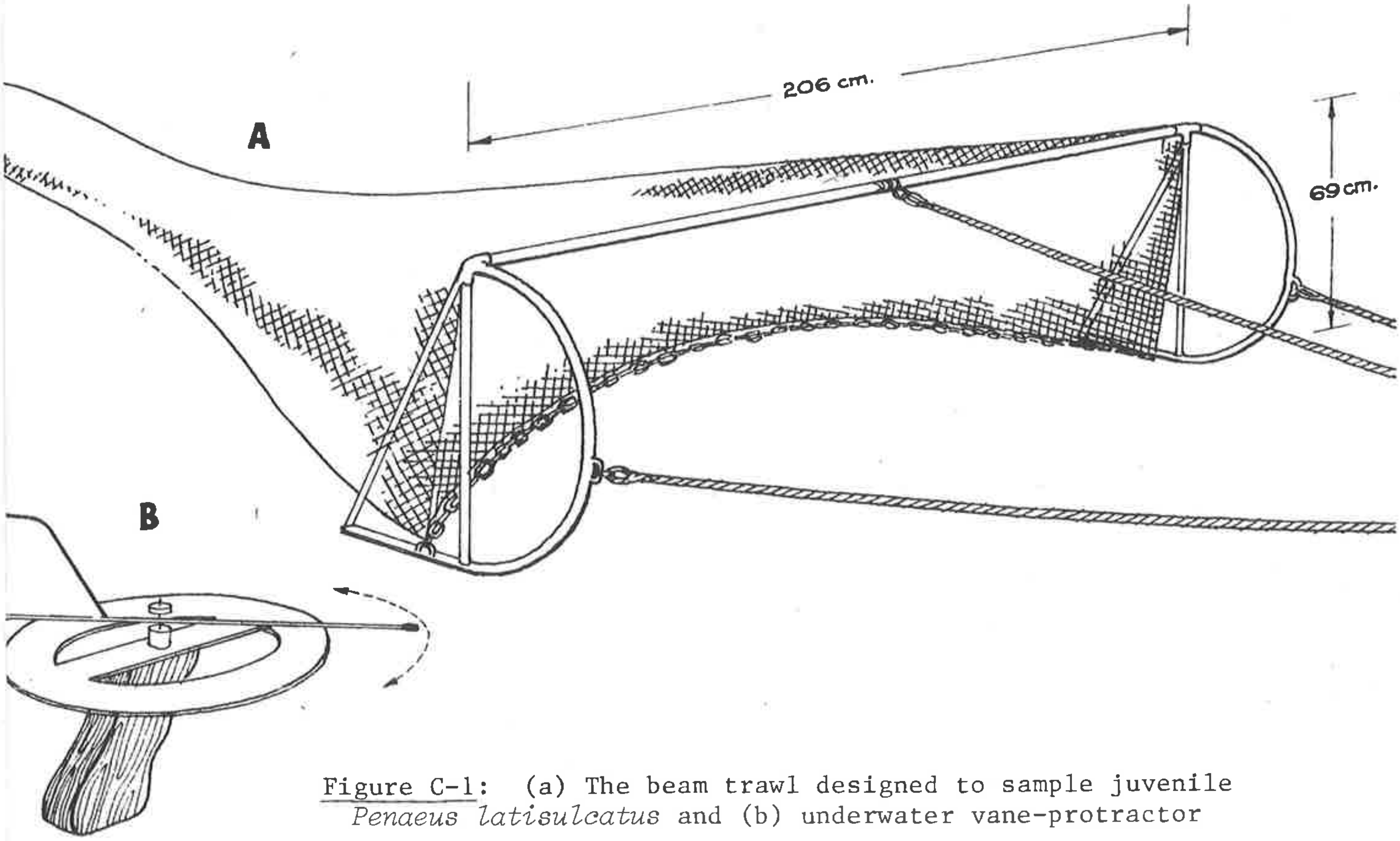



Figure C-1: (a) The beam trawl designed to sample juvenile *Penaeus latisulcatus* and (b) underwater vane-protractor

A standard trawl consisted of the beam trawl being towed behind a 7 m boat at constant engine revolutions. The net was always towed into the tidal flow giving an approximate water speed of 2½ kn (1.3 m/s). Trawl times varies between 6 to 15 minutes and the catch was recorded as number of prawns per minute. In the initial stages of the programme samples were collected at all stages of the tide and moon phase.

Other sampling gear used for juvenile prawns consisted of a drag net and a small dip net, each with similar sized net (½") to the beam trawl. The drag net was similar to a traditional haul or beach sein net in that it consisted of a net strung between two poles, a weighted bottom line and a 3 m head line with floats. However, unlike the traditional gear the middle portion or bunt was formed into a "belly" and "cod end". The net was used in two ways: firstly, by using the poles to drag the net by hand in the shallows and secondly, by driving the poles with stakes and guy ropes into the bed of tidal creeks. The latter method was used in an attempt to study the activity of juvenile prawns in relation to the ebb and flood tides. However, the use of set nets was later abandoned as impractical due to the small number of prawns and large quantities of drifting seagrass caught in the net.

Permanent monthly stations for juveniles were at Chinamen's Creek in northern Spencer Gulf and Barker's Inlet, St. Kilda in Gulf St. Vincent (Figure C-2). In addition the distribution of juveniles was ascertained by extensive shallow water trawling at irregular intervals in both gulfs as well as on the north coast of Kangaroo Island.

Samples of juvenile prawns were preserved in 10 per cent formalin and subsequently weighed and measured in the laboratory. Many morphometric data were taken, but the carapace length (distance between the post-orbital groove and the median posterior margin of

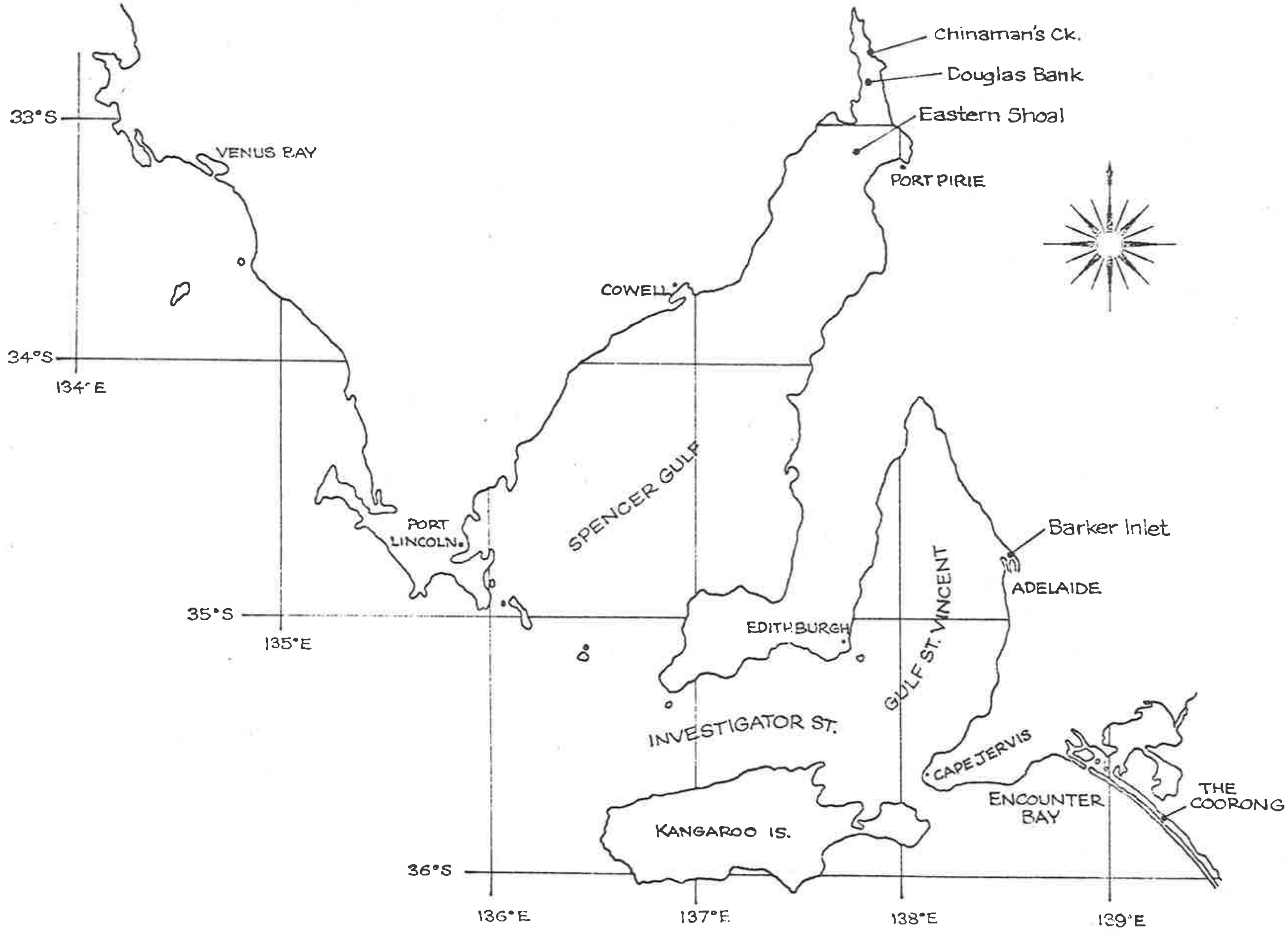



FIGURE C-2: Map of general study area in South Australia showing the main areas referred to in the text.

the carapace) was used as the most reliable index of size.

b. Adults

Adult prawns were sampled by working from commercial trawlers and permanent monthly stations were maintained at Douglas Bank and Eastern Shoal, both in Spencer Gulf (Figure C-2). Studies were carried out at other locations opportunistically. On several occasions a trawler was used on extended surveys of both Gulfs and Investigator Strait. These surveys of 3 to 4 nights duration gave a more or less "instantaneous picture" of the size composition, abundance, etc. of the populations. The effectiveness of these survey programmes was reduced by not having the use of a fisheries research vessel.

More recently (August 1976) research work was started on a regular basis in Investigator Strait using commercial vessels. A fisheries research vessel is now being fitted with trawling gear and regular research cruises are planned for the Gulf of St. Vincent.

2. DIVING OBSERVATIONS

The behaviour of juvenile prawns in relation to tidal flow, light and season was studied using SCUBA equipment. Net covered cages with no bottom were anchored to the substrate in a tidal creek. Each cage had a trap door to enable a diver to gain access to the inside of the cage. Eight to 15 juvenile prawns ranging in size from 7 mm to 28 mm C.L. were placed in the cage; their activity recorded by diving at hourly intervals. Since the eyes of many crustaceans are insensitive to light from the red end of the spectrum (Waterman 1961, Fernandez 1973); underwater torches adapted with a red filter were used during the night. Observations suggested that the behaviour of prawns was not affected by either the torch or the presence of a diver. A vane-protractor was designed, built and subsequently used to measure the orientation of prawns in relation to the tidal flow (Figure C-1).

3. GROWTH AND MIGRATION

As with other crustacea, it is impossible to estimate age accurately due to the periodic loss of the exoskeleton during ecdysis; there are no layered hard parts which can assist in determining age and growth. In this present study, age and growth were estimated by following the progression of modes and other features of the length-frequency histograms of samples of both juveniles and adults. Growth of adult prawns was also calculated by tagging and recapture studies.

Various tagging and marking techniques have been used in studies of other penaeid prawn stocks. Petersen disc tags were first used on *Penaeus setiferus* in 1935 in the Gulf of Mexico fishery (Lindner and Anderson 1956) and a similar tag was used on juvenile *P. latisulcatus* in this present study (Figure C-3). In adult *P. latisulcatus* the more rapid method in which plastic tags were placed in the muscle tissue between the first and second abdominal segment by means of a mechanical applicator was used (Figure C-3). This method has been described by Penn (1973).

4. REPRODUCTION

In the early stages of the study, conventional histological techniques were used to study the development of the female ovary (Tuma 1967). Using this information, a method of assessing the reproductive condition of female prawns using macroscopic criteria was developed. The method depends on criteria such as ovary size, shape and colouration and, since it does not require the use of a microscope, can be easily used at sea.

FIGURE C-3: Tagging equipment, showing (1) mechanical tag applicator (2) coloured tags used in migration studies on adults (3) numbered tags used in growth studies and (4) Petersen-type tags used on juveniles. An adult prawn is shown with a number tag inserted between the first and second abdominal segment.

# SECTION I - JUVENILES

## D. RESULTS - I. JUVENILES

### 1. ENVIRONMENT

Juvenile *P. latisulcatus* were found in sheltered areas of the coastline such as shallow bays, coves and tidal creeks. These areas were invariably associated with seagrass communities (*Posidonia australia, Zostera mucronata, Heterozostera tasmanica* and sometimes *Amphibolus antarctica* and *Halophila*). Many, but not all, were associated with stands of mangroves (*Avicennia marina*). The substrate in the nursery areas varied from silty to clean sand with some shell grit. Substrates of soft mud or large quantities of shell grit appeared not to be preferred by juvenile *P. latisulcatus*.

The juveniles of most other penaeid species are found in the brackish waters of river mouths (Ruello 1973, Munro 1973). There are no permanent rivers emptying in Spencer Gulf or Gulf St. Vincent although freshwater runoff into tidal creeks may be considerable during winter rains. In contrast to other species, juvenile *P. latisulcatus* were found in waters which were hypersaline. Table 1-1 shows the monthly subsurface water temperatures and salinities at one sampling station (Chinaman's Creek, northern Spencer Gulf). In all nursery areas examined, the salinity of the water was higher than that of adjacent offshore areas where adult animals were found.

### 2. DISTRIBUTION AND ABUNDANCE

#### A. Areal

During the early part of this study notes were kept on all the sightings of juvenile *P. latisulcatus*. Many reports of juvenile prawns were obtained from amateur and commercial fishermen using gill nets or dip nets for garfish (*Hemiramphus melanochir*) on calm nights. At night juvenile prawns were observed actively feeding or swimming in the water body; although highest concentrations

| | TEMP. (°C) | | SAL. (°/oo) | |
|---|---|---|---|---|
| | EBB | FLOOD | EBB | FLOOD |
| 21.01.74 | 26.0 | 24.0 | 45.6 | 46.4 |
| 20.02.74 | 22.5 | 23.0 | 42.6 | 42.5 |
| 26.03.74 | 24.0 | 25.5 | 43.7 | 43.5 |
| 02.05.74 | 14.0 | 13.5 | 43.5 | 43.7 |
| 20.06.74 | 12.5 | 12.5 | 42.4 | 42.6 |
| 20.08.74 | 14.0 | 14.0 | 43.0 | 42.2 |
| 17.09.74 | 16.0 | 16.0 | 43.0 | 42.3 |
| 17.10.74 | 16.5 | 16.5 | 41.3 | 41.5 |
| 12.11.74 | 19.0 | 17.0 | 42.7 | 44.4 |
| 17.12.74 | 22.0 | 22.0 | 43.0 | -- |
| 15.01.75 | 22.0 | 23.0 | 42.9 | 42.8 |
| 12.02.75 | 22.0 | 23.0 | 43.9 | 42.7 |
| 20.03.75 | 18.5 | 20.0 | 43.1 | 42.9 |
| 12.05.75 | 13.0 | 13.0 | 42.3 | 42.7 |
| 12.06.75 | 12.5 | 13.0 | 42.2 | 42.3 |
| 08.07.75 | 13.0 | 13.0 | 42.5 | 42.4 |
| 07.08.75 | 13.5 | 14.0 | 42.2 | 42.0 |
| 09.09.75 | 13.0 | 13.5 | 41.7 | 41.1 |
| 06.10.75 | 17.0 | 17.0 | 41.4 | 41.6 |
| 04.11.75 | 18.5 | 18.5 | 41.3 | 41.5 |
| 04.12.75 | 23.0 | 22.5 | -- | 44.0 |
| 03.01.76 | 24.5 | 24.0 | 41.5 | 41.7 |
| 03.03.76 | 23.5 | 23.0 | 42.0 | 41.8 |
| 02.04.76 | 20.0 | 20.0 | 41.3 | 41.2 |
| 29.05.76 | 13.5 | 13.5 | | |

TABLE 1-1 : Subsurface (30 cm depth) water temperature (°C) and salinities (°/oo) at Chinaman's Ck. northern Spencer Gulf; readings taken at approximately mid-tide on both ebb and flood.

were found closest to the bottom they were often seen jumping on the surface when disturbed.

Sampling has been carried out during the night at most reported or suspected nursery areas by using the following three types of gear; the beam trawl, the drag net and a small dip net on a handle. (Methods - Section C). The beam trawl was preferred because the data obtained could be more easily quantified (as numbers caught per minute under standard trawling conditions). In tests, the drag net had approximately 60% of the catching efficiency of the beam trawl and a correction factor was applied to data obtained using this method. No attempt was made to quantify catches made with the dip net.

As trawling abundance in the nursery areas altered over the season (Section 2b), a correction factor was added to standardise data obtained at different times of the year. The results of the survey for juvenile nursery areas are presented in Figures 2-1 (Upper Spencer Gulf), 2-2 (Lower Spencer Gulf), 2-3 (Gulf St. Vincent) and 2-4 (Kangaroo Island). The South Australian coast to the west of Coffin Bay has not been examined.

In general, sheltered areas to the north of both Spencer and St. Vincent Gulfs are more favoured than southerly locations; however, large concentrations of juveniles are sometimes found in some isolated southerly areas (e.g. Spalding cove near Port Lincoln).

b. Seasonal

All nursery areas examined were similar in that catch rates of juvenile *P. latisulcatus* altered over the season as shown in fig. 6-4, page 31 . This figure shows the mean catch rates on a monthly basis at Barker's Inlet during 1976.

Catches rates increased rapidly after December, as very small prawns became susceptible to the sampling gear (Appendix 3) and reached a maximum during the period February to May. After this

FIGURE 2-1:

Nursery areas for juvenile Penaeus latisulcatus in Upper Spencer Gulf. Standardized trawling abundance is indicated as numbers caught per minute.

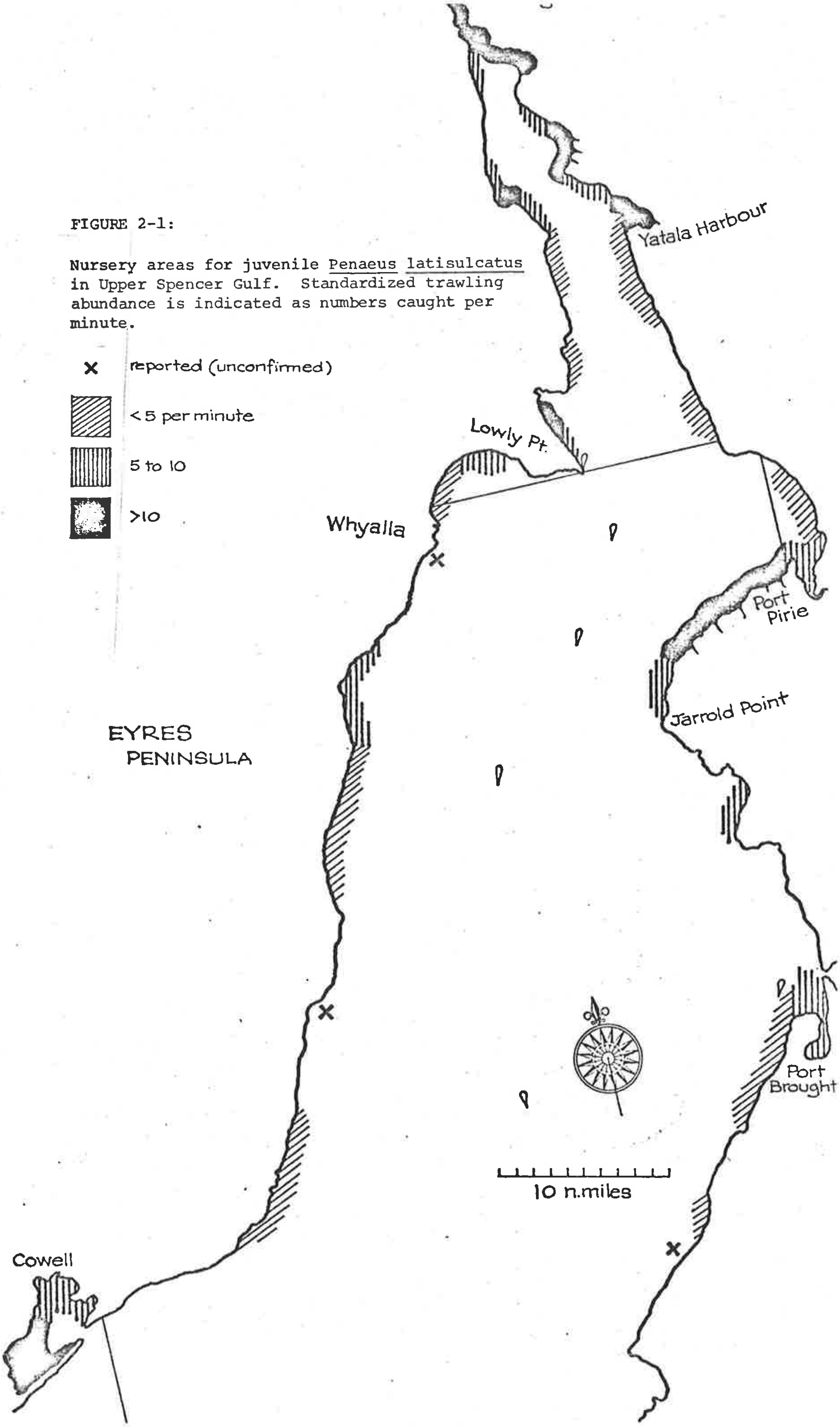
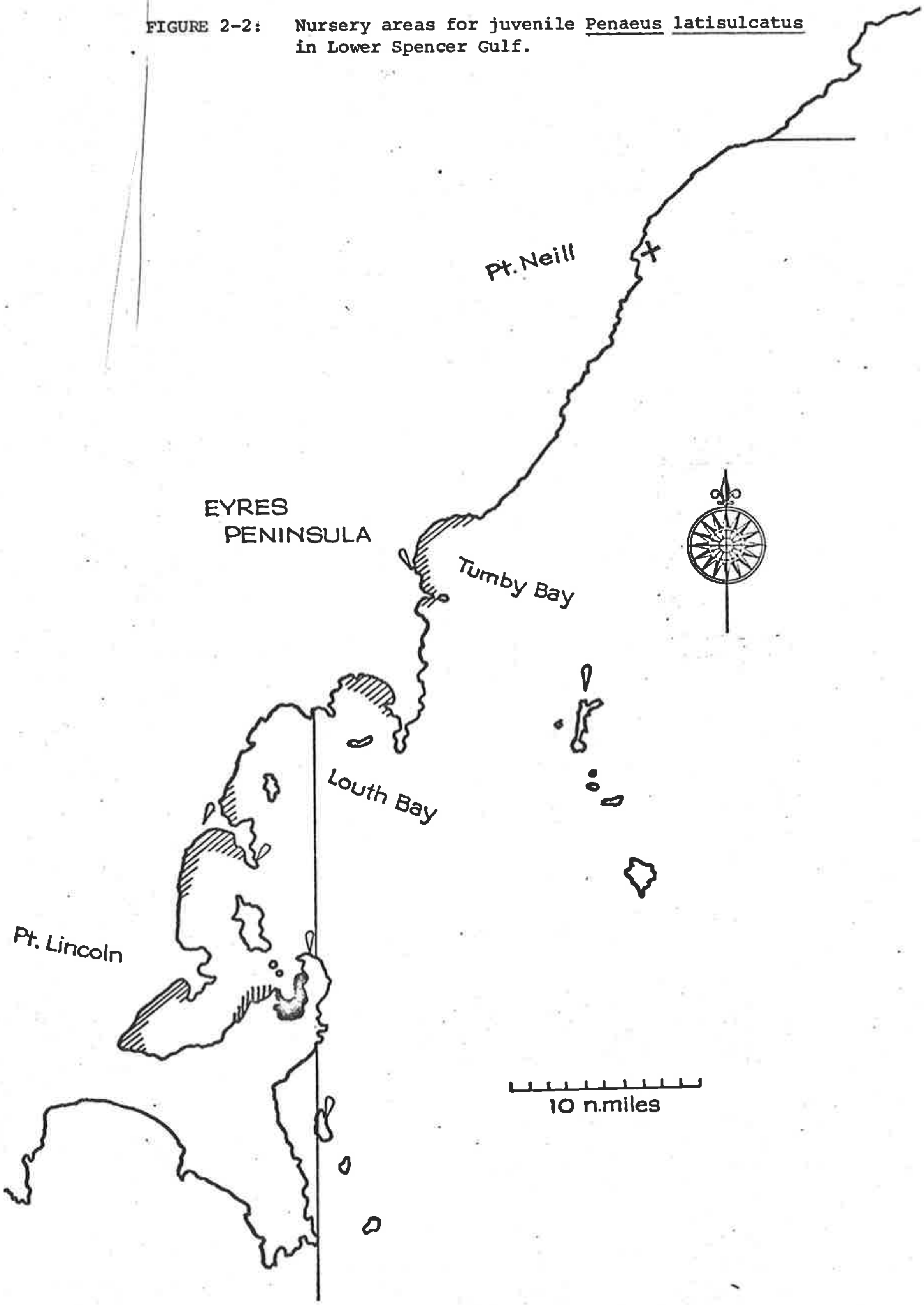


FIGURE 2-2: Nursery areas for juvenile <u>Penaeus latisulcatus</u> in Lower Spencer Gulf.



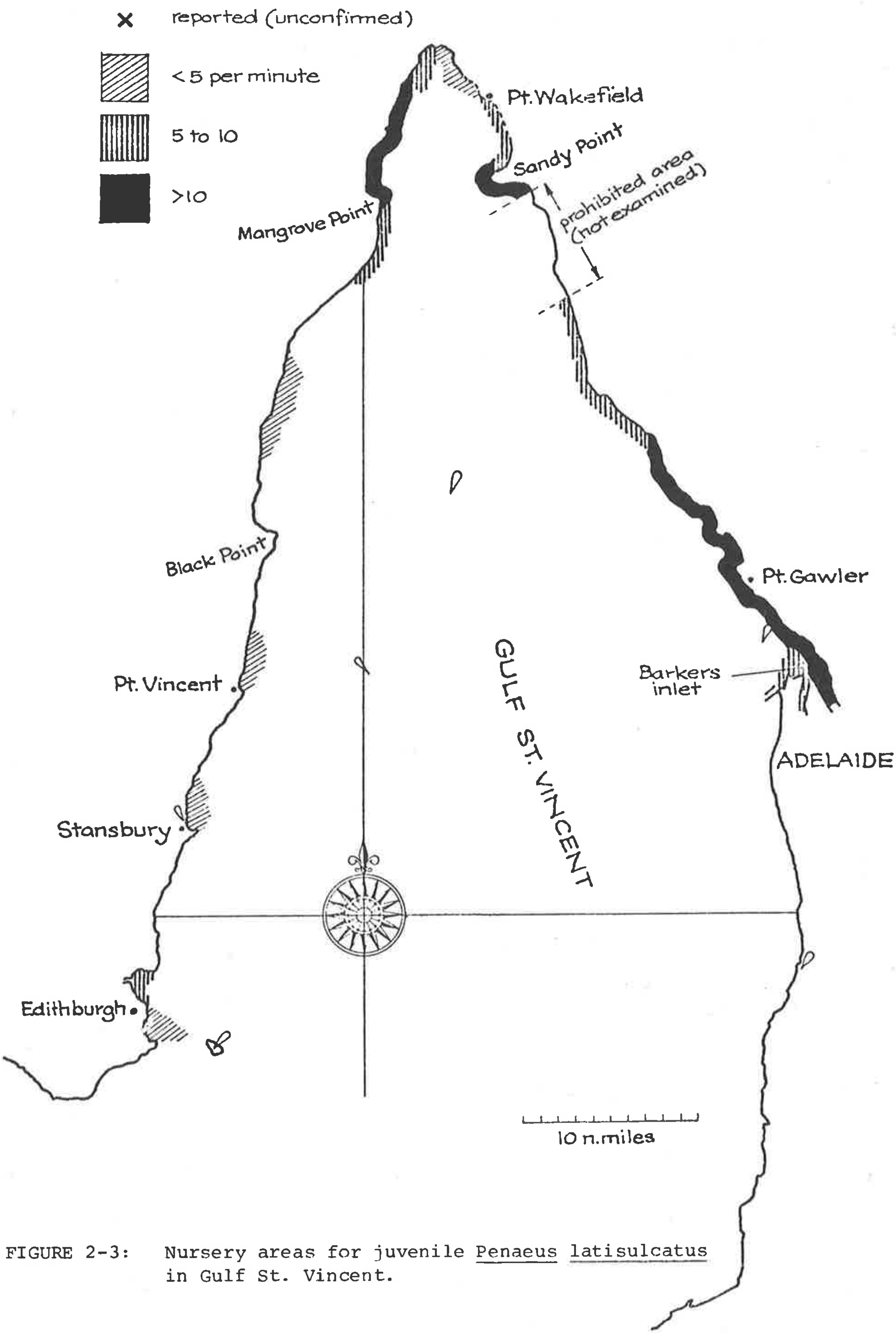



FIGURE 2-3: Nursery areas for juvenile <u>Penaeus latisulcatus</u> in Gulf St. Vincent.


FIGURE 2-4: Nursery areas for juvenile <u>Penaeus latisulcatus</u> in Investigator Strait.

date catch rates dropped to a minimum which coincided with the lowest water temperatures of the year (Section I-1). Long term (seasonal) and short term (daily and monthly) changes in vulnerability to the net were considered to be related to changes in activity of *P. latisulcatus* (Section I-6).

Catches increased after September to form a second mode (Figure 6-4). After November numbers of large juvenile prawns in the nursery area decreased rapidly. This was considered to be a result of the emigration to offshore fishing grounds (Section 6.b).

3. LENGTH FREQUENCIES

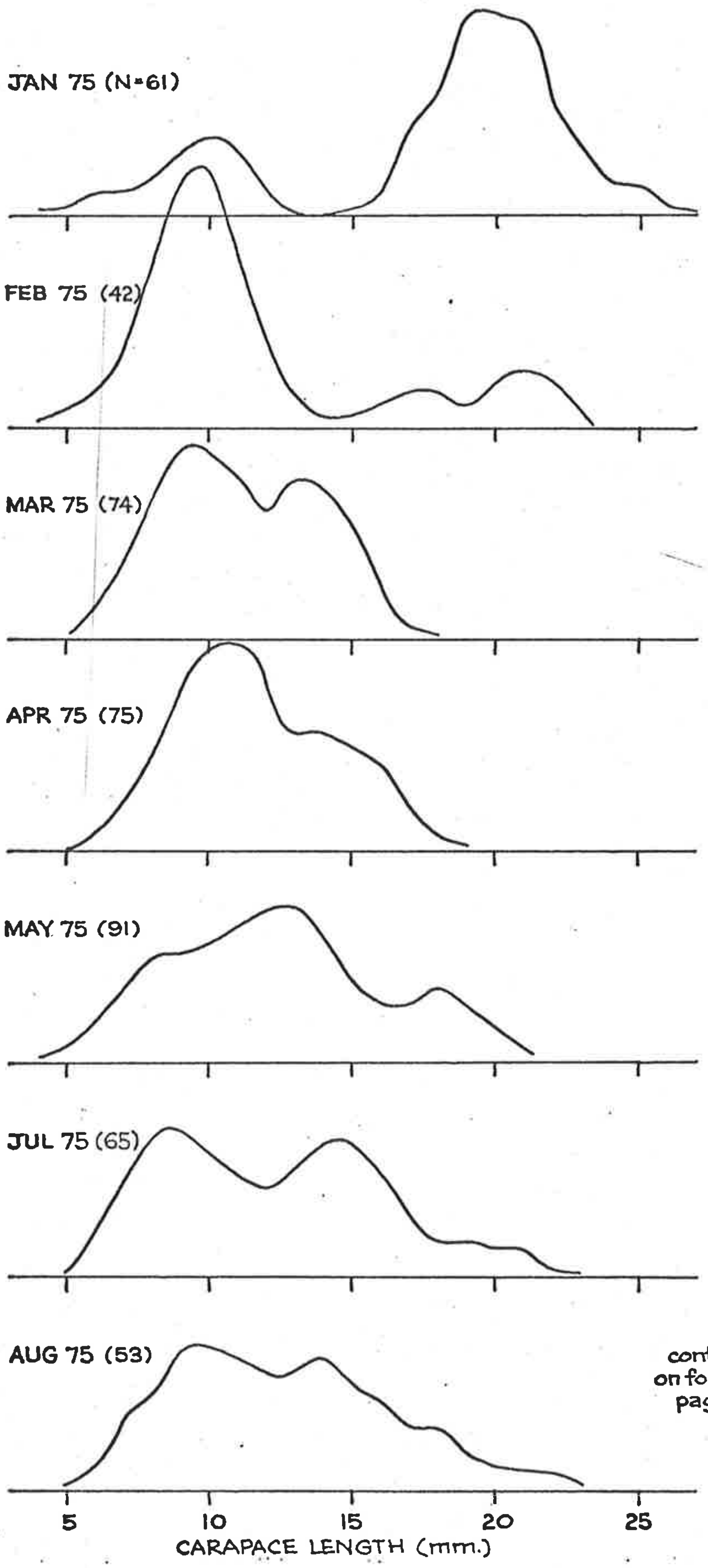
Samples of juvenile *P. latisulcatus* were obtained from many nursery areas in Spencer Gulf, Investigator Strait and the Gulf St. Vincent. Two nursery areas, namely Chinaman's Creek in northern Spencer Gulf and Barkers Inlet in Gulf St. Vincent, were sampled at monthly intervals.

Juvenile prawns in all samples were measured and the data recorded in class intervals of 1 mm carapace length. The sex of individuals larger than 11 mm carapace length (C.L.) was easily determined macroscopically: although sexes were separated in animals over 11 mm C.L. differences in length-frequency distributions between the sexes were small. Subsequently both sexes were combined for the purpose of length-frequency analysis.

Length-frequency distributions of juvenile prawns caught by beam trawling during the monthly stations at Chinaman's Creek are summarised in Table 3-1 and illustrated in Figure 3-1. The data in the latter have been smoothed by applying a moving average of n=3 (Spiegal 1972) before constructing the length frequency diagrams shown in figure 3-1. Irregular sampling at other nursery areas indicated the general pattern of the regular influx of smaller sizes, followed by orderly modal progression and emigration offshore.

**TABLE 3.1** Length frequency distributions (no. of individuals) for juvenile *Penaeus latisulcatus* at Chinaman's Creek, Northern Spencer Gulf. Lengths were measured as mm. carapace length (C.L.) Means ($X_1$, $X_2$ and $X_3$) of the monthly data are shown for each of the three year classes. The Chinaman's Creek station was abandoned after May 1976 but a subsequent sample was obtained in November 1976.

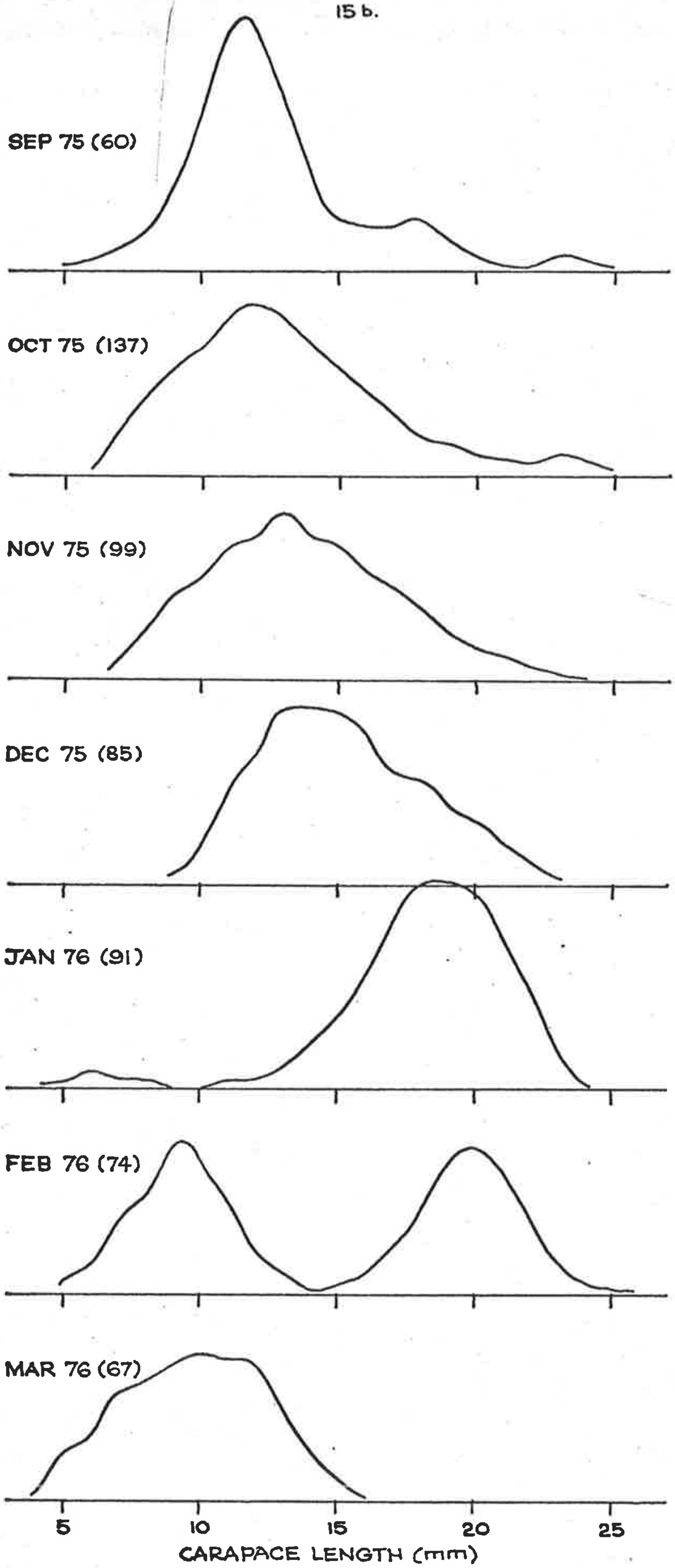
| C.L. (mm) | A | S | O | N | D | 1975 J | F | M | A | M | J | J | A | S | O | N | D | 1976 J | F | M | A | M | J | J | A | S | O | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | | | | | 1 | 1 | | | 1 | | | | | | | | 1 | | 1 | | 5 | | | | | | |
| 6 | | 2 | 1 | | 2 | 0 | 1 | | 1 | 2 | | 1 | 1 | 1 | | | | 0 | 3 | 6 | 1 | 3 | | | | | | |
| 7 | | 0 | 1 | 1 | 1 | 2 | 1 | 5 | 2 | 5 | | 5 | 2 | 0 | 2 | | | 2 | 2 | 3 | 4 | 8 | | | | | | 1 |
| 8 | 1 | 3 | 3 | 4 | | 1 | 5 | 7 | 5 | 7 | | 7 | 5 | 2 | 11 | 5 | | | 7 | 7 | 12 | 8 | | | | | | 11 |
| 9 | 3 | 6 | 5 | 7 | | 2 | 9 | 10 | 8 | 8 | | 7 | 4 | 3 | 10 | 6 | | | 7 | 8 | 12 | 21 | | | | | | 14 |
| 10 | 11 | 9 | 12 | 22 | | 5 | 8 | 13 | 12 | 6 | | 6 | 7 | 6 | 12 | 7 | 2 | | 10 | 5 | 20 | 17 | | | | | | 13 |
| 11 | 9 | 10 | 18 | 17 | 5 | 3 | 6 | 6 | 12 | 9 | | 4 | 5 | 13 | 16 | 9 | 5 | | 3 | 9 | 10 | 18 | | | | | | 15 |
| 12 | 10 | 8 | 9 | 20 | 6 | | 2 | 7 | 9 | 11 | NO SAMPLE | 4 | 3 | 12 | 19 | 13 | 10 | | 3 | 13 | 17 | 13 | | | | | | 16 |
| 13 | 6 | 9 | 17 | 25 | 10 | | 0 | 7 | 6 | 9 | | 4 | 5 | 7 | 16 | 9 | 9 | 2 | 1 | 7 | 18 | 12 | | | | | | 17 |
| 14 | 9 | 10 | 22 | 27 | 14 | | 1 | 11 | 4 | 10 | | 7 | 5 | 4 | 13 | 14 | 13 | 2 | | 5 | 14 | 10 | ←NO SAMPLES→ | | | | | 18 |
| 15 | 7 | 8 | 15 | 34 | 10 | | | 6 | 9 | 5 | | 7 | 5 | 2 | 11 | 8 | 11 | 5 | | 2 | 12 | 11 | | | | | | 13 |
| 16 | 1 | 5 | 9 | 24 | 12 | 1 | | 1 | 4 | 1 | | 4 | 2 | 1 | 9 | 7 | 8 | 7 | 2 | 1 | 8 | 9 | | | | | | 9 |
| 17 | 2 | 3 | 9 | 14 | 17 | 2 | 2 | 1 | 1 | 6 | | 3 | 3 | 3 | 5 | 8 | 9 | 11 | 1 | | 1 | 3 | | | | | | 6 |
| 18 | 2 | 2 | 4 | 15 | 11 | 8 | 1 | | 2 | 4 | | 1 | 2 | 2 | 5 | 5 | 4 | 15 | 5 | | 6 | 6 | | | | | | 4 |
| 19 | 1 | 1 | 1 | 12 | 5 | 6 | 0 | | | 4 | | 1 | 2 | 2 | 2 | 2 | 7 | 15 | 7 | | 2 | 1 | | | | | | 3 |
| 20 | 2 | | 3 | 8 | 5 | 12 | 1 | | | 3 | | 3 | 0 | 0 | 3 | 3 | 3 | 11 | 9 | | 1 | 2 | | | | | | 1 |
| 21 | | | 1 | 2 | 1 | 8 | 3 | | | | | 0 | 1 | 0 | 0 | 2 | 2 | 13 | 8 | | | 5 | | | | | | 0 |
| 22 | | | | | 0 | 5 | 1 | | | | | 1 | 1 | 1 | 1 | 0 | 2 | 6 | 4 | | | 1 | | | | | | 1 |
| 23 | | | | | 1 | 1 | | | | | | | | 0 | 1 | 1 | | 1 | 1 | | | | | | | | | 1 |
| 24 | | | | | | 3 | | | | | | | | 1 | 1 | | | | 0 | | | | | | | | | |
| 25 | | | | | | 0 | | | | | | | | | | | | | 1 | | | | | | | | | |
| 26 | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | |
| $X_1$ | 12.8 | 12.5 | 13.3 | 14.2 | 15.7 | 20.1 | 19.6 | | | | | | | | | | | | | | | | | | | | | |
| $X_2$ | | | | | 6.3 | 9.1 | 9.5 | 11.2 | 11.7 | 12.4 | | 12.3 | 12.6 | 12.7 | 12.8 | 13.7 | 15.2 | 18.5 | 19.9 | | | | | | | | | |
| $X_3$ | | | | | | | | | | | | | | | | | | 6.3 | 9.3 | 10.5 | 12.1 | 11.9 | | | | | | 12.7 |




continued on following page →

FIGURE 3-1: Length-frequency distributions of juvenile Penaeus latisulcatus from samples taken at Chinaman's Creek, Northern Spencer Gulf.

15 b.


SEP 75 (60)
OCT 75 (137)
NOV 75 (99)
DEC 75 (85)
JAN 76 (91)
FEB 76 (74)
MAR 76 (67)
5
10
15
20
25
CARAPACE LENGTH (mm)

Small prawns first appeared in the beam trawl catches about December or January. Although the smallest prawn caught had a carapace length of 4 mm, mesh selectivity experiments (Appendix 4) showed that prawns of this size were not adequately sampled by the beam-trawl. After the first appearance of small prawns several modal groups were recognizable in the length-frequency distributions over the following months. The different modal groups, although indistinct, indicated that immigration of larval stages into the nursery areas occurred in waves over a 5 or 6 month period. Modes first appearing at 6 or 7 mm carapace length progressed through the following 10 to 12 months and ceased around January or February the following year, suggesting that maximum offshore migration occurred at this time.

Since the characteristics of the length-frequencies obtained at all the other nursery areas were similar, it is concluded that the sampling programme provided valid information on the juvenile stage of the prawn's life history.

## 4. GROWTH

In most studies on fish and molluscs, growth rates are traditionally calculated by the analysis of annular growth rings on various hard parts such as otoliths, scales or shells. In crustacea the only hard part, the exoskeleton, is shed at intervals and is, therefore, unsuitable in assessing age.

Other than by the analysis of hard parts, growth rate may be calculated by length-frequency analysis and by tagging experiments. Both of these methods were attempted in the present study. However, tagging of juvenile prawns was discontinued after an initial field test, when only 2 of the 567 tagged prawns released at Chinaman's Creek were recaptured in offshore areas (Douglas Bank).

Analysis of length frequency data has been used by many authors to estimate the growth of crustacea. Usually this is done by tracing the progression of modes (Tabb *et al.* 1962, Williams 1955, Bishara 1976) or the change in the mean size of the sampled population (Forster 1955). Both of these methods present practical problems in the analysis of populations in other than ideal conditions.

Small prawns were being added to the lower part of the range while larger prawns were emigrating out of the upper part of the range. Samples taken in the same locality, therefore, do not necessarily represent the same population. The continued gain of small individuals and loss of large individuals can reduce the rate of increase of the mean size of prawns in the sampled population. This method can, therefore, only be used accurately when immigration and emigration in the sampled area is distinct and occurs over a short time interval.

Analysis of the progression of modes is also difficult unless immigration into the nursery area is in a series of waves or pulses that produce distinct modes in the monthly length-frequency data. In practice, the length-frequency distributions may consist of several overlapping curves and the modes are often difficult to follow over more than a few months of data.

A third method, which has been used by a few workers (Leosch 1965), is to estimate growth rates by joining the extremes of the range of length frequency distributions. Until immigration into the nursery area is complete the upper extremes are used to indicate growth and later when emigration from the area occurs the lower extremes provide an indication of growth. None of the authors using this method have pointed out the main deficiency of estimating growth rates in this way - that is, that the initial part of the growth curve (during immigration) will be based on the largest and perhaps fastest growing animals whereas the latter part (during emigration) will be based on the smallest and perhaps slowest growing animals. For the method to be strictly accurate, all individuals in the population should be growing at a similar rate. The simplest method of determining whether this factor is likely to be relevant is by examining the length-frequency data where they are uninfluenced by either immigration or emigration, i.e. in the 'middle' few distributions (Figure 4-1). If the range of the 'middle' length-frequency distribution is not increasing, i.e. the lines AB and CD in Figure 4-1 are parallel it is a reasonable assumption that growth of the animals is not subject to significant increases in variance and the method can validly be used.

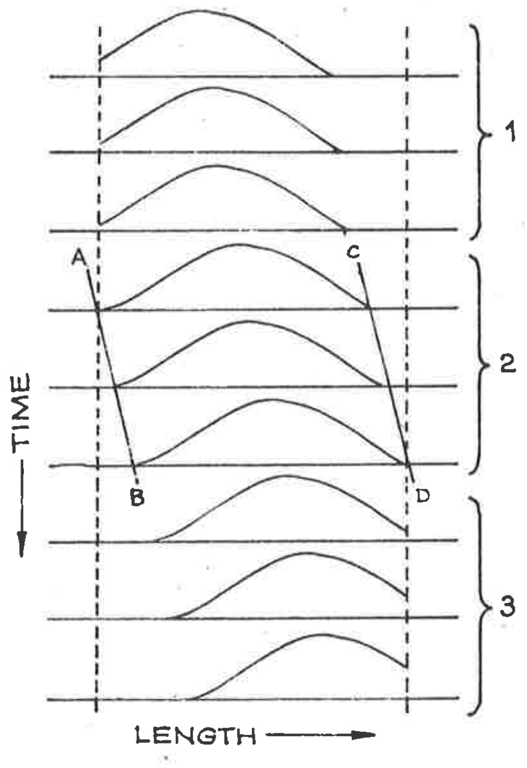



FIGURE 4-1. Diagrammatic representation of length-frequency distributions showing initial part (1) affected by immigration, middle part (2) unaffected by either immigration or emigration and a final part (3) affected by emigration.

A summary of the three methods of estimating growth from length-frequency data with suggested deficiencies and uses is given in the table below.

TABLE 4-1

| METHOD | DEFICIENCIES | CONDITIONS OF USE |
|---|---|---|
| 1. Change in mean length | Affected by extended or continuous immigration and emigration | When immigration and emigration is distinct and short-lived. |
| 2. Modal progression | Affected by extended immigration at a constant level. | When immigration is distinct and short-lived <u>or</u> When immigration occurs in distinct waves. |
| 3. Progression of extremes | Based on growth of the smallest animals using the lower extremes and largest animals using the higher extremes. | All individuals in the population are growing at a similar rate. |

Figure 4-2 shows the mean carapace lengths of each year class of juveniles caught at the monthly station at Chinaman's Creek. However, from examination of the length-frequency data (Figure 3-1) it appears that the data have been affected by immigration and emigration. The reliable use of method 1 (change in mean length) is therefore precluded. It is probable that this method underestimates growth rates in the early months (December to June) due to the mean being kept low by prolonged immigration into the nursery area. Similarly, growth rates in the latter months (September to January) are likely to be underestimated due to the emigration of larger individuals.

Although individual modes in the length-frequency data (Table 3-1) can be followed over some months the analysis of modes over the whole inshore period (up to 12 months) is difficult. The criteria suggested for method 2 in Table 4-1 were not fulfilled and it was decided that method 3 represented the most reliable way of estimating growth in juvenile *P. latisulcatus*.

The length-frequency data in Table 3-1 was smoothed by applying a moving average of n = 3 (Spiegal 1972) and the extremes of the range of each age class plotted. In Figure 4-2 the extremes are joined by a broken line. These lines were combined to give an estimated growth curve for juvenile prawns at Chinaman's Creek. Assuming that the length-frequency distribution for August was unaffected by immigration or emigration, the mean carapace length of the sample for this month (12.6 mm) was used as a basis for constructing the estimated growth curve shown in Figure 4-3.

This curve shows that prawns of post larval size (2 to 3 mm carapace length) in February grew rapidly at 3 to 4 mm per month. The growth rate decreased to a minimum in midwinter (July) and increased to about 3 mm per month prior to migration offshore. Studies offshore (Section 11-5) showed that offshore migration resulting in recruitment to the adult stock reaches a peak in January. Using the estimated growth curve juveniles would have reached a carapace length of approximately 23 mm (sexes combined) by this time. Studies on adult populations (Sections 11-4 and 5) substantiated these results and prawns of this size represented the smallest taken in commercial catches offshore.

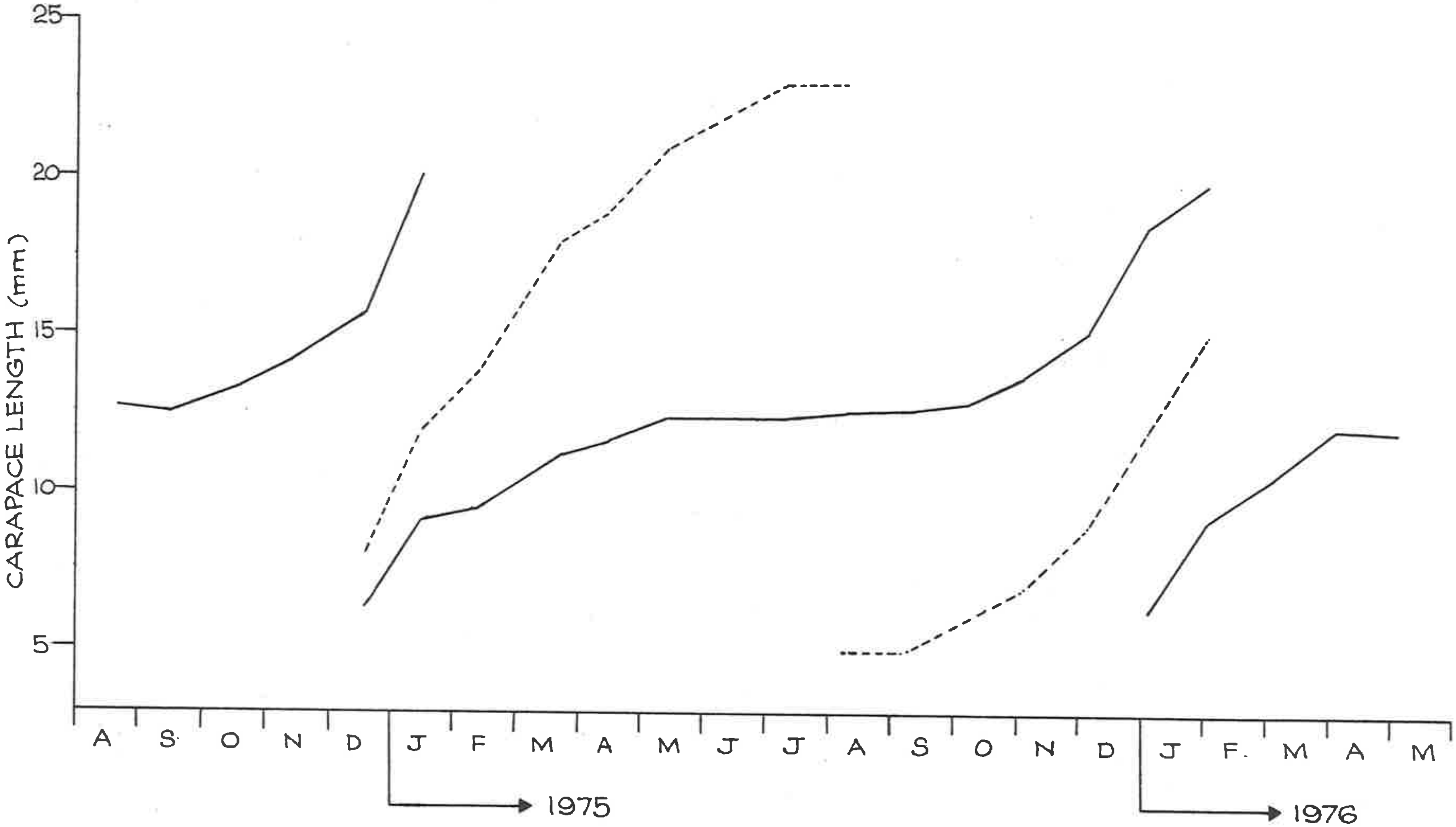



FIGURE 4-2: Mean carapace lengths (mm) of juvenile *Penaeus latisulcatus* caught during monthly sampling at Chinaman's Creek, Northern Spencer Gulf. Broken lines join the extremes of the range of each length frequency distribution (smoothed data).

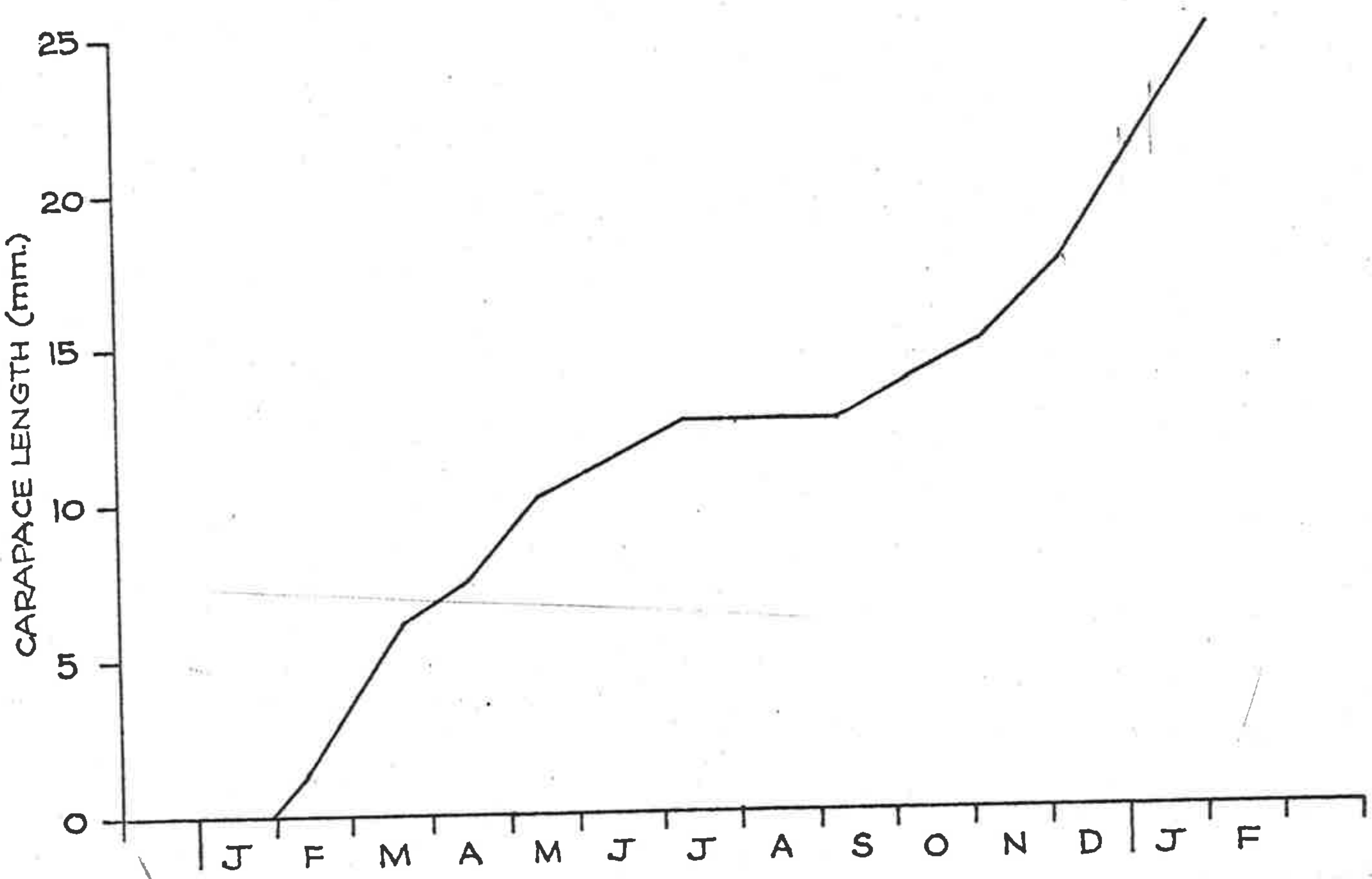



FIGURE 4-3 Estimated growth curve for juvenile Penaeus latisulcatus based on the extremes of the length frequency data, Chinaman's Creek, and a mean carapace length of 12.6 mm at August 1975.

## 5. FEEDING

During diving experiments with SCUBA, juvenile *Penaeus latisulcatus* were observed to be actively feeding at night on or near the bottom. Using underwater lights covered with red filters (Section C), juvenile prawns were seen probing and picking at the substrate with the first two pairs of chelate legs (pereiopods 1 and 2). It has been noted in *Penaeus merguiensis* that many appendages (including chelae, antennules, maxillipeds and mouth parts) function as chemosensory organs in the location of certain food substances (Hindley 1973).

In a typical feeding position objects were held onto by the pareiopods while the mouthparts and 1st pair of chelate pareiopods were working over the surface. During this activity, particles were passed to the mouthparts where some were rejected.

Juvenile prawns were often observed grasping pieces of seagrass (*Posidonia australis*) and large shells of dead gastropods in the feeding position. It is possible that algal or bacterial films were being used as a food source in these instances. It has been suggested that *Metapenaeus bennettae* selectively seeks "clusters of micro-organisms" on the substrate (Dall 1967) and evidence for this was presented by Moriarty (1976). In some instances juvenile prawns were observed feeding on the remains of larger animals (fish offal, etc. discarded by fishermen) and only on two occasions were prawns seen to take mobile prey (in both cases marine worms). However, in a study on the food of several penaeid prawns, Moriarty (1977) suggested that live food is important.

At several times during the study period samples of prawns were taken for the analysis of stomach contents. Each prawn was slit along the ventral surface, preserved in buffered 5% formalin and examined in the laboratory within 48 hours.

The digestive system of prawns is such that the stomach contents are finely ground and mostly unrecognisable. In the present study over 50% of the stomach contents of *Penaeus latisulcatus* appeared to consist of unidentifiable detritus and sand grains. Food material appeared to be sorted and cut up by the mandibles before ingestion. The digestive system has been considered (for *P. setiferus*, Young 1959) as consisting of 3 parts, the foregut, midgut and hind gut. In the foregut the food is crushed by the gastric mill before entering the stomach or midgut. However, resistant fragments such as shells, bristles and exoskeletons were sometimes recognisable, enabling the following list of food organisms to be constructed. These are listed in order of most frequent occurrence:

Mollusca: shell grit, fragments of mussel shells (*Modiolus inconstans*?)

Plant material: fibrous and woody material, fragments of seagrass

Crustacea: portions of exoskeletons of crabs, shrimps (*Leander* sp.) limbs of amphipods and isopods, crustacean larvae, whole segments of sea centipedes (Idoteidae)

Polychaeta: bristles and parapodia of bristle worms, calcareous material (tubes?)

Bryozoa: fragments of lace coral

Pisces: scales of small fish

Although the above list refers collectively to food material found in the gut contents of several separate samples, there were some differences in the importance of various food items in different areas. From these and aquaria observations, juvenile *P. latisulcatus* appear to be opportunistic feeders and will take whatever food is most abundant. In aquaria, *P. latisulcatus* will eat many foods which would not be present *in vivo* - e.g. compressed cereal (commercial dog food) and fresh meat. In aquaria *P. latisulcatus* is sometimes cannibalistic although this may not occur in natural conditions - no exoskeleton fragments found in the gut contents could be identified as *P. latisulcatus*.

There has been no published account of the diet of *P. latisulcatus* but gut analyses of other species of penaeid prawns (Williams 1955, Racek 1959, Dall 1968, Joubert 1943, Ruello 1973, Moriarty 1977) show similarity mainly in that a wide range of food types are used.

# 6. BEHAVIOUR

## (a) Activity

Cyclic activity patterns have been reported for many species of penaeid prawns (Williams 1955, Racek 1957, 1959, Dall 1958, Fuss 1964, Fuss and Ogren 1966, Wickham 1967, Hughes 1969, Clark and Caillouet 1975, Wickham and Minkler 1975, Lakshmi *et al.* 1976). These studies, some of them under laboratory conditions, in general indicate that the activity of penaeid prawns is related to a (1) diurnal cycle, (2) monthly lunar cycle and (3) seasonal temperature cycle. The activity of juvenile *P. latisulcatus* in relation to these cycles was examined in the present study.

(1) diurnal cycle:

During the early stages of the study when the beam trawl was being developed, trawling was carried out by day and night. Juvenile prawns were rarely caught in the trawl during the day. While diving during daylight to observe the action of the net, prawns were found buried in the substrate and, in some instances, were found buried in wet sand above the low tide mark. In the laboratory, prawns kept in aquaria were observed to bury during daylight.

Diving experiments were carried on in underwater cages in which 9 to 13 juvenile prawns were observed at hourly intervals. Two separate experiments were conducted at different times of the year; the first when sea temperatures were close to the minimum (1st and 2nd October, 1973) and the second when temperatures were at a maximum (21st to 23rd January, 1974). Both experiments were completed within 5 days of the new moon.

In the October experiment, two cages were used with 9 and 13 juvenile *P. latisulcatus*. Observations were made at hourly intervals over approximately a 20 hour period. At the time of the experiment there was light cloud cover (10 to 15%) and the subsurface (30 cm depth) sea temperatures were 15.0$^{o}$C and 14.0$^{o}$C on the ebb and flood night tides respectively. Salinities, sampled at the same time, were 49.6‰ and 48.8‰ respectively. The results of this experiment are shown in Figure 6-1.

In the January experiment two cages were used with 11 and 12 juvenile *P. latisulcatus* in each. Observations were made at hourly intervals over approximately two days, except that no observations were made between approximately 0900 hours and 1400 hours on the second day. The subsurface (30 cm depth) water temperatures were 26.0$^{o}$C and 24.0$^{o}$C on the ebb and flood night tides respectively; salinities taken at the same time were 45.6‰ and 46.4‰ respectively. Results are shown in Figure 6-2. Central summer time and official times of sunset and sunrise are also given in this figure. Results of both experiments indicate a diurnal rythm in activity for juvenile *P. latisulcatus* which is correlated with the daily light/dark cycle.

(2) monthly lunar cycle:

Standard trawling conditions during this study included carrying out trawls at each station at the same stage of the lunar cycle. This obviated the necessity of allowing for any variation in catch rate that might occur with the lunar phase. However, during the course of another experiment, trawling at Barker's Inlet was carried out at several different days of the lunar month. Three to five trawls were made in the same area during each night and the catch rates (in nos. per minute) are shown in Figure 6-3.

The data appear inadequate to demonstrate whether or not any lunar periodicity in catch rates occurs. It will be necessary

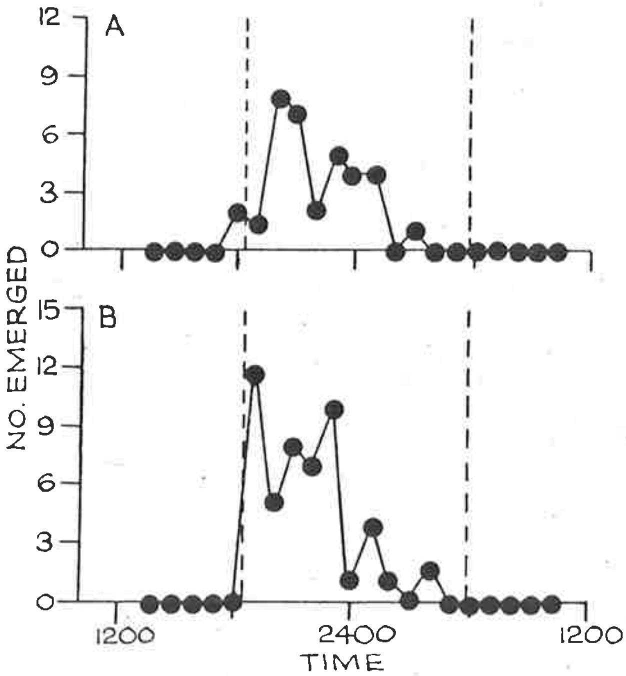



Figure 6-1 Numbers of juvenile *Penaeus latisulcatus* emerged from the substrate. Observations on two underwater cages A and B with 9 and 13 prawns in each respectively (1st and 2nd October, 1973). The vertical broken lines indicate times of sunset and sunrise.

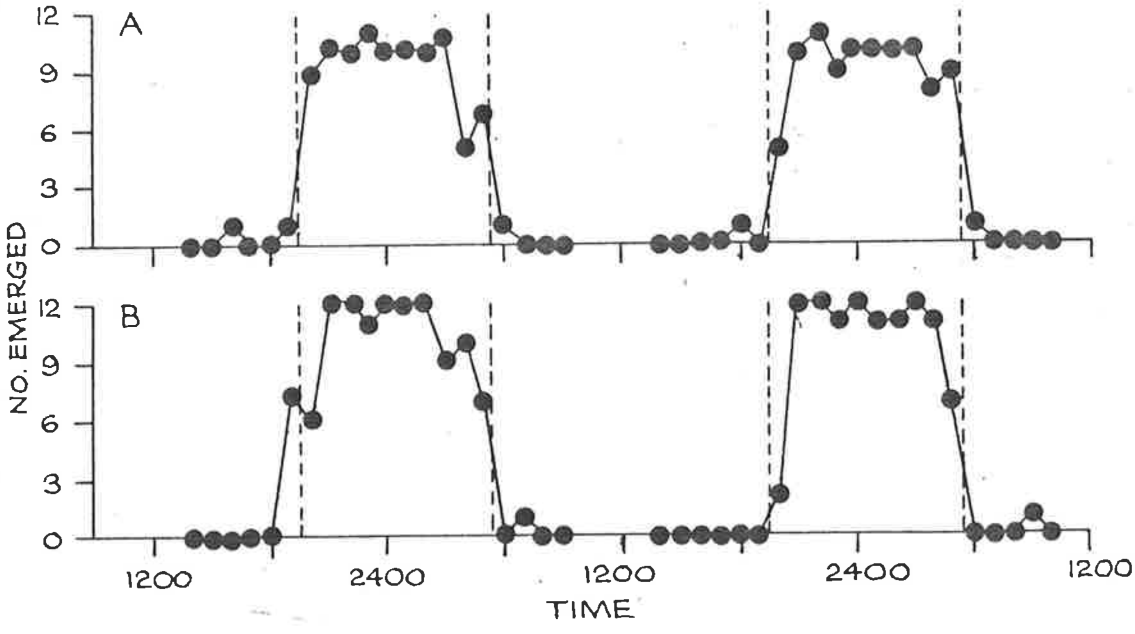



Figure 6-2 Numbers of juvenile *Penaeus latisulcatus* emerged from the substrate. Observations at hourly intervals on two underwater cages A and B with 11 and 12 prawns in each respectively. (21st to 23rd January, 1974). No observations were made between approximately 0900 hours and 1400 hours on the second day. The vertical broken lines indicate times of sunset and sunrise.

to conduct a planned experiment when the trawling abundance of juvenile *P. latisulcatus* increases (October/November, 1977). Trawling will be carried out every 2 to 4 days in the same area over at least one lunar month.

Lunar influence on behaviour has been studied in several penaeid prawns; juvenile (and adult?) *P. duorarum* were found to be more active during the new moon and first-quarter (Bishop and Herrnkind 1976). Other studies have been on adult penaeids and these are discussed in Section II-9a. In the present study catch rates of adult *P. latisulcatus* have been shown to vary with the lunar cycle.

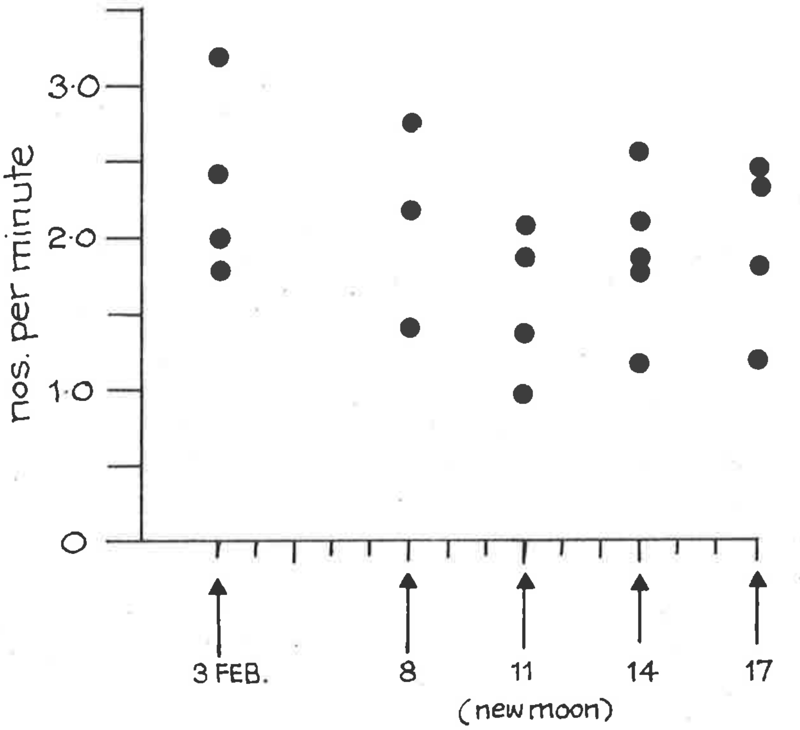



Figure 6-3 Trawling abundance (nos. per minute) of juvenile *Penaeus latisulcatus* in Barker's Inlet during February, 1975.

(3) seasonal temperature cycle:

After the juvenile prawns are fully recruited into the nursery area and fully susceptible to the beam trawl the number of prawns should decrease due to natural mortality (Section 7). However, using the beam trawl catch rates as indices of numbers present, it has been shown (e.g. Figure 6-4) that catch rates decrease and then increase to a second maximum. Two explanations for the low winter catch rates are, firstly, that juvenile prawns leave the usual nursery areas during the winter months and secondly that prawns are less vulnerable to the beam trawl during this period. Extensive searches of surrounding areas and offshore trawling provided no support for the first hypothesis and the second alternative was accepted, i.e. the catch rates were dependent on the "vulnerability" of the stock (the fraction of the stock which is accessible to a defined unit of fishing effort - Ricker, 1975).

Water temperatures at Barker's Inlet are shown in Figure 6-4 with the catch rates of juvenile *P. latisulcatus*. Data from other areas and years are similar in that periods of minimum catch rates and minimum water temperatures coincide. The design of the beam trawl (as with commercial otter trawls) was such that prawns below the substrate were inaccessible; this suggested that during periods of low temperature, juvenile prawns spent longer periods buried in the substrate.

Results of the cage experiments (Section 6.a.1) also showed that activity patterns of juvenile *P. latisulcatus* during winter were different from those in summer. Maximum activity appeared to be restricted to the early hours of darkness whereas, in summer, prawns were above the substrate for most of the hours of darkness.

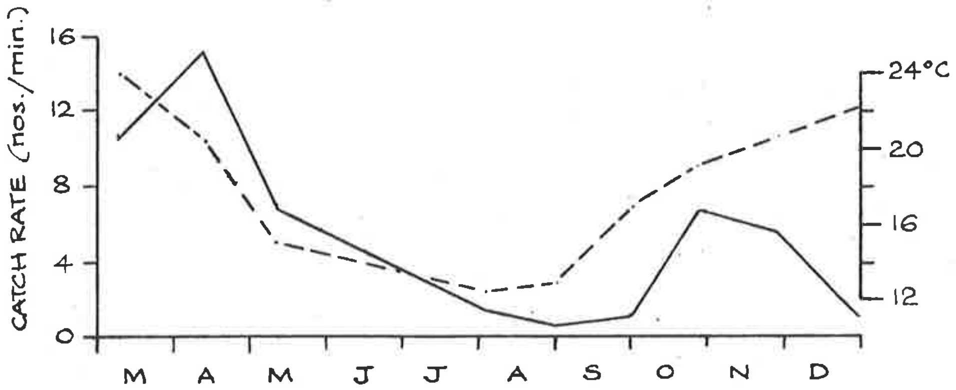



Figure 6-4 Mean catch rates of juvenile *Penaeus latisulcatus* (nos. per minute) at Barker's Inlet during 1976 - indicated by the solid line. Subsurface (30 cm depth) sea temperatures during the night of each monthly survey are indicated by the broken line.

Fuss and Ogren (1966) found a direct relationship between nocturnal activity and water temperature in *P. duorarum* where at temperatures below 14°C to 16°C, less than half of the prawns were active; at temperatures of less than 10°C all activity ceased. Reduced activity in another species, *Metapenaeus mastersii*, was found to occur at about 16°C (Dall 1958). Winter water temperatures in the nursery areas of *P. latisulcatus* around the coast of South Australia were approximately 11°C to 13°C (Section I-1). This appears to be close to the lower temperature limit for activity in many species of penaeid prawns. In summary, low winter temperatures appear to be correlated with reduced activity in juvenile *P. latisulcatus*; reduced activity is, in turn, related to reduced catchability. Similar changes in catchability are evident for adults (Section II-10) and have a marked effect on commercial catches during winter months.

(b) Emigration

Juvenile *P. latisulcatus* are found in inshore nursery areas which are often a considerable distance from the adult populations.

In Spencer Gulf most areas where adults are trawled are separated from the nearest known nursery areas by from 30 to 70 km. Some aspects of the mechanisms whereby the juveniles were able to emigrate from the nursery areas were examined in the present study.

During the course of the experiments on underwater cages (Section 6a) the orientation of juvenile prawns in relation to tidal flow was measured using a vane-protractor (Section C). Orientation was observed in both ebb and flood tides in both the October and January experiments. In the cages, juvenile *P. latisulcatus* were almost invariably facing into the current and maintaining their position in the water flow which reached an approximate speed of 0.28 m/sec. These results, however, appeared to be an artifact of the experimental cage situation. Juvenile prawns outside the cage, although orientated into the current, appeared to drift along with the water body rather than maintain their position.

It has been suggested that other penaeids are able to discriminate between and use ebb and flood tides for transport (Tabb *et al.* 1962, Hughes 1972); *P. duorarum* is capable of distinguishing salinity differences between tides (Highes 1969). However, as there was very little salinity difference between the ebb and flood tides in the present study, juvenile *P. latisulcatus* are not likely to share this capability. The lack of any obvious environmental stimuli and the results of underwater observations suggest that juvenile *P. latisulcatus* do not actively use tidal transport to emigrate offshore.

An alternate method of tidal transport for *P. latisulcatus* larvae has been suggested by Penn (1975) who also suggested that the mechanism may assist in the offshore migration of juveniles. Penn suggested that during particular times of the year, the nocturnal tidal cycle is dominated by ebb tides; this results in a net displacement of juveniles in an offshore direction. Contrary to

Penn's suggestion, however, the timing of the tidal cycle at Port Lincoln does not coincide with the time of emigration and recruitment to the Spencer Gulf fishery. In this present study it was found that recruitment to this fishery is mostly from the nursery areas to the north of the Gulf. Accordingly, the tidal cycle in these areas was examined.

Port Pirie in northern Spencer Gulf was chosen as it is a "standard port" for which tidal predictions are available (tide tables - Department of Marine and Harbors) and it is situated amongst known nursery areas. From the tide tables the number of hours of ebb and flood tides were calculated for four periods during each lunar month - full moon, first quarter, new moon and last quarter. These are plotted in Figure 6-5.

Figure 6-5 indicates a seasonal cycle in night tides which results in a net movement of water offshore. The timing of the net offshore movement (January to May) coincides with the time of juvenile emigration and it appears that the transport mechanism may be of general importance in the north of Spencer Gulf.

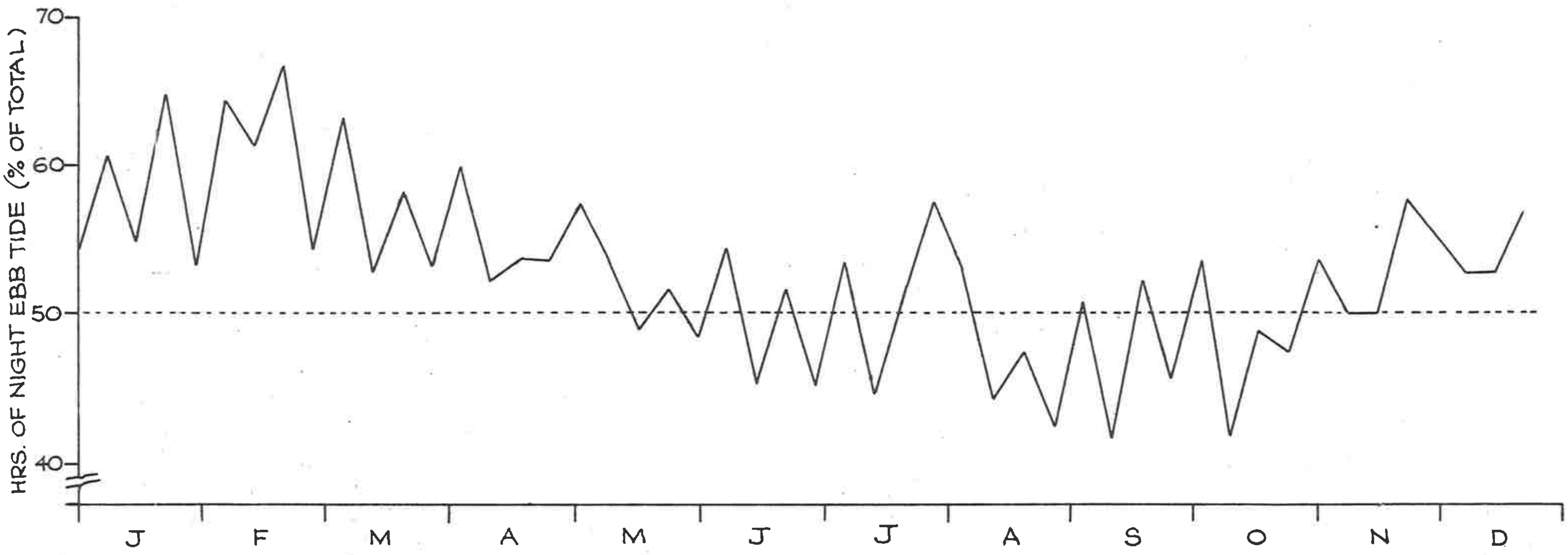



Fig. 6-5: Yearly tidal cycle at Port Pirie, South Australia. The number of hours of darkness during which there was an ebbing tide is expressed as a percentage of the total hours of darkness. Points have been plotted for the time of full moon, first quarter, new moon and last quarter.

## 7. MORTALITY

Together with growth, mortality is one of the most basic and important parameters of a population. Each species has evolved a certain intrinsic mortality rate and a maximum attainable age which are balanced by a similarly evolved rate of growth and reproduction.

Three to four basic types of survivorship curves have been presented by various authors (Deevey 1947, Slobodkin 1961) and these are summarised in Figure 7-1. In type 1, mortality rates are high in the older animals, types 2 and 3 describe cases where the number of mortalities per unit time and the mortality rate respectively are constant. In type 4, the young (eggs, larvae, juveniles, etc.) suffer high mortality rates. I suggest that a 5th type of suvivorship curve in which both the very young and the very old are at risk would also be common in certain species (e.g. mammals).

In marine populations, where high fecundity is common, the type 4 mortality curve is most common. Eggs and larval stages appear to be more at risk than later stages - exceptions are where mass mortalities occur due to environmental stress. In most studies of marine fishes it has been assumed that mortality rates are constant over time (type 3 curve). This may be a reasonable assumption if only a small segment of the life-cycle is being considered - e.g. the adults in the exploitable part of the population (Section II-10) or the juveniles during the inshore period (this Section). The type 3 curve has the advantage of being a straight line when the logarithms of the number of survivors are plotted against time.

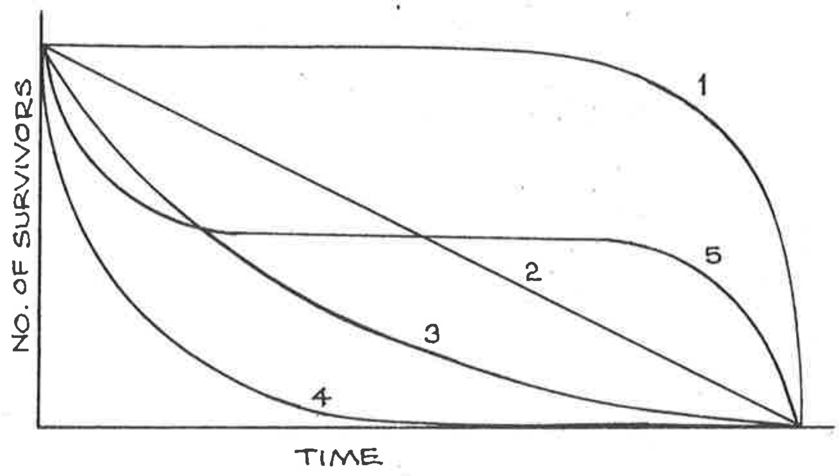



Figure 7-1 Types of survivorship curves for various species.

The use of catch per unit of effort as a measure of abundance in a population has been documented in several works (Beverton & Holt 1957, Ricker 1975, Gulland 1969). In the study of mortality in juvenile *P. latisulcatus*, the catch-rates taken by beam trawl in the nursery areas were used as indices of abundance. Repetitive trawls were made in each area on a monthly basis. As shown in a previous section (I-2b), juvenile prawns reach a maximum trawling abundance in the nursery areas in late summer to early autumn (February to April). The rate at which numbers caught per minute trawling decreased after this period represents the mortality rate.

However, besides mortality, the catch rates were also dependent on the 'vulnerability' of the stock (Ricker 1975) - i.e. the fraction of the stock which is accessible to a defined unit of fishing effort. In the initial stages of the study several changes in vulnerability of juvenile prawns to the beam trawl were suggested. These were related to a (1) diurnal cycle, (2) lunar cycles and (3) seasonal cycle (Section I-6).

Although it is possible that other factors such as cloud cover, tidal flow, etc. could have affected the vulnerability of

*P. latisulcatus*, it is assumed that the three factors listed above were the most important. To exclude the possible effects of (1) and (2), trawling was confined to the hours of darkness and as near as practicable to the same stage of the lunar month. Reduced vulnerability during the winter months remained the most serious obstable to estimating mortality from decreasing catch rates over the whole inshore period (10-12 months). In addition, two other factors had to be taken into account in calculating mortality by this method. Firstly, mesh selectivity experiments (Appendix 3a) have shown that juvenile prawns smaller than 12 mm carapace length were not fully susceptible to the beam trawl; secondly, catch rates rapidly decreased during November to January as juvenile prawns emigrated offshore. All three factors discussed are shown in Figure 7-2.

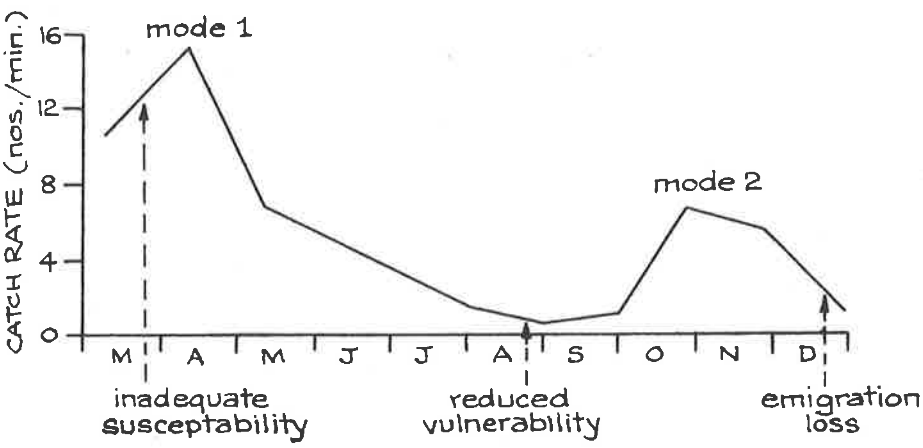



Figure 7-2 Mean catch rates of juvenile *Penaeus latisulcatus* (nos. per minute) at Barker's Inlet during 1976. Periods of inadequate susceptibility, reduced vulnerability and loss by emigration are shown.

As shown in Figure 7-2, catch rate distributions over a year are typically bimodal. Distributions for other years and other nursery areas are similar and have been presented in Section I-2b.

For the purpose of obtaining mortality estimates, periods of inadequate susceptibility, reduced vulnerability and emigration loss (Figure 7-2) have been excluded from the calculations. The assumption was made that catch rates made immediately after prawns became susceptible to the gear (Mode 1, Figure 7-2) and immediately before emigration (Mode 2, Figure 7-2) provided adequate indices of the relative numbers of juvenile prawns in the nursery area. Length frequency data through the winter months (presented in Section I-3) indicated that prawns in both modes 1 and 2 were from the same population. If the mortality rate between the two modes is assumed to be constant the rate at which the numbers (N) in the population are decreasing can be represented by Ricker's (1975) equation ......

$$\frac{dN}{dt} = -ZN \quad \text{.............................(1)}$$

where Z is the instantaneous total mortality coefficient. Adapting the equation for use in the present situation, the number $N_2$ left alive by the time $t_2$ of the second mode can be represented by .....

$$N_2 = N_1 \ e^{-z(t_2-t_1)} \quad \text{..................(2)}$$

where $N_1$ is the number alive at the time, $t_1$, of the first mode. By exchanging terms equation (2) becomes ......

$$e^{-z(t_2-t_1)} = \frac{N_2}{N_1} \quad \text{........................(3)}$$

which may be expressed as ......

$$Z(t_2-t_1) = \ln \frac{N_2}{N_1} \quad \text{......................(4)}$$

Total mortality, z, is usually thought of as being made up of the fishing mortality (F) and mortality due to natural factors (M). As juvenile populations of *P. latisulcatus* are unexploited in South Australia, Z is approximately equal to the natural mortality M.

To calculate M, regression lines were drawn through catch rates of individual trawls made in the months associated with mode 1 (time t ) and mode 2 (time t ) in Figure 7-2. Catch data for surveys at Barker's Inlet during 1976 are shown in Table 7-1 and the regression line in Figure 7-3. The value of M represented by the slope of the line, is 0.026 (approximately 3%) per week. An estimate of M from another nursery area (Chinaman's Creek, 1976) was 0.007 per week; it is therefore likely that juvenile morality is highly variable in *P. latisulcatus*.

TABLE 7-1: Catch rates (nos/min) of juvenile Penaeus latisulcatus caught dur-ng monthly surveys at Barker's Inlet during 1976

| DATE | TRAWL No. 1 | No. 2 | No. 3 | No. 4 | No. 5 |
|---|---|---|---|---|---|
| 9 March | 13.08 | 11.42 | 10.31 | 9.33 | 10.31 |
| 13 April | 14.78 | 15.79 | 14.84 | | |
| 11 May | 9.41 | 6.88 | 7.42 | | |
| 4 August | 1.50 | | | | |
| 31 August | 0.47 | 0.67 | | | |
| 30 September | 1.92 | 0.50 | | | |
| 29 October | 4.17 | 4.53 | 10.71 | 6.82 | |
| 28 November | 7.89 | 7.00 | 6.50 | 3.00 | 4.13 |
| 30 December | 1.33 | 1.25 | 0.57 | 0.78 | 0.98 |

(b) Predators/Intraspecific associations

While beam trawling in nursery areas for juvenile *P. latisulcatus* field notes were kept on species caught incidentally in the net. The gut contents of many likely predators were examined and underwater observations were made during night dives with SCUBA apparatus.

Table 7-2 shows species caught during beam trawling operations in both Spencer Gulf and the Gulf St. Vincent. An indication of abundance is given (common, occasional or rare) but it is likely that some species are more susceptible to the beam trawl than others. Fast moving species (e.g. mullet *Mugil forsteri*) and burrowing species (e.g. the cockle *Katelysia* spp.) are known to be much more common than is indicated by the beam trawl catches (personal observation). Species indicated by an asterisk in Table 7-2 were found to be predators of juvenile *P. latisulcatus*.

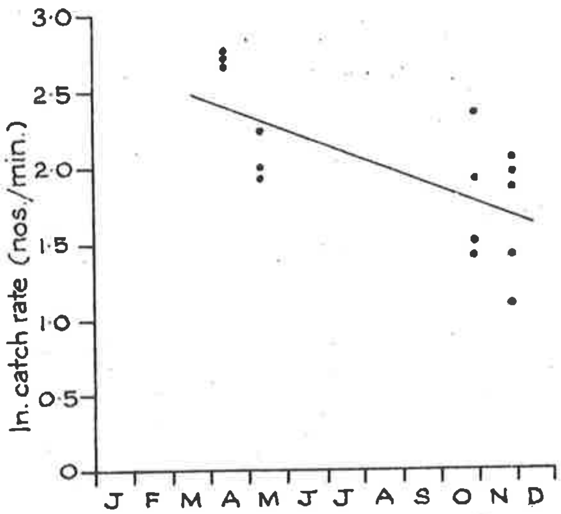



FIGURE 7-3: Regression line (fitted by least squares) through catch rates (natural logarithms) of juvenile Penaeus latisulcatus in Barker's Inlet during 1976

TABLE 5. Species caught by beam trawling for juvenile *Penaeus latisulcatus* in shallow water nursery areas of Spencer Gulf and the Gulf St.Vincent. Relative abundance in the beam trawl is indicated by C (common), O (occasional) or R (rare). Species marked with an asterisk are known, from gut analyses and underwater observations, to be predators of juvenile *Penaeus latisulcatus*.

| Common Name | Scientific Name | Abundance |
|---|---|---|
| ELASMOBRANCHS | | |
| *Shovelnose Ray | Aptychotrema vincentiana | R |
| *Smooth Stingray | Dasyatis brevicaudata | O |
| Melbourne Skate | Raja whitleyi | R |
| TELEOSTS | | |
| Blue Sprat | Spratelloides robustus | O |
| Estuary Catfish | Cnidoglanis macrocephalus | O |
| Short-Headed Worm-Eel | Muraenichthys breviceps | O |
| S.A.Garfish | Hemiramphus melanochir | C |
| *Greenback Flounder | Rhombosolea tapirina | O |
| Pipefish | Stigmatophora nigra | C |
| Jumping Mullet | Liza argentea | O |
| Yellow-Eye Mullet | Aldrichetta forsteri | C |
| Hardyhead | Taeniomembras sp. | C |
| Dusky Flathead | Platycephalus fuscus | C |
| South Aust.Cobbler | Gymnapistes marmoratus | C |
| Ling | Genypterus blacodes | R |
| Spotted Whiting | Sillaginodes punctatus | C |
| Silver Whiting | Sillago bassensis | O |
| *Black Bream | Acanthopagrus butcheri | C |
| Tommy Rough | Arripis georgianus | O |
| Striped Perch | Helotes sexlineatus | C |
| Bridled Goby | Gobius bifrenatus | C |
| Long-Finned Goby | Gobius lateralis | O |
| Crested Weedfish | Cristiceps australis | O |
| Weedy Whiting | Haletta semifasciata | O |
| *Banded Toadfish | Torquigener pleurogramma | O |
| Smooth Toadfish | Sphaeroides glaber | C |
| Velvet Leatherjacket | Navodon australis | O |
| (?)Bridled Leatherjacket | Acanthaluteres spilomelanurus | O |
| CRUSTACEANS | | |
| Shrimp | Leander intermedius | C |
| Snapping-Prawn | Crangon novae-zelandiae | C |
| Strawberry Prawn | Metapenaeopsis crassissima | C |
| Sand Crab | Ovalipes australiensis | O |
| *Blue Swimming Crab | Portunus pelagicus | C |

In addition to the above species a variety of small crustaceans (amphipods, isopods, sea-centipedes, etc.), molluscs, marine worms, medusae and algae (*Ulva lactuca* etc.) are caught by the beam trawl. Because of the catching characteristics of the sampling gear and the sampling programme, the above list is biassed towards relatively slow moving nocturnal organisms.
Common and scientific names of fishes are as given by Scott, Glover and Southcott (1974).

(?) Identification uncertain

# SECTION II - ADULTS

## II. ADULTS

### 1. THE FISHERY

#### a. History

The presence of Western King prawns in South Australian waters has been known for many years and yet it was only a few years ago (1968) that the first commercial catches were made. Small prawns have been caught in shallow water areas of Spencer Gulf and the Gulf of St. Vincent for perhaps one hundred years. These small prawns were probably caught incidentally while fishing for other species such as garfish (*Reporhamphus melanochir*) and in 1927 Hale recorded that they were 'occasionally sold in Adelaide fish shops as "shrimps".

The shallow water prawns that were caught in these early years of South Australia were small and similar to the shrimps marketed in many European countries. It was not known, at the time, that many penaeid prawns spend the early part of their life-cycle in shallow water areas and migrate out to join the deep water stocks as young adults.

One of the more colourful rumours of the beginning of the prawn industry in South Australian waters is that it was not realised that large, marketable prawns existed in Gulf waters until a local fisherman at Wallaroo found several undigested prawns in the gut of a snapper that he had caught. In fact the start of the fishery was probably dependent on several circumstances. In 1968, for example, there were several large rock lobster and tuna fishing boats operating in South Australian waters - without these larger vessels trial trawling for prawns would have been impossible. In other States and this State many fishermen with experience in trawling were looking for greener pastures. Combining these circumstances with the fact that a ready market already existed for prawns, conditions were ideal for the fishery to be 'discovered'.

In the summer of 1967/68 a rock lobster fisherman from Port Lincoln named Roger Howlett, having obtained technical advice from interstate prawn fishermen, made an investigation of the mid-Spencer Gulf area on the vessel 'Cape Byron' using a beam trawl. After many unsuccessful tries it was decided to make one final 'shot' in an area now known by prawn fishermen as the Gutter (approximately 25 n.m. west of Moonta). This final trawl resulted in what is generally regarded as the first commercial size catch made in South Australia. Soon 6 vessels were involved in the infant fishery - 'Dinjerra', 'Cape Byron', 'Naracoopa' (later destroyed by fire), 'Caroline Star', 'Challenge' (later renamed the 'Yalata') and 'Bintang Terang'. More boats were subsequently converted to prawning and on some occasions individual catches of more than 1 000 kg per night were made.

In March 1968 the Department of Fisheries closed all South Australian waters to trawling and 40 permits were issued on a zone basis which required vessels newly entering the fishery to carry out exploratory trawling rather than fish the recently discovered grounds. Only 25 permits were eventually used. The early action in protecting the fledgling industry was initiated by the then Director of Fisheries (A.M. Olsen) and has, so far, prevented any overexploitation or overinvestment in the fishery as may have occurred had open entry been allowed in the formative years.

b. Fishing methods

At present, boats range in length from 10.0 m to 25.7 m (mean length 15.7 m) and the majority of these have the following characteristics: a forward wheelhouse, crew accommodation below in the fo'c'sle and double fishing rig with booms hinged to 'goal post' frames positioned on each side deck. One otter-type trawl of synthetic material (or two in the case of double rigged vessels) is towed over the sea bottom at a speed of less than 3 knots. A typical net is shown in Figure 1-1.

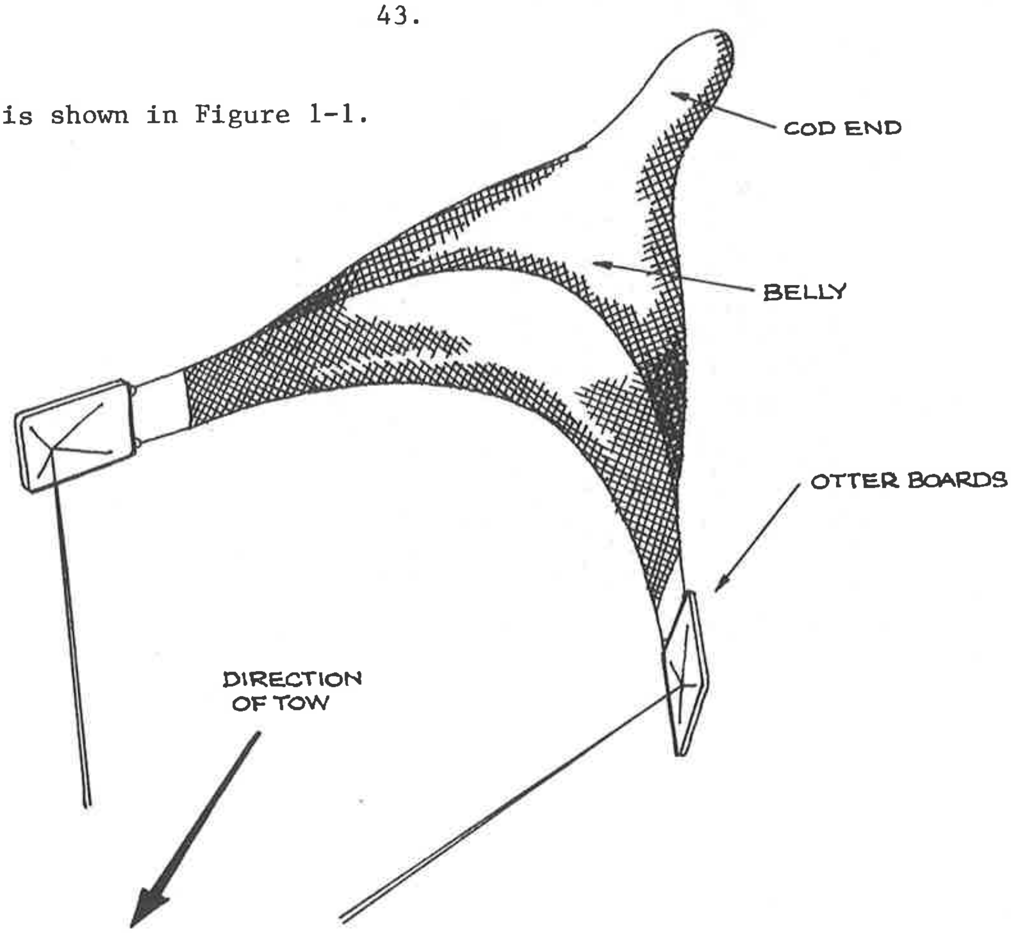



Figure 1-1: A typical otter trawl used in the South Australian fishery for *Penaeus latisulcatus*.

Crew size varies from two on smaller boats to five or more on larger boats; in some cases an extra crew member is kept ashore to repair nets or rotate duties with the sea-going crew. Fishing trips (between off-loadings) generally last between one and four nights depending on the nightly catch rate and area fished - in the Gulf of St. Vincent, for example, where fishing grounds are located close to the home port and smaller (single rigged) vessels are used, short trips are more common.

Except during some periods of high average catch rates during the early months of the year, Western king prawns are taken during the hours of darkness. Echo sounders are used to identify suitable trawling bottom and the use of try nets to determine prawn concentrations is rare. Boats usually begin the first 'shot' at dusk and trawl for over eight hours each night. The duration of each shot can vary from about 30 minutes to over two hours, depending on the characteristics of the fishing ground being worked. After each shot the catch is emptied from the cod ends onto a sorting table installed on deck. As the prawns are sorted from the 'trash' fish, etc. they are usually stored uncooked ("green") in built-in tanks of chilled brine. The prawns are unloaded at ports where suitable facilities exist, the major ones being Kingscote in Investigator Strait, Port Adelaide and Edithburgh in the Gulf of St. Vincent, Port Pirie, Whyalla, Cowell and Port Lincoln in Spencer Gulf and Venus Bay on the west coast of the State (Figure 1-2). At these ports the prawns are usually unloaded, packed into ice-chilled bins and transported to the factories by road.

c. Management

(1) Licence limitation:

Licence limitation has been applied since the beginning of the fishery and the numbers of vessels increased with caution. The historical annual increase in number of vessels and total landings are given in Table 1-1.

TABLE 1-1

Number of vessels and catch weight per year

| YEAR | VESSELS | TOTAL CATCH (tonnes) |
|---|---|---|
| 1968 | 25* | 397 |
| 1969 | 32 | 698 |
| 1970 | 38 | 1 159 |
| 1971 | 45 | 1 337 |
| 1972 | 46 | 1 535 |
| 1973 | 46 | 2 051 |
| 1974 | 54 | 3 066 |
| 1975 | 57 | 2 250 |
| 1976 | 61 | 2 839 |

*In 1968 all vessels were operating under a permit system. In April 1969, "The Preservation of Prawn Resources Regulations" were introduced and vessels were then issued with authorities to trawl for prawns. Ministerial permits may still be issued on a temporary and conditional basis to encourage fishing outside established trawling areas.

On 4 February, 1974, the formation of a Prawn Fishing Industry Advisory Committee was approved by Cabinet to assess applications for prawn authorities and make recommendations concerning management of the fishery to the Government. This Committee was disbanded on the 5th November, 1976 and a ballot system introduced to select new entrants to the fishery.

(2) Zone restrictions:

The fishery has been divided into a number of geographical zones for management purposes and authorities or permits issued for boats to operate within these various zones. The separation is largely a convenient one based on the geographical characteristics of the coastline. No consistent biological differences have been noted or are suspected between the stocks of each area. As effort, vessel power factors and catch differ from zone to zone, however, each must be considered separately.

In September, 1970, the original zones were altered to encourage further exploratory fishing. As from this date the zones have been as shown in Figure 1-2.

In June 1971, the distinction between vessels authorised to fish in Zones C and D was abolished and the boats were allowed to move freely between these zones. After this date the majority of these boats worked in Spencer Gulf (Zone D) with up to 5 or 6 vessels working the fishing grounds in Anxious Bay during the winter and early spring (May to October). At present the numbers of authorities and permits issued for the various zones are as follows:

| ZONE | AUTHORITIES | PERMITS |
|---|---|---|
| A & B (West Coast) | - | 2 |
| C (West Coast) | - | 1 |
| C & D (West Coast and Spencer Gulf) | 39 | - |
| E (St. Vincent Gulf) | 14 | - |
| E (Investigator Strait) | - | 5 |
| | 53 | 8 |

(3) Closures:

<u>Permanent</u>

In July 1968 all waters of the State less than 9 m deep and the Northern part of Spencer Gulf were closed to trawling. This action was taken to protect juvenile prawns which were known to exist in these areas and also to prevent interference with the 'inshore' scale fisheries (e.g. whiting, tommy ruff, garfish, etc.).

At present three areas of the waters of the State are closed permanently to trawling for prawns (see Figure 1-2). They are:

a. The waters of Spencer Gulf north of a line joining Port Whyalla to Jarrold Point.

b. All the waters of the State of less than ten metres in depth at low water mark.

c. The waters of Spencer Gulf adjacent to Franklin Harbour generally from Gibbon Point easterly, then northerly, to near the Shoal Water light.

<u>Seasonal</u>

In 1971 an additional part of northern Spencer Gulf was closed to trawling from February to May to prevent large numbers of newly recruited prawns being taken in this fishery. This closure was again imposed during February and March 1972.

On 22 March, 1973, a proclamation was passed closing the area above the parrallel of latitude passing through the Yarraville Shoal light from 15 January to 15 March each year (Figure 1-2).

(4) Vessel and gear restrictions:

At present all the Gulf of St. Vincent vessels are restricted to single rig. In other zones the type of rig is a matter of choice but the majority of vessels are double rigged. The maximum length of

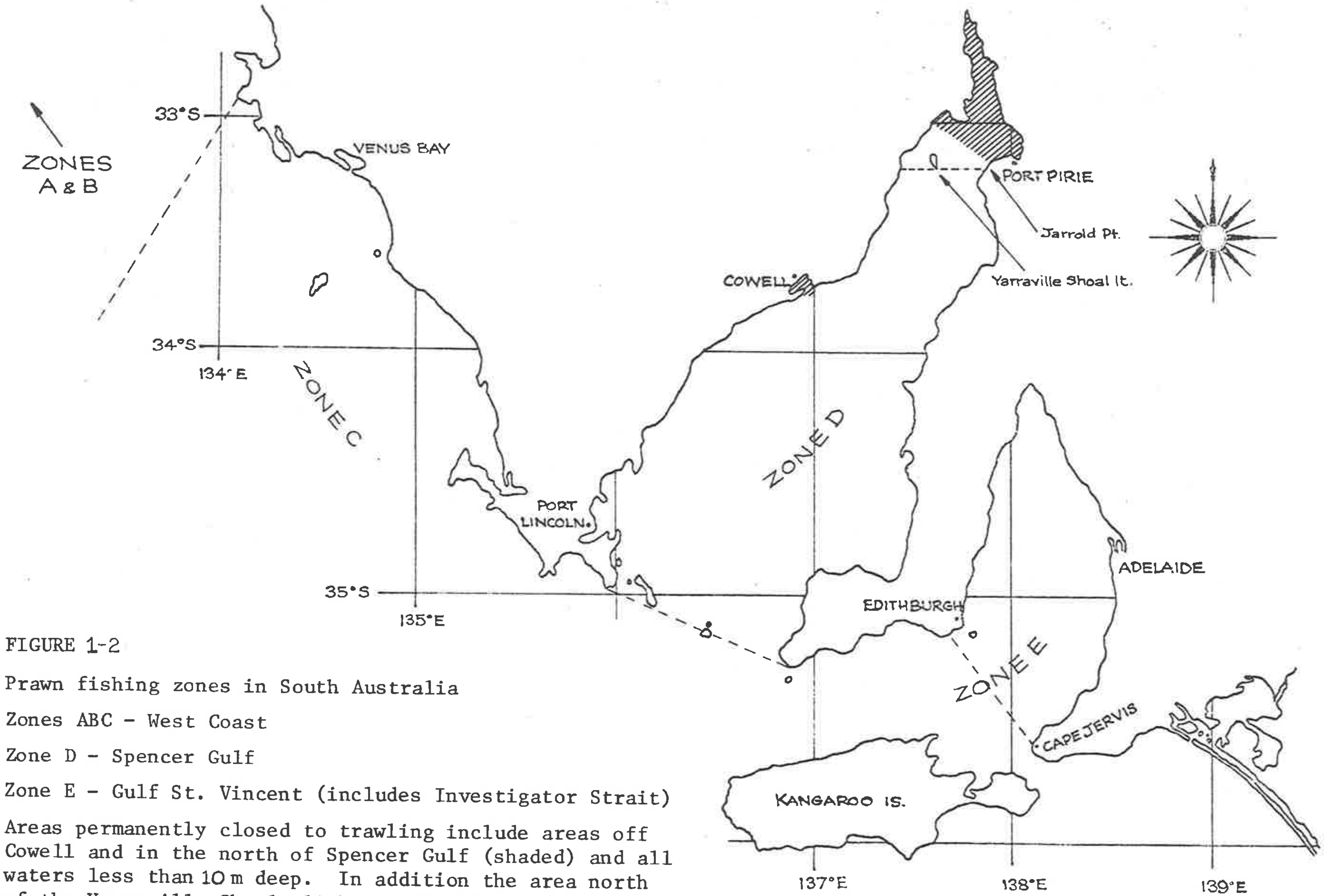



FIGURE 1-2

Prawn fishing zones in South Australia

Zones ABC - West Coast

Zone D - Spencer Gulf

Zone E - Gulf St. Vincent (includes Investigator Strait)

Areas permanently closed to trawling include areas off Cowell and in the north of Spencer Gulf (shaded) and all waters less than 10 m deep. In addition the area north of the Yarraville Shoals light is closed each year from 15 January to 15 March.

vessels brought into the fishery as replacements for existing vessels is not permitted to exceed 13.7 m (45 ft.) in the Gulf of St. Vincent (Zone E) and 16.7 m (55 ft.) in other zones. A two per cent length tolerance is allowed for replacement vessels.

Trawl nets used in the fishery are at present limited by restricting mesh sizes and the length of headline. The legal minimum size of the mesh in prawn otter trawl nets used in Australian Proclaimed Waters adjacent to South Australia is now 4.5 cm in the cod end and 5 cm in all other parts of the net*.

The maximum allowable headline length of the trawl net (or sum of both trawl nets in the case of double rigged vessels) is 40 m for a 26 m vessel and decreasing proportionately for smaller vessels in accordance with the following table.

Maximum headline lengths of trawl nets

| Surveyed Length of vessel (metres) | Headline Length net (metres) | Surveyed Length of vessel (metres) | Headline Length net (metres) |
|---|---|---|---|
| 9 | 25.0 | 18 | 32.9 |
| 10 | 25.9 | 19 | 33.8 |
| 11 | 26.8 | 20 | 34.7 |
| 12 | 27.7 | 21 | 35.6 |
| 13 | 28.6 | 22 | 36.5 |
| 14 | 29.4 | 23 | 37.4 |
| 15 | 30.3 | 24 | 38.2 |
| 16 | 31.2 | 25 | 39.1 |
| 17 | 32.1 | 26 | 40.0 |

*measured as the diagonal distance between the knots in stretched mesh.

d. <u>Catch statistics</u>

Since the beginnings of the South Australian prawn fishery in 1968, its development has been controlled by limiting the number of licences issued. One of the conditions of acceptance of an authorization to fish for prawns is the undertaking to supply accurate daily logs listing details of estimated catch, hours trawled and areas fished. A daily log sheet (which is issued in book form) is shown in Figure 1-3.

The use of catch statistics in supplying some of the vital parameters of a fishery has been well documented in text books (e.g. Gulland 1969). However, most of these uses are based on fisheries on long lived species and, as noted by Lucas (1973), prawn fisheries, with their extended recruitment and short life span, present problems in applying conventional techniques. In spite of these problems, the catch statistics have many uses in assessing the fishery.

In the study on the adult population of *P. latisulcatus* catch statistics were used in the following ways:

(1) Catch per unit effort data were used to determine the geographical extent of the fishery (Section II-3).

(2) Catch rates during the period of recruitment were used to estimate the 'size' of recruitment (Section II-5).

(3) Decline in catch rates after recruitment was used in obtaining mortality estimates (Section II-10).

(4) The increase in catch per vessel over the years since 1968 has been used to examine the factors which have caused this increase in fishing power (the catch which can be taken from a given density of fish per unit time - Ricker 1975) in Appendix 4.

In addition, catch statistics over a long term may be used to find the approximate position of the fishery on a yield curve and provide base-line information for economic assessment. The latter aspect is beyond the scope of this study, but yield assessments are discussed in Section II-11.

**DAILY LOG SHEET** Date 12 / 4 /1977 Vessel Name Saucy Sue

Boat Reg. No. Skipper Lucky Sam

Total Hours Under Way out of 24 10½

| Shot No. | Grid Reference | R.P.M. | Start Time | Duration of Trawl (Mins.) | Estimated Catch (kg) Western King Prawn | Remarks (Bottom conditions, other species, water temp., weather, etc.) |
|---|---|---|---|---|---|---|
| 1 | E476 | 750 | 1840 | 45 | 65 | few sand crabs, 2 kg of |
| 2 | E476 | " | 1935 | 63 | 60 | mixed fish |
| 3 | E476 | " | 2045 | 45 | 52 | " " |
| 4 | E476 | " | 2142 | 65 | 74 | many sandcrabs, approx 12 kg |
| 5 | E477 | " | 2256 | 60 | 38 | of flathead, squid. |
| 6 | E477 | " | 0012 | 45 | 30 | rough bottom – approx. 80 kg. coral |
| 7 | E478 | " | 0250 | 65 | 45 | 4 kg. mixed fish. – prawns |
| 8 | | | | | | Small (about 35 to the lb.) |
| 9 | | | | | | – strong S.W wind |
| 10 | | | | | | seas rising. |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| 16 | | | | | | |
| 17 | | | | | | |

| Major Grid Reference | Totals | Minutes | Kilograms | Details of Catch Landed: Port of Landing | Quantity (kg) |
|---|---|---|---|---|---|
| E476 | | 388 | 364 | Kingscote | 375 |

FIGURE 1-3: Example of a daily fishing log filled in by all State authorised prawn fishermen in South Australia.

In the following two subsections, catch and effort statistics over the long term (annual statistics during the time span of the fishery) and short term (during a year or "season") are presented.

(1) Annual catch statistics:

Historically the annual catch of *Penaeus latisulcatus* has increased since the start of the fishery in 1968 (Figure 1-4) up to 1974. The 1975 season was notable for the fact that for the first time in the history of the fishery there was a drop in the total annual catch compared with the previous year. This is almost certainly due to the high 1974 recruitment followed by a relatively low 1975 recruitment in Spencer Gulf (Section II-5) and it cannot at this stage be interpreted that effort in this fishery has exceeded the optimum. These aspects are discussed in the section on yield (Section II-11).

Although annual catches have increased over the years, effort, defined as the number of hours trawled, has also increased. Fluctuations in mean annual catch rates (Figure 1-5) are likely to reflect differences in the size of recruitment to the fishery (Section II-5). Apart from 1974, the annual catch rates have not generally altered. In interpreting this, however, it should be noted that the effective effort of the fleet may have increased over the years - that is, the vulnerability of the stock has increased with increases in the "fishing power" (Ricker 1975) of the fleet. Factors that could have been involved in any increase in fishing power include:

(a) The development of new fishing techniques including finer otter board adjustment and the use of lighter 'tickler' chains.

(b) The use of more efficient net styles.

(c) Increased use of technical equipment such as radar.

(d) Increase in skill and knowledge of skippers.

(e) Increase in engine horsepower and, therefore, net towing speed.

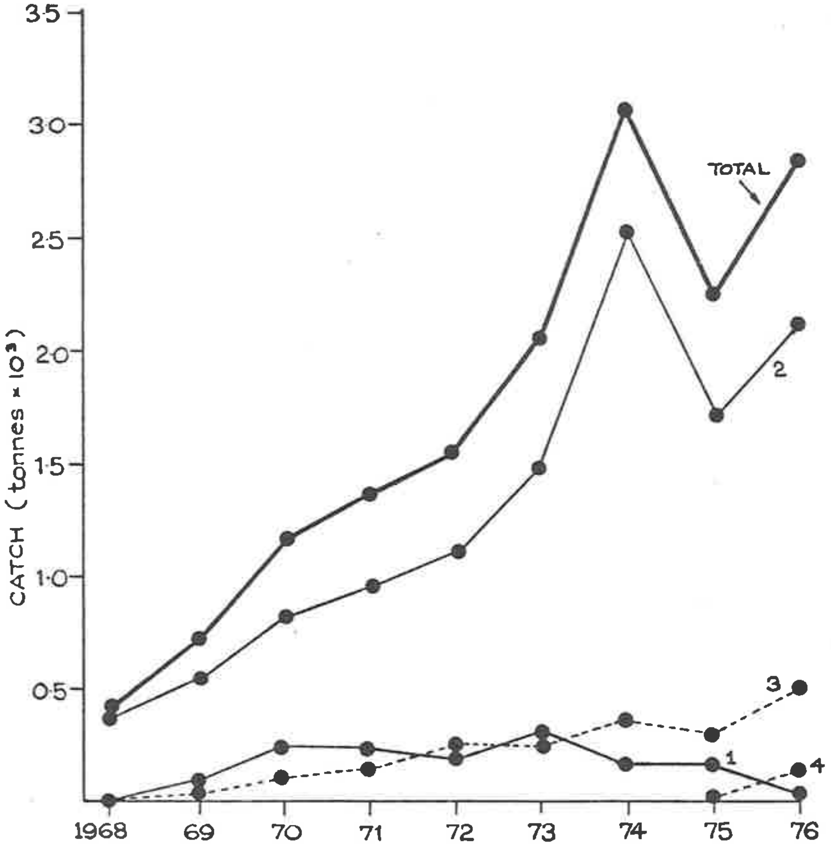



FIGURE 1-4: Total annual catch (tonnes x $10^3$) of western king prawns in South Australia (heavy line). Catches of individual areas are shown as (1) West Coast, (2) Spencer Gulf, (3) Gulf St. Vincent and (4) Investigator Strait.

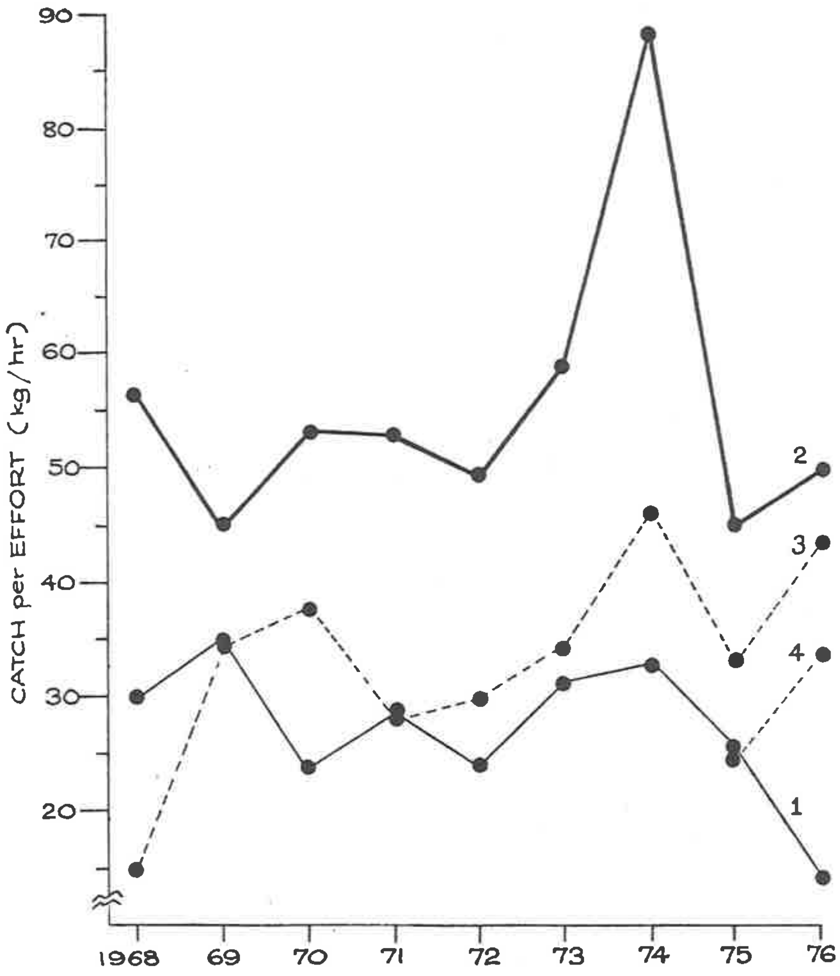



FIGURE 1-5: Mean annual catch rates (kg per hour trawled) of western king prawns in areas (1) West Coast, (2) Spencer Gulf, (3) Gulf St. Vincent and Investigator Strait.

The fact that annual catch rates have not generally increased indicates one of two things - firstly, there has been no real increase in fishing power or, secondly, if there has been an increase in fishing power it has been balanced out by a decreased availability of the prawns.

It is most probable that the factors listed above have been important in the formative years of the fishery only. At present, differences in fishing power of individual vessels appear to be a result of differences in measurable characteristics such as boat length, engine horsepower, type of rig (see Appendix 4) and the unquantifiable factor of skipper skill and attitude.

(2) Seasonal catch statistics:

A full summary of catch, effort and catch rate by month for Spencer Gulf, Gulf of St. Vincent, Investigator Strait and the West Coast is given in tables in Appendix 2.

Maximum catch rates occur during the period of juvenile recruitment to the adult stocks (February to April - see Section II-5) especially in Spencer Gulf. Catch rates in the Gulf of St. Vincent are less variable over the year as co-operation between the smaller number of boats operating in this zone enables them to avoid areas where small newly-recruited prawns are found (Figure 1-6).

Catch rates decrease over the winter months to a minimum around July to October and usually increase slightly towards the end of the year. This trend in catchability, which appears to be related to the seasonal sea temperature cycle, is discussed in Section II-9.

Seasonal trawling effort varies with each zone; in Spencer Gulf, where fishing is highly competitive, effort is greatest when large numbers of newly recruited prawns are present (February to April); in the Gulf of St. Vincent, seasonal effort is less variable but effort is often greater in the later months of the year (November to

December) when the catch rate of large prawns is high; in the West Coast, maximum effort is spent during the calmer winter months.

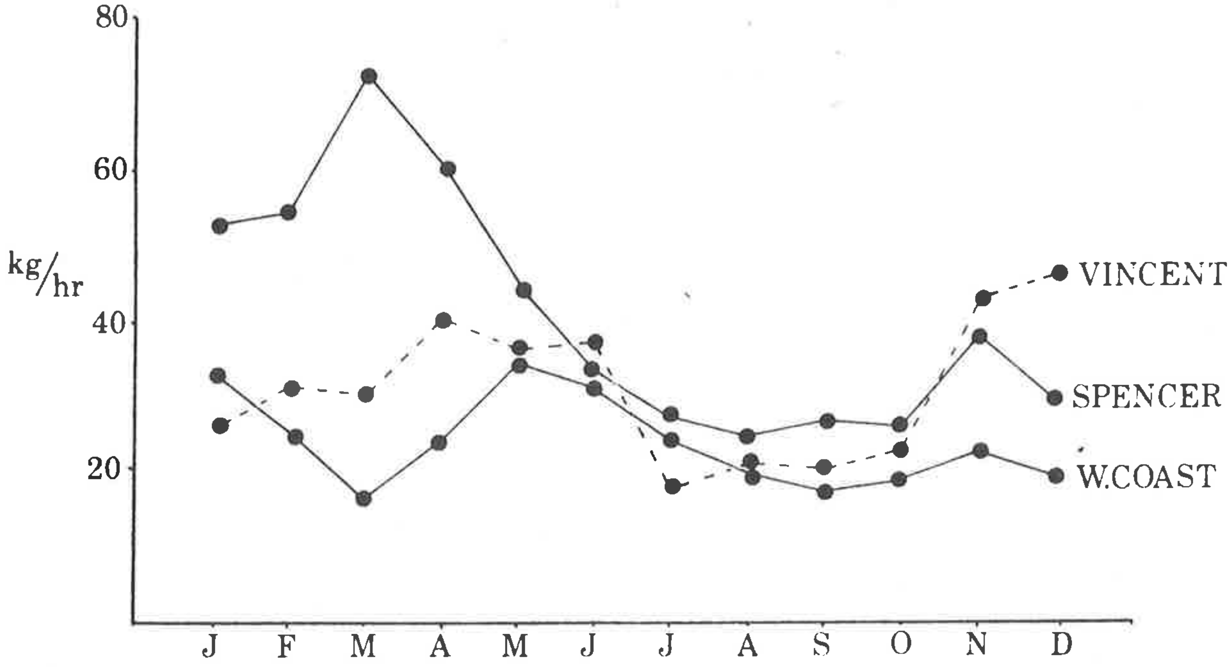



Figure 1-6 Catch rates (kg/hr) per month (1975) for:
(1) Spencer Gulf
(2) Gulf of St. Vincent
(3) West Coast.

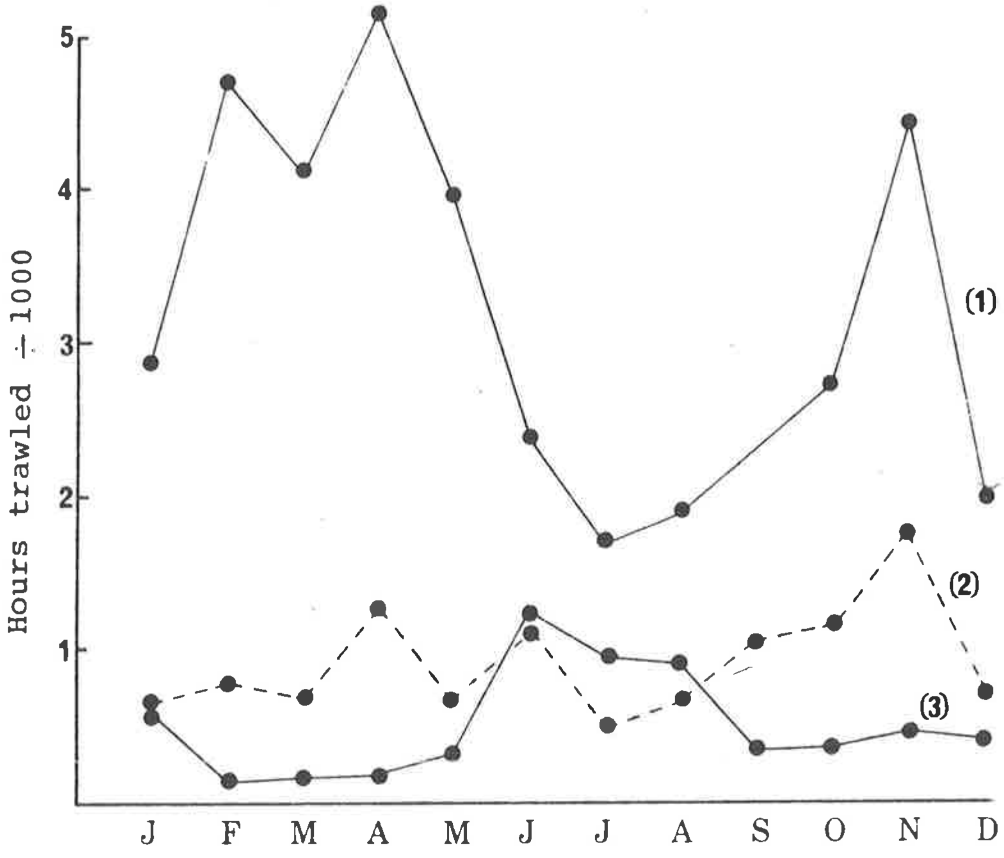



Figure 1-7 Effort (hours trawled) per month (1975) for:
(1) Spencer Gulf
(2) Gulf of St. Vincent
(3) West Coast

## 2. THE ENVIRONMENT

Newly recruited and adult prawns are usually trawled in deeper areas such as the channels associated with banks or shoals. Approximate ranges of depths on the fishing grounds are as follows:

| Zone or Location | Depth range (m) |
|---|---|
| West Coast | 20 to 55 |
| Spencer Gulf | 14 to 40 |
| Gulf St. Vincent | 12 to 36 |
| Investigator Strait | 18 to 32 |

From limited diving observations (N. Spencer Gulf and Orontes Bank, Gulf St. Vincent) the sea-floor on the fishing grounds appears to be bare sand with some silt and patches of shell grit, sponge, bryozoans, etc. A list of species associated with *Penaeus latisulcatus* is given in Section 10.

Water circulation in partially enclosed system such as the Gulfs and Investigator Strait is likely to be a product of temperature/ salinity distributions, prevailing winds and currents in adjacent ocean waters.

Across the mouth of Spencer Gulf the salinity increases with distance from west to east (Bullock 1975) and in the northern end of the Gulf high summer salinities are known to occur (maximum of 43‰ - Table 2-1). From major trawling surveys, differences in summer surface temperatures of up to $4^{o}C$ were found between north Spencer Gulf and Investigator Strait. From the salinity distribution Bullock suggests that Southern Ocean waters flow into Spencer Gulf on the western side where its salinity is increased by evaporation and mixing before flowing out on the eastern side (Figure 2-1). This circulation pattern is not inconsistent with the prevailing south west winds (S.A. Bureau of Meteorology records) and the west wind drift (U.S. Hydrographic office 1969) to the south of Spencer Gulf.

From an examination of the hydrology of Gulf St. Vincent (Bullock 1974), it appears that the general circulation of water masses in this Gulf is basically similar to that in Spencer Gulf (Figure 2-1). Information on the circulation in Gulf St. Vincent and Investigator Strait has been reviewed by Bye (1976) who suggested that local winds are an important contributing factor.

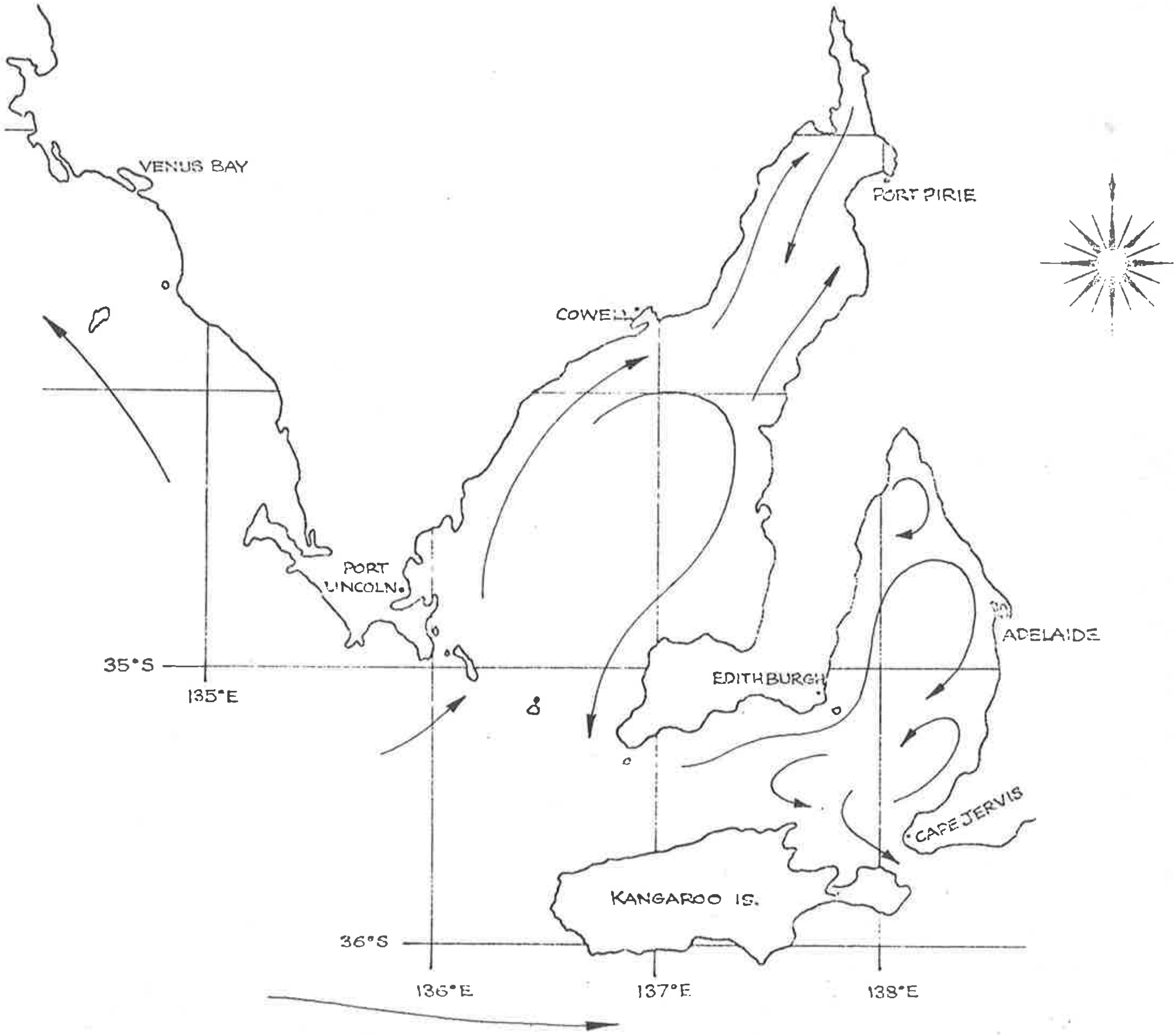



Figure 2-1 General water circulation in South Australia - from various sources including Bullock 1975, 1974, Bye and Whitehead 1975, Bye 1976.

| DATE | DOUGLAS BANK | | EASTERN SHOAL | |
|---|---|---|---|---|
| | TEMP °C | SAL. °/oo | TEMP °C | SAL. °/oo |
| 15.01.74 | 25.0 | 40.7 | 24.5 | 40.2 |
| 14.02.74 | -- | -- | 24.5 | 40.5 |
| 18.03.74 | 25.0 | 40.9 | 24.5 | 39.8 |
| 09.04.74 | 22.0 | 41.0 | 21.5 | 40.5 |
| 15.05.74 | 18.5 | 41.8 | 18.5 | 41.1 |
| 11.06.74 | 15.0 | 41.7 | 15.5 | 41.5 |
| 11.07.74 | 14.0 | 41.8 | 13.5 | 41.6 |
| 17.08.74 | 13.5 | 42.2 | 13.5 | 41.9 |
| 09.09.74 | 15.5 | 41.1 | 15.0 | 40.7 |
| 08.10.74 | 16.5 | 40.3 | 16.0 | 40.1 |
| 06.11.74 | 18.5 | 40.1 | 18.5 | -- |
| 03.12.74 | 20.5 | 39.7 | 20.0 | 39.5 |
| 05.01.75 | 21.0 | 40.0 | 21.5 | 39.6 |
| 06.02.75 | 24.5 | 40.8 | 24.0 | 40.0 |
| 05.03.75 | 24.0 | 40.9 | 23.5 | 40.7 |
| 07.04.75 | 19.5 | 42.0 | 19.5 | 40.6 |
| 05.05.75 | 19.0 | 40.8 | 18.5 | 40.2 |
| 02.06.75 | 16.5 | 40.5 | 16.0 | 40.1 |
| 03.07.75 | -- | -- | 12.5 | 40.4 |
| 01.08.75 | 13.5 | 40.7 | 13.0 | 39.8 |
| 28.08.75 | 12.5 | 40.1 | 12.5 | 39.9 |
| 25.09.75 | 16.0 | 40.2 | 15.5 | 39.9 |
| 20.10.75 | 17.5 | 39.7 | -- | -- |
| 26.11.75 | 21.5 | 42.5 | 21.0 | 41.8 |
| 29.01.76 | 22.0 | 39.5 | 21.5 | 39.5 |
| 23.02.76 | 24.5 | 40.0 | 24.0 | 39.9 |
| 24.03.76 | 21.5 | 43.0 | 21.5 | 40.8 |
| 20.04.76 | 19.0 | 40.1 | 18.5 | 40.9 |
| 21.05.76 | 16.0 | 40.5 | 16.0 | 40.3 |
| 17.06.76 | 14.0 | 42.3 | 13.0 | 41.6 |

TABLE 2-1 : Surface water temperatures (°C) and salinities (°/oo) at Douglas Bank and Eastern Shoal in northern Spencer Gulf.

3. DISTRIBUTION

Major fishing grounds are located in Spencer and St. Vincent Gulfs and, to a lesser extent, Investigator Strait and in Anxious Bay on the West Coast of South Australia. The division of these areas into separate zones is discussed in Section II.c.2. Distribution of adult prawns by trawling abundance in both Spencer and St. Vincent Gulfs is indicated in Figure 3-1 which gives the annual catch per 6 x 5 n. mile grid area. Distribution of the main fishing areas on the west coast of the State are shown in Figure 3-2.

There have been several attempts to expand the fishery beyond its present geographical limits. In 1971 a survey of waters to the South East of the State as far as Cape Northumberland failed to locate Western king prawns; in addition much of the sea bottom was found to be too rocky for prawn trawling. At times reports have been received of prawns in South Eastern and other ocean waters such as off the south coast of Kangaroo Island. In some cases where samples have been obtained these have been identified as *Metapenaeopsis crassissima*. This species, which is widely distributed in South Australian waters, is often mistaken for juvenile King prawns.

In 1973 a contract was signed with the owner of the trawler 'Explorer' to carry out a survey of prawn resources in the waters off the far west coast of South Australia. The area prescribed in the contract was near Fowlers Bay - further west than any of the established West Coast fishing grounds, but the results were, in general, disappointing; maximum catch rates recorded were 15 kg/hr.

In 1974 trawling surveys in Investigator Strait produced promising results (King 1974 ) and expansion of the prawn fishery into this area has been encouraged by issuing permits for trawling. There are now five vessels operating by permit in Investigator Strait and more permits may be issued if data being obtained indicate that the additional fishing effort will not adversely affect the fishery.

For the first time on record, there have been reports of *P. latisulcatus* in the Coorong in April 1977 (Figure C-1). The reports have since been substantiated but the presence of the species in the Coorong is likely to be a chance occurrence due to unusual hydrological conditions. At the end of the 1975/76 spawning season of *P. latisulcatus* there were several months (February to July, 1975) of very low water flow from the River Murray mouth. During this period the ingress of larvae through the mouth into the Coorong waterways would account for prawns of the size found in April and May, 1977.

As in many other invertebrates the larval phase of *P. latisulcatus* allows for the wide dispersal of the species by ocean currents. The distribution of *P. latisulcatus* is likely to be defined by the general water circulation discussed in Section 2 (Figure 2-1). Larval loss through Backstairs Passage, for example, could account for occasional reports of adult prawns in Encounter Bay. In addition, periods of unusual hydrological conditions could result in irregular occurrences of the species in areas beyond the limits of the present fishery. The extent of the fishery appears to be restricted to the relatively consistent fishing grounds described above and the prospects for geographical expansion are limited.

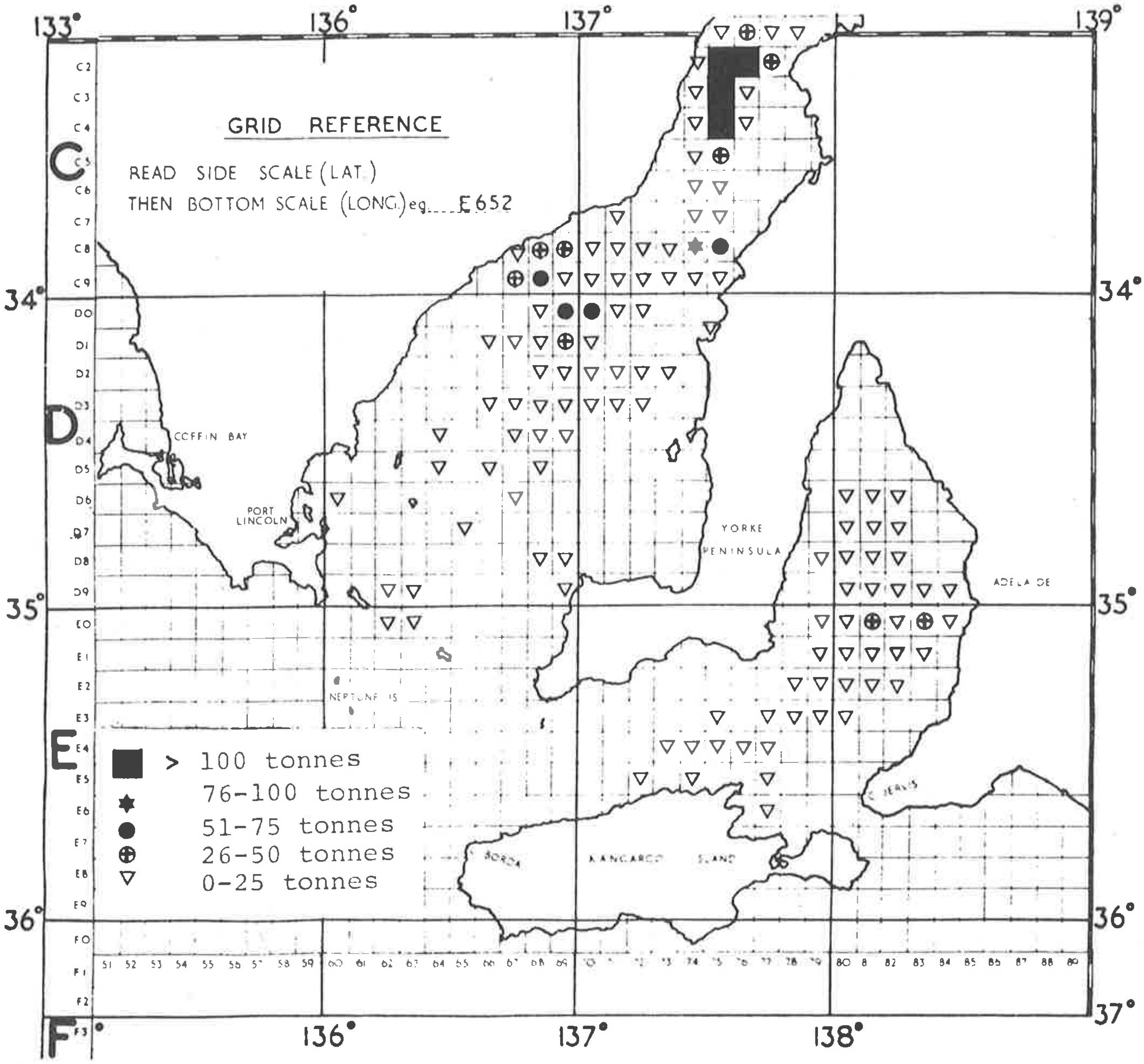



Figure 3-1 Total annual catch per 6 x 5 n. mile grid area in Spencer Gulf, the Gulf of St. Vincent and Investigator Strait (1973 data).

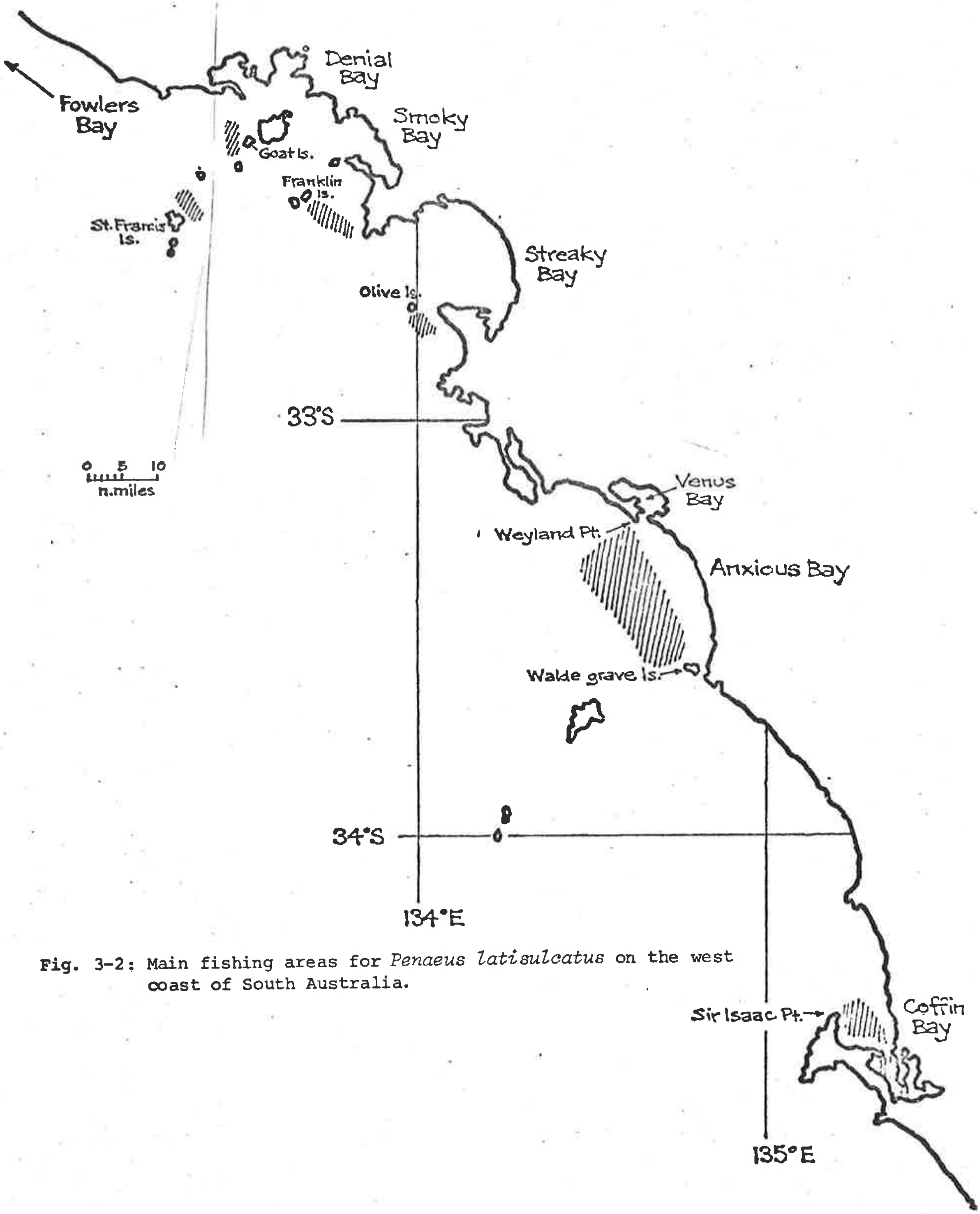



Fig. 3-2: Main fishing areas for *Penaeus latisulcatus* on the west coast of South Australia.

## 4. LENGTH FREQUENCIES

Carapace lengths of adult *P. latisulcatus* were measured from samples obtained on board several commercial trawlers operating in Spencer Gulf, The Gulf of St. Vincent and Investigator Strait. In the main fishing zone (Spencer Gulf) monthly stations have been maintained at Douglas Bank and Eastern Shoal from January, 1973 to June, 1976. More recently regular sampling stations have been set up in Investigator Strait and the Gulf St. Vincent. On occasions length frequencies of samples were measured at processing factories.

On several occasions, major surveys from Port Pirie in Spencer Gulf to Port Adelaide in the Gulf of St. Vincent were made on the trawler 'Caroline Star'. On these surveys trawling was carried out at as many fishing grounds in Spencer Gulf, Investigator Strait and the Gulf of St. Vincent as could be done in three to four nights.

Carapace lengths of samples of prawns from all areas have been smoothed by applying a moving average of n=3 (Spiegal 1972) and used to construct length-frequency diagrams. Figures 4-1 and 4-2 show data from Douglas Bank and Investigator Strait respectively. Length-frequency distributions from all areas have the following characteristics in common: a regression of the mean carapace length during the period when sub-adult prawns were joining the adult stocks (recruitment) followed by a progression of modes until the following recruitment (see Section II-5). In data from previously unexploited areas (Investigator Strait, Figure 4-2) length frequency data can be separated into at least 2 modal groups for each sex - the first mode representing newly recruited stocks and the second mode representing the previous year's stock.

Length frequency data from one of the major surveys is shown in Tables 4-1 and 4-2. These data aided in assessing the information from tagging experiments (Section II-9 - migration) and in estimating mean lengths of prawns for mortality estimates (Section II-10 - mortality). From these data it can be seen that, in the post-recruitment period, smaller prawns were more common on the fishing grounds to the north of both Spencer Gulf and the Gulf of St. Vincent.

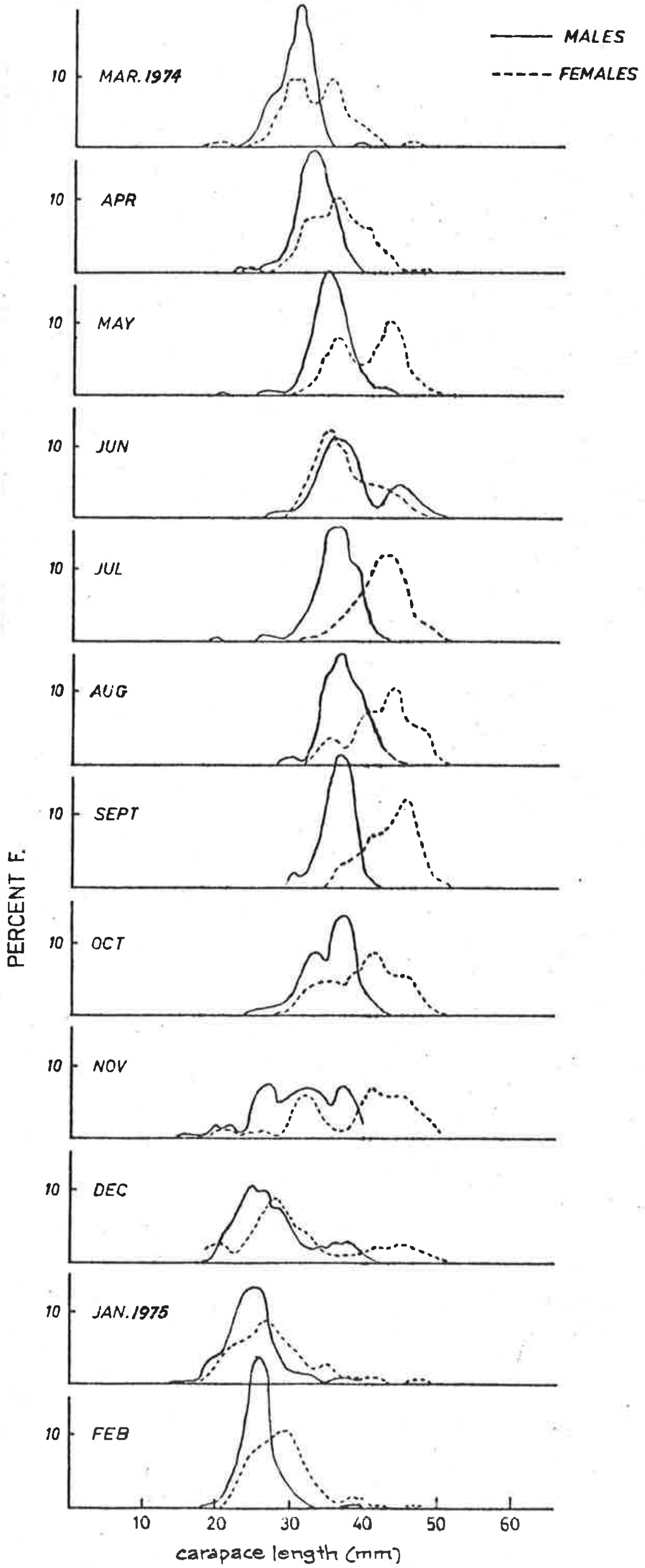



Fig. 4-1: Length frequency data for adult *Penaeus latisulcatus* caught at Douglas Bank in northern Spencer Gulf from March 1974 to February 1975. Modal values from other periods are given in tables 6-3 and 6-4 in section 6.

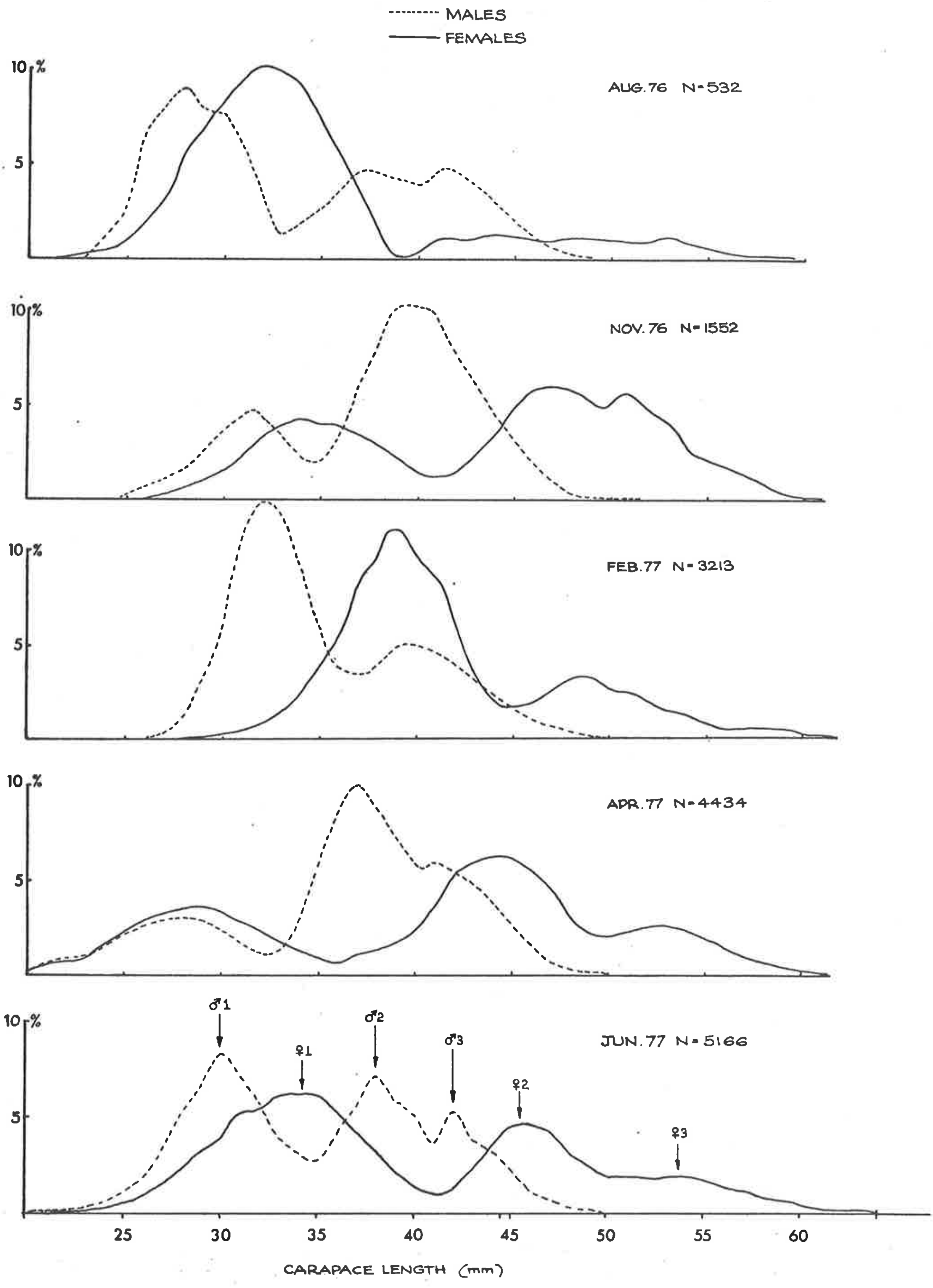



FIGURE 4-2: Length-frequency data (%) for adult Penaeus latisulcatus from Investigator Strait. Male and female distributions are shown by broken and solid lines respectively.

TABLE 4-1: Length-frequencies (percentages) of male Penaeus latisulcatus from stations in Spencer Gulf, Investigator Strait and Gulf St. Vincent, July, 1974

| Carapace Length (mm) | Station Number (see figure 4-3) ..... 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 1.3 | | | | | | | | | | | |
| 21 | | | | | | | | | | | | |
| 22 | | 1.6 | | | | | | | | | | |
| 23 | | 0 | | | | | | | | 2.1 | | |
| 24 | | 0.8 | | | | | | | | 1.0 | | |
| 25 | | 1.6 | 0.8 | | | | | | | 1.0 | 1.4 | |
| 26 | | 1.6 | 0.8 | 0.8 | | | 1.5 | | | 2.1 | 0 | |
| 27 | 1.3 | 2.4 | 0.8 | 1.6 | | | 0.7 | | 1.8 | 2.1 | 0 | |
| 28 | 0 | 4.8 | 3.9 | 0.8 | 2.9 | 2.9 | 8.9 | | 0 | 1.0 | 0 | |
| 29 | 0 | 6.4 | 3.9 | 0 | 5.9 | 6.9 | 14.1 | | 5.5 | 5.2 | 1.4 | |
| 30 | 1.3 | 5.6 | 4.6 | 2.4 | 9.6 | 20.6 | 23.0 | | 1.8 | 3.1 | 0 | |
| 31 | 1.3 | 7.1 | 4.6 | 3.2 | 13.2 | 19.6 | 19.3 | | 9.1 | 3.1 | 1.4 | |
| 32 | 4.0 | 11.9 | 6.9 | 4.0 | 19.9 | 14.7 | 8.9 | | 5.5 | 6.3 | 1.4 | |
| 33 | 2.7 | 15.9 | 3.1 | 9.6 | 19.9 | 15.7 | 5.2 | | 1.8 | 9.4 | 1.4 | |
| 34 | 8.0 | 7.9 | 3.1 | 9.6 | 11.8 | 7.8 | 1.5 | | 5.5 | 3.1 | 4.1 | 1.9 |
| 35 | 14.7 | 11.1 | 9.2 | 13.6 | 9.6 | 4.9 | 0.7 | 2.2 | 9.1 | 8.3 | 8.2 | 5.8 |
| 36 | 22.7 | 8.7 | 6.2 | 11.2 | 2.9 | 2.0 | 0.7 | 0 | 7.3 | 13.5 | 9.6 | 5.8 |
| 37 | 9.3 | 9.5 | 12.3 | 8.0 | 1.5 | 0 | 2.2 | 11.1 | 10.9 | 15.6 | 5.5 | 1.9 |
| 38 | 14.7 | 1.6 | 14.6 | 10.4 | 2.9 | 2.9 | 2.2 | 17.8 | 10.9 | 14.6 | 6.9 | 13.5 |
| 39 | 9.3 | 0.8 | 13.1 | 12.8 | | 1.0 | 7.4 | 4.4 | 16.4 | 4.2 | 15.1 | 19.2 |
| 40 | 6.7 | 0.8 | 4.6 | 4.0 | | 1.0 | 2.2 | 13.3 | 5.5 | 4.2 | 16.4 | 16.4 |
| 41 | 0 | | 2.3 | 5.6 | | | 0.7 | 15.6 | 7.3 | | 11.0 | 11.5 |
| 42 | 0 | | 1.5 | 0 | | | 0 | 6.7 | 1.8 | | 6.9 | 11.5 |
| 43 | 2.7 | | 1.5 | 0.8 | | | 0 | 8.9 | | | 4.1 | 1.9 |
| 44 | | | 0 | 0.8 | | | 0.7 | 4.4 | | | 4.1 | 0 |
| 45 | | | 1.5 | 0 | | | | 2.2 | | | | 0 |
| 46 | | | 0.8 | 0 | | | | 6.7 | | | | 1.9 |
| 47 | | | | 0.8 | | | | 6.7 | | | | 1.9 |
| 48 | | | | | | | | | | | | |
| 49 | | | | | | | | | | | | |
| 50 | | | | | | | | | | | | |
| Sample size | 75 | 126 | 130 | 125 | 136 | 102 | 135 | 45 | 55 | 96 | 73 | 52 |

TABLE 4·2: Length-frequencies (percentages) of female <u>Penaeus</u> <u>latisulcatus</u> from stations in Spencer Gulf, Investigator Strait and Gulf St. Vincent, July, 1974.

| Carapace Length (mm) | Station Number (see figure 4-3)... | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 10 | 11 | 12 | 14 |
| 22 | | | | | | | | | | | 1.1 | |
| 23 | | | | | | | | | | 2.0 | 0 | |
| 24 | | 1.1 | | | | | | | | 0 | 0 | |
| 25 | | 2.2 | | | | | | | | 0 | 0 | |
| 26 | | 2.2 | | | | | | | | 0 | 1.1 | |
| 27 | | 2.2 | 1.8 | | | | | | | 0 | 0 | |
| 28 | | 1.1 | 1.8 | | | | 4.7 | | | 3.9 | 1.1 | |
| 29 | | 0 | 4.5 | 1.1 | 2.0 | 1.5 | 2.3 | | | 7.8 | 0 | |
| 30 | | 5.4 | 3.6 | 0 | 6.1 | 4.6 | 9.3 | | 1.7 | 9.8 | 0 | |
| 31 | | 9.8 | 1.8 | 2.3 | 8.2 | 0 | 12.8 | | 0 | 2.0 | 0 | |
| 32 | 1 | 14.1 | 6.3 | 1.1 | 12.2 | 7.7 | 20.9 | | 5.2 | 0 | 0 | |
| 33 | 1 | 7.6 | 5.4 | 4.5 | 12.2 | 9.2 | 15.1 | | 1.7 | 2.0 | 0 | |
| 34 | 0 | 5.4 | 6.3 | 4.5 | 12.2 | 10.8 | 9.3 | 2.4 | 6.9 | 0 | 1.1 | |
| 35 | 1.9 | 9.8 | 5.4 | 5.6 | 16.3 | 4.6 | 5.8 | 0 | 6.9 | 3.9 | 0 | |
| 36 | 1.9 | 7.6 | 5.4 | 5.6 | 10.2 | 12.3 | 4.7 | 0 | 1.7 | 2.0 | 1.1 | |
| 37 | 5.7 | 7.6 | 3.6 | 2.3 | 2.0 | 9.2 | 1.2 | 0 | 5.2 | 5.9 | 6.7 | |
| 38 | 2.9 | 2.2 | 2.7 | 3.4 | 2.0 | 13.9 | 1.2 | 0 | 3.5 | 3.9 | 5.6 | |
| 39 | 5.7 | 4.4 | 2.7 | 4.5 | 8.2 | 7.7 | 2.3 | 0 | 6.9 | 0 | 5.6 | 1.9 |
| 40 | 9.5 | 4.4 | 1.8 | 7.9 | 4.1 | 7.7 | 0 | 0 | 6.9 | 2.0 | 4.4 | 3.7 |
| 41 | 5.7 | 4.4 | 1.8 | 7.9 | 2.0 | 0 | 1.2 | 2.4 | 0 | 2.0 | 8.9 | 1.9 |
| 42 | 14.3 | 1.1 | 3.6 | 9.0 | 0 | 3.1 | 1.2 | 0 | 3.5 | 9.8 | 6.7 | 5.6 |
| 43 | 13.3 | 2.2 | 8.0 | 3.4 | 0 | 1.5 | 0 | 12.2 | 6.9 | 5.9 | 6.7 | 5.6 |
| 44 | 8.6 | 0 | 5.4 | 11.2 | 0 | 1.5 | 0 | 4.9 | 6.9 | 7.8 | 13.3 | 7.4 |
| 45 | 13.3 | 0 | 8.9 | 3.4 | 0 | 1.5 | 3.5 | 7.3 | 12.1 | 11.8 | 5.6 | 13.0 |
| 46 | 4.8 | 2.2 | 2.7 | 5.6 | 0 | 0 | 0 | 14.6 | 5.2 | 11.8 | 4.4 | 14.8 |
| 47 | 2.9 | 0 | 8.9 | 10.1 | 2.0 | 1.5 | 2.3 | 12.2 | 8.6 | 2.0 | 6.7 | 11.1 |
| 48 | 2.9 | 3.3 | 1.8 | 5.6 | 0 | 0 | 1.2 | 2.4 | 5.2 | 3.9 | 6.7 | 9.3 |
| 49 | 2.9 | 0 | 2.7 | | | 0 | 0 | 14.6 | 0 | | 2.2 | 13.0 |
| 50 | 1 | 0 | 2.7 | | | 0 | 0 | 0 | 1.7 | | 1.1 | 3.7 |
| 51 | 1 | | 0.9 | | | 0 | 1.2 | 9.8 | 3.5 | | 4.4 | 1.9 |
| 52 | | | | | | 0 | | 4.9 | | | 2.2 | 1.9 |
| 53 | | | | | | 1.5 | | 4.9 | | | 1.1 | 0 |
| 54 | | | | | | | | 2.4 | | | 0 | 0 |
| 55 | | | | | | | | 0 | | | 1.1 | 1.9 |
| 56 | | | | | | | | 0 | | | 0 | 1.9 |
| 57 | | | | | | | | 2.4 | | | 0 | 1.9 |
| 58 | | | | | | | | 0 | | | 0 | 0 |
| 59 | | | | | | | | 0 | | | 0 | |
| 60 | | | | | | | | 2.4 | | | 1.1 | |
| Sample size | 105 | 92 | 112 | 89 | 49 | 65 | 86 | 41 | 58 | 51 | 90 | 54 |

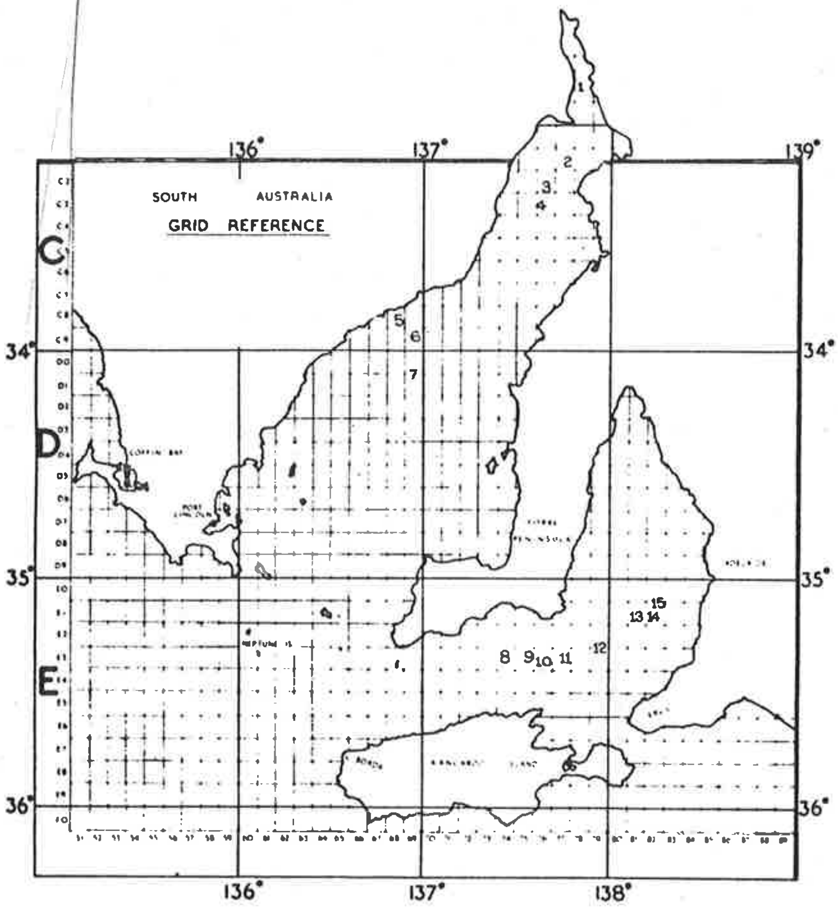



Fig. 4-3: Location of areas trawled during survey of Spencer Gulf, Investigator Strait and Gulf St. Vincent (July 1974 survey.)

## 5. RECRUITMENT

As suggested in previous sections, *P. latisulcatus* migrate out from the nursery areas as sub-adults to join the adult stocks in offshore areas. During this period of recruitment, maximum catch rates occur in the commercial fishery (Figure 1-6).

### a. Size at recruitment

Studies on the juvenile stocks (Section I-4) indicated that *P. latisulcatus* attained an approximate mean size of 23 mm C.L. (sexes combined) before migrating out from the nursery areas. Mesh selectivity experiments (Appendix 3) using commercial fishing gear, although inconclusive, indicated that 24.5 mm carapace length represents the size of prawn at which half are retained and half escape.

Catch rates at the monthly station at Douglas Bank reached a maximum in the period January to March. This station is close to known nursery areas at Chinaman's Creek (Section I-2). Two prawns tagged at Chinaman's Creek were subsequently caught at Douglas Bank, confirming that some recruitment occurred from these nursery areas. During the period of maximum catch rates at Douglas Bank the modal sizes (to the nearest 0.5 mm carapace length) of newly recruited prawns during the years of study were as follows:

| Time of maximum catch rate | Modal size (mm C.L.) | |
|---|---|---|
| | male | female |
| 12 Feburary 1973 | 28 | 29 |
| 18 March 1974 | 31 | 31 |
| 5 March 1975 | 28 | 31 |
| 28 January 1976 | 28 | 29.5 |

### b. Time of recruitment

Time of maximum recruitment was calculated by expressing the combined catch of males $\leqslant$ 28 and females $\leqslant$ 31 mm carapace length, as a percentage of the total monthly sample taken at various stations. The results at one station in the north of Spencer Gulf (Douglas Bank, Figure 5-1) indicated that recruitment at a low level was spread over several months with a peak from December to February.

On more southerly fishing grounds, which were not close to the major nursery areas to the north, recruitment occurred later and at a larger carapace length. Time of maximum recruitment to the fishing grounds in Investigator Strait occurred around April 1977 (Figure 4-2 p.64). It is suggested that the delay in time of recruitment to the southerly fishing grounds is a result of the time taken for newly recruited prawns to reach the area from northern nursery areas.

c. Recruitment strength

An estimate of the 'size' of recruitment for each year was calculated by measuring the increase in catch rate during the period of maximum recruitment above the minimum catch rate immediately prior to the recruitment period. The minimum catch rate was assumed to represent an index of the numbers of residual stock remaining from the previous year's recruitment. The method is illustrated in Figure 5-2. Catch rates in kg/hr were converted to numbers of individual caught per minute from the average growth curve presented in Section II-6.

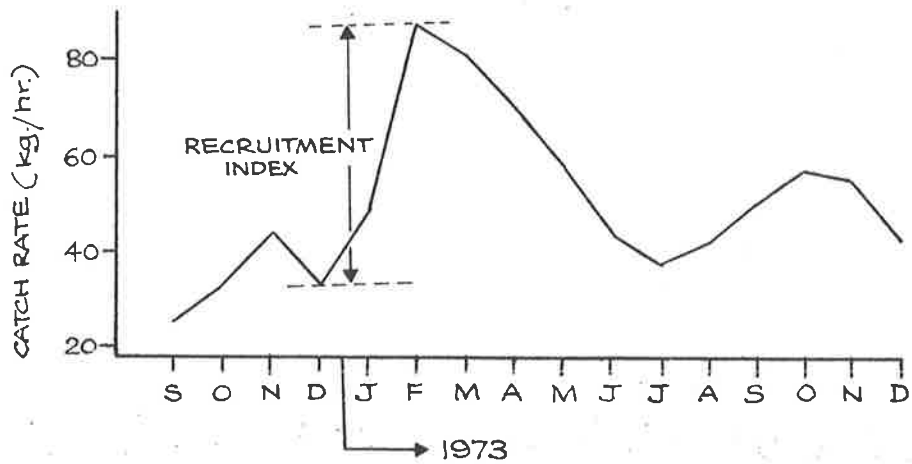



Figure 5-2. Catch rate (kg/hr) of *Penaeus latisulcatus* from Spencer Gulf 1973, showing the method of calculating an index of recruitment to this fishery.

For the Spencer Gulf fishery the values of the recruitment indices were as follows:

| Beginning of year | Increase in C/E (nos/min) |
|---|---|
| 1969 | 37.1 |
| 1970 | 61.5 |
| 1971 | 77.8 |
| 1972 | 55.3 |
| 1973 | 101.3 |
| 1974 | 160.7 |
| 1975 | 55.3 |
| 1976 | 65.6 |

From these results recruitment of *P. latisulcatus* to the adult stocks appears to fluctuate from year to year. Variable recruitment patterns have been observed for other penaeid prawns (Racek 1959, Lucas 1974) and such recruitment appears to be widespread in crustacean populations.

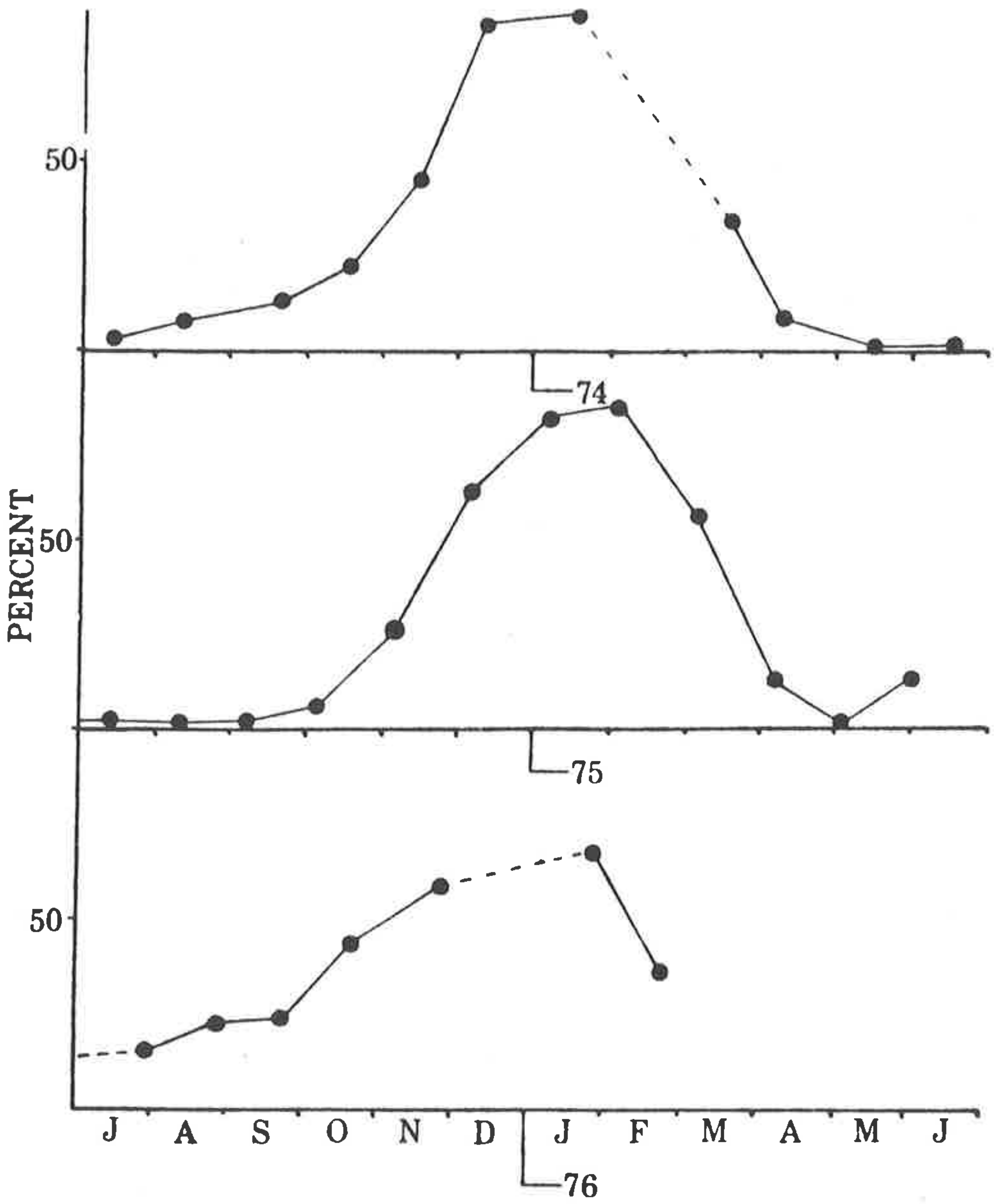



FIGURE 5-1 Combined monthly catch of males ≤ 28 mm C.L. and females ≤ 31 mm C.L. expressed as percentage of total monthly sample (n. Spencer Gulf)

## 6. GROWTH

In the study of exploited fish populations, the growth of many species has been traditionally described by the von Bertalannfy (1938) equation:

$$L_t = L_\infty \ (1 - e^{-k(t-t_0)}) \ \ldots\ldots\ldots\ldots\ldots(1)$$

where $L_t$ = length at time t

$L_\infty$ = average asymptotic length

K = growth coefficient

$t_0$ = theoretical age at which length is zero.

Tradition aside, there are several reasons why equation (1) has been used to describe growth in many studies - its exponential nature has been found to fit data from various species and its parameters can be readily incorporated into population assessment studies (Gulland 1969). The equation also has a physiological basis, where K is related to the metabolism of the species.

Several authors have used equation (1) to describe the growth of penaeid prawns (Linder and Anderson 1956, Iversen and Jones 1961, Klima 1974, Somers 1973, Lucas 1974); all of these authors have used tagging techniques to estimate the growth parameters. In the present study, both tagging and length-frequency analysis were used to calculate growth rates for adult *P. latisulcatus*.

### a. Growth by tag-recapture experiments

During monthly surveys on commercial trawlers in the north of Spencer Gulf, adult specimens of *P. latisulcatus* were measured, tagged and released. Over 200 individuals with number coded tags were subsequently caught in many separate fishing grounds in the Gulf. Many of those recaptured in the first four weeks after release had not grown and recaptures in this period were excluded from the analysis. It has been suggested (Penn 1975a) that the tagging process may interfere with the first and perhaps second moult after release. Other recaptures were misplaced by factory workers or fishermen or were returned damaged. Details of the remaining 68 recaptures are given in Table 6-1 and shown graphically in Figure 6-1.

The data in Table 6-1 were analysed by two methods: firstly by calculating growth increments per mean length during time free, and secondly by estimating $L_\infty$ and solving equation (1) for K for each individual.

Method 1

From the general growth equation (1), it can be seen that the growth curve has a slope which decreases towards zero with increasing age of the organism, i.e. the rate of growth $\frac{dl}{dt}$ decreases with increasing age. The rate of growth at any single length is not known but, in the case of tagging data, changes in length over various time intervals are known. If the times between release ($t_1$) and recapture ($t_2$) are close together a close approximation to the instantaneous rate of growth is given by $\frac{L_2 - L_1}{t_2 - t_1}$, where $L_1$ and $L_2$ are the lengths at time $t_1$ and $t_2$ respectively (Gulland 1969).

From Table 6-1, the growth increments $\frac{L_2 - L_1}{t_2 - t_1}$ were plotted against the mean length between release and recapture $\frac{L_2 - L_1}{2}$ (Figure 6-2). From this graph the rate of growth can be seen to decrease with increase in length; the slope of the line of best fit through these data provides an estimate of -K and the intercept on the x-axis, an estimate of $L_\infty$ (i.e. the growth parameters in equation (1)).

Gulland and Holt (1957) have suggested a method in which successive approximations of the value of K can be obtained if some of the time intervals between release and recapture are long. In the present study the time intervals were sufficiently short to

TABLE 6-1 Tag-recapture data for adult Penaeus latisulcatus in Spencer Gulf (releases from 1973 to 1975)

| FEMALES | | | | | MALES | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Carapace length (mm) at release | at recapture | Time Free (weeks) | Growth (mm/wk) | Mean Length (mm) | Carapace length (mm) at release | at recapture | Time Free (weeks) | Growth (mm/wk) | Mean Length (mm) |
| 27.4 | 42.8 | 34.3 | 0.45 | 35.1 | 24.0 | 26.0 | 5 | 0.40 | 25.0 |
| 28.2 | 34.0 | 17.0 | 0.34 | 31.1 | 24.7 | 29.8 | 8.7 | 0.59 | 27.3 |
| 29.5 | 30.9 | 5.4 | 0.26 | 30.2 | 26.0 | 33.5 | 18.3 | 0.41 | 29.8 |
| 29.7 | 35.2 | 14.7 | 0.37 | 32.5 | 27.1 | 33.3 | 14.6 | 0.42 | 30.2 |
| 30.6 | 35.7 | 16.9 | 0.30 | 33.2 | 28.0 | 29.2 | 5.0 | 0.24 | 28.6 |
| 31.2 | 32.6 | 5.4 | 0.26 | 31.9 | 28.2 | 34.0 | 17.7 | 0.33 | 31.1 |
| 31.8 | 34.1 | 4.7 | 0.49 | 33.0 | 29.7 | 30.8 | 13.9 | 0.08 | 30.3 |
| 31.8 | 32.2 | 6.3 | 0.06 | 32.0 | 29.8 | 33.2 | 8.9 | 0.38 | 31.5 |
| 32.1 | 34.7 | 9.3 | 0.28 | 33.4 | 30.3 | 30.5 | 6.3 | 0.03 | 30.4 |
| 32.2 | 36.0 | 12.1 | 0.31 | 34.1 | 31.2 | 32.9 | 8.9 | 0.19 | 32.1 |
| 33.2 | 37.4 | 8.7 | 0.48 | 35.3 | 31.2 | 31.6 | 5.7 | 0.07 | 31.4 |
| 33.7 | 34.5 | 5.7 | 0.14 | 34.1 | 31.7 | 33.1 | 5.4 | 0.26 | 32.4 |
| 34.0 | 35.9 | 9.9 | 0.19 | 35.0 | 31.7 | 34.7 | 8.7 | 0.34 | 33.2 |
| 34.1 | 41.4 | 35.6 | 0.21 | 37.8 | 32.2 | 33.0 | 4.7 | 0.17 | 32.6 |
| 34.1 | 35.7 | 7.7 | 0.21 | 34.9 | 32.4 | 33.0 | 5.7 | 0.11 | 32.7 |
| 35.0 | 38.2 | 21.0 | 0.15 | 36.6 | 32.6 | 35.3 | 5.4 | 0.50 | 34.0 |
| 35.1 | 37.5 | 9.3 | 0.26 | 36.3 | 32.9 | 34.3 | 5.4 | 0.26 | 33.6 |
| 35.5 | 36.5 | 9.9 | 0.10 | 36.0 | 33.0 | 35.5 | 16.7 | 0.15 | 34.3 |
| 35.9 | 36.2 | 5.4 | 0.06 | 36.1 | 33.8 | 35.0 | 5.4 | 0.22 | 34.4 |
| 36.5 | 38.6 | 16.3 | 0.13 | 37.6 | 34.0 | 35.0 | 5.3 | 0.19 | 34.5 |
| 37.6 | 41.5 | 33.9 | 0.12 | 39.6 | 34.1 | 34.2 | 8.7 | 0.01 | 34.2 |
| 37.8 | 39.0 | 21.9 | 0.05 | 38.4 | 34.2 | 34.3 | 5.4 | 0.02 | 34.3 |
| 37.7 | 39.3 | 13.9 | 0.12 | 38.5 | 34.3 | 37.3 | 18.4 | 0.16 | 35.8 |
| 38.4 | 38.5 | 5.4 | 0.02 | 38.5 | 34.6 | 38.5 | 33.1 | 0.12 | 36.6 |
| 38.7 | 42.0 | 18.6 | 0.18 | 40.4 | 34.6 | 35.0 | 8.7 | 0.05 | 34.8 |
| 38.9 | 39.3 | 6.3 | 0.06 | 39.1 | 34.8 | 37.0 | 22.3 | 0.10 | 35.9 |
| 39.9 | 44.5 | 24.0 | 0.19 | 42.2 | 35.0 | 36.5 | 5.4 | 0.28 | 35.8 |
| 40.0 | 40.3 | 5.4 | 0.06 | 40.2 | 35.1 | 35.6 | 5.4 | 0.09 | 35.4 |
| 40.7 | 46.5 | 44.6 | 0.13 | 43.6 | 35.5 | 36.7 | 8.9 | 0.13 | 36.1 |
| 42.1 | 44.5 | 36.0 | 0.07 | 43.3 | 35.7 | 39.5 | 48.3 | 0.08 | 37.6 |
| 43.5 | 43.6 | 5.4 | 0.02 | 43.5 | 36.3 | 36.7 | 5.4 | 0.07 | 36.5 |
| 45.0 | 45.8 | 4.1 | 0.20 | 45.4 | 37.0 | 37.9 | 5.7 | 0.16 | 37.5 |
| | | | | | 37.3 | 41.4 | 56.6 | 0.07 | 39.4 |
| | | | | | 37.4 | 39.6 | 19.4 | 0.11 | 38.5 |
| | | | | | 37.9 | 38.0 | 5.0 | 0.02 | 38.0 |
| | | | | | 38.2 | 38.5 | 8.7 | 0.03 | 38.4 |

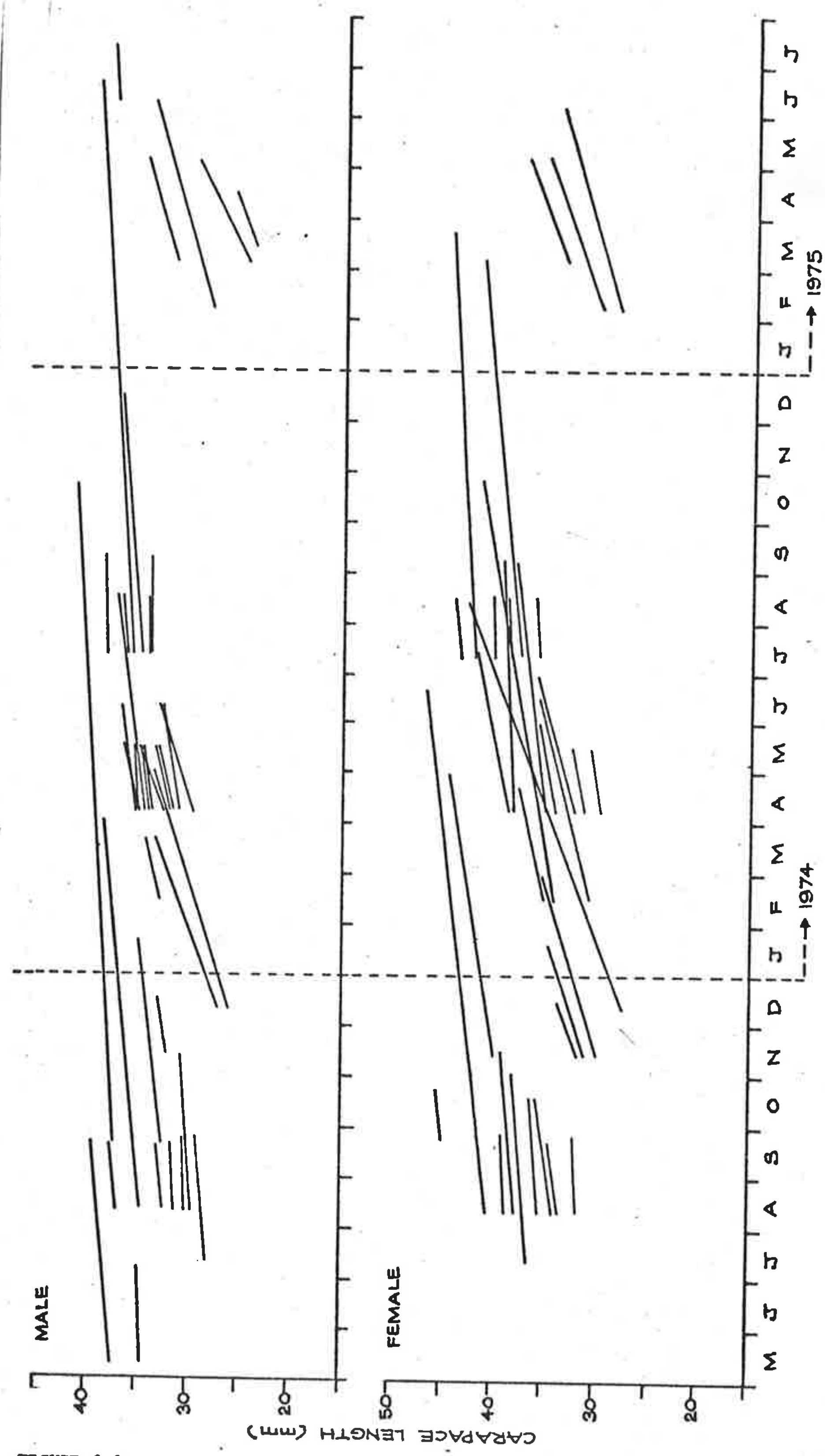



FIGURE 6-1:

Tag release/recapture data for adult Penaeus latisulcatus in Spencer Gulf. The beginning and end of each line represents the time and size at release and recapture respectively.

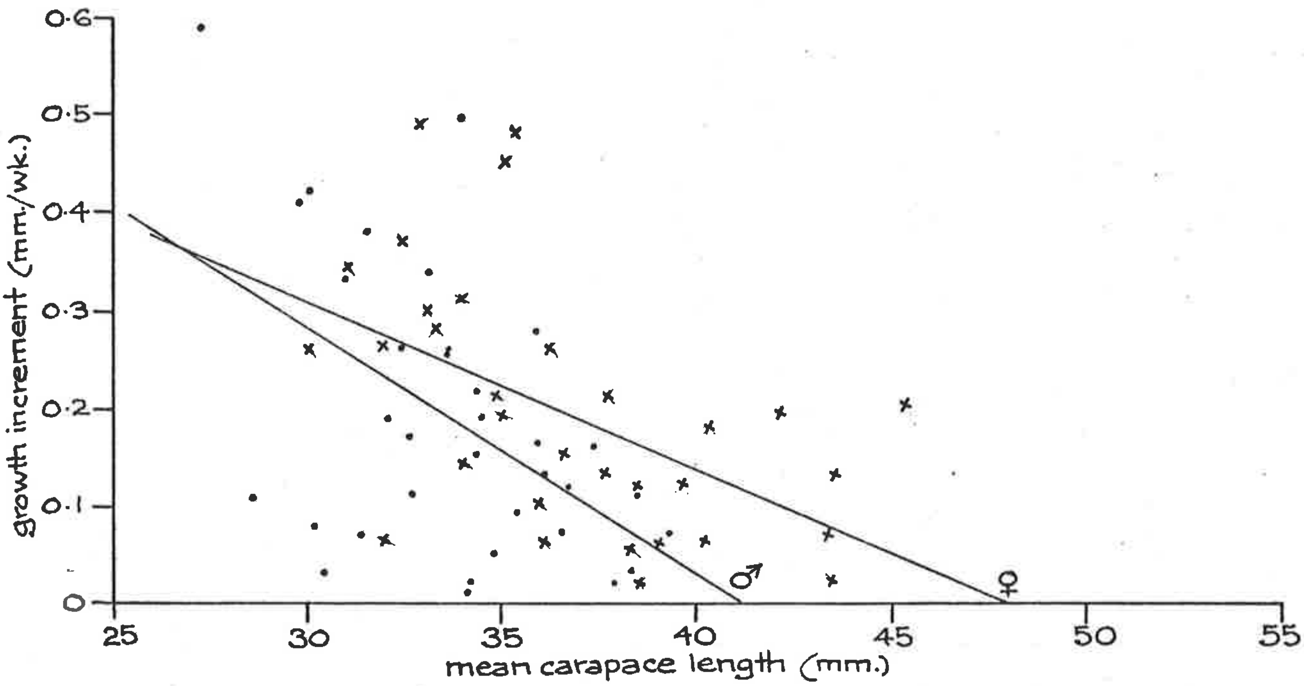



FIGURE 6-2: Growth increment (mm/wk) of adult <u>Penaeus</u> <u>latisulcatus</u> against mean length during time free. Data from tag recapture experiments, Spencer Gulf.

accept the first value of the slope (-K) and x-axis intercept ($L_\infty$) in the regression of growth increment against mean length.

Estimates of the growth parameter were $L_\infty$ = 41.2 and 48.1 mm carapace length and K = 0.025 and 0.017 per week for males and females respectively.

Method 2

Equation (1) describes the length at any age t. If the interval between the time of release ($t_1$) and recapture ($t_2$) is represented by i then at recapture the length is:

$$L_{t+i} = L_\infty (1 - e^{-K(t + i - t_0)}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The growth increment during the period free (i) is therefore:

$$L_{t+i} - L_t = L_\infty (1 - e^{-K(t + i - t_0)}) - L_\infty (1 - e^{-K(t - t_0)})$$

$$= L_\infty e^{-K(t - t_0)} - L_\infty e^{-K(t + i - t_0)}$$

$$= L_\infty e^{-K(t - t_0)} (1 - e^{-Ki}) \quad \ldots\ldots\ldots\ldots \quad (3)$$

by changing terms equation (1) becomes

$$L_\infty e^{-K(t - t_0)} = L_\infty - L_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

substituting equation (4) in equation (3)

$$L_{t+i} - L_t = (L_\infty - L_t)(1 - e^{-Ki}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$e^{-Ki} = 1 - \frac{L_{t+i} - L}{L_\infty - L}$$

$$-K = \frac{\ln\left(1 - \frac{L_{t+i} - L}{L_\infty - L_t}\right)}{i} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Using equation (6) it is not necessary to know the value of $t_0$ as in equation (1) but a value of the theoretical maximum length $L_\infty$ is required to solve for K. The largest specimens taken in Spencer Gulf were 48.5 mm C.L. (male) and 62.8 mm C.L. (female). However, as these may represent sizes reached by unusually fast growing individuals, it seemed more reasonable to use the average of the maximum sizes found in the length-frequency data; these were 47.8 mm (male) and 60.2 mm (female).

These estimated values of $L_\infty$ were used in equation (6) to calculate a value of K for each recaptured prawn (Table 6-2). The mean values and standard deviations for K were:

males K = 0.013 ± 0.0085 per week ....... (7)

females K = 0.008 ± 0.0049 per week ....... (8)

b. Growth by length-frequency analysis

The use of length-frequency data has been discussed previously in relation to the growth of juvenile *P. latisulcatus* (Section I-4). Although recruitment to the fishery is extended over several months there is a period of maximum recruitment (January to March in Spencer Gulf). The mode resulting from this recruitment can be followed in the length-frequency data obtained on the fishing grounds. Two such fishing grounds where length-frequency data were regularly collected were at Douglas Bank in northern Spencer Gulf and in Investigator Strait. Length-frequency diagrams for both areas were presented in Section II-4.

Northern Spencer Gulf

Tables 6-3 and 6-4 show the modes of male and female *P. latisulcatus* respectively. The modes were taken from the smoothed length-frequency data for Douglas Bank from 1973-1975 inclusive. Dashes indicate months where no obvious modes were evident. Towards the latter part of each period (December to May) the numbers of larger animals were small; to compensate for this, modes from each 2 months' samples were averaged.

Using the technique similar to that described previously the growth increments $\frac{L_2 - L_1}{t_2 - t_1}$ were plotted against the mean length between surveys (Figure 6-3). The calculated line of best fit through these data had a slope of K = 0.025 mm (males) and 0.018 mm (females). Values of the incepts were $L_\infty$ = 47.3 mm (males) and 72.6 mm (females).

TABEL 6-2: Values of the growth parameter K for recaptured tagged *Penaeus latisulcatus*, Spencer Gulf

| MALES | | | FEMALES | | |
|---|---|---|---|---|---|
| Length increase (mm) $L_{t+i} - L_t$ | Time free (weeks) $i$ | -K | Length increase (mm) $L_{t+i} - L_t$ | Time free (weeks) $i$ | -K |
| 2.0 | 5.0 | 0.018 | 15.4 | 34.3 | 0.018 |
| 5.1 | 8.7 | 0.029 | 5.8 | 17.0 | 0.012 |
| 7.5 | 18.3 | 0.023 | 1.4 | 5.4 | 0.009 |
| 6.2 | 14.6 | 0.024 | 5.5 | 14.7 | 0.014 |
| 1.2 | 5.0 | 0.013 | 5.1 | 16.9 | 0.011 |
| 5.8 | 17.7 | 0.020 | 1.4 | 5.4 | 0.009 |
| 1.1 | 13.9 | 0.005 | 2.3 | 4.7 | 0.018 |
| 3.4 | 8.9 | 0.024 | 0.4 | 6.3 | 0.002 |
| 0.2 | 6.3 | 0.002 | 2.6 | 9.3 | 0.010 |
| 1.7 | 8.9 | 0.012 | 3.8 | 12.1 | 0.012 |
| 0.4 | 5.7 | 0.004 | 4.2 | 8.7 | 0.019 |
| 1.4 | 5.4 | 0.017 | 0.8 | 5.7 | 0.005 |
| 3.0 | 8.7 | 0.024 | 1.9 | 9.9 | 0.008 |
| 0.8 | 4.7 | 0.011 | 7.3 | 35.6 | 0.009 |
| 0.6 | 5.7 | 0.007 | 1.6 | 7.7 | 0.008 |
| 2.7 | 5.4 | 0.036 | 3.2 | 21.0 | 0.006 |
| 1.4 | 5.4 | 0.018 | 2.4 | 9.3 | 0.011 |
| 2.5 | 16.7 | 0.011 | 1.0 | 9.9 | 0.004 |
| 1.2 | 5.4 | 0.017 | 0.3 | 5.4 | 0.002 |
| 1.0 | 5.3 | 0.014 | 2.1 | 16.3 | 0.006 |
| 0.1 | 8.7 | 0.001 | 3.9 | 33.9 | 0.006 |
| 0.1 | 5.4 | 0.001 | 1.2 | 21.9 | 0.003 |
| 3.0 | 18.4 | 0.014 | 1.6 | 13.9 | 0.005 |
| 3.9 | 33.1 | 0.011 | 0.1 | 5.4 | 0.001 |
| 0.4 | 8.7 | 0.004 | 3.3 | 18.6 | 0.009 |
| 2.2 | 22.3 | 0.008 | 0.4 | 6.3 | 0.003 |
| 1.5 | 5.4 | 0.023 | 4.6 | 24.0 | 0.011 |
| 0.5 | 5.4 | 0.007 | 0.3 | 5.4 | 0.003 |
| 1.2 | 8.9 | 0.016 | 5.8 | 44.6 | 0.008 |
| 3.8 | 48.3 | 0.008 | 2.4 | 36.0 | 0.004 |
| 0.4 | 5.4 | 0.007 | 0.1 | 5.4 | 0.001 |
| 0.9 | 5.7 | 0.015 | 0.8 | 4.1 | 0.013 |
| 4.1 | 56.6 | 0.009 | | | |
| 2.2 | 19.4 | 0.012 | | | |
| 0.1 | 5.0 | 0.002 | | | |
| 0.3 | 8.7 | 0.004 | | | |

CH ✓

TABLE 6-3 : Growth data for adult male <u>Penaeus latisuleatus</u> by modal progression from Douglas Bank, northern Spencer Gulf. Modes are from years 1973 to 1975 inclusive.

| | Recruitment of 1973 | Recruitment of 1974 | Recruitment of 1975 | Mean modal C.L. (mm) | Mean C.L. between surveys (mm) | Growth increment weekly (mm/wk) |
|---|---|---|---|---|---|---|
| January | 26 | 25 | 25.5 | 25.5 | | |
| | | | | | 26.3 | 0.38 |
| February | 28 | N.S. | 26 | 27.0 | | |
| | | | | | 28.4 | 0.63 |
| March | 30 | 31 | 28 | 29.7 | | |
| | | | | | 30.7 | 0.50 |
| April | 30 | 33 | 32 | 31.7 | | |
| | | | | | 33.3 | 0.78 |
| May | 36 | 35 | 33.5 | 34.8 | | |
| | | | | | 35.3 | 0.23 |
| June | 37 | 35 | 35 | 35.7 | | |
| | | | | | 36.0 | 0.15 |
| July | 36 | 36.5 | -- | 36.3 | | |
| | | | | | 36.7 | 0.18 |
| August | 37 | 37 | -- | 37.0 | | |
| | | | | | 37.0 | 0.00 |
| September | 37 | 37 | -- | 37.0 | | |
| | | | | | 36.5 | -- |
| October | 36 | 37 | 35 | 36.0 | | |
| | | | | | 36.4 | 0.18 |
| November | 37 | 37 | 36 | 36.7 | | |
| | | | | | 37.1 | 0.13 |
| Dec/Jan | 37 | 38 | -- | 37.5 | | |
| | | | | | 38.0 | 0.13 |
| Feb/Mar | 39 | 39 | 37.5 | 38.5 | | |
| | | | | | 40.8 | 0.56 |
| April/May | 43 | 43 | -- | 43.0 | | |

TABLE 6-4: Growth data for adult female *Penaeus latisuleatus* by modal progression from Douglas Bank northern Spencer Gulf. Modes are from years 1973 to 1975 inclusive.

| | Recruitment of 1973 | Recruitment of 1974 | Recruitment of 1975 | Mean modal C.L. (mm) | Mean C.L. between surveys (mm) | Growth increment (mm/wk) |
|---|---|---|---|---|---|---|
| January | 26 | 26 | 27 | 26.3 | 27.8 | 0.75 |
| February | 29 | -- | 29.5 | 29.3 | 29.6 | 0.13 |
| March | 27.5 | 31 | 31 | 29.8 | | |
| April | 29.5 | 36 | 35 | 33.5 | 31.7 | 0.93 |
| May | 41 | -- | 38 | 39.5 | 36.5 | 1.50 |
| June | 46 | -- | 41 | 43.5 | 41.5 | 1.00 |
| July | 43 | 43.5 | -- | 43.3 | 43.4 | -- |
| August | 46 | 44 | -- | 45.0 | 44.2 | 0.43 |
| September | 45 | 46 | 41 | 44.0 | 44.5 | -- |
| October | 47 | 45 | 42 | 44.7 | 44.4 | 0.18 |
| November | 47.5 | 45 | 41.5 | 44.7 | 44.7 | 0.00 |
| Dec/Jan | 52 | 47.8 | 48 | 49.3 | 47.0 | 0.77 |
| Feb/Mar | -- | 47.5 | 52 | 49.8 | 49.6 | 0.06 |
| April/May | -- | 53 | 55 | 54.0 | 51.9 | 0.53 |

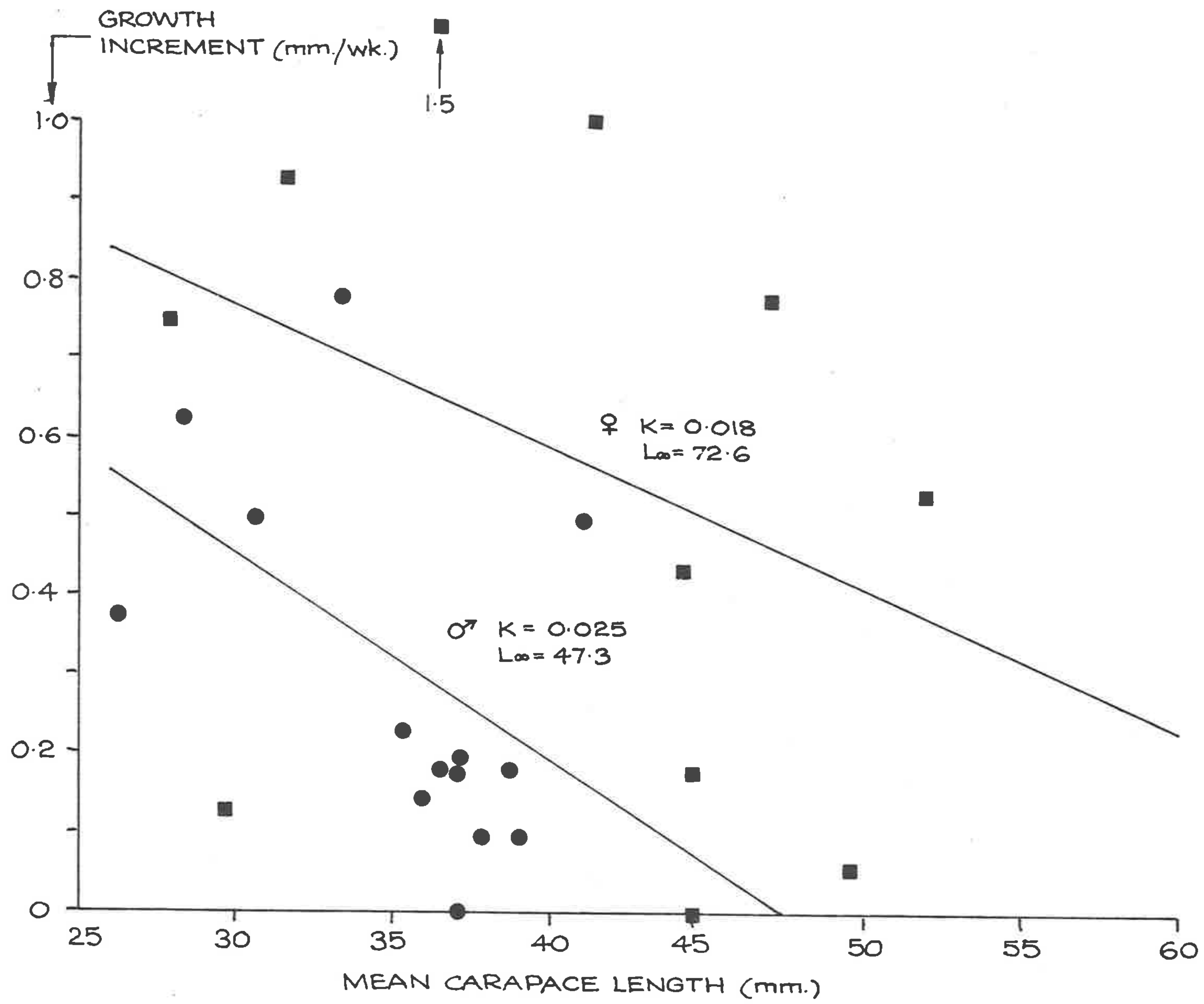



FIGURE 6-3: Growth increment (mm/wk) of adult *Penaeus latisulcatus* against mean length between surveys at Douglas Bank, Northern Spencer Gulf. Data from tables 6-3 and 6-4.

Investigator Strait

Major surveys in Investigator Strait were carried out at 3 and later 2 monthly intervals. Modes from the length-frequency data with estimated growth increments per week are shown in Table 6-5. These data were analysed in two ways. Firstly, by using the progression of modes as in the data for Douglas Bank (i.e. by "working down" the columns in Table 6-5). Secondly, by using the difference between the modal lengths of the three separate age classes in the length-frequency data of the April and June, 1977 surveys (i.e. by "working across" the rows at the bottom of Table 6-5).

Method 1

The modal values were treated in the same manner as the data from Douglas Bank. The regression of growth increments against mean length (Figure 6-4) had a slope of K = 0.014 per wk. (males) and 0.014 per wk. (females). Values of $L_\infty$ were 48.0 mm (males) and 65.5 mm (females).

Method 2

In the April and June 1977 length-frequency data for Investigator Strait, three separate modes were evident. The difference between the modes were considered to represent annual growth increments. From rearranging equation (5) and substituting a time interval of i = 1 year, the following expression was obtained:

$$L_{t+i} - L_t = L_\infty (1 - e^{-K}) - L_t(1 - e^{-K}) \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

which is of the linear form Y = A + BX where A is a constant and B represents the slope. From this the familiar plot (Gulland 1969) of growth increment $L_{t+i} - L_t$ against initial length $L_t$ give a line of slope $-(1 - e^{-K})$. From the data of the April and June surveys 4 points were obtained to plot the regression line in Figure 6-5. Values of K were 0.010 per week (males) and 0.008 per week (females) with intercepts of $L_\infty$ = 45.0 mm (males) and 65.3 mm (females).

TABLE 6-5: Growth data for *Penaeus latisulcatus* by modal progression - length frequency data from Investigator Strait, August 1976 to June 1977. Size classes refer to those indicated in the length frequency data for June 1977 (fig. 4-2).

| | SIZE CLASS 3 | | | SIZE CLASS 2 | | | SIZE CLASS 1 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Modal length (mm) | Growth incr. per week | Mean length (mm) | Modal length (mm) | Growth incr. per week | Mean length (mm) | Modal length (mm) | Growth incr. per week | Mean length (mm) |
| **MALE** | | | | | | | | | |
| August 12 | 39.0 | | | 28.0 | | | | | |
| | | 0.04 | 39.25 | | 0.25 | 29.75 | | | |
| November 24 | 39.5 | | | 31.5 | | | | | |
| | | 0.05 | 39.75 | | 0.09 | 32.00 | | | |
| February 14 | 40.0 | | | 32.5 | | | | | |
| | | 0.11 | 40.50 | | 0.50 | 34.75 | | | |
| 1977 April 18 | 41.0 | | | 37.0 | | | 28.0 | | |
| | | 0.13 | 41.50 | | 0.13 | 37.50 | | 0.25 | 29.0 |
| June 20 | 42.0 | | | 38.0 | | | 30.0 | | |
| **FEMALE** | | | | | | | | | |
| August 12 | 48.0 | | | 32.0 | | | | | |
| | | 0.04 | 48.25 | | 0.14 | 33.00 | | | |
| November 24 | 48.5 | | | 34.0 | | | | | |
| | | 0.05 | 48.75 | | 0.45 | 36.50 | | | |
| February 14 | 49.0 | | | 39.0 | | | | | |
| | | 0.33 | 50.50 | | 0.56 | 41.50 | | | |
| 1977 April 18 | 52.0 | | | 44.0 | | | 29.0 | | |
| | | 0.25 | 53.00 | | 0.19 | 44.75 | | 0.63 | 31.5 |
| June 20 | 54.0 | | | 45.5 | | | 34.0 | | |

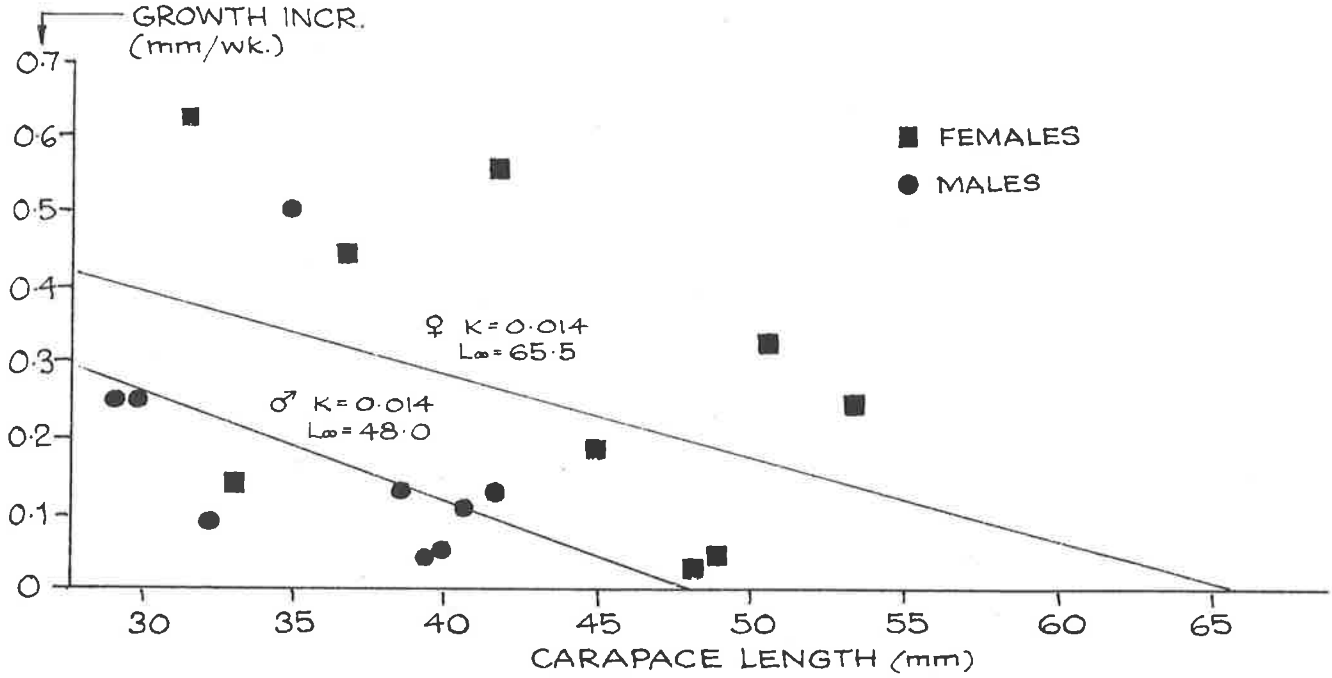



FIGURE 6-4 Growth increment (mm/wk) of adult Penaeus latisulcatus against mean length between surveys. Data from Investigator Strait (Table 6-5)

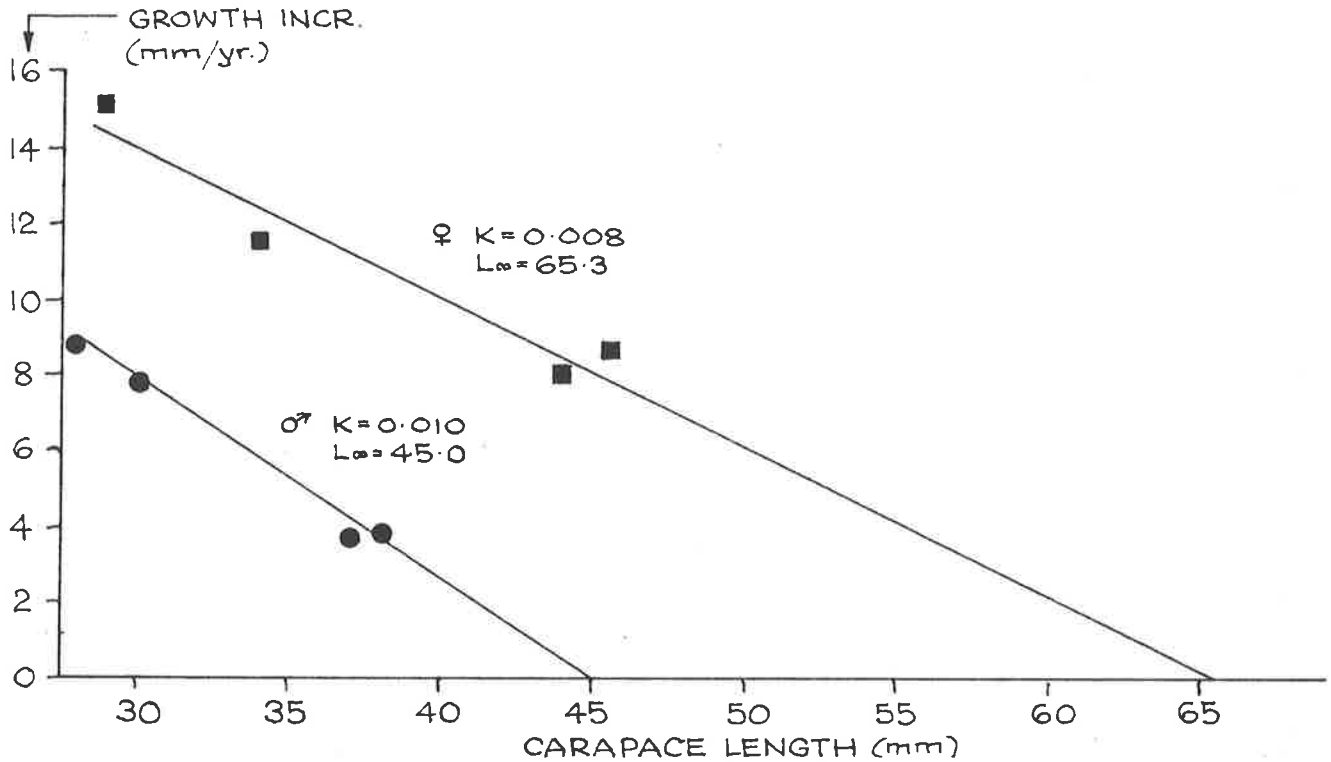



FIGURE 6-5: Annual growth increment of adult Penaeus latisulcatus against initial length. Data from 3 separate size classes, Investigator Strait surveys of April and June 1977. (Table 6-5)

In summary, the growth parameters calculated by various methods at each station are given in the table below:

TABLE 6-6

Summary of growth parameters obtained for adult *P. latisulcatus*

| METHOD | LOCATION | K | | $L_\infty$ | |
|---|---|---|---|---|---|
| | | MALE | FEMALE | MALE | FEMALE |
| 1. tagging (calculated $L_\infty$) | Spencer Gulf | 0.025 | 0.017 | 41.2 | 48.1 |
| 2. tagging (estimated $L_\infty$) | Spencer Gulf | 0.013 | 0.008 | 47.8 | 60.2 |
| 3. modal progression | Spencer Gulf | 0.025 | 0.018 | 47.3 | 72.6 |
| 4. modal progression | Invest. Strait | 0.014 | 0.014 | 48.0 | 65.5 |
| 5. age class analysis | Invest. Strait | 0.010 | 0.008 | 45.0 | 65.3 |

The difference in the parameters obtained may be attributed to attempting to fit a theoretical growth curve of the von Bertalanffy type to the data obtained. Both the length-frequency and tagging data indicate that there is a marked slowing down of growth during the winter months. The von Bertalanffy curve, however, is one in which the slope decreases with increasing age and approaches an upper asymptote at $L_\infty$. In the actual data there is likely to be a series of asymptotes - one for each winter. Figure 6-6 shows modal points at Douglas Bank and the tagging data has been shown in Figure 6-1; both diagrams indicate slow winter growth.

Because of the relatively short life of *P. latisulcatus*, especially in more heavily exploited areas, it was not possible to eliminate the effect of reduced winter growth. In long-lived species this can be done by considering several year-classes at one time or the progress of particular age-classes over several years.

The only data approaching "long-term" status in the present study were provided by method 5 - i.e. the age class analysis in

Investigator Strait. This fishing ground has been relatively unexploited in the past and three separate age classes were evident in the stock. However, although temperature effects were eliminated by this method its deficiencies are (1) growth increments obtained do not correspond to any single group of animals (Gulland 1969) and (2) the assumption that the modes in the length-frequency represent separate year classes remains unproven.

The tagging data from Spencer Gulf (Method 1) have the advantage of providing growth information on individual animals and the data was obtained over a reasonably long time period but the calculated values of $L_\infty$ appeared low; it is suggested that these values represent the levelling off in growth during the winter rather than actual maximum lengths.

To construct a general growth curve, values obtained in Method 1 (K = 0.021 per week and $L_\infty$ = 45 mm) were substituted in equation (1). To solve the equation, the value of $t_o$ was chosen so that at t = o, Lt was the mean length of the prawns at recruitment, i.e. Lt = 26.5 mm The value obtained for $t_o$ was -36.7 weeks. The von Bertallanfy growth curve is shown in Figure 6-7 with the curve drawn (by hand) through the actual modal values from northern Spencer Gulf. Both curves were used in Section II-11, to estimate yield and the 'actual data' curve was used (Table 6-8) in several instances to convert catch weight per hour to numbers per hour.

The values for the von Bertallanfy growth parameters obtained in the present study are compared to those of other species in Table 6-7. It should be stressed, however, that the estimated values of $L_\infty$ and K represent a method of incorporating growth data into yield equations rather than an accurate description of growth. The dangers of putting a too literal meaning on K and $L_\infty$ and extrapolating too far beyond the available data have been stressed by Knight (1968).

TABLE 6-7

Estimates of the von Bertallanfy growth parameter K

for various species of penaeid prawns

| SPECIES AND AREA | METHOD | K (PER WEEK) | REFERENCE |
|---|---|---|---|
| *P. duorarum* Gulf of Mexico | tagging | 0.07 | Kutkuhn (1966) |
| *P. setiferus* Gulf of Mexico | tagging | 0.09 | Klima (1974) |
| *P. plebejus* Moreton Bay, Qld. | tagging | 0.10 | Lucas (1974) |
| *P. latisulcatus* Spencer Gulf, S.A. | tagging | 0.02 | (present study) |

TABLE 6-8: Growth in carapace length (C.L.) and wet weight of adult Penaeus latisulcatus (sexes combined).

| MONTH | MEAN C.L. (mm) | WET WT.* (g) |
|---|---|---|
| Jan | 26.5 | 9.94 |
| Feb | 28.5 | 12.25 |
| Mar | 31.8 | 16.78 |
| Apr | 33.5 | 19.48 |
| May | 36.5 | 24.91 |
| June | 39.1 | 30.35 |
| July | 40.4 | 33.34 |
| Aug | 41.1 | 35.02 |
| Sept | 41.4 | 35.76 |
| Oct | 41.7 | 36.51 |
| Nov | 42.0 | 37.27 |
| Dec | 42.5 | 38.55 |
| Jan | 43.2 | 40.40 |
| Feb | 44.2 | 43.15 |
| Mar | 45.4 | 46.59 |
| Apr | 46.9 | 51.15 |
| May | 48.5 | 56.32 |

CHV

* Weight data were predicted from the geometric curve $W = aL^b$ where the variables W and L represent liveweight and carapace length respectively; the constant a = 0.00082 and the exponent b = 2.86925 (see appendix 1).

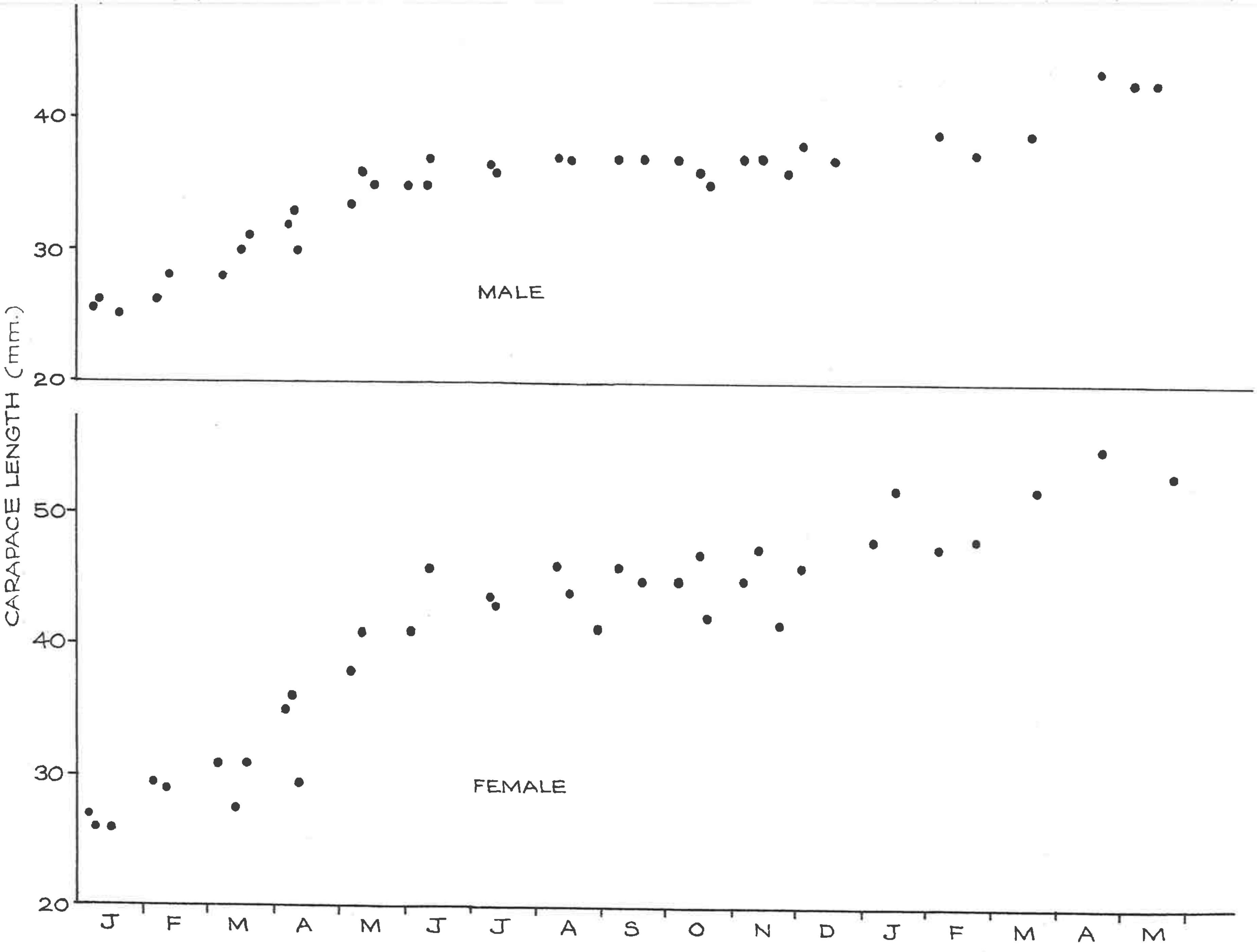



FIGURE 6-6: Modal values from adult Penaeus latisulcatus length data. Data taken at approximately monthly intervals over 1973, 1974 and 1975, Douglas Bank, Northern Spencer Gulf.

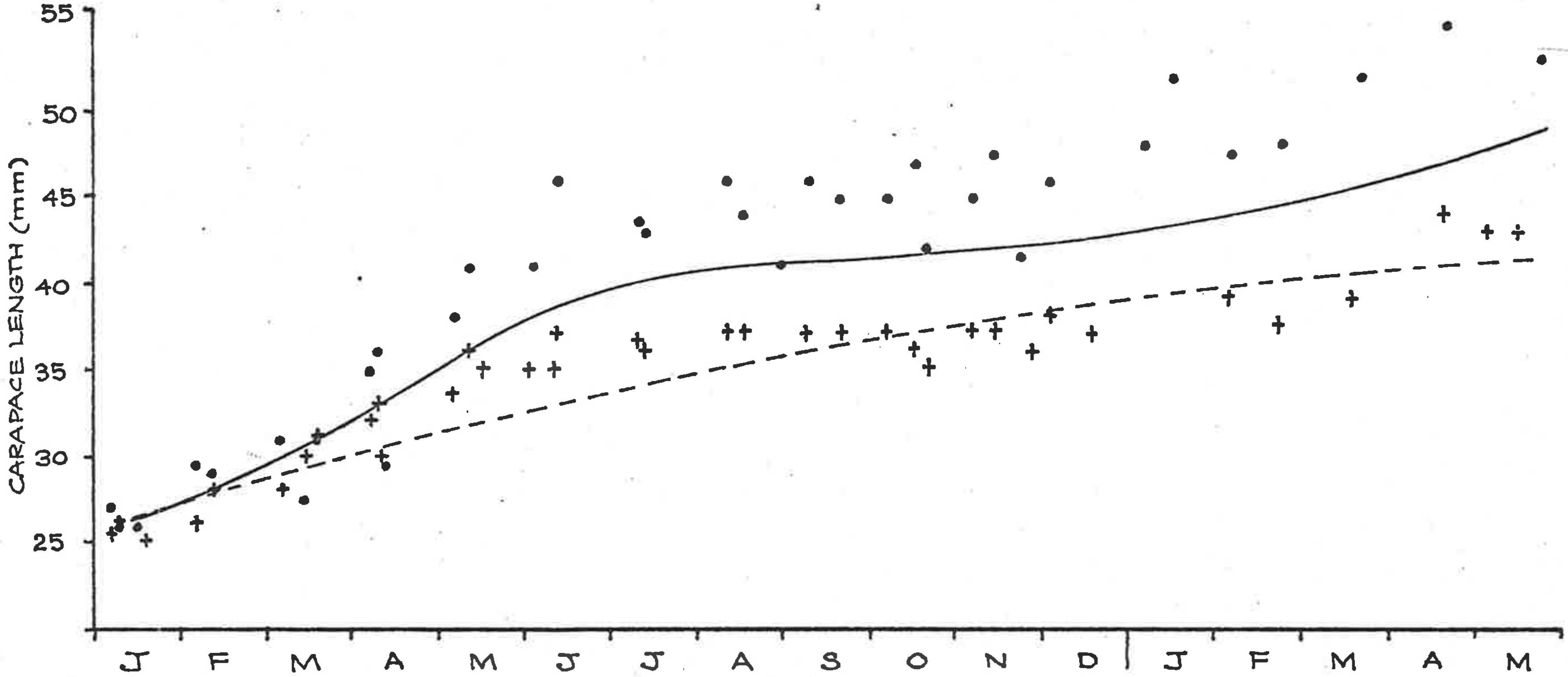



FIGURE 6-7: General growth curve for adult *Penaeus latisulcatus*. Line fitted by eye through monthly modal values in Northern Spencer Gulf over three years (1973, 1974 and 1975). The von Bertalanffy growth curve is shown as a broken line.

## 7. REPRODUCTION

### a. Reproductive biology

The sex of Western King prawns is distinguishable by the appearance of the genitalia. The male sex organ (petasma) is formed by the development of the first pair of pleonic endopodites. In mature males the endopodites join along the medial margin by the interlocking of hook-like structures (King 1948) to form a single organ. The petasma has been observed (Hudinaga 1942) to be instrumental in the transfer of spermatophores to the ventral surface of the female.

The reproductive system of female *P. latisulcatus* consists of paired ovaries and oviducts terminating at the thelycum composed of two distinctive lateral plates. In the sexually mature female, the ovaries extend almost the full length of the animal; in the cephalothoracic region the organ is full and many-lobed with a pair of lobes, one from each ovary, extending the length of the abdomen. In live or recently killed prawns the ovaries are visible through the surrounding tissue and exoskeleton.

### b. Development of the ovary

(1) Histology:

Ovaries taken from prawns in the monthly samples at Douglas Bank were sectioned and stained using haematoxylin and eosin dyes. Permanent slides were made before being assessed. Ovarian development was divided into the five arbitrary stages described by Tuma (1967) for *P. merguiensis*; these were stage 1 (quiescent), stage 2 (developing), stage 3 (early maturity), stage 4 (ripe) and stage 5 (spent).

The stages observed were catalogued and compared with accompanying macroscopic changes in size, form and colour of the ovary.

(2) Morphology:

It was observed that the ovaries of *P. latisulcatus* progressed through a series of size, form and colour changes during development. These macroscopic changes were divided into 5 arbitrary stages as shown diagramatically in Figure 7-1. These stages correspond to those based on the histology of the ovary in the manner shown in Table 7-1. It was not possible to distinguish spent individuals by macroscopic inspection.

TABLE 7-1

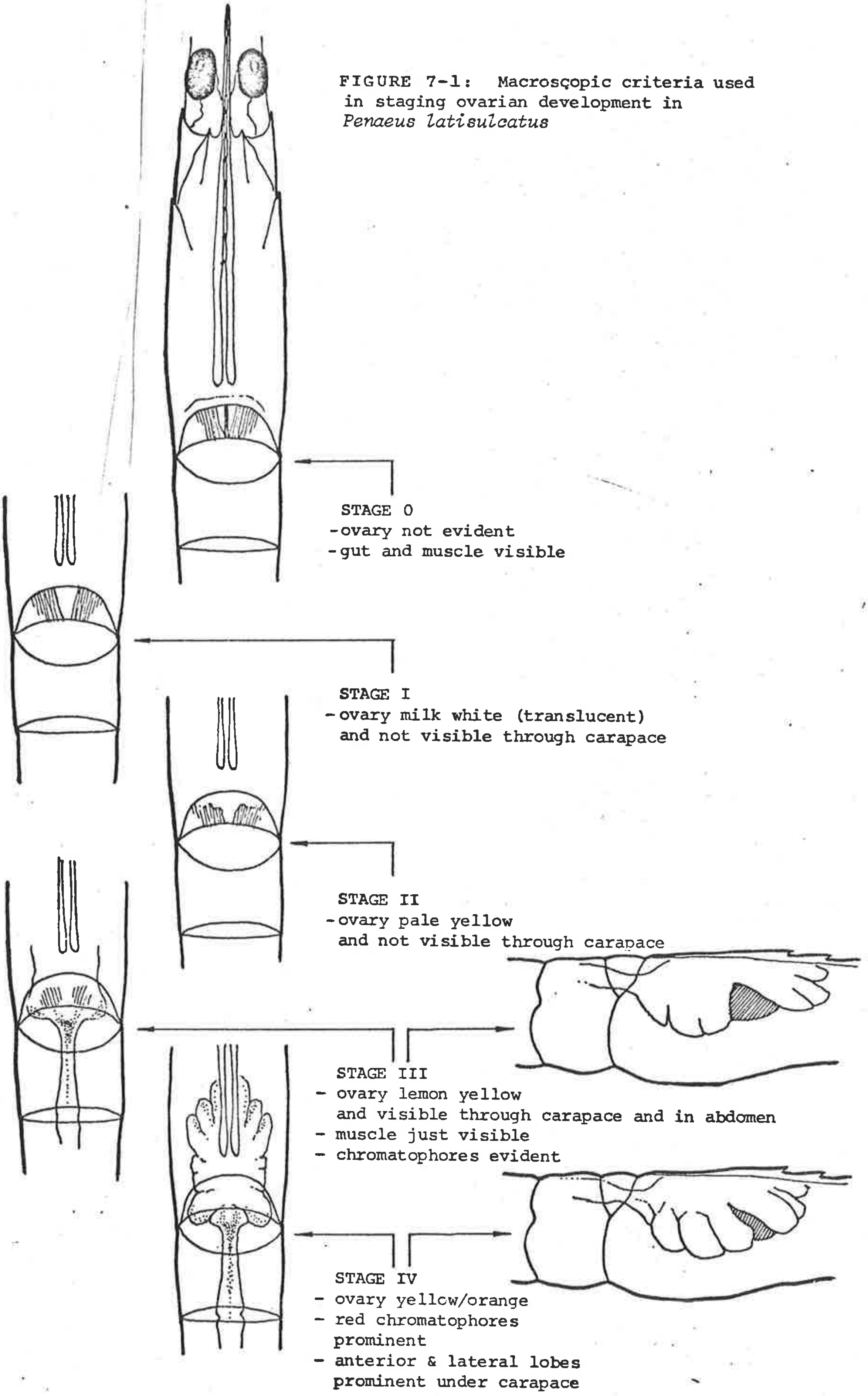
Comparison of the stages of ovarian development using microscopic criteria after Tuma, 1967, (arabic numerals) and macroscopic criteria (roman numerals)

| | Microscopic | Macroscopic |
|---|---|---|
| Undeveloped | Stage 1 | Stage 0 |
| Developing | Stage 2 | Stage I and II |
| Early maturity | Stage 3 | Stage III |
| Ripe | Stage 4 | Stage IV |
| Spent | Stage 5 | Not distinguishable |

The method of assessing the reproductive condition of female prawns using macroscopic criteria had the advantage of being easy to use in the field (at sea) and it was not necessary to sacrifice the animal in the process. It is also possible for workers without biological training to use the method.

The main disadvantage of the method is that it could only be used without difficulty on live or recently killed specimens. One of the earliest post-mortem changes in prawns is from transparent to opaque tissue; this opacity obscured the organs beneath and made

FIGURE 7-1: Macroscopic criteria used in staging ovarian development in *Penaeus latisulcatus*



macroscopic assessment difficult. This change occurs within about 3 hours at 28°C and about 5 hours at 12°C. After this period, however, gonad colour could still be viewed through the dorsal carapace/tail joint.

The method was used throughout most of the research at sea and to a lesser extent in processing factories. In the ensuing part of this paper, ovary stages referred to are those based on macroscopic criteria.

c. Size at sexual maturity

The main stage in the external sexual development of the male is the joining of the endopodite to form the male sex organ (petasma). After this stage the petasma continues to increase in length and it has been noted by Tuma (1967) that extra thickening of the lateral ridges of the organ occurs. Figure 7-2 shows that, in an examination of 957 males of less than 35 mm C.L. the first pair of pleonic endopodites are joined in 50% of individuals of 21 mm carapace length (90 mm total length). All males over 25 mm carapace length possessed joined endopodites.

The development of the ovary has been described in previous sections. Figure 7-2 shows that in 428 female prawns examined, developing ovaries (Stage 1 or greater) were found in prawns as small as 22 mm carapace length. At a length of approximately 27 mm carapace length (112 mm total length) 50% of female prawns had developing ovaries.

Although mature males (joined endopodites) could be found in the inshore nursery areas all females in such areas were immature.

d. Spawning cycle

A method has been described of macroscopically assessing the reproductive condition of female prawns. Working from commercial trawlers, the method was used at set monthly stations in northern Spencer Gulf and provided information on seasonal ovary development.

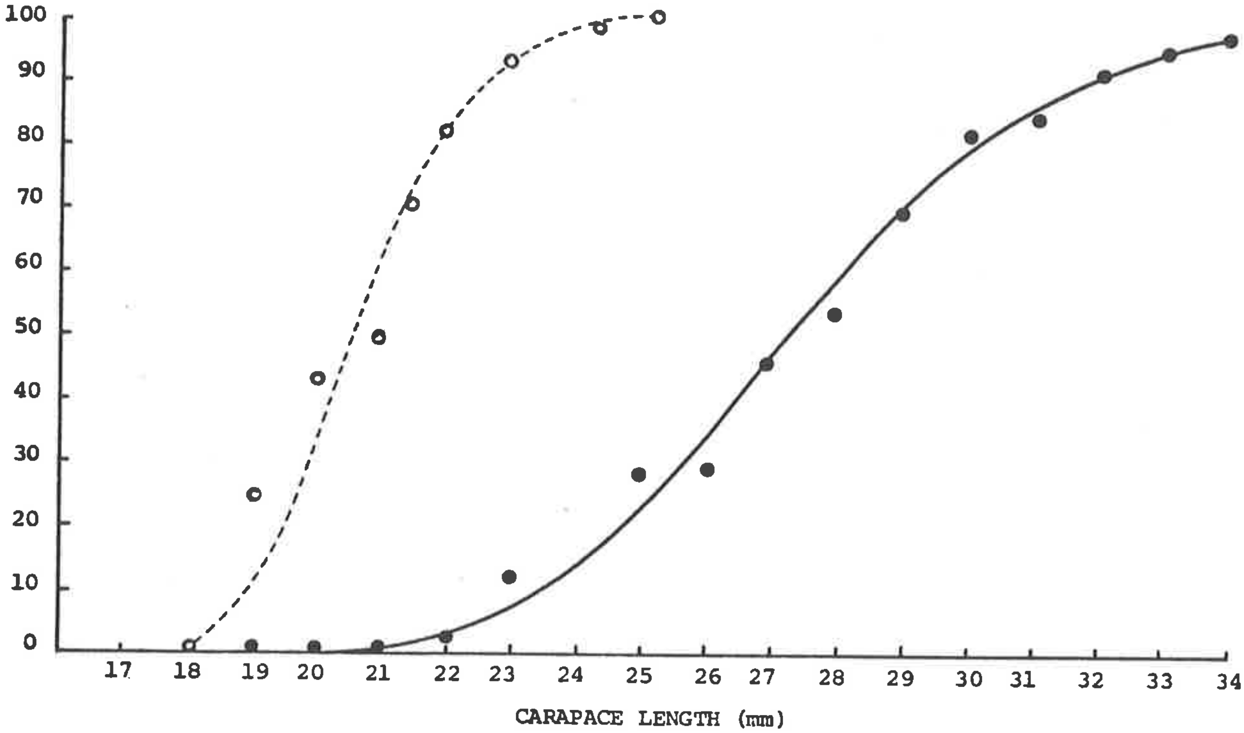



FIGURE 7·2: Broken line: percentage of males (in one mm size classes) with first pair of pleonic endopodites joined to form the petasma - sample of 957 males from nursery areas and offshore, Northern Spencer Gulf.
Solid line: percentage of females ( in one mm size classes) developing ovaries (stage 1 or greater) - sample 428 females from Northern Spencer Gulf, November to February.

Figure 7-3, based on observations over 2 years at Douglas Bank in northern Spencer Gulf, shows that females with developing ovaries were found in all but the coldest months of the year. A peak in ovary development occurred in November and the data suggested that there was a second peak in the early months of the following year. Table 7-2 shows the monthly length frequency distributions of females in stages III and IV ovary condition over the same period illustrated in Figure 7-3. These data indicated that older prawns contributed to the spawning stock in November. From December to March newly recruited prawns were added to form a second peak in ovary development (Figure 7-3). Catch sampling in lower Spencer Gulf, Investigator Strait and Gulf of St. Vincent indicates that this seasonal cycle is general over these areas.

e. Spawning areas

Sampling during the spawning season was carried out in Gulf and Strait waters mainly on an opportunistic basis. However, one major survey of these waters was made on October 1974 (Figure 7-4) and at present regular programmes are being maintained in Investigator Strait and Gulf of St. Vincent.

Females with well developed ovaries appeared to be widely distributed over the fishing grounds and there was no evidence to suggest the existence of particular or well defined spawning areas.

f. Sex ratios

In the 26 monthly samples taken at Douglas Bank, totalling 9 068 prawns there were 4 765 males and 4 303 females, a ratio of 53 per cent males to 47 per cent females. However, some monthly samples varied significantly from an expected 1:1 ratio. Figure 7-5 shows the manner in which sex ratios varied over the year. Although no distinct patterns predominate, the lower proportion of females

TABLE 7-2: Monthly length distributions (no. of individuals) of female prawns in Stage III and IV ovary condition. Data from Douglas Bank during spawning seasons of 1974/75 (top of table) and 1975/76 (bottom).

| Size class (mm. C.L.) | SEP | OCT | NOV | DEC | →1975 JAN | FEB | MAR |
|---|---|---|---|---|---|---|---|
| 25–27 | | 3 | | 8 | 7 | 5 | 1 |
| 28–30 | | 5 | 2 | 12 | 10 | 18 | 13 |
| 31–33 | | 4 | 8 | 7 | 8 | 11 | 18 |
| 34–36 | | 1 | 2 | 4 | 3 | 3 | 7 |
| 37–39 | | | | 2 | 1 | 3 | |
| 40–42 | | 1 | 8 | 4 | | | 1 |
| 43–45 | | 3 | 7 | | | 1 | |
| 46–48 | | 2 | 8 | 5 | 2 | | |
| 49–51 | | | 2 | | 1 | | |
| 52–54 | | | 1 | | | | |
| 55–58 | | | | | | | |
| | SEP | OCT | NOV | DEC | →1976 JAN | FEB | MAR |
| 25–27 | | 2 | | | | | |
| 28–30 | | 3 | | | 2 | 2 | |
| 31–33 | | 1 | | | 5 | 4 | |
| 34–36 | 1 | 2 | 1 | | 1 | 7 | |
| 37–39 | | 1 | 1 | | | 4 | 3 |
| 40–42 | 1 | | 2 | No sample | | | 2 |
| 43–45 | 2 | 2 | | | | | 1 |
| 46–48 | 1 | 2 | 2 | | | | |
| 49–51 | | 1 | 3 | | | | |
| 52–54 | | 5 | 8 | | | | 1 |
| 55–58 | | 1 | 1 | | 2 | | |

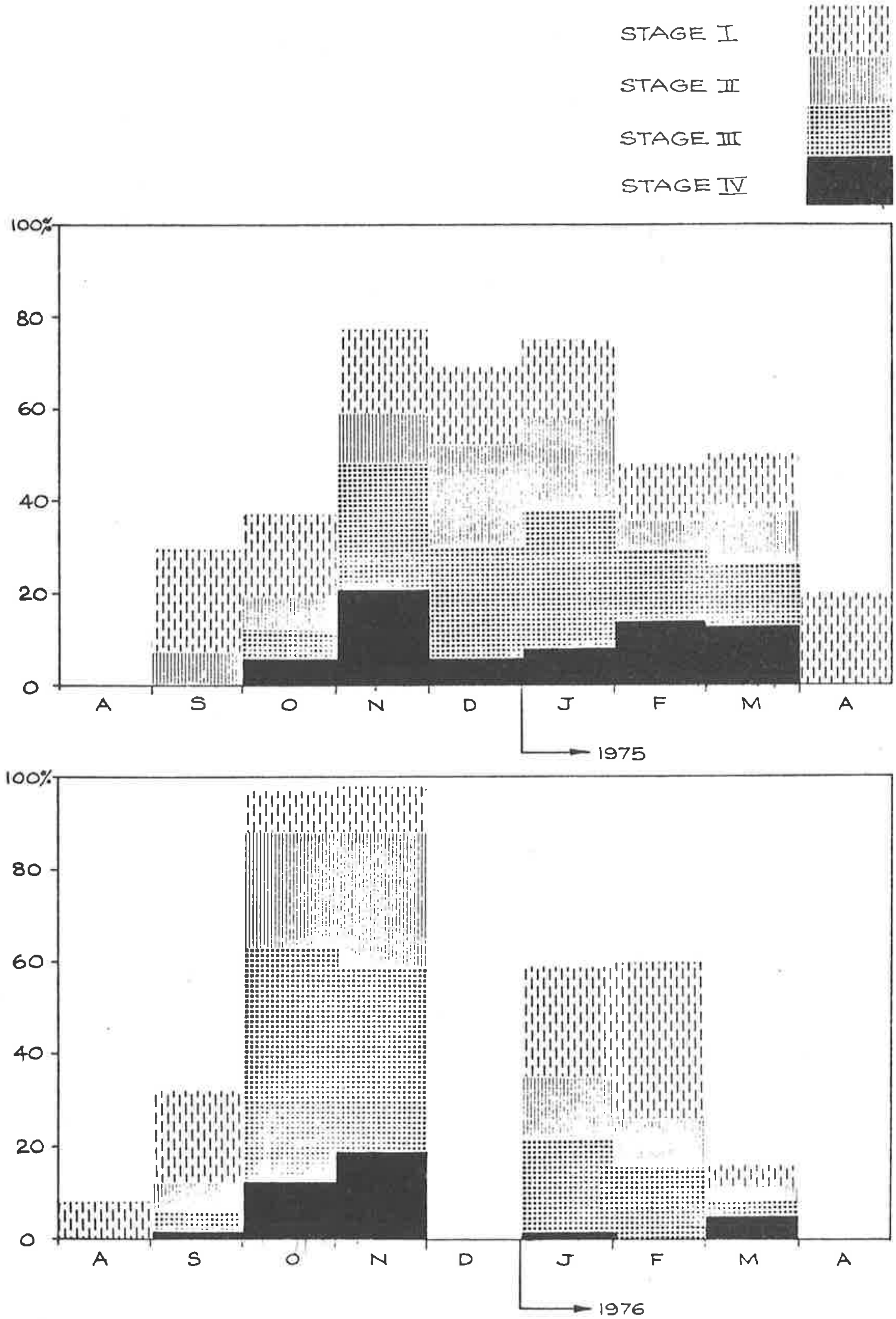



FIGURE 7-3 Histogram of ovary developmental stages 0-IV in monthly samples of Penaeus latisulcatus from Douglas Bank, Northern Spencer Gulf. (N = 46 to 143)

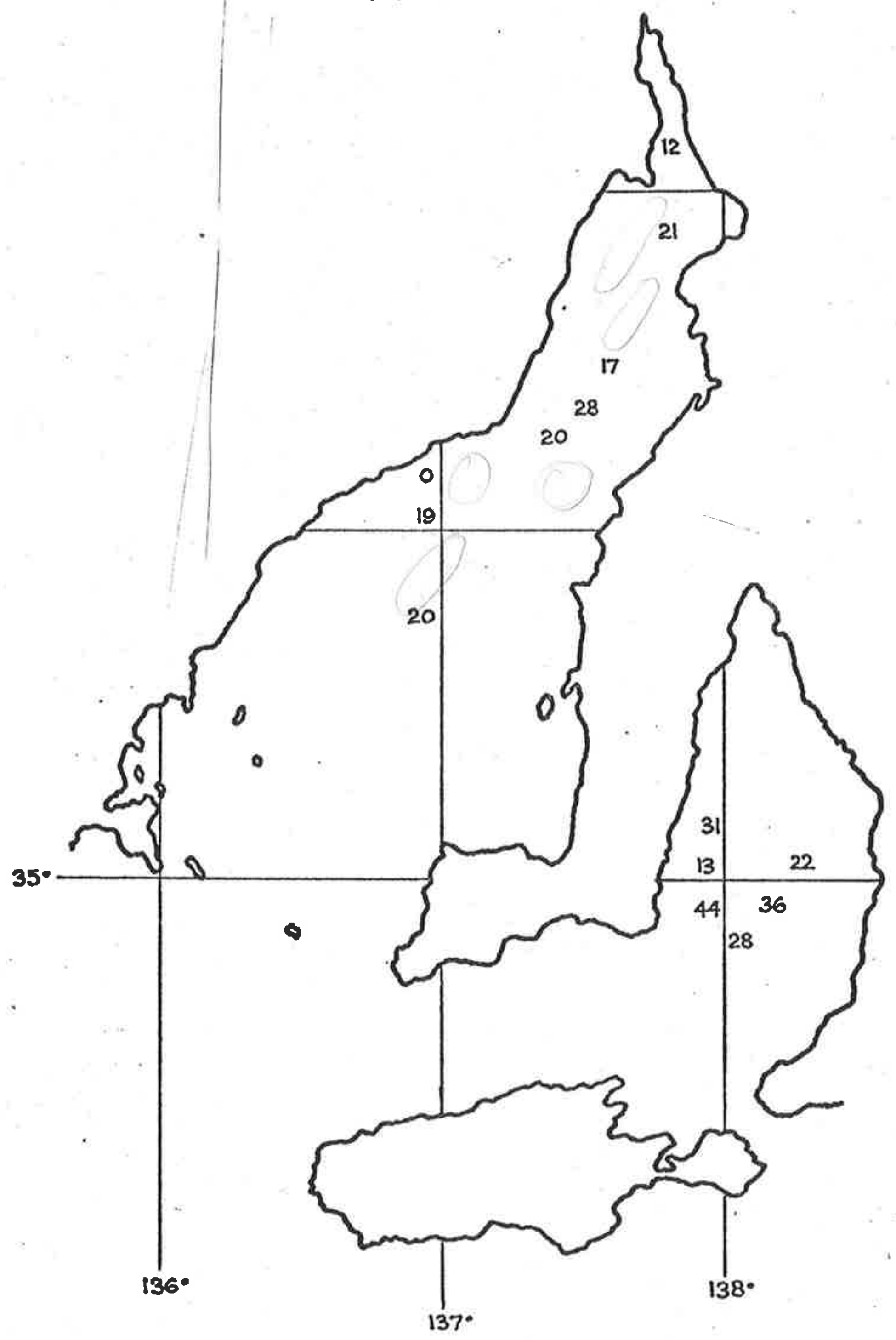



Fig. 7-4: Areas trawled during a survey of Spencer Gulf and the Gulf of St. Vincent in October 1974; the percentage of females with mature ovaries (stages III and IV) are shown for each area.

in the catch after the spawning season may indicate that, during this period, female mortality is high or that females are less vulnerable to the gear.

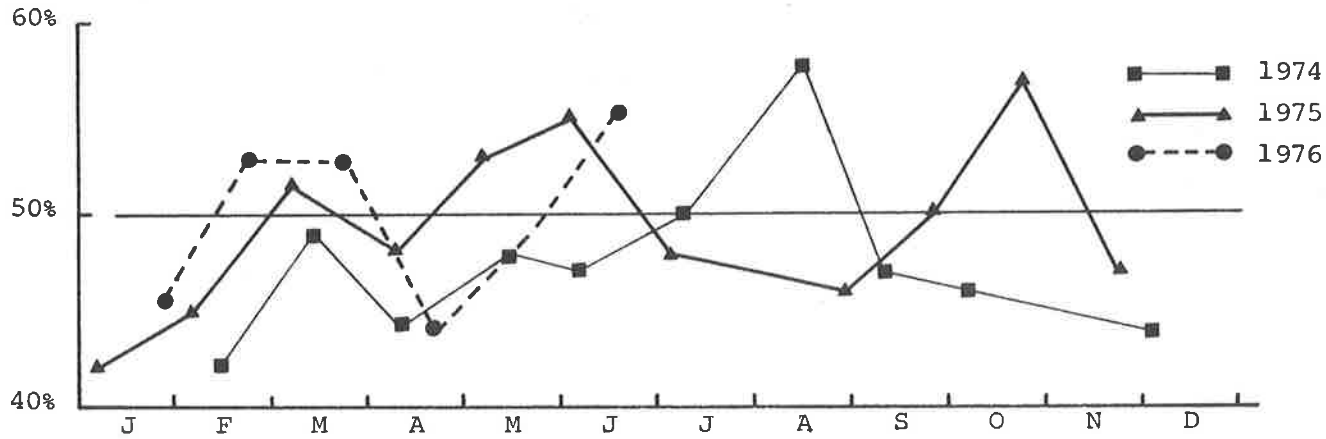



Figure 7-5: Number of female prawns expressed as a percentage of the total sample (n = 187 to 943), northern Spencer Gulf.

g. Spawner/recruit relationship

In many fisheries a positive relationship has been demonstrated between the number of spawning females in the population and the number of resulting recruits entering the fishery. In fisheries where this positive relationship exists there is value, from a conservational point of view, in preserving or protecting the breeding stock. However, this relationship has usually only been demonstrated in long lived, less fecund animals such as Cod and Hadock (Jones 1973) and much less often in highly fecund animals such as Ocean shrimp, *Pandalanus jordani* (Gotshall 1972).

Steeply positive-sloping, spawner-recruit relationships have not been demonstrated for the penaeid prawns, although Neal (1973) suggested that the reproductive capacity of *P. setiferus* may have been reduced by heavy fishing. In *P. latisulcatus* catch and effort data have been used to estimate the relative abundances of spawning females and resulting recruits in the Spencer Gulf fishery.

There are 2 main difficulties in using catch rates as an index of relative abundance of both spawners and recruits. Firstly, the periods of spawning and recruitment tend to overlap; secondly the spawning stock consists of both older stock and a substantial number of newly recruited females. These conditions are illustrated in Figure 7-6.

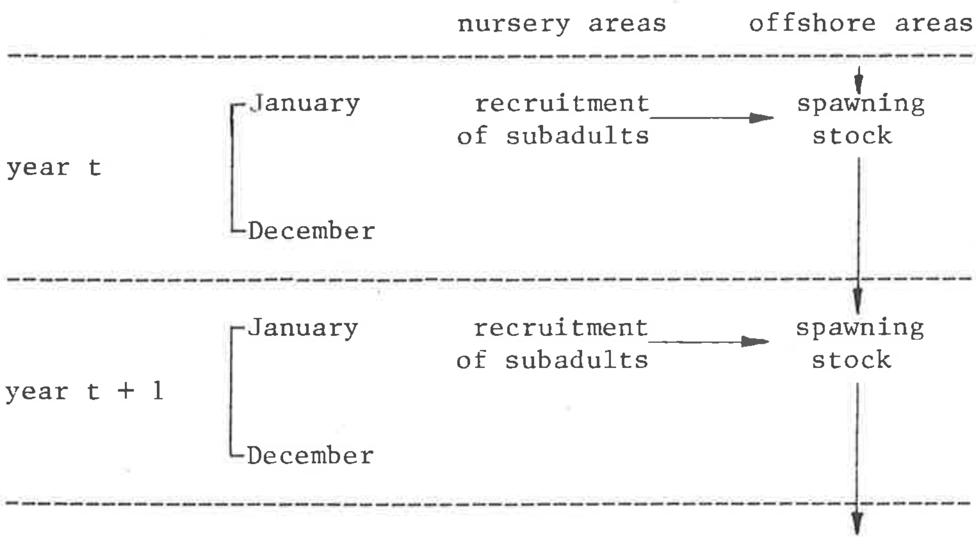



Figure 7-6: The spawning stock in year t + 1 consists of mature females from the previous year's recruitment (year t) and the present year's recruitment (year t + 1).

Indices of sizes of recruitment and spawning stocks were calculated for *P. latisulcatus* in Spencer Gulf in the following manner:

1. An index of a recruitment in year t + 2 was calculated as in Section 5; i.e. by calculating the increase in catch rate (no. of prawns caught per minute) in the period of maximum catch rate (recruitment peak) over the minimum catch rate immediately prior to the recruitment period (residual stock from year t + 1).
2. Spawning stock in year t + 1 was calculated as a sum of:

   (a) the residual* female stock from year t, calculated by the average number of females caught per minute in the period of minimum catch rate prior to recruitment.

(b) Half** the newly recruited females from year t + 1 (calculated as in 1 above).

* The sex ratio was assumed to be 50:50 - i.e. half of the number caught per minute were assumed to be female.

** Some newly recruited females were immature or recruited too late to contribute to the spawning stock of the current year. As an approximation only half of the newly recruited females were included in the calculations of spawning stock size.

Table 7-3 shows the calculated indices of both the size of the spawning stock and recruitment in the Spencer Gulf fishery. The spawning stock present at the beginning of one year was related to the resulting size of recruitment approximately one year later. Figure 7-7 shows this relationship superimposed on a hypothetical spawner-recruit curve for penaeid prawns, proposed by Neal (1973).

The data in the present study are inadequate in that information is available from too short a period. Ricker (1975) has suggested that at least 15 years of observations are required to demonstrate spawner-recruit relationships. However, the wide spread of points in Figure 7-7 indicates that at present levels of fishing effort, there is no evidence of a positive relationship between the number of spawners and the numbers of resulting recruits, i.e. fishing mortality is unlikely to be affecting the reproductive potential of the population. In *P. latisulcatus*, environmental factors are more likely to be the cause of fluctuations in annual recruitment.

TABLE 7-3 : Indices of size of spawning stock and recruitment in the Spencer Gulf fishery for Penaeus latisulcatus

| | Period of min catch rate | | Period of max catch rate | | RECRUITMENT - increase in nos/min | SPAWNING STOCK ($\frac{1}{2}$A+$\frac{1}{4}$C) |
|---|---|---|---|---|---|---|
| | kg/hr | nos/min* (A) | kg/hr | nos/min* (B) | (B-A=C) | |
| 1969 | 38.0 | 14.4 | 60.2 | 51.5 | 37.1 | 16.5 |
| 1970 | 36.4 | 15.4 | 90.0 | 76.9 | 61.5 | 23.1 |
| 1971 | 38.7 | 15.5 | 86.8 | 93.3 | 77.8 | 27.3 |
| 1972 | 47.6 | 19.2 | 69.3 | 74.5 | 55.3 | 23.4 |
| 1973 | 32.2 | 13.6 | 86.2 | 114.9 | 101.3 | 32.1 |
| 1974 | 41.5 | 17.5 | 165.7 | 178.2 | 160.7 | 48.9 |
| 1975 | 55.1 | 22.1 | 72.0 | 77.4 | 55.3 | 24.9 |
| 1976 | 29.5 | 12.5 | 72.6 | 78.1 | 65.6 | 22.7 |

*calculated from the general growth curve presented in figure 6-7

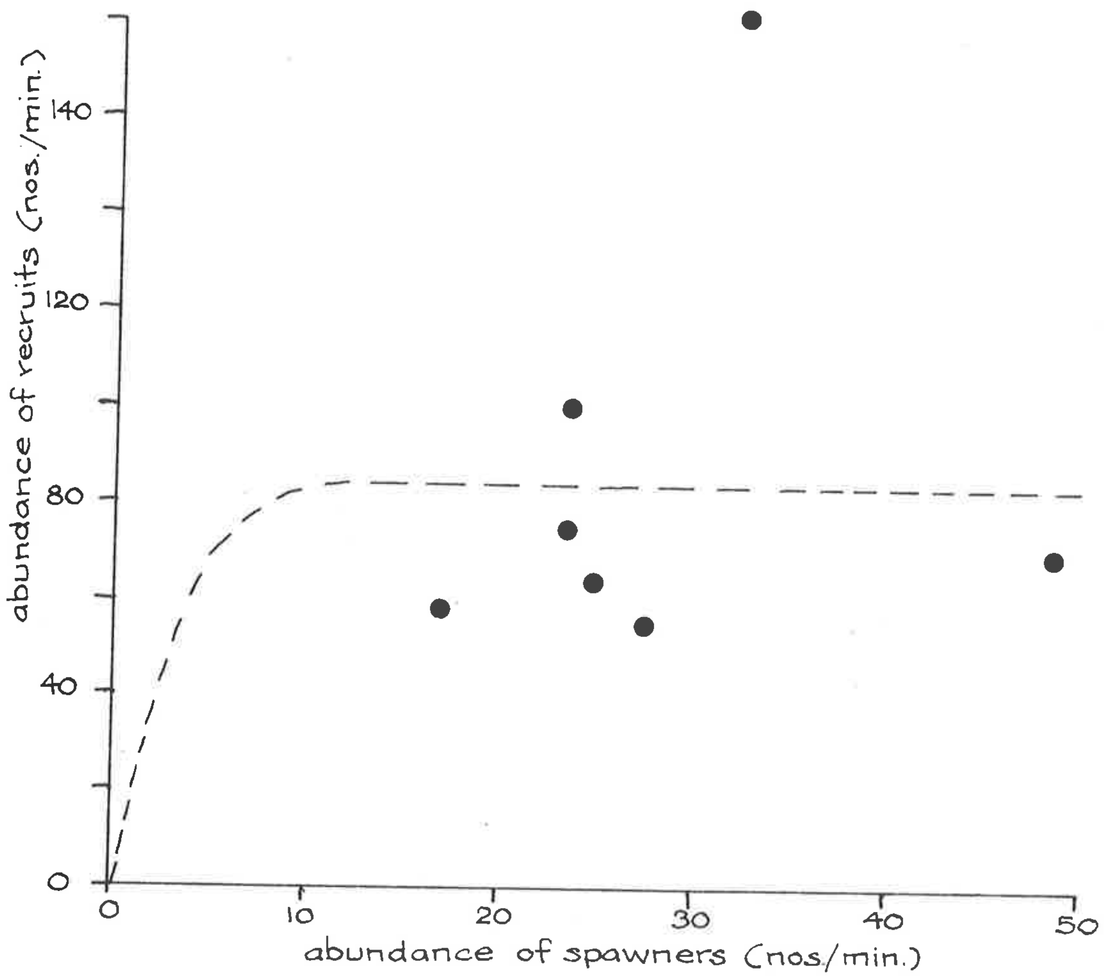



FIGURE 7-7: The relationship of recruits in a particular year to the number of spawning stock in the previous year. A hyperthetical spawner/recruit curve as suggested by Neal (1973) is shown as a dotted line.

## 8. FEEDING

The digestive system and feeding behaviour of juvenile *Penaeus latisulcatus* have been discussed in Section I-5. From aquaria studies and limited diving observations, the feeding behaviour of adults appears to be similar to that described for juveniles.

As for juveniles, samples of adult prawns were taken for the analysis of stomach contents. At least 50% of the stomach contents consisted of unidentifiable detritus but the following list of food organisms was constructed from resistant material which remained recognisable. The organisms are listed in approximate order of most frequent occurrence:

| | |
|---|---|
| Crustacea: | Portions of chela and exoskeleton of unknown crustaceans, limbs of isopods, appendages of penaeid prawns. |
| Mollusca: | Fragments of bivalve shells. |
| Echinodermata: | Spines of sea-urchin, part of sea-urchin test (?) |
| Bryozoa: | Fragments of lace coral. |
| Pisces: | Scales of small fish. |
| Plant material: | Algal fragments (Rhodophycean). |

The diet of adult *P. latisulcatus* was found to be similar to that of juveniles in that a wide range of food types were used. However, the proportion of various organisms present appeared different. Macroscopic plant material, which seemed to be an important food item for juvenile prawns, appeared not to be so for adult prawns.

## 9. BEHAVIOUR

### a. Activity

The effects of light and temperature on the behaviour of juvenile *P. latisulcatus* has been discussed in Section I-6. Adults appear to be similar in that cyclic patterns in catch rates occur in the commercial fishery.

(1) Daily light/dark cycle:

Commercial trawling gear has developed to the extent that the sea bottom is minimally disturbed (underwater film made during the study is on file in the Fisheries Branch). This ensures that the amount of 'trash' - sponge, bryozoa, crabs, etc. - caught in the nets is small and that the fisherman's work of sorting the catch is reduced. Consequently, prawns must be above or on the bottom to be caught by the nets. Low catch rates, therefore, indicate one of two things; either prawns are absent from the area or they are buried below the substrate.

Trawling during daylight is rarely successful. The exceptions to this are during certain times (e.g. just after recruitment) and in some deeper areas ($>40$ m) off the western coast of the State. The fact that, in most cases, catch rates rapidly increase after sunset and decrease at sunrise suggests that *P. latisulcatus* is nocturnal and remains buried during the day.

Catch rates of the commercial fleet were examined over longer periods (months and years) to determine whether the lunar and seasonal cycles demonstrated for juveniles (Section I-6) applied to adult *P. latisulcatus*.

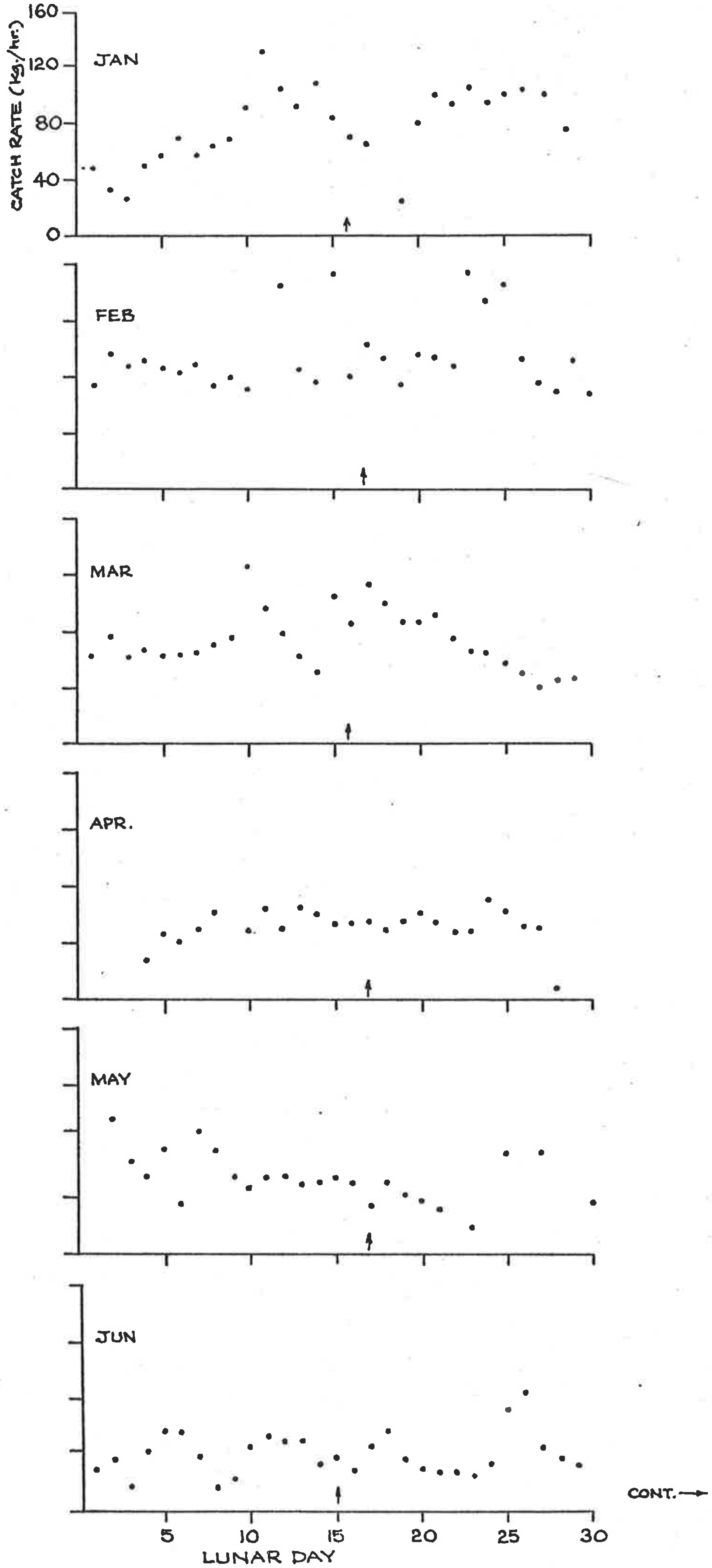
(2) Monthly lunar cycle:

Using catch statistics from the log sheets of all fishermen in one area (Spencer Gulf), catch rates of the whole fleet were calculated on a daily basis. As virtually the whole fleet was fishing at one time, it was not necessary to correct individual boat catch rates for relative fishing power. The individual catch rates of each vessel were totalled to provide a mean catch rate (kg per hour trawled) for each day of the year. The data for 1973 in Spencer Gulf is shown in Figure 9-1.

Results show that at least in the early months of the year (after recruitment) the mean catch rates of the Spencer Gulf fleet appear highest near the period of the new moon. This suggests a lunar periodicity in activity of adult *P. latisulcatus* in which more time is spent on or above the substrate during the dark period than light period of the lunar month.

Lunar rythms in activity had been demonstrated in several species of penaeid prawn in laboratory conditions (see discussion in juvenile Section 1-6). In commercial stocks, catch rates of *Metapenaeus macleayii* and *Penaeus plebejus* were shown to reach a maximum 3-4 days before the new moon (Racek 1957). In *Metapenaeus mastersii* (Dall 1958) and *Penaeus duorarum* (Fuss and Ogren 1966) the effect of moonlight on reducing activity has been discussed. However, there is no evidence that reduced activity during the time of full moon is due to the direct inhibiting effect of moonlight. Racek considered it unlikely that direct moonlight could so affect a bottom dwelling species. This claim is supported by the fact that at least one fishery on a basically nocturnal species of penaeid prawn, *P. esculentus*, has maximum catch rates about 3-4 days before the full moon (White 1973). In some species such as *P. plebejus* in Queensland there is some evidence of a lunar cycle in vulnerability to trawls (Lucas 1973) but times of the lunar period when best catch rates occur differ according to area.

In summary, catch analysis shows that the activity of adult *P. latisulcatus* appears related to the lunar cycle. Whether


CATCH RATE (kg./hr.)
160
120
80
40
0
JAN
FEB
MAR
APR.
MAY
JUN
5
10
15
20
25
30
LUNAR DAY
CONT.

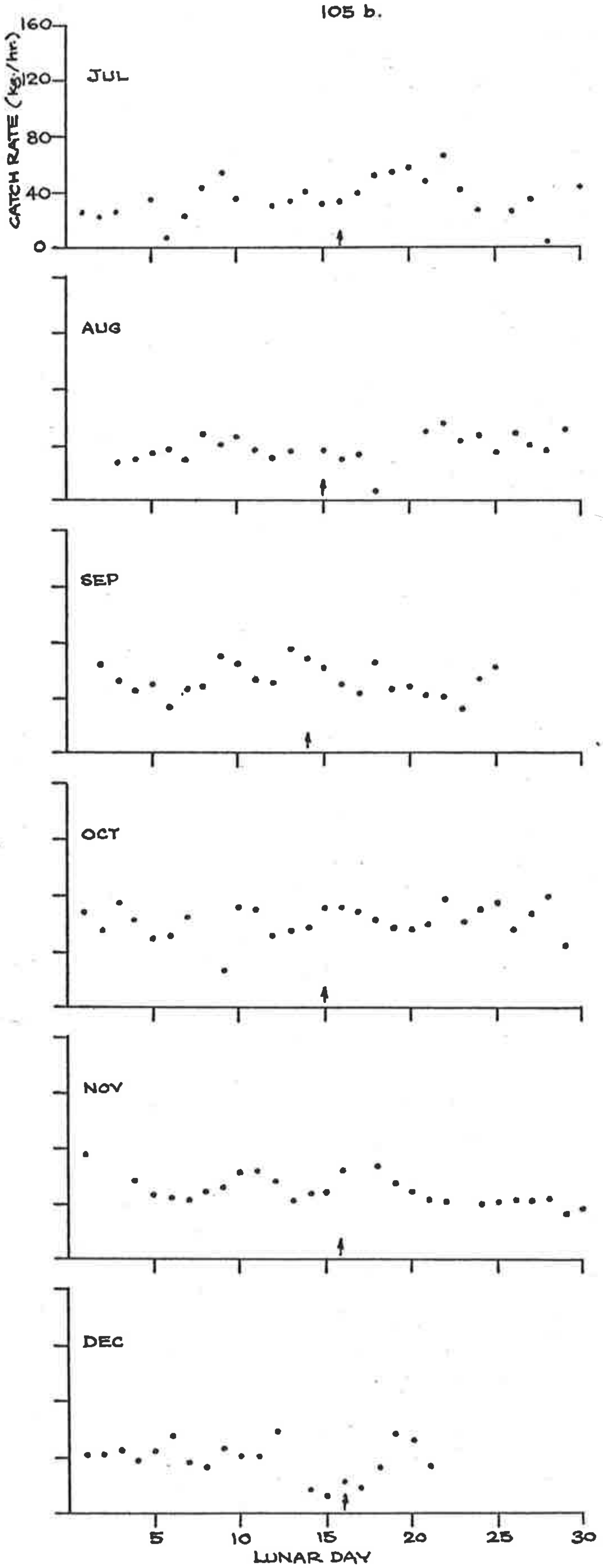



Fig. 9-1: Mean catch rates per day (kg/hr) of adult *Penaeus latisulcatus* in Spencer Gulf during 1973. Time of new moon indicated by arrows.

activity is related to moonlight *per se* or some associated aspect, such as tide, moulting, etc. is not known.

(3) Seasonal temperature cycle:

After recruitment to the adult stocks (December to March in northern Spencer Gulf) maximum catch rates are taken by the commercial fleet. As described for juvenile *P. latisulcatus* catch rates decrease to a minimum during the winter before reaching a second, but lower, maximum in the spring. The catch rates in Spencer Gulf during 1973 are shown in Figure 9-2. Mean catch rates in kg/hr have been converted to numbers per hour by using the general growth curve presented in Section 6. Subsurface water temperatures taken at one station (Eastern Shoal) in Spencer Gulf are also shown.

The data for adult and juvenile *P. latisulcatus* are similar in that periods of minimum water temperatures and minimum catch rates coincide. As for the juveniles, it is suggested that reduced vulnerability of adults during winter is due to reduced activity. A preliminary analysis of patterns of nightly catch rates in both winter and summer was made by examining the catches of individual vessels. Figure 9-3 compares the catch rates during the months of July and December of one vessel operating in Investigator Strait. In each of the two months the vessel was working in similar areas and doubtful catch rates (e.g. those made when nets were damaged) have been excluded. Sea temperatures taken at the Kingscote jetty (Kangaroo Island) were 13°C and 21°C in July and December respectively. In Figure 9-3, individual catch rates (black dots) over the whole month are combined in each diagram to indicate how catch rates vary over the night. The mean values for catch rates at each hour of the night have been joined by the solid line.

These results indicate that differences in summer and winter nightly catch patterns could exist. The vulnerability of prawns

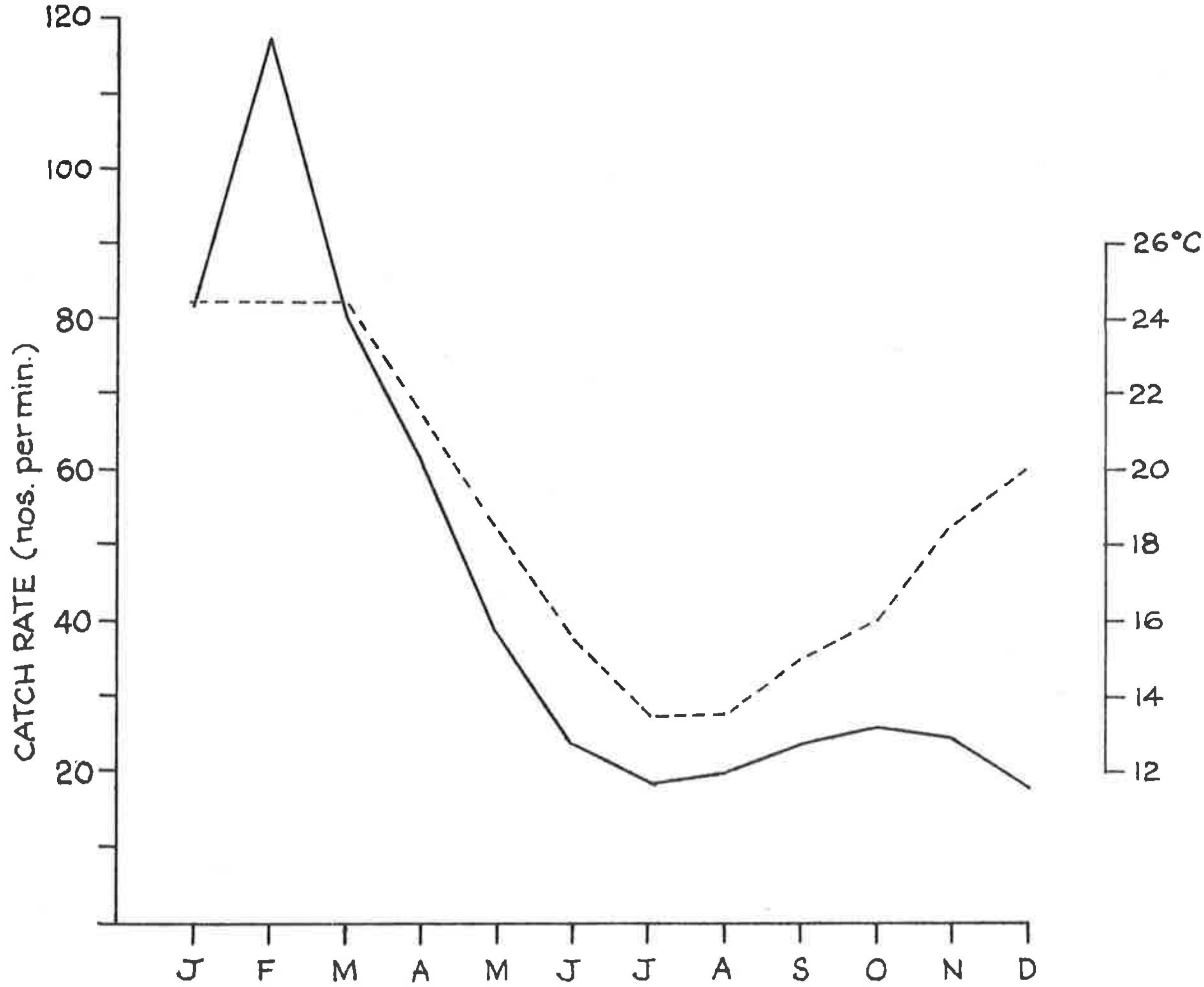



Fig. 9-2: Mean catch rates (nos. caught per minute trawled) in Spencer Gulf. Subsurface sea temperatures at Eastern Shoal are indicated by the broken line.

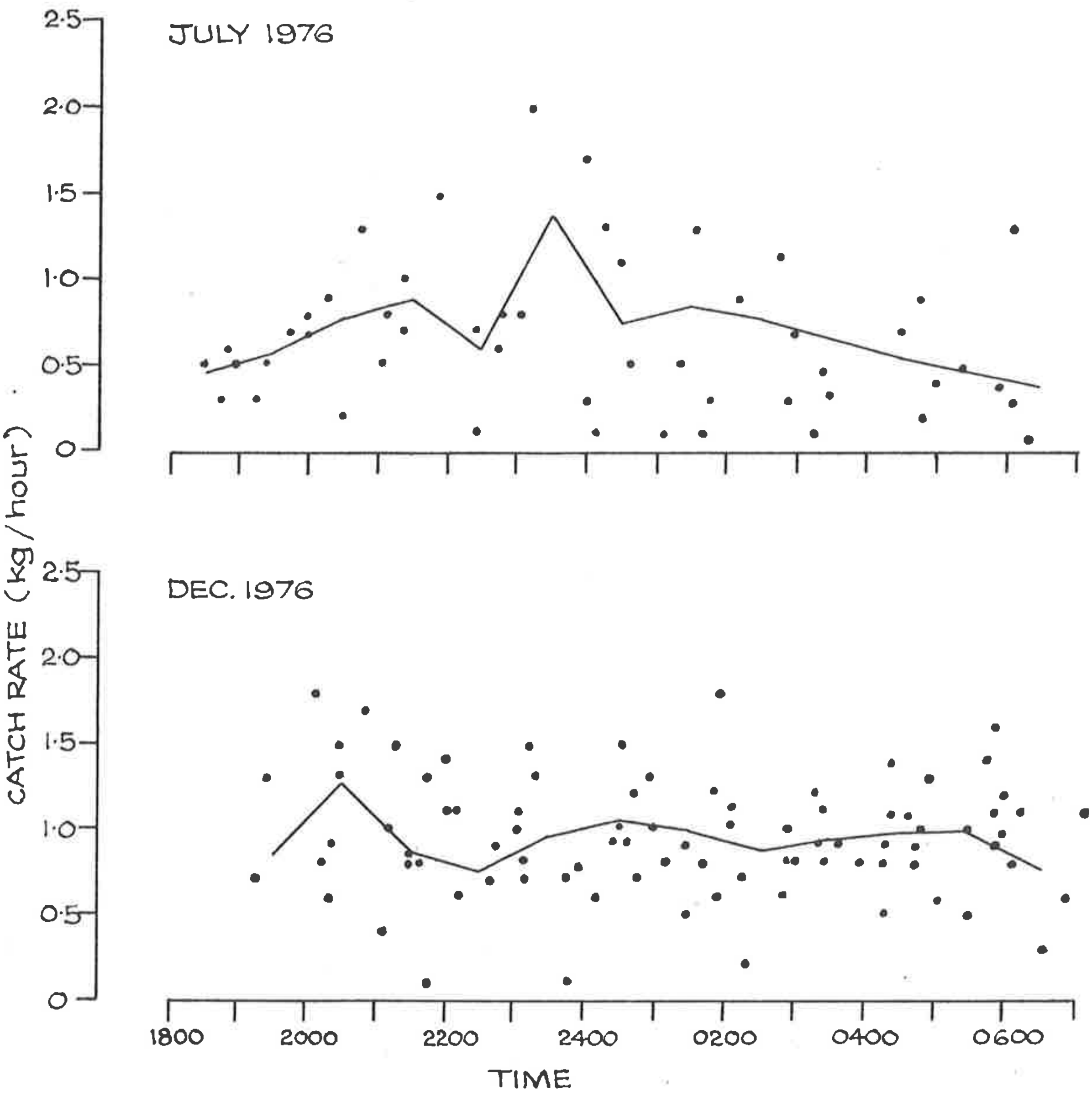



FIGURE 9-3: Catch rates of individual trawls made at various times through the night (the value on the X-axis represents the midpoint of the trawling time). Data combined over one month from one vessel fishing in one area of Investigator Strait. The solid line joins the mean value for each hour class interval.

during July appears to reach a peak around midnight whereas that in December appeared to be more even over the period of darkness. A more extensive analysis involving extraction of the hour by hour catch rates of a large number of vessels will be necessary to reach a firm conclusion. However, the preliminary analysis shows that adult *P. latisulcatus* may be similar to juveniles in that reduced activity occurs in the winter months. In low temperatures adult prawns may spend only a limited period on or above the substrate.

b. Moulting Cycle

In crustaceans, initiation of moulting is controlled by a moult-inhibiting hormone produced in certain neurosecretary cells of the X-organs (Passano 1960). The X-organs are situated in the eye-stalks. Because of the organs' situation they have been thought to be light sensitive. Photoperiod (Aiken 1969) and both constant illumination and constant darkness (Passano 1960) have all been shown to inhibit moulting in certain species. The moult cycle in many nocturnal crustaceans may, therefore, be related to the lunar phase.

Penaeid prawns appear to be similar to other decapod crustaceans in the physiology of moulting. Dall (1965) found that the moult-inhibiting hormone in *Metapenaeus* was produced largely in the eye-stalk: light was thought to be an important factor in influencing the moult cycle of this species. Racek (1959) in an examination of the abundance of recently moulted *M. macleayi* in the commercial catch in Eastern Australia, concluded that moulting in adults was correlated with the lunar cycle. In a similar way White (1973) determined that the moulting cycle of *P. esculentus* was influenced by the lunar cycle.

Commercial catches of adult *Penaeus latisulcatus* are landed at several major ports where they are transported to the factories for processing (Section II-1b). The prawns are subsequently graded into various size classes. At one factory (Australian Bight Fishermen's

Society Ltd.), prawns unsuitable for grading are classed as "meat"; this class includes some damaged or small prawns but the majority are "soft-shelled" - i.e. recently moulted.

In order to study the cyclic nature of moulting in *P. latisulcatus* the factory records were examined to obtain the percentage of the landings over the lunar cycle which were classes as "meat". To reduce the effects of small prawns included in the "meat" class a three month period after the time of maximum recruitment was examined - percentages of the total catch classed as meat were combined in one week class intervals over the lunar month (Figure 9-4).

There are several problems in interpreting the above results. Firstly the low range in numbers of soft shelled animals in the catch (17.8% to 30.5% of the catch classed as meat) indicates that moulting prawns may be less vulnerable to the trawling gear than intermoult prawns. It is possible that during the moulting period, prawns remain buried in the substrate and consequently only a small percentage of the total number of soft shelled animals are caught in the net. In aquaria *P. latisulcatus* were observed to moult and remain buried while soft-shelled (less than 24 hours). In spite of the limitations of the method used, the results indicate that moulting in *P. latisulcatus* is related to the lunar cycle.

c. <u>Migration</u>

The movement of penaeid prawns was studied using Petersen disc tags by Lindner and Anderson (1956). Since that study several other authors have used various tagging methods for a similar purpose (Iverson and Idyll 1960, Iverson and Jones 1961, Potter 1973, Lucas 1975 and Ruello 1975). In the present study western king prawns were tagged using P.V.C. toggle tags inserted with a mechanical applicator (Methods - Section C).

The majority of tagging was carried out in Spencer Gulf and

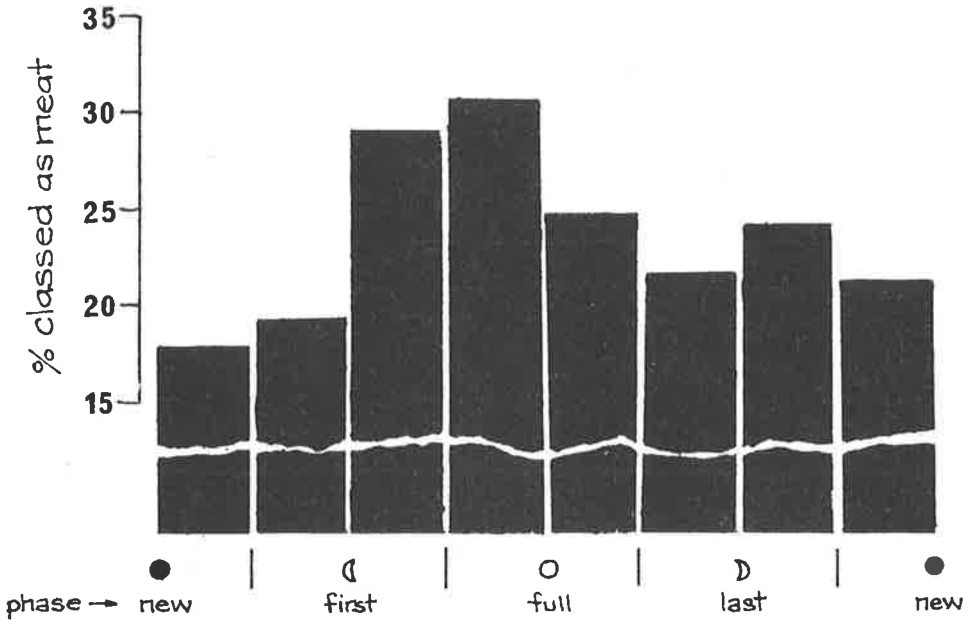



Figure 9-4: Percentage of commercial prawn catch classed as "meat" (soft-shell and damaged). Data from catch during April, May and June, 1974, processed at Australian Bight Fishermen's Society Ltd.

more recently some releases have been made in the Gulf of St. Vincent and Investigator Strait. Results presented in this section are those from Spencer Gulf. Most recovered tagged prawns were returned within a short time and had not moved from the point of release. However, many were free for periods up to 443 days and moved distances up to a maximum of 84 n. miles (156 km).

(1) Distance and speed of migration:

Table 9-1 shows the relationship between distance moved and time free. These factors do not seem directly related and most prawns at liberty over 100 days were recovered less than 10 n. miles from the point of release. The fact that there is not an exact relationship between distance moved and time free indicates that either:-

(a) prawns have moved from the point of release to the point of capture by indirect routes.

(b) only some prawns migrate

(c) migration is seasonal.

(2) Time of migration:

Over the years 1974 and 1975 prawns were tagged and released on a monthly basis at Eastern Shoal in northern Spencer Gulf. Recoveries of tagged prawns from these releases are shown in Table 9-2 which lists the numbers recovered in different as well as the same location. For the purpose of this analysis only recoveries made between 20 and 60 days were included.

Although the number of returns during some months was small, there is a general indication that most movements of tagged prawns occured during the summer and autumn.

(3) Direction of migration:

During the years 1973 to 1975 several major releases of tagged prawns were made from commercial vessels. Results from two such releases at Eastern Shoal (10 January, 1973) and Wallaroo (6 April, 1973) are summarized in Figures 9-5 and 9-6 respectively. In these figures each point represents one tag return.

Results of recaptures from all major and minor releases were summarised according to season of return in Figure 9-7. From these data and length-frequency distributions (Section II-4), there appears to be a general southerly movement of small newly recruited prawns in spring and summer. Movements of prawns appear to loosely coincide with the general water circulation in Spencer Gulf (Section II-2, Figure 2-1). If this is so, southerly movements may take place down the middle of the Gulf, while northerly movements of larger prawns (during the winter) may occur closer to the coast.

TABLE 9-1

Distance moved by tagged *Penaeus latisulcatus* in Spencer Gulf in relation to number of days free.

| Days free | Distance moved (nautical miles) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-60 | 61-70 | 70 |
| 1-10 | 287 | | | | | | | 14 |
| 11-20 | | | | 1 | | | | |
| 21-30 | 72 | 1 | | 1 | | | | |
| 31-40 | 77 | 7 | | | 1 | | 8 | 6 |
| 41-50 | 9 | 7 | 1 | 2 | | | | 1 |
| 51-60 | 50 | 11 | 7 | 1 | | | 4 | |
| 61-70 | 22 | 2 | 3 | 1 | | | | 2 |
| 71-80 | 6 | | | 1 | 2 | | 1 | 4 |
| 81-90 | 12 | 3 | 2 | | 2 | | 3 | |
| 91-100 | 6 | | | | 2 | | | |
| 101-110 | 1 | | | | | 2 | | |
| 111-120 | 10 | | 3 | 1 | 2 | 1 | | |
| 121-130 | 2 | | | | | | | |
| 131-140 | 1 | | | | | | | |
| 141-150 | 1 | | | | | | | |
| 151-200 | 8 | | | | | | | |
| 201-250 | 6 | | | | | | | |
| 251-300 | 3 | | | | | 1 | | |
| 301-350 | | | | | | | | |
| 351-400 | 10 | | | | | | | |
| 401-450 | 10 | | | | | | | |

TABLE 9-2

Recoveries of tagged *Penaeus latisulcatus* per month showing numbers moved and numbers recovered in same location (prawns recovered within 20 days after 60 days excluded).

| Month of recovery | Different location | Same location |
|---|---|---|
| January | 0 | 1 |
| February | 8 | 9 |
| March | 11 | 28 |
| April | 40 | 44 |
| May | 9 | 84 |
| June | 1 | 0 |
| July | 0 | 5 |
| August | 0 | 7 |
| September | 0 | 16 |
| October | 0 | 2 |
| November | 0 | 1 |
| December | 2 | 0 |

CH✓

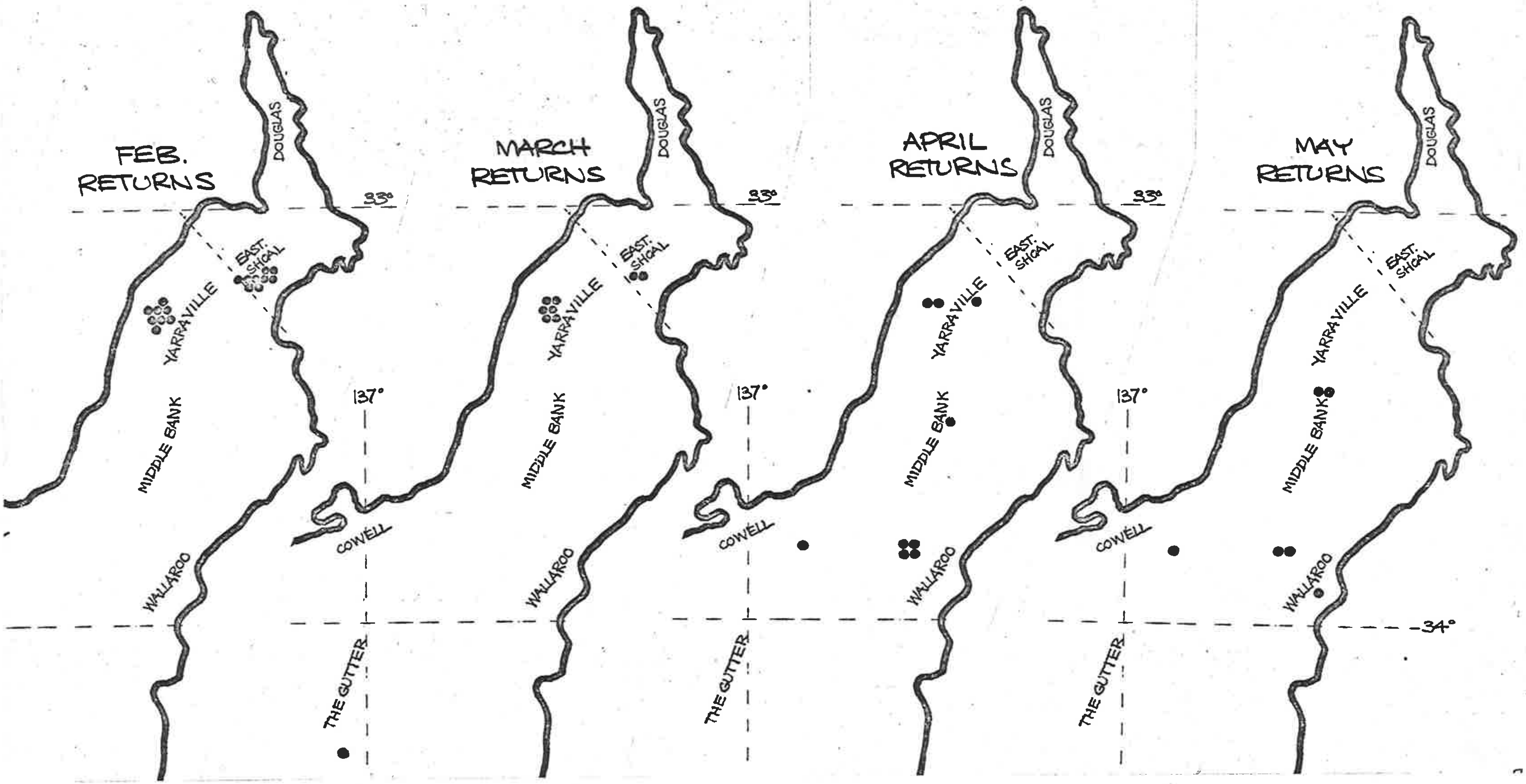



Fig. 9-5: Summary of tag returns for the months of February, March, April and May, 1973 from a release of 3 640 tagged (colour - yellow) prawns at Eastern Shoal, Spencer Gulf on 10 January, 1973. Each point represents one tag return.

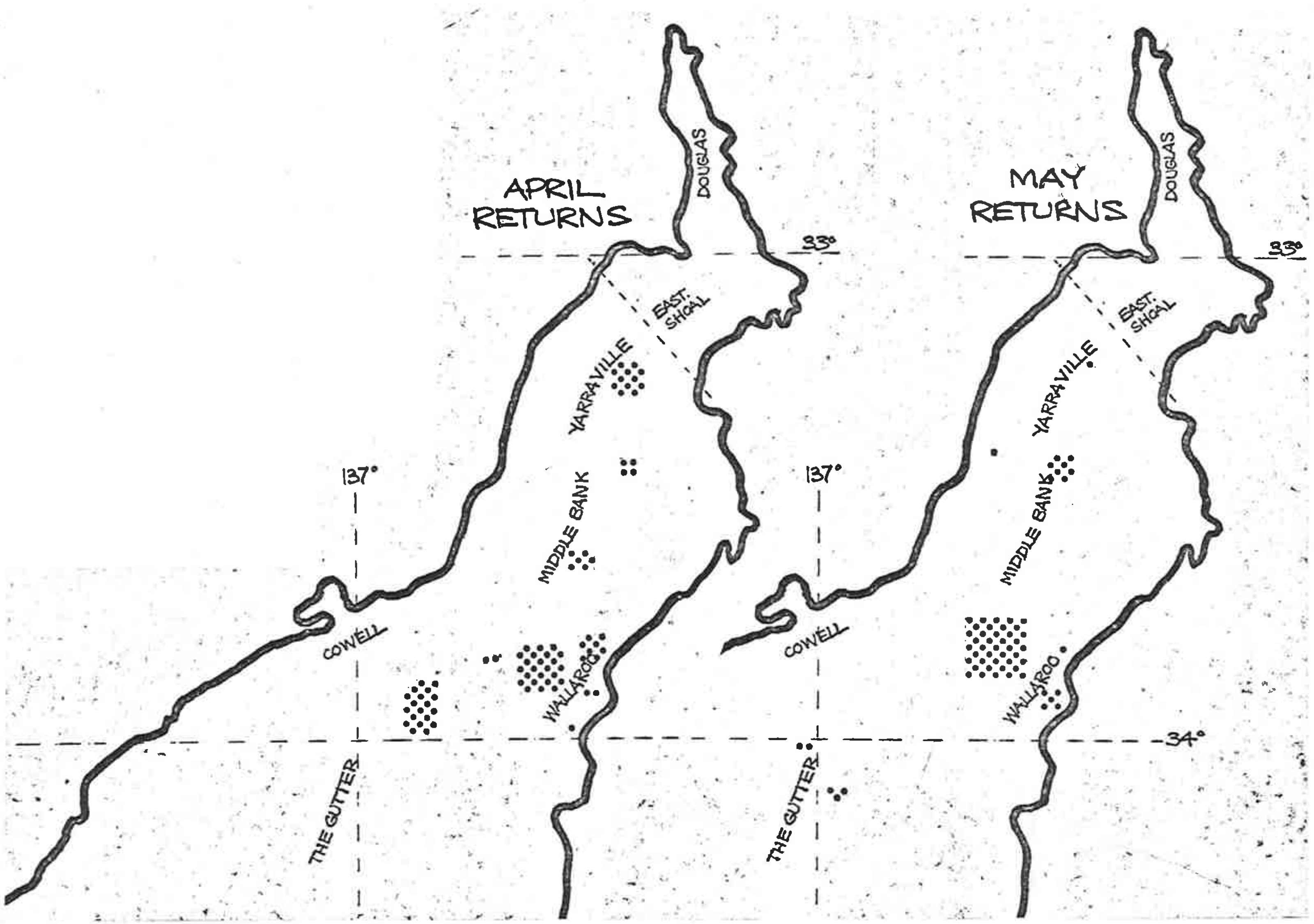



Fig. 9-6: Summary of tag returns for April and May, 1973 from a release of 1 435 tagged (colour - yellow and brown) prawns at Wallaroo, Spencer Gulf, on 6 April, 1973. Each point represents one tag return.

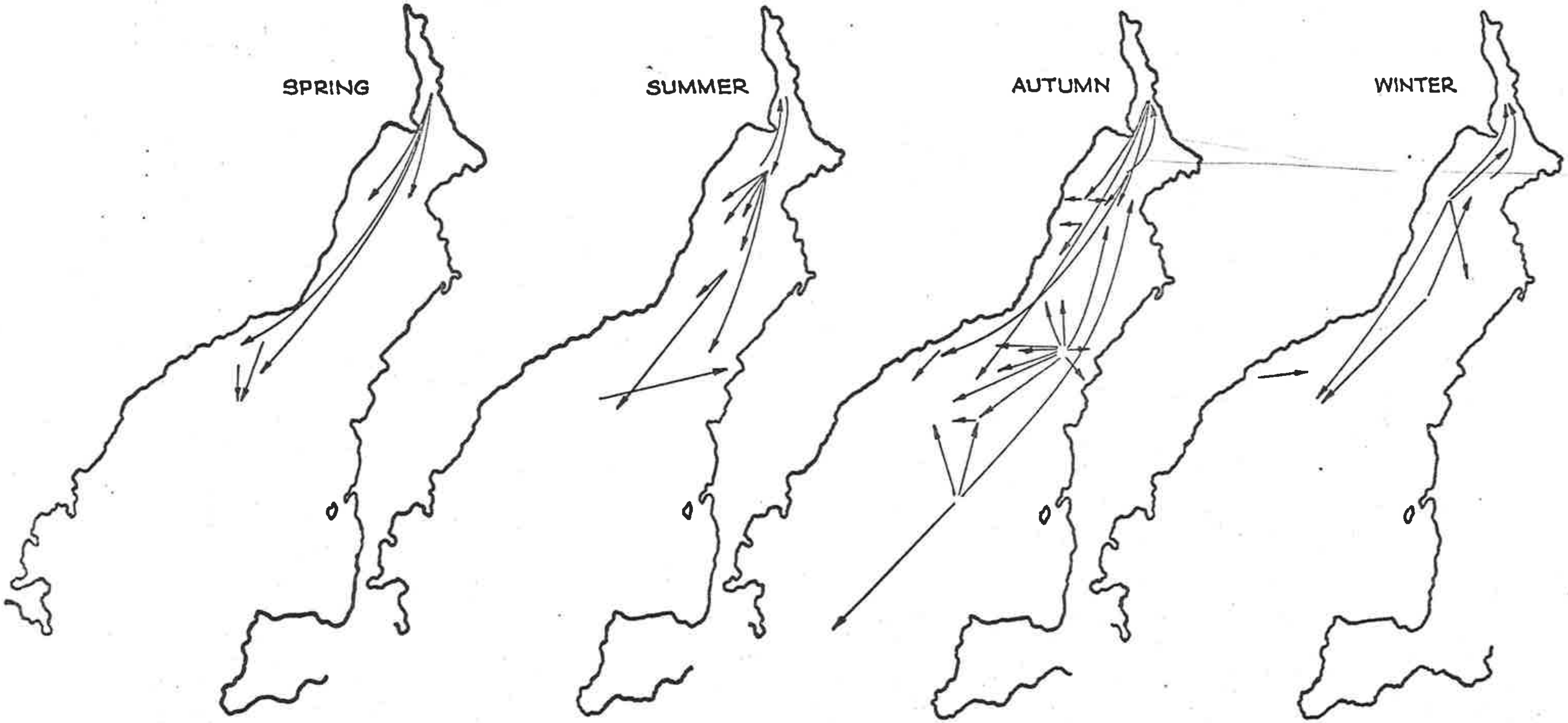



Fig. 9-7: Summary of general movements of tagged prawns in Spencer Gulf from tag returns received in Spring (Sept. to Nov.), Summer (Dec. to Feb.), Autumn (Mar. to May) and Winter (June to Aug.).

## 10. MORTALITY

Mortality in relation to juvenile prawns has been discussed in Section I-7. Sound fisheries management often involves the infliction of a known and planned mortality on the exploited species. The planned mortality is directly related to the level of fishing effort (number of boats, hours worked, etc.) in the fishery. Unplanned mortality can be caused by several natural factors including disease, parasitism, starvation, adverse physical conditions and, probably least common of all, old age. Thus, using the notation of Ricker (1975) the total mortality (Z) can be divided into two classes: fishing mortality (F) and natural mortality (M).

By definition, $Z = F + M$ ............... (1)

In the following sections, total fishing and natural mortality estimates are obtained and discussed for adult *P. latisulcatus*.

### a. Total Mortality

As described for juveniles, catch rates were used as indices of abundance of adult *P. latisulcatus* over time. The reduction in mean catch rate of the fleet (in numbers per minute trawled) was used to estimate mortality. There were thought to be two main problems in using this method - firstly the variation in "fishing power" between individual fishing units and secondly the variation in vulnerability of the stock over the year; each of these factors is discussed in the following pages, using the 1975 data for Spencer Gulf as an example.

The "power" of a particular fishing unit is defined as the catch that it can take from a given density of fish per unit fishing time (Gulland 1969). Factors contributing to a vessel's fishing power in the prawn fishery are discussed in Appendix 4. The importance of taking into account fishing powers of vessels can be illustrated as follows. If, for some reason, the more efficient vessels (i.e. those with a high fishing power) tend to fish early in the year and the less efficient vessels tend to fish later in the year, the mortality rate value obtained from calculating the reduction in catch rates over the year will be too high. In the Spencer Gulf fishery it was not suspected that there were any major differences between the fishing patterns of vessels with low and high fishing power values. However, it was decided to use the data for 1975 to examine whether power factors should be taken into account in the calculation of mortality rates.

The catch data for 1975 were refined by taking into account the differences between the fishing power of the various vessels. A convenient method of doing this is to compare the catches of a particular skipper and his vessel with that of the average catch of the fleet as a whole. This method has been used by Lucas (1974) by averaging the catches over one month, which may in fact be too short a time period to allow for fluctuations due to other factors, e.g. a particular skipper may take 'time off' to trawl in an unproved area with low stock density.

In this study the landing statistics of the total Spencer Gulf fleet of 39 vessels were used from a three month period (January 1975 to March 1975 inclusive - Table 10-1). From the daily logs the daily catch rates (Ci) were calculated for each individual vessel by:

$$Ci = \frac{Wi}{Ei} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where Wi = weight of catch and Ei = effort in hours trawled. For the test period of 3 months the average catch rate for the individual vessel is given by:

$$\overline{Ci} = \frac{\Sigma Wi}{\Sigma Ei} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

For the whole fleet the average catch rate was calculated by:

$$\overline{C}_F = \frac{1}{39} \sum_{i=1}^{39} \overline{C}i \qquad \text{.......................... (4)}$$

Comparison of the figure for an individual vessel with the average catch rate for the fleet gives the vessels power factor thus:

$$Pi = \frac{\overline{C}i}{\overline{C}_F} \qquad \text{................................ (5)}$$

The vessels power factor varied from 0.4 to 1.7 compared to the average of 1.0 (Table 10.1).

Using the power factors the standardized monthly effort for each individual vessel was calculated as:

$$Eis = \frac{Ei}{Pi} \qquad \text{................................ (6)}$$

and a standardized monthly catch rate for each vessel by:

$$Cis = \frac{\Sigma Wi}{\Sigma Eis} \qquad \text{.............................. (7)}$$

From the standardized catch rates for individual vessels the total monthly catch per standardized effort was calculated for the Spencer Gulf fishery in Table 10-2. In this table the growth curve in Section II-6 (Table 6-7) was used to convert catch rates in weight to numbers of individuals caught per standardized effort. Figure 10-1 shows how these catch rates vary for 1975 in Spencer Gulf.

TABLE 10-1 Vessel power factors obtained from catch statistics of Spencer Gulf fleet from 1/1/75 to 31/3/75.

| Vessel No. | Catch (kg) | Effort (hrs) | Catch rate (kg/hour) | Power factor |
|---|---|---|---|---|
| 1 | 13 354 | 173 | 77.2 | 1.3 |
| 2 | 4 534 | 218 | 20.8 | .4 |
| 3 | 36 175 | 511 | 70.8 | 1.2 |
| 4 | 30 028 | 528 | 56.9 | .9 |
| 5 | 16 971 | 173 | 98.1 | 1.7 |
| 6 | 13 663 | 256 | 53.4 | .9 |
| 7 | 1 315 | 26 | 50.6 | .9 |
| 8 | 19 491 | 273 | 71.4 | 1.2 |
| 9 | 8 251 | 153 | 54.0 | .9 |
| 10 | 12 020 | 301 | 39.9 | .7 |
| 11 | 28 149 | 417 | 67.5 | 1.2 |
| 12 | 25 578 | 350 | 73.1 | 1.3 |
| 13 | 34 304 | 427 | 80.3 | 1.4 |
| 14 | 13 821 | 278 | 49.7 | .9 |
| 15 | 5 001 | 76 | 65.8 | 1.1 |
| 16 | 13 613 | 289 | 47.1 | .8 |
| 17 | 3 273 | 77 | 42.5 | .7 |
| 18 | 6 053 | 147 | 41.2 | .7 |
| 19 | 25 165 | 381 | 66.1 | 1.1 |
| 20 | 33 481 | 350 | 60.9 | 1.1 |
| 21 | 31 493 | 438 | 71.9 | 1.2 |
| 22 | 16 284 | 304 | 53.6 | .9 |
| 23 | 27 014 | 389 | 69.4 | 1.2 |
| 24 | 27 612 | 418 | 66.1 | 1.1 |
| 25 | 22 532 | 411 | 54.8 | .9 |
| 26 | 10 076 | 219 | 46.0 | .8 |
| 27 | 14 622 | 222 | 65.9 | 1.1 |
| 28 | 1 140 | 24 | 47.5 | .8 |
| 29 | 15 195 | 347 | 43.8 | .8 |
| 30 | 32 218 | 432 | 74.6 | 1.3 |
| 31 | 10 478 | 319 | 32.9 | .6 |
| 32 | 21 669 | 356 | 60.9 | 1.1 |
| 33 | 14 145 | 279 | 50.7 | .9 |
| 34 | 12 230 | 232 | 52.7 | .9 |
| 35 | 33 420 | 515 | 64.9 | 1.1 |
| 36 | 18 383 | 309 | 59.5 | 1.0 |
| 37 | 29 645 | 483 | 61.4 | 1.1 |
| 38 | 21 126 | 419 | 50.4 | .9 |
| 39 | 17 037 | 232 | 73.4 | 1.3 |

$\Sigma \bar{C}_i = 2287.7$ $\left(\frac{1}{39}\sum_{i=1}^{39}\bar{C}_i = 58.7\right)$

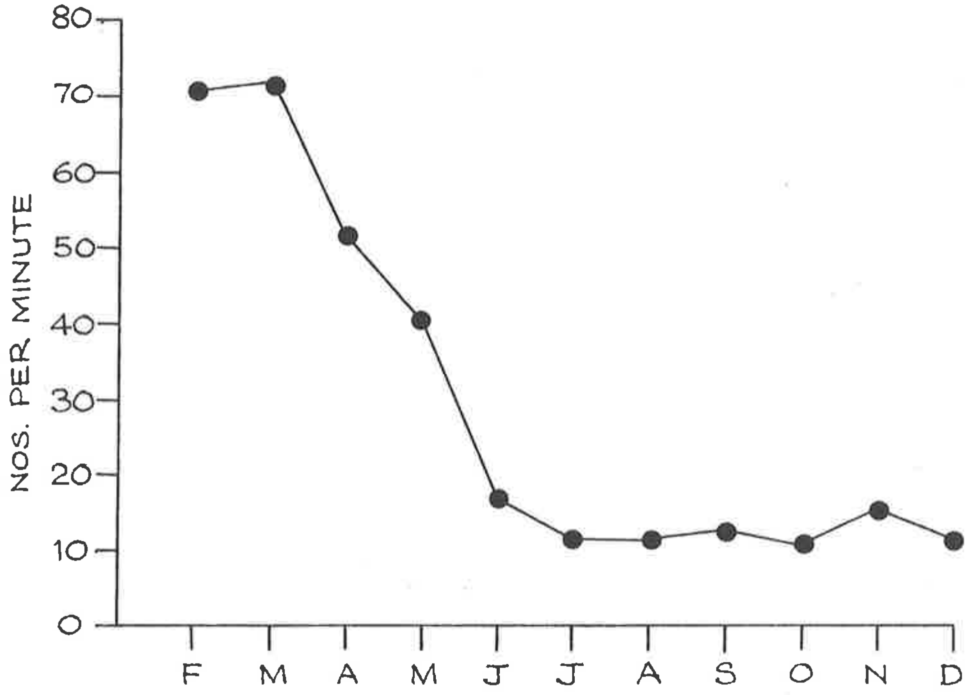



Figure 10-1: Mean standardised catch rate (nos. per minute of trawling) in Spencer Gulf.

As was the case in juveniles (Section I-7), the catch rates of adult *P. latisulcatus* over a year are typically bimodal - i.e. the vulnerability of the stock is not constant over the year. In Section II-5 it was shown that a recruitment peak occurred about February 1975; by March this recruitment was virtually complete. Catch rates reached a minimum during the period of lowest sea temperatures and it was suggested in Section II-9 that the vulnerability of *P. latisulcatus* is temperature dependent. To allow for this it was decided to exclude the months with the lowest sea temperatures from the calculations and compare catch rates from the post-recruitment period (usually March) and the end of 'season' period (usually November); during both of these periods, the sea temperatures were similar. Table 10-3 shows the mean catch rates (both actual and standardised) for the 3 months associated with each of the two maxima

TABLE 10-2: Actual and standardised catch rates (mean of all vessels) from Spencer Gulf, 1975

| MONTH | ACTUAL CATCH RATE (kg/hr) | STANDARDISED CATCH RATE (kg/hr) |
|---|---|---|
| January | 55.1 | 52.4 |
| February | 53.4 | 52.5 |
| March | 72.0 | 72.3 |
| April | 60.8 | 59.1 |
| May | 43.8 | 42.8 |
| June | 33.3 | 30.9 |
| July | 27.1 | 24.6 |
| August | 24.6 | 25.0 |
| September | 26.2 | 28.3 |
| October | 25.3 | 24.4 |
| November | 37.2 | 36.0 |
| December | 29.5 | 28.0 |

TABLE 10-3 Mean catch rates (actual and standardised) in kg per hour and numbers per minute for each of the 3 months associated with the two annual maxima in the Spencer Gulf fishery, 1975. Catch weights were converted to numbers of individuals using the general growth data presented in Section II-6. Values of the instantaneous total mortality co-efficient (Z) are shown at right.

| | | FIRST MAXIMA | | | | SECOND MAXIMA | | | Z |
|---|---|---|---|---|---|---|---|---|---|
| | | kg/hr | nos/min | ln | | kg/hr | nos/min | ln | (per wk.) |
| Actual data | feb | 53.4 | 72.7 | 4.29 | oct | 25.3 | 11.6 | 2.45 | |
| | mar | 72.0 | 71.5 | 4.27 | nov | 37.2 | 16.6 | 2.81 | .0476 |
| | apr | 60.8 | 52.0 | 3.95 | dec | 29.5 | 12.8 | 2.55 | |
| Standardised | feb | 52.5 | 71.4 | 4.27 | oct | 24.4 | 11.1 | 2.41 | |
| | mar | 72.3 | 71.8 | 4.27 | nov | 36.0 | 16.1 | 2.78 | .0485 |
| | apr | 59.1 | 50.6 | 3.92 | dec | 28.0 | 12.1 | 2.49 | |

CHV

in the catch statistics for 1975. The mean catch rates were plotted against time as in fig.7-3 (p.40). The slope of the regression line fitted by the least squares method was used to estimate the total mortality.

As shown in Table 10-3 there is very little difference between mortality estimates obtained using actual and standardised data (Z = 0.0476 and 0.0485 per week, respectively). As suspected, it appeared that there were no major differences in the fishing patterns of both low power and high power fishing units, i.e. whenever the weather was suitable, virtually all vessels were fishing. Accordingly it was decided to use actual data for the calculation of total mortality rates.

Using catch statistics obtained since the beginning of the fishery in 1968, Table 10-4 was prepared in the same manner as Table 10-3. Table 10-4 shows that values of total mortality Z over the period 1969 to 1976 varied between 0.0216 and 0.0507.

b. Fishing Mortality (F)

An examination of the catch statistics for Spencer Gulf (Appendix 2) shows that the amount of fishing effort has dramatically increased over the years. As shown in the previous section this has resulted in a general increase in total mortality (Table 10-4). Increase in the efficiency of the fishing fleet is believed to have played only a minimal part in this increase (Section II-1 and Appendix 4).

Fishing mortality is directly related to the fishing effort, i.e.:

$$F = qf \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where q is a constant and f represents fishing effort. Substituting equation (8) in equation (1):

$$Z = qf + M \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

TABLE 10-4: Mean catch rates in kg per hour and numbers per minute for each of the 3 months associated with the two annual maxima in the Spencer Gulf fishery. Catchweights were converted to numbers of individuals using the general growth data presented in Section II-6. Values of the instantaneous total mortality coefficient (Z) are shown at right.

| | | FIRST MAXIMA | | | | SECOND MAXIMA | | | |
|---|---|---|---|---|---|---|---|---|---|
| YEAR | | kg/hr | nos/min | ln | | kg/hr | nos/min | ln | $Z(wk^{-1})$ |
| 1969 | mar | 40.4 | 40.1 | 3.69 | oct | 37.9 | 17.3 | 2.85 | |
| | apr | 60.2 | 51.5 | 3.94 | nov | 41.2 | 18.4 | 2.91 | 0.0316 |
| | may | 57.3 | 38.3 | 3.65 | dec | 36.4 | 15.7 | 2.76 | |
| 1970 | mar | 89.7 | 89.1 | 4.49 | nov | 36.1 | 16.1 | 2.78 | |
| | apr | 90.0 | 77.0 | 4.34 | dec | 40.2 | 17.4 | 2.86 | 0.0216 |
| | may | 59.3 | 39.7 | 3.68 | jan | 38.7 | 16.0 | 2.77 | |
| 1971 | feb | 70.3 | 95.7 | 4.56 | oct | 38.8 | 17.7 | 2.87 | |
| | mar | 86.8 | 86.2 | 4.46 | nov | 57.0 | 25.5 | 3.24 | 0.0385 |
| | apr | 61.8 | 52.9 | 3.96 | dec | 51.9 | 22.4 | 3.11 | |
| 1972 | feb | 66.7 | 90.8 | 4.51 | oct | 33.8 | 14.4 | 2.74 | |
| | mar | 69.3 | 68.8 | 4.23 | nov | 44.2 | 19.8 | 2.98 | 0.0453 |
| | apr | 64.6 | 55.3 | 4.01 | dec | 32.2 | 13.9 | 2.65 | |
| 1973 | jan | 48.6 | 81.5 | 4.40 | sep | 49.8 | 23.2 | 3.14 | |
| | feb | 86.2 | 117.3 | 4.76 | oct | 56.4 | 25.8 | 3.25 | 0.0395 |
| | mar | 80.5 | 80.0 | 4.38 | nov | 54.2 | 24.2 | 3.19 | |
| 1974 | feb | 113,3 | 154.2 | 5.04 | oct | 58.8 | 26.8 | 3.29 | |
| | mar | 165.7 | 164.6 | 5.10 | nov | 75.5 | 33.8 | 3.52 | 0.0507 |
| | apr | 146.1 | 125.0 | 4.83 | dec | 55.3 | 23.9 | 3.17 | |
| 1975 | feb | 53.4 | 72.7 | 4.29 | oct | 25.3 | 11.6 | 2.45 | |
| | mar | 72.0 | 71.5 | 4.27 | nov | 37.2 | 16.6 | 2.81 | 0.0476 |
| | apr | 60.8 | 52.0 | 3.95 | dec | 29.5 | 12.8 | 2.35 | |
| 1976 | feb | 56.7 | 77.1 | 4.35 | oct | 39.8 | 18.2 | 2.90 | |
| | mar | 72.6 | 72.1 | 4.28 | nov | 50.7 | 22.7 | 3.12 | 0.0372 |
| | apr | 58.5 | 50.1 | 3.91 | dec | 42.6 | 18.4 | 2.91 | |

CH ✓

This equation is of a linear form where q is the slope and M the intercept on the y-axis. Figure 10-2 shows the plot of Z against total annual effort in which the line of best fit (by least squares) has the slope $q = 0.450 \times 10^{-6}$ and intercept $M = 0.0276$ the correlation coefficient was 0.523.

Using equation (8) the values for fishing mortality (F) for each year were as follows:

| | |
|---|---|
| 1969 | 0.0056 |
| 1970 | 0.0069 |
| 1971 | 0.0080 |
| 1972 | 0.0098 |
| 1973 | 0.0113 |
| 1974 | 0.0129 |
| 1975 | 0.0174 |
| 1976 | 0.0192 |

c. Natural mortality (M)

In the previous subsection (b) a value of natural mortality, (M = 0.0276 per week) was obtained from the intercept on the y-axis in Figure 10-2. This value represents an average value for natural mortality over the time span of the fishery.

In subsection (a), the Spencer Gulf commercial fishery landing data were used to calculate total mortality. A small area of the north of this Gulf is permanently closed to trawling. Fishing in this area was restricted to a 2 night survey on a commercial vessel once every month; there have been, at times, reports of trawlers poaching within the closed area but this has been regarded as minimal. Catch data from this area were used to check the value obtained above for natural mortality.

In an unexploited population the total mortality coefficient Z approximately equals natural mortality M. That is, from Section I-7, equation (4) becomes:

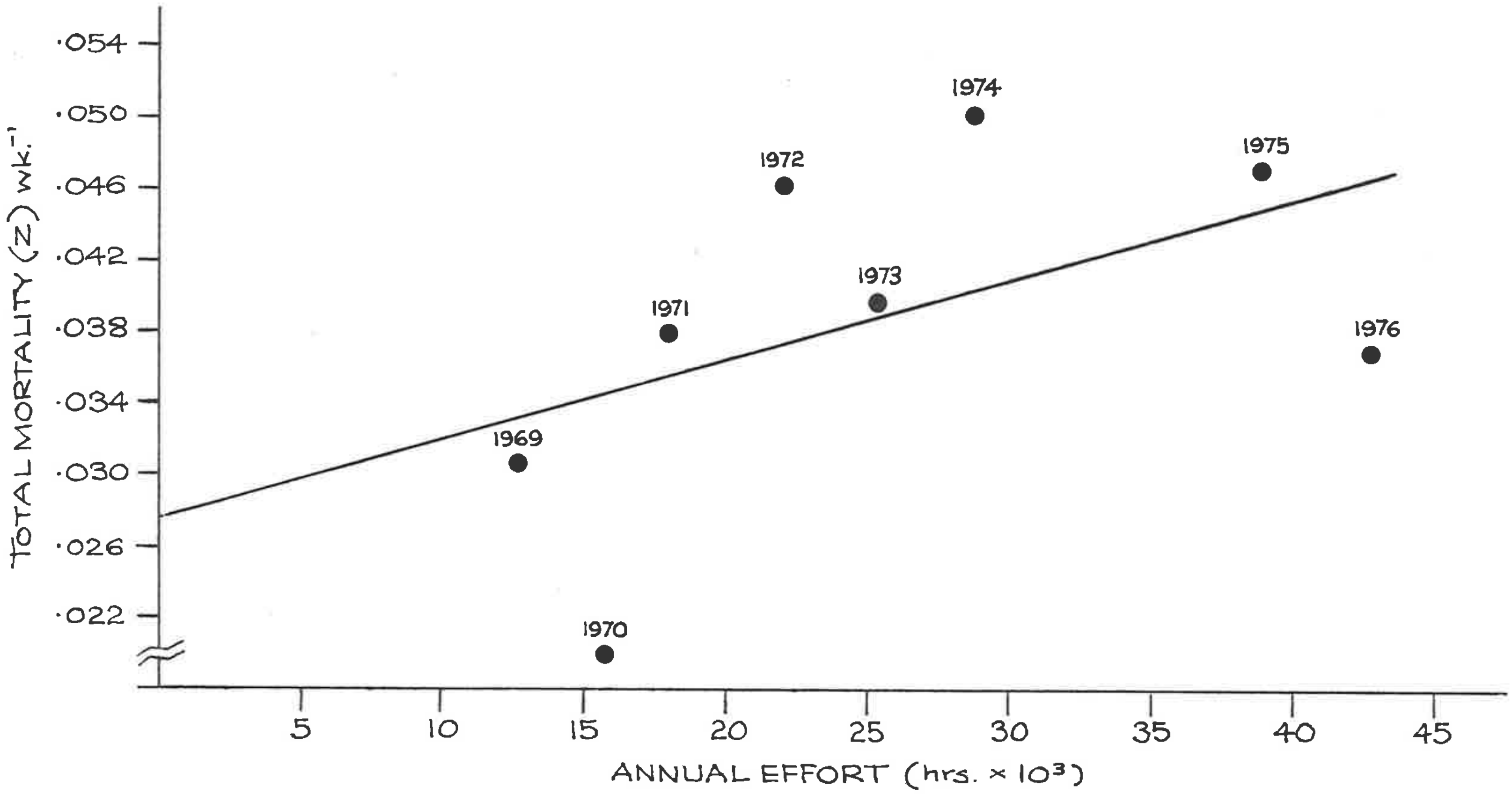



FIGURE 10-2: Relationship of annual total mortality (Z) to effort (hours trawled).

$$M(t_2 - t_1) = \ln \frac{N_2}{N_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where $N_1$ and $N_2$ are the numbers of individuals alive at times $t_1$ and $t_2$ respectively. However it was shown in Section II-9 that prawns migrate southward out of the closed area; allowing for the loss due to emigration (E) equation (10) becomes:

$$(M + E) \quad (t_2 - t_1) = \ln \frac{N_2}{N_1} \quad \ldots\ldots\ldots\ldots \quad (11)$$

In tagging experiments carried out in the closed area to the north of Spencer Gulf, 3 640 tagged prawns were released at Eastern Shoal on 10 January 1973. By October 1973, 44 prawns had been recaptured (ignoring recaptures made at the time of tagging). Of these 44, 13 were subsequently found in the same area and 31 had migrated south and were recovered at various fishing grounds. The total effort (days trawled) at these fishing grounds in the period from January to May was 19 boat days. At Eastern Shoal in the closed area effort over the equivalent period was only 4 boat days - i.e. research surveys only. The rate of tag returns were, therefore, adjusted as shown in Table 10-5.

TABLE 10-5

Estimation of emigration from the closed area in the north of Spencer Gulf from a release of 3 640 tagged prawns in January 1973

| | In closed area | South of closed area |
|---|---|---|
| No. recaptured | 13 | 31 |
| Approx. effort (days) | 4 | 19 |
| Tags per boat day | 3.25 | 1.63 |
| Percentage | 66.6 | 33.4 |

Table 10-5 indicates that 33.4% of the tagged population had moved south out of the closed area in a four month period. This is equivalent to an "instantaneous" loss of about 0.025 per week, i.e. E in equation (11) is equal to 0.025 per week.

Catch rates at one station (Eastern Shoal) in the closed area were calculated. and regression lines through these data are shown in Figure 10-3; periods of low vulnerability have been excluded from the calculation. The slope of the lines represents the values of M + E in equation (11) - these were 0.063 per week (1974) and 0.047 per week (1975).

Assuming that loss due to emigration from the area is similar during each year - i.e. E = 0.025 per week, values of natural mortality were 0.038 and 0.022 per week for 1974 and 1975 respectively. These values suggest that the estimate of M = 0.028 per week obtained previously is a reasonable one.

In summary, levels of fishing mortality in Spencer Gulf have ranged from 0.007 in 1969 to 0.019 per week in 1976. By extrapolation the present level of fishing mortality is likely to be 0.022 per week. The average value for natural mortality was estimated to be 0.028 per week. These estimates of mortality have been used with growth data (Section II-6) to calculate yield from the fishery in Section II-11.

(2) Predators/Intraspecific associations:

Operating from commercial trawlers, field notes were kept on species encountered in the trawl nets. Table 10-7 shows associated species caught in trawling operations in Spencer Gulf, Investigator Strait and Gulf St. Vincent. An indication of general relative abundance is given (common, occasional or rare) but it is stressed that abundance may vary with area trawled - e.g. the most abundant crab encountered in the trawl nets in Investigator Strait is

*Ovalipes australiensis*, while in the upper Gulfs, *Portunus pelagicus* is dominant. Some species (e.g. Trevally *Usacaranx georgianus*) were so regularly associated with *P. latisulcatus* that the species could be used as an indicator of the presence of prawns.

Gut contents of most of the associated species in Table 10-7 were examined; from these results, and underwater observations, the species indicated by an asterisk were determined to be predators of *P. latisulcatus*. Other predators may be pelagic and fast moving therefore less likely to be caught by otter trawling. Racek (1959) has noted that a stranded dolphin (cetacea) was found in New South Wales with its stomach entirely filled with large penaeid prawns.

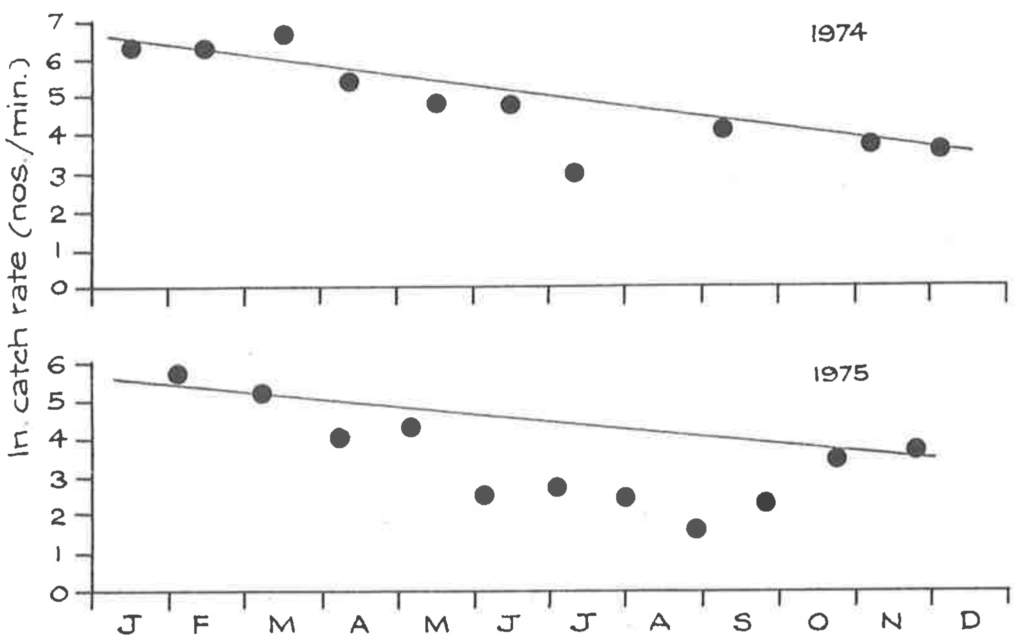



FIGURE 10-3: Numbers of adult Penaeus latisulcatus caught per minute (expressed as natural logarithms) during surveys at Eastern Shoal in Northern Spencer Gulf. The regression line was calculated, by least squares, through all points excluding months when sea temperatures were lowest (June to September inclusive).

TABLE 10-7: Species caught by prawn trawling in Spencer Gulf, Investigator Strait and Gulf St. Vincent. Relative abundance in the trawl nets is indicated by C (common), O (occasional) and R (rare). Species marked with an asterisk are known, from underwater observations and gut analysis, to be predators of adult *Penaeus latisulcatus*.

| Common Name | Scientific Name | Abundance |
|---|---|---|
| ELASMOBRANCHS | | |
| *Ornate Angel Shark | *Squatina tergocellata* | O |
| *Port Jackson Shark | *Heterodontus portusjacksoni* | C |
| Common Saw Shark | *Pristiophorus cirratus* | R |
| School Shark | *Galeorhinus australis* | C |
| Gummy Shark | *Mustelus antarcticus* | O |
| Gulf Wobbegong | *Orectolobus ornatus halei* | O |
| *Southern Fiddler | *Trygonorhina fasciata guanerius* | C |
| Eagle Ray | *Myliobatis australis* | O |
| *Shovelnose Ray | *Aptychotrema vincentiana* | C |
| *Smooth Stingray | *Dasyatis brevicaudata* | C |
| Numbfish | *Hypnos monopterygium* | R |
| TELEOSTS | | |
| ORDER CLUPEIFORMES (herring-like fish) | | |
| Southern Anchovy | *Engraulis australis antipodum* | O |
| Blue Sprat | *Spratelloides robustus* | O |
| Beaked Salmon | *Gonorhynchus greyi* | C |
| ORDER BELONIFORMES (garfishes) | | |
| South Australian Garfish | *Hemiramphus melanochir* | O |
| ORDER PLEURONECTIFORMES (flounders and soles) | | |
| *Greenback Flounder | *Rhombosolea tapirina* | O |
| *Small Toothed Flounder | *Pseudohombus jenynsii* | C |
| ORDER SYNGNATHIFORMES (pipefishes and seahorses) | | |
| Pipefish | *Syngnathus* sp. | O |
| Common Seadragon | *Phyllopteryx taeniolatus taeniolatus* | O |
| Leafy Seadragon | *Phycodurus eques eques* | R |
| ORDER PEGASIFORMES (dragon-fishes) | | |
| Sea Moth | *Acanthopegasus lancifer* | O |
| ORDER MUGILIFORMES (mullets, hardyheads etc.) | | |
| Snook | *Australuzza novaehollandiae* | O |
| ORDER PERCIFORMES (perch-like fishes) | | |
| Barracouta | *Leionura atun* | O |
| *Sand Flathead | *Platycephalus bassensis bassensis* | C |
| Dusky Flathead | *Platycephalus fuscus* | O |
| Tassel-snouted Flathead | *Thysanophrys cirronasus* | R |
| Red Gurnard | *Chelidonichthys kumu* | C |

| | | |
|---|---|---|
| Gurnard Perch | *Neosebastes pandus* | O |
| Gulf Gurnard Perch | *Neosebastes panticus* | R |
| Little Scorpion Fish | *Neosebastes scabriceps* | O |
| South Australian Cobbler | *Gymnapistes marmoratus* | O |
| Goblin Fish | *Glyptauchen panduratus deruptus* | R |
| Common Stinkfish | *Callionymus calauropomus* | O |
| Spotted Stinkfish | *Callionymus calcaratus* | C |
| Ling | *Genypterus blacodes* | O |
| Horse Mackerel | *Trachurus declivis* | O |
| Trevally | *Usacaranx georgianus* | C |
| Yellowtail Kingfish | *Seriola grandis* | O |
| Red Mullet | *Upeneichthys porosus* | C |
| Silver Whiting | *Sillago bassensis* | O |
| Spotted Whiting | *Sillaginodes punctatus* | O |
| Slender Bullseye | *Parapriacanthus elongatus* | C |
| Southern Cardinal Fish | *Vincentiana novaehollandiae* | O |
| *Mulloway | *Sciaena antarctica antarctica* | R |
| Silverbelly (Lowfin) | *Parequula melbournensis* | O |
| *Snapper | *Chrysophrys unicolor* | O |
| Coral Fish | *Chelmonops truncatus* | R |
| Blue Morwong | *Nemadactylus valenciennesi* | R |
| Tommy Rough | *Arripis georgianus* | O |
| Striped Perch | *Helotes sexlineatus* | O |
| * Long Snouted Boarfish | *Pentaceropsis vecurvirostris* | O |
| Wavy Grubfish | *Parapercis haackei* | O |
| Stargazer | *Kathetostoma laeve* | O |
| Congolli | *Pseudaphritis urvilli* | O |

ORDER LOPHIIFORMES (angler fishes)

| | | |
|---|---|---|
| Tasselled Angler Fish | *Rhycherus filamentosus* | O |
| Glauerts Angler Fish | *Echinophryne glauerti* | R |

ORDER LABRIFORMES (parrot fishes etc.)

| | | |
|---|---|---|
| Weedy Whiting | *Haletta semifasciata* | O |

ORDER TETRAODONTIFORMES (leatherjackets, toadfishes etc.)

| | | |
|---|---|---|
| Chinaman Leatherjacket | *Navodon ayraud* | O |
| Deep Bodied Leatherjacket | *Weerutta ovalis* | O |
| Rough Leatherjacket | *Scobinichthys granulatus granulatus* | R |
| Spiny Tailed Leatherjacket | *Acanthaluteres brownii* | O |
| Toothbrush Leatherjacket | *Acanthaluteres guntheri* | R |
| Velvet Leatherjacket | *Navodon australis* | C |
| Bridled Leatherjacket | *Acanthaluteres spilomelanurus* | O |
| Banded Toadfish | *Torquigener pleurogramma* | O |
| Smooth Toadfish | *Sphaeroides glaber* | O |
| Porcupine Fish | *Allomycterus pilatus* | C |
| Globe Fish | *Atopomycterus nicthemerus* | C |
| Ornate Cowfish | *Aracana ornata* | C |
| Shaw's Cowfish | *Aracana aurita* | O |

CRUSTACEANS

| | | |
|---|---|---|
| *Blue Swimmer Crab | *Portunus pelagicus* | C |
| Sand Crab | *Ovalipes australiensis* | C |
| *Morten Bay Bug (Squagga) | *Ibacus incisus* | O |
| Strawberry Prawn | *Metapenaeopsis crassisima* | C |
| Mantis Shrimp | *Squilla miles* | O |

MOLLUSCS

| | | |
|---|---|---|
| Cuttlefish | *Sepia apama* | O |
| Goulds Squid | *Nototodarus gouldi* | O |
| Ethridge's Squid | *Loligo etheridgei* | O |
| Southern Calamary Squid | *Sepioteuthis australis* | C |
| Queen Scallop | *Equichlamys bifrons* | C |
| King Scallop | *Notovola alba* | O |

---

In addition to the above species, a variety of small crustaceans, molluscs, worms, sponges, bryozoans, medusa and algae are caught in usually, small quantities.

Common names and taxonomy of fishes are as given by Scott, Glover and Southcott (1974).

## 11. YIELD

The estimates of growth and mortality obtained in previous sections are of scientific importance in adding to the knowledge of the life cycle of *Penaeus latisulcatus*. However, they are of less direct importance in the management of the fishery on this species. More important, in this respect, is the total maximum yield or catch weight (biomass) that may be taken under varying levels of fishing effort and size of first capture.

Estimates of growth (Section II) indicated that immediately after the period of maximum recruitment in Spencer Gulf (about January) small prawns grew rapidly (2-3 mm carapace length per month). Growth rates over the winter months were low but increased in the spring. Total mortality at present fishing levels was estimated to be 0.052 per week (Section II-10). Thus the biomass of the population is both increasing rapidly through individual growth and decreasing through the reduction in numbers of individuals.

Having obtained values representing growth (K and $L_\infty$) and mortality (F and M), these parameters may be combined in a yield equation. One such equation is that given by Gulland (1969) as:

$$Y' = \frac{F}{F+M}\left(1 - \frac{L_c}{L_\infty}\right)^{\frac{M}{K}} \sum_{n=0}^{3} \frac{U_n\left(1 - \frac{L_c}{L_\infty}\right)^n}{1 + \frac{nK}{M}\left(1 - \frac{F}{F+M}\right)} \quad \ldots\ldots (1)$$

where $Y'$ = yield per recruit

$L_c$ = size at first capture

$U_0 = 1;\ U_1 = -3;\ U_2 = 3;\ U_3 = -1$ ,

other parameters have been defined previously.

The use of this equation, however, assumes that growth conforms to the von Bertalannfy model - i.e. that the parameters K and $L_\infty$ adequately describe growth over the period under consideration. It has been suggested in Section II-6 that this may not be so as growth rates appear to be depressed during the winter months. Accordingly it was decided to estimate yield by two methods: firstly by using equation (1) and substituting various values for $L_c$; secondly by disregarding the von Bertalannfy growth parameters and calculating yield from the general growth curve presented in Section II-6. For the sake of comparison the same value for mortality (M = 0.03 per week) was used. Size at first capture was taken to be 26.5 mm carapace length.

Figure 11-1 shows yield curves calculated by both of the methods described above. Both curves have maxima (indicated by arrows) at different values of fishing mortality F. Each curve, however, is flat for values of F greater than about 0.05 per week, indicated that for above this value there would be little change in yield for large increases in fishing effort. Both curves indicate that if fishing mortality was doubled, yield in biomass would increase by approximately 26%.

Figure 11-2 shows the yield per recruit calculated using the von Bertalannfy growth parameters for various values of size of first capture $L_c$. Using the obtained curve yield is maximised at a carapace length of 21.6 mm (sexes combined). This represents a size slightly below the modal size (23 mm) at which juvenile *P. latisulcatus* leave the nursery areas. Accordingly there is likely to be little benefit in yield from the fishery by reducing net mesh sizes and catching smaller prawns.

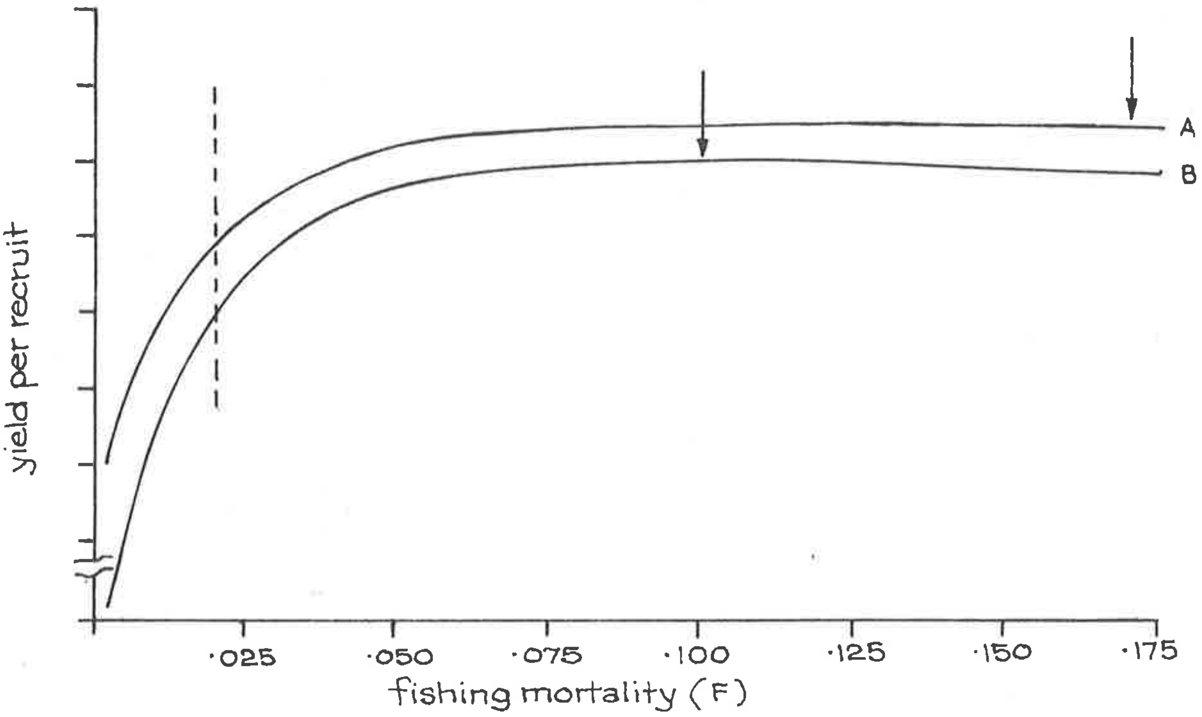



FIGURE 11-1: Yield curves for *Penaeus latisulcatus* in Spencer Gulf. Curve A calculated using the Von Bertalannfy growth parameters; curve B using 'actual' growth data (figure 6-7). Maxima are shown by arrows.

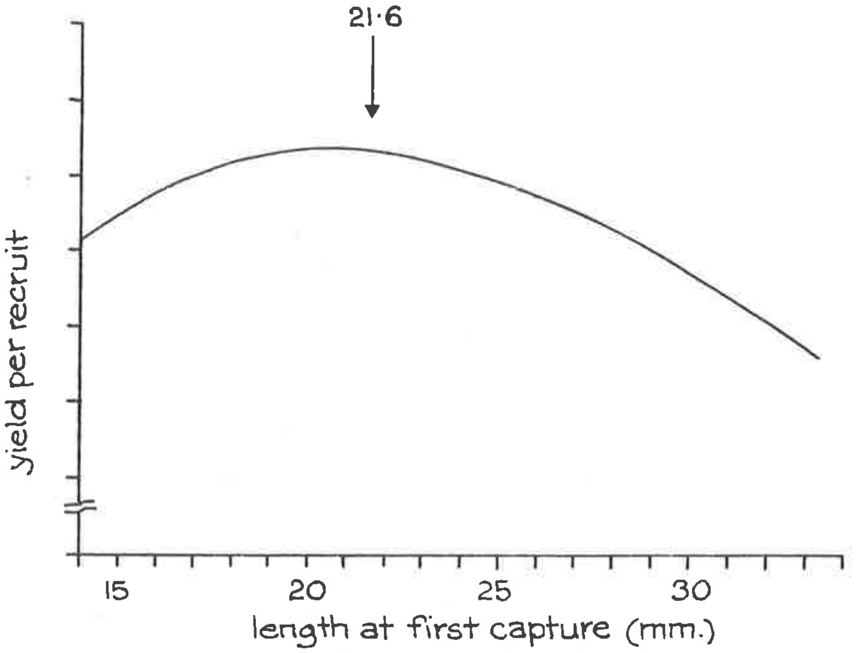



FIGURE 11-2: Yield per recruit for *Penaeus latisulcatus* for various sizes of first capture ($L_c$). The value of $L_c$ giving the maximum yield is indicated by the arrow.

# REFERENCES

## F. REFERENCES

Aiken, D.E. (1969) Photoperiod, endocrinology and the crustacean moult cycle. Science, 164, 149-55.

Beverton, J.H. and Holt, S.J. (1957) On the dynamics of exploited fish populations. Fish. Invest. ser. 2, 19 Min. of Ag. Fish & Food, 533 pp.

Bishara, N.F. (1976) Contributions to the biology of penaeid prawns in Lake Manzalah, Egypt. 1. Growth studies and length-weight relationship, Aquaculture, 8: 337-49.

Bishop, J.M. and Herrnkind, W.F. (1976) Burying and moulting of pink shrimp *Penaeus duorarum* (Crustacea: Penaeidae), under selected photoperiod of white light and UV-light. Biol. Bull., 150: 163-83.

Blackburn, M. (1950) Studies on the age, growth and life history of the pilchard, *Sardinops neopilchardus* (Steindachner) in Southern and Western Australia. Aust. J. mar. Freshw. Res. 1 (2): 221-58.

Boerema, L.K. (1956) Some experiments on factors influencing mesh selection in trawls. J. Cons. Internat. Expl. Mer., 21 (2), 175-91.

Bullock, D.A. (1974) Cruise Report No. 1. Flinders Institute for Atmospheric & Marine Services, The Flinders Univ. of South Australia.

Bullock, D.A. (1975) The general circulation of Spencer Gulf, South Australia for the period February to May. Trans. R. Soc. S. Aust. 99, 43-57.

Butler, A.J., Depers, A.M., McKillup, S.C. and Thomas, D.P. (1977) Distribution and sediments of mangrove forests in South Australia. Trans. R. Soc. S. Aust. 101, 35-44.

Bye, J.A.T. and Whitehead, J.A. (1975) A theoretical model of the flow in the mouth of Spencer Gulf, South Australia. Estuarine and Coastal Marine Science, 3, 477-81.

Bye, J.A.T. (1976) Physical oceanography of Gulf St. Vincent and Investigator Strait, in Twidale *et al.* (eds.). Natural History of the Adelaide Region, 189 pp.

Clark, S.H. and Caillouet, C.W. (1975) Diel fluctuations in catches of juvenile brown and white shrimp in a Texas estuarine canal. Contrib. Mar. Science, 19, 119-24.

Costello, T.J. and Allen, D.M. (1960) Notes on the migration and growth of pink shrimp (*Penaeus duorarum*). Proc. Gulf Caribb. Fish. Inst. Twelfth Ann. Session, 5-9.

Costello, T.J. and Allen, D.M. (1961) Survival of stained, tagged and unmarked shrimp in the presence of predators. Proc. Gulf Caribb. Fish. Inst., Fourteenth Ann. Sess., 16-20.

Condrey, R.E. *et al.* (1972) Comparison of the assimilation of different diets by *Penaeus setiferus* and *P. aztecus*. Fish. Bull. U.S. 70 (4), p. 1281.

Dall, W. (1958) Observations on the biology of the greentail prawn *Metapenaeus mastersii* (Haswell) (Crustacea Decapoda: Penaeidae). Aust. J. mar. Freshw. Res. 9: 111-34.

Dall, W. (1965) Studies on the physiology of a shrimp, *Metapenaeus* sp. (Crustacea: Decapoda: Penaeidae). II. Endocrines and control of moulting. Aust. J. mar. Freshwat. Res., 16 (1), 1-12.

Dall, W. (1967) The functional anatomy of the digestive tract of a shrimp *Metapenaeus bennettae* Racek & Dall (Crustacea: Decapoda: Penaeidae). Aust. J. Zool., 15, 699-714.

Dall, W. (1968) Food and feeding of some Australian penaeid shrimp. F.A.O. Fisheries Reports 57 (2), 251-58.

DeBruin, G.H.P. (1970) The Distribution of Penaeid prawns in Ceylon waters. Bull. Fish. Res. Stn., Ceylon 21 (2), 67-73.

Deevey, E.S. (1947) Life tables for natural populations of animals. Quart. Rev. Biol., 22: 283-314.

Edwards, R.R.C. and Bowers, A.B. (1974) Shrimp research in lagoons of Mexico's Pacific coast. Fishing News International.

Fernandez, H.R. (1973) Spectral sensitivity and visual pigments of the compound eye of the galatheid crab *Pleuroncodes planipes*. Marine Biol., 20, 148-53.

Forster, G.R. (1955) The biology of the common prawn *Leander serratus* Pennant. Plymouth Lab. Rep. 333-59.

Fuss, C.M. (1964) Observations on burrowing behaviour of the pink shrimp, *Penaeus duorarum* Burkenroad. Bull. mar. Sci. Gulf Caribb. 14, 62-73.

Fuss. C.M. and Ogren, L.H. (1966) Factors affecting activity and burrowing habits of the pink shrimp *Penaeus duorarum* Burkenroad. Biol. Bull., 130 (2), 170-91.

Garcia, S. (1973) Marquages de *Penaeus duorarum* en Cote d'Ivoire resultats preliminaires: taux de recapture, migrations et croissance. Doc. Scient. Centre Rech. Océanogr. Abidjan, 4 (3), 29-48.

Gotshall, D.W. (1972) Population size, mortality rates and growth rates of northern California ocean shrimp *Pandalus jordani*, 1965 through 1968. Calif. Dept. Fish and Game, Fish Bull., 155, 1-47.

Gulland, J.A. and Holt, S.J. (1957) Estimation of growth parameters for data at unequal time intervals. J. Cons. Internat. Expl. Mer. 25, 47-49.

Gulland, J.A. (1968) The concept of the maximum sustainable yield and fishery management. FAO Fisheries Tech. paper no. 70, Rome. 13p.

Gulland, J.A. (1969) Manual of methods for fish stock assessment Part 1. FAO Man. Fish. Sci.

Gulland, J.A. (1972) Some introductory guidelines to management of shrimp fisheries. IOFC/DEV/72/24, FAO, IIOFSDP Rome. 12p.

Hale, H.M. (1927) The crustaceans of South Australia. Govt. Printer, Adelaide, 201 pp.

Hancock, D.A. (1973) The basis for management of West Australian prawn fisheries. National Prawn Seminar, Maroochydore, Queensland.

Harris, J.A. (1968) Age structure, growth rate and spawning cycle of a population of yellow-eye mullet *Aldrichetta forsteri* (cuv. and val.) from the Coorong Lagoon, South Australia. Trans. Roy. Soc. S.A. vol. 92.

Hayasi, S. (1971) Stock assessment. IOFC/DEV/71/3, FAO, IIOFSDP, Rome 34p.

Hindley, J.P.R. (1973) The location of food by *Penaeus merguiensis*. National Prawn Seminar, Maroochydore, Queensland.

Hudinaga, M. (1942) Reproduction, development and rearing of *Penaeus japonicus* Bate. Jap. J. Zool. 10, 305-93.

Hudinaga, M. (1963) Culture of Karuma shrimp (*Penaeus japonicus*). Curr. Aff. Bull. Indo-Pacif. Fish. Coun. 36, 10-11.

Hughes, D.A. (1969) Responses to salinity change as a tidal transport mechanism of pink shrimp, *Penaeus duorarum*. Biol. Bull. 136, 43-53.

Ivanov, B.G. and Hassan (1976) Penaeid shrimps (Decapoda, Penaeidae) collected off East Africa by the fishing vessel "Van Gogh", 1. *Solenocera ramadani* sp. nov. and commercial species of the genera *Penaeus* and *Metapenaeus*. Crustaceana 30 (3).

Iversen, E.S. and Idyll, C.P. (1960) Aspects of the biology of the Tortugas pink shrimp *Penaeus duorarum*. Trans. Am. Fish. Soc. 89 (1).

Iversen, E.S. and Jones, A.C. (1961) Growth and migration of the Tortugas pink shrimp, *Penaeus duorarum*, and changes in the catch per unit effort of the fishery. Fla. St. Bd Conserv. Tech. Ser. no. 34.

Jones, R. (1973) Stock and recruitment with special reference to cod and haddock. Rapp. P.V. Reun. Cons. Perm. Int. Explor. Mer. 164, 156-73.

Joubert, L.S. (1965) A preliminary report of the Penaeid prawns of Durban Bay. S.A. Assoc. mar. Biol. Res. Invest. Rep. 11.

King, J.E. (1948) A study of the reproductive organs of the common marine shrimp *Penaeus setiferus* (Linnaeus). Biol. Bull. mar. biol. Lab., Woods Hole 94, 244-62.

King, M.G. (1974) Trawl survey of prawns in Spencer Gulf, Investigator Strait and the Gulf St. Vincent. SAFIC No.1. Dept. of Agric. & Fish.S.Aust.

King, M.G. (1977) Cultivation of the pacific oyster, *Crassostrea gigas* in a non-tidal hypersaline pond. Aquaculture 11, 123-36.

Kirkegaard, I. (1973) Observations of penaeid larvae around Australia. National Prawn Seminar, Queensland.

Klima, E.F. (1964) Mark recapture experiments with the brown and white shrimp in the northern Gulf of Mexico. Gulf Caribb. Fish. Inst. Univ. Miami. Proc. 16, 52-64.

Klima, E.F. (1974) A white shrimp mark-recapture study. Trans. Am. Fish. Soc. 103, 107-13.

Knight, W. (1968) Asymptotic growth: An example of nonsense disguised as mathematics. J. Fish. Res. Bd. Canada. 25, 1303-7.

Kutkuhn, J.H. (1966) Dynamics of a penaeid shrimp population and management implications. U.S. Wildl. Serv. Fish. Bull. 65, 313-38

Lakshmi, G.J., Venkataramiah, A. and Gunter, G. (1976) Effects of salinity and photoperiod on the burying behaviour of brown shrimp *Penaeus aztecus* Ives. Aquaculture 8, 327-36.

Lewis, A.H., Jones, D.A., Ghamrawi, M., Khosham, S. (1973) An analysis of the Arabian Gulf shrimp resources landed in Saudi Arabia 1965-71. Bull. mar. Res. Centre, Saudi Arabia 4.

Ling, J.K. (1956) The life history of the sea garfish *Reporhamphus melanochir* (cuv. and val.) (Hemirhamhidae) in South Australia. M.Sc. thesis, University of Adelaide.

Lindner, M. and Anderson, W.W. (1956) Growth, migration, spawning and size distribution of shrimp *Penaeus setiferus*. Fish. Bull. U.S. 56, no. 106.

Loesch, H. (1965) Distribution and growth of Penaeid shrimp in Mobile Bay, Alabama. Publications of the Institute of Marine Science University of Texas 10: 41-58.

Lucas, C. (1973) The collection and use of landing statistics. National Prawn Seminar, Queensland.

Lucas, C. (1974) Preliminary estimates of stocks of the King prawn *Penaeus plebejus* in South-East Queensland. Aust. J. mar. Freshwat. Res., 25, 35-47.

Lucas, C. (1975) Eastern king prawn migrations in southern Queensland. Aust. Fisheries, May.

Lucas, C. Young, P.C. and Brundritt, J.K. (1972) Preliminary mortality rates of marked King Prawns *Penacus plabejus*, in laboratory tanks. Aust. J. mar. Freshwat. Res., 23, 143-9.

Moriarty, D.J.W. (1976) Quantitative studies on bacteria and algae in the food of the mullet *Mugil cephalus* L. and the prawn *Metapenaeus bennettae* (Racek & Dall). J. Exp. Mar. Biol. Ecol. 22, 131-43.

Moriarty, D.J.W. (1977) Quantification of Carbon, Nitrogen and Bacterial Biomass in the food of some penaeid prawns. Aust. J. mar. Freshwat. Res., 28, 113-18.

Munro, I.S.R. (1968) The prawn, its habitat and life. The life of the banana prawn. Aust. Fish. Newsletter 27 (1), 25-27.

Munro, I.S.R. (1973) Biology of the Banana prawn (*Penaeus merguiensis*) in the South-East corner of the Gulf of Carpentaria. National Prawn Seminar, Queensland.

Neal, R.A. (1973) The Gulf of Mexico research and fishery on penaeid prawns. National Prawn Seminar, Queensland.

Olsen, A.M. (1973) The South Australian Prawn Fishery. National Prawn Seminar, Queensland.

Passano, L.M. (1960) Moulting and its control-in T.H. Waterman (ed.) The Physiology of Crustacea. Vol. 1: Metabolism and Growth. Academic Press, New York.

Penn, J.W. (1973) Tagging experiments with the Western King Prawn *Penaeus latisulcatus* Kishinouye. National Prawn Seminar, Maroochydore, Queensland.

Penn, J.W. (1975a) Tagging experiments with Western King Prawn *Penaeus latisulcatus* Kishinouye. I. Survival, growth and reproduction of tagged prawns. Aust. J. mar. Freshwat. Res. 26, 197-211.

Penn, J.W. (1975b) The influence of Tidal cycles on the distributional pathway of *Penaeus latisulcatus* Kishinouye in Shark Bay, Western Australia. Aust. J. mar. Freshwat. Res., 26, 93-102.

Pope, J.A. (1966) Manual of methods for fish stock assessment. Part III. Selection of fishing gear. FAO Fish. tech. pap. 41, 41 pp.

Potter, M.A. (1973) Movements of the eastern king prawn *Penaeus plebejus*, in Southern Queensland waters. National prawn seminar, Maroochydore, Queensland.

Racek, A.A. (1955) Littoral Penaeidae from New South Wales and adjacent Queensland Waters. Aust. J. mar. Freshwat. Res. 6, 209-41.

Racek, A.A. (1957) Penaeid prawn fisheries of Australia with special reference to New South Wales. Res. Bull. St. Fish. N.S.W. 3, 19 pp.

Racek, A.A. (1959) Prawn investigations in Eastern Australia. Res. Bull. St. Fish. N.S.W. 6, 1-57.

Racek, A.A. and Dall, W. (1965) Littoral penaeinae (Crustacea:Decapoda) from northern Australia, New Guinea and adjacent waters. Verh. Akad. Wet. Amst. (b) 56 (3) 1 – 119.

Rapson , A.M. and McIntosh, C.R. (1971) Prawn surveys in Papua New Guinea. Dept. of Agriculture, Stock and Fisheries. Fisheries Bulletin no. 3.

Ricker, W.E. (1948) Methods of estimating vital statistics of fish populations. Bloomington, Indiana Univ. Pub., Sci. Ser., No. 15. 101p.

Ricker, W.E. (1975) Computation and interpretation of biological statistics of fish populations. Bull. 191. Fish. Res. Bd. Canada. 382 pp.

Ruello, N.V. (1970) Prawn tagging experiments in New South Wales. Proc. Lin. Soc. N.S.W. 94 (3), 277-87.

Ruello, N.V. (1973) The influence of rainfall on the distribution and abundance of the school prawn (*Metapenaeus macleayi*) in the Hunter River region (Australia). Marine Biology 23, 221-28.

Ruello, N.V. (1975) Geographical distribution, growth and breeding migration of the eastern Australian King prawn *Penaeus plebejus* Hess. Aust. J. mar. Freshwat. Res. 26, 343-54.

Slack Smith, R.J. (1969) The prawn fishery of Shark Bay, Western Australia. FAO Fish. Rep., 57 (3), pp. 717-34.

Shepherd, S.A. (1973) Studies on southern Australian abalone (genus *Haliotis*) I. The ecology of five sympatric species. Aust. J. mar. Freshwat. Res. 24, 217-57.

Scott, T.D., Glover, C.J.M. and Southcott, R.V. (1974) The marine and freshwater fishes of South Australia. Govt. Printer, Adelaide.

Somers, I. (1973) Growth of eastern King prawns (*Penaeus plebejus*). National Prawn Seminar, Queensland.

Slobodkin, L.B. (1961) Growth and regulation of animal populations. Holt, Rinehart and Winston, 184 pp.

Spiegal, M.R. (1972) Theory and problems of statistics. McGraw-Hill Book Co., New York.

Tabb, D.C. Dubrow, D.L., Jones, A.E. (1962) Studies on the biology of the pink shrimp (*Penaeus duorarum*) Burkenroad, in Everglades National Park, Florida. Fla. St. Bd. Cons., Univ. Miam. Mar. Lab., Tech. Ser. 37.

Tuma, D.J. (1967) A description of the development of primary and secondary sexual characters in the banana prawn, *Penaeus Merguiensis* de Man (Crustacea: Decapoda: Penaeinae). Aust. J. mar. Freshwat. Res., 18, 73-88.

U.S. Naval Oceanographic Office H.O. publication no. 107 (1969).

Von Bertalannfy, L. (1938) A quantitative theory of organic growth. Hum. Biol. 10, 181-213.

Waterman, T.H. ed. (1961) Light sensitivity and vision. In 'Physiology of Crustacea, Volume 2'. Academic Press, New York & London.

White, T. (1973) Factors affecting the catchability of a penaeid shrimp *Penaeus esculentus*. National Prawn Seminar, Queensland.

Wickham, D.A. (1967) Observations on the activity patterns in juveniles of the pink shrimp, *Penaeus duorarum*. Bull. mar. Sci. Gulf Caribb. 17 (4), 769-86.

Wickham, D.A. and Minkler, F.C. (1975) Laboratory observations of daily patterns of burrowing and locomotor activity of pink shrimp, *Penaeus duorarum*, brown shrimp, *Penaeus aztecus* and white shrimp, *Penaeus setiferus*. Contrib. Mar. Sci. 19, 21-35.

Williams, A.B. (1955) A contribution to the life histories of commercial shrimps (Penaeidae) in North Carolina. Bull. mar. Sci. Gulf Caribb. 5, 116-46.

Winstanley, R.H. (1975) Western King prawns caught in Victorian waters. Australian Fisheries, No. 5.

Young, J.H. (1959) Morphology of the white shrimp, *Penaeus setiferus* (Linnaeus 1758). Fishery Bull. U.S. Fish. Wildl. Serv. 59 (145), 1-168.

# APPENDICES

APPENDIX 1: Morphometric data for adult *Penaeus latisulcatus*

TABLE 1 . MORPHOMETRIC DATA - MALE ADULTS

| CARAPACE LENGTH (mm) | TOTAL LENGTH (mm) | WHOLE WEIGHT (g) | NOS/LB (WHOLE) | NOS/KG (WHOLE) | TAIL WEIGHT (g) | NOS/LB (TAILS) | NOS/KG (TAILS) |
|---|---|---|---|---|---|---|---|
| 20 | 86.22 | 4.40 | 103 | 227 | 2.69 | 169 | 372 |
| 21 | 90.08 | 5.08 | 89 | 197 | 3.09 | 147 | 324 |
| 22 | 93.95 | 5.82 | 78 | 172 | 3.52 | 129 | 284 |
| 23 | 97.82 | 6.64 | 68 | 151 | 4.00 | 114 | 250 |
| 24 | 101.68 | 7.52 | 60 | 133 | 4.51 | 101 | 222 |
| 25 | 105.55 | 8.48 | 54 | 118 | 5.07 | 90 | 197 |
| 26 | 109.42 | 9.51 | 48 | 105 | 5.68 | 80 | 176 |
| 27 | 113.28 | 10.62 | 43 | 94 | 6.33 | 72 | 158 |
| 28 | 117.15 | 11.82 | 38 | 85 | 7.03 | 65 | 142 |
| 29 | 121.02 | 13.10 | 35 | 76 | 7.78 | 58 | 129 |
| 30 | 124.88 | 14.47 | 31 | 69 | 8.58 | 53 | 117 |
| 31 | 128.75 | 15.93 | 28 | 63 | 9.43 | 48 | 106 |
| 32 | 132.62 | 17.49 | 26 | 57 | 10.34 | 44 | 97 |
| 33 | 136.48 | 19.14 | 24 | 52 | 11.31 | 40 | 88 |
| 34 | 140.35 | 20.89 | 22 | 48 | 12.33 | 37 | 81 |
| 35 | 144.22 | 22.75 | 20 | 44 | 13.42 | 34 | 75 |
| 36 | 148.08 | 24.71 | 18 | 40 | 14.56 | 31 | 69 |
| 37 | 151.95 | 26.78 | 17 | 37 | 15.77 | 29 | 63 |
| 38 | 155,82 | 28.95 | 16 | 35 | 17.04 | 27 | 59 |
| 39 | 159.68 | 31.25 | 15 | 32 | 18.39 | 25 | 54 |
| 40 | 163,55 | 33.66 | 13 | 30 | 19.79 | 23 | 51 |
| 41 | 167.42 | 36.19 | 13 | 28 | 21.27 | 21 | 47 |
| 42 | 171,28 | 38.84 | 12 | 26 | 22.82 | 20 | 44 |
| 43 | 175.15 | 41.61 | 11 | 24 | 24.45 | 19 | 41 |
| 44 | 179.02 | 44.52 | 10 | 22 | 26.14 | 17 | 38 |
| 45 | 182.88 | 47.55 | 10 | 21 | 27.92 | 16 | 36 |

TABLE 2 . MORPHOMETRIC DATA - FEMALE ADULTS

| CARAPACE LENGTH (mm) | TOTAL LENGTH (mm) | WHOLE WEIGHT (g) | NOS/LB (WHOLE) | NOS/KG (WHOLE) | TAIL WEIGHT (g) | NOS/LB (TAILS) | NOS/KG (TAILS) |
|---|---|---|---|---|---|---|---|
| 20 | 86.81 | 4.35 | 104 | 230 | 2.98 | 152 | 335 |
| 21 | 90.36 | 5.00 | 91 | 200 | 3.35 | 136 | 299 |
| 22 | 93.91 | 5.72 | 79 | 175 | 3.74 | 121 | 267 |
| 23 | 97.45 | 6.51 | 70 | 154 | 4.18 | 109 | 239 |
| 24 | 101.00 | 7.36 | 62 | 136 | 4.65 | 98 | 215 |
| 25 | 104.55 | 8.28 | 55 | 121 | 5.16 | 88 | 194 |
| 26 | 108.10 | 9.27 | 49 | 108 | 5.70 | 80 | 175 |
| 27 | 111.64 | 10.34 | 44 | 97 | 6.29 | 72 | 159 |
| 28 | 115.19 | 11.48 | 40 | 87 | 6.93 | 66 | 144 |
| 29 | 118.74 | 12.70 | 36 | 79 | 7.60 | 60 | 132 |
| 30 | 122.28 | 14.01 | 32 | 71 | 8.33 | 55 | 120 |
| 31 | 125.83 | 15.40 | 29 | 65 | 9.09 | 50 | 110 |
| 32 | 129.38 | 16.88 | 27 | 59 | 9.91 | 46 | 101 |
| 33 | 132.92 | 18.45 | 25 | 54 | 10.78 | 42 | 93 |
| 34 | 136.47 | 20.11 | 23 | 50 | 11.70 | 39 | 85 |
| 35 | 140.02 | 21.87 | 21 | 46 | 12.67 | 36 | 79 |
| 36 | 143.57 | 23.72 | 19 | 42 | 13.69 | 33 | 73 |
| 37 | 147.11 | 25.67 | 18 | 39 | 14.77 | 31 | 68 |
| 38 | 150.66 | 27.73 | 16 | 36 | 15.91 | 29 | 63 |
| 39 | 154.21 | 29.89 | 15 | 33 | 17.10 | 27 | 58 |
| 40 | 157.75 | 32.16 | 14 | 31 | 18.35 | 25 | 54 |
| 41 | 161.30 | 34.53 | 13 | 29 | 19.66 | 23 | 51 |
| 42 | 164.88 | 37.02 | 12 | 27 | 21.04 | 22 | 48 |
| 43 | 168.39 | 39.63 | 11 | 25 | 22.48 | 20 | 44 |
| 44 | 171.94 | 42.35 | 11 | 24 | 23.98 | 19 | 42 |
| 45 | 175.49 | 45.19 | 10 | 22 | 25.55 | 18 | 39 |
| 46 | 179.04 | 48.15 | 9 | 21 | 27.19 | 17 | 37 |
| 47 | 182.58 | 51.23 | 9 | 20 | 28.89 | 16 | 35 |
| 48 | 186.13 | 54.44 | 8 | 18 | 30.66 | 15 | 33 |
| 49 | 189.68 | 57.78 | 8 | 17 | 32.51 | 14 | 31 |
| 50 | 193.22 | 61.25 | 7 | 16 | 34.43 | 13 | 29 |
| 51 | 196.77 | 64.86 | 7 | 15 | 36.42 | 12 | 27 |
| 52 | 200.32 | 68.60 | 7 | 15 | 38.49 | 12 | 26 |
| 53 | 203.86 | 72.48 | 6 | 14 | 40.63 | 11 | 25 |
| 54 | 207.41 | 76.50 | 6 | 13 | 42.85 | 11 | 23 |
| 55 | 210.96 | 80.66 | 6 | 12 | 45.15 | 10 | 22 |
| 56 | 214.51 | 84.97 | 5 | 12 | 47.53 | 10 | 21 |
| 57 | 218.05 | 89.43 | 5 | 11 | 49.99 | 9 | 20 |
| 58 | 221.60 | 94.03 | 5 | 11 | 52.54 | 9 | 19 |
| 59 | 225.15 | 98.79 | 5 | 10 | 55.17 | 8 | 18 |
| 60 | 228.69 | 103.70 | 4 | 10 | 57.88 | 8 | 17 |

APPENDIX 2 : Catch statistics for <u>Penaeus latisulcatus</u> in South Australia. Data from 1968 to 1973 were from daily log sheets only (estimated catch).

| MONTH | WEST COAST | | | SPENCER GULF | | | ST. VINCENT GULF | | |
|---|---|---|---|---|---|---|---|---|---|
| | CATCH (kg) | EFFORT (hr) | C/E (kg/hr) | CATCH (kg) | EFFORT (hr) | C/E (kg/hr) | CATCH (kg) | EFFORT (hr) | C/E (kg/hr) |
| **1968** | | | | | | | | | |
| January | 0 | 0 | - | 5151 | 126 | 40.9 | 0 | 0 | - |
| February | 0 | 0 | - | 7087 | 189 | 37.5 | 0 | 0 | - |
| March | 0 | 0 | - | 20365 | 256 | 79.6 | 0 | 0 | - |
| April | 0 | 0 | - | 9725 | 89 | 109.3 | 0 | 0 | - |
| May | 1034 | 30 | 34.5 | 38814 | 368 | 105.5 | 58 | 7 | 8.3 |
| June | 445 | 55 | 8.1 | 51955 | 883 | 58.8 | 980 | 46 | 21.3 |
| July | 181 | 5 | 36.2 | 31347 | 703 | 44.6 | 957 | 60 | 16.0 |
| August | 61 | 4 | 15.3 | 24190 | 536 | 45.1 | 483 | 23 | 21.0 |
| September | 670 | 39 | 17.2 | 47671 | 786 | 60.7 | 628 | 56 | 11.2 |
| October | 721 | 18 | 40.1 | 42910 | 1017 | 42.2 | 1459 | 98 | 14.9 |
| November | 424 | 20 | 21.2 | 67165 | 1011 | 66.4 | 1015 | 81 | 12.5 |
| December | 4110 | 86 | 47.8 | 37298 | 831 | 44.9 | | | |
| TOTAL | 7646 | 257 | 29.8 | 383678 | 6795 | 56.5 | 5580 | 371 | 15.0 |
| **1969** | | | | | | | | | |
| January | 2414 | 58 | 41.6 | 32135 | 753 | 42.7 | 2280 | 49 | 46.5 |
| February | 452 | 32 | 14.1 | 19818 | 522 | 38.0 | 1915 | 49 | 39.1 |
| March | 0 | 0 | - | 20623 | 511 | 40.4 | 1800 | 51 | 35.3 |
| April | 0 | 0 | - | 72200 | 1199 | 60.2 | 1301 | 36 | 36.1 |
| May | 0 | 0 | - | 65380 | 1142 | 57.3 | 1401 | 35 | 40.0 |
| June | 0 | 0 | - | 46712 | 1302 | 35.9 | 3127 | 73 | 42.8 |
| July | 672 | 41 | 16.4 | 82096 | 1458 | 56.3 | 3521 | 126 | 27.9 |
| August | 17140 | 408 | 42.0 | 31890 | 859 | 37.1 | 3530 | 151 | 23.4 |
| September | 18511 | 455 | 40.7 | 37147 | 810 | 45.9 | 7773 | 206 | 37.7 |
| October | 14665 | 468 | 31.3 | 52154 | 1377 | 37.9 | 7563 | 185 | 40.9 |
| November | 27300 | 752 | 36.3 | 60866 | 1479 | 41.2 | 1817 | 72 | 25.2 |
| December | 18060 | 586 | 30.8 | 36299 | 997 | 36.4 | 5456 | 182 | 30.0 |
| TOTAL | 99214 | 2800 | 35.0 | 557320 | 12409 | 44.9 | 41484 | 1215 | 34.1 |
| **1970** | | | | | | | | | |
| January | 25823 | 799 | 32.3 | 50101 | 1107 | 45.3 | 8195 | 222 | 36.9 |
| February | 12005 | 605 | 19.8 | 65894 | 1546 | 42.6 | 8977 | 282 | 31.8 |
| March | 14801 | 634 | 23.4 | 153270 | 1708 | 89.7 | 10084 | 271 | 37.2 |
| April | 22849 | 766 | 29.8 | 171158 | 1901 | 90.0 | 12540 | 293 | 42.8 |
| May | 34276 | 1263 | 27.1 | 109664 | 1848 | 59.3 | 22501 | 405 | 55.6 |
| June | 20367 | 760 | 27.2 | 81159 | 1363 | 59.5 | 9217 | 160 | 57.6 |
| July | 28762 | 994 | 28.9 | 44637 | 1552 | 28.8 | 1038 | 61 | 17.0 |
| August | 14574 | 611 | 23.9 | 14260 | 577 | 24.7 | 764 | 46 | 16.6 |
| September | 17630 | 878 | 20.1 | 17750 | 669 | 26.5 | 2113 | 135 | 15.7 |
| October | 16575 | 990 | 16.7 | 34269 | 1104 | 31.0 | 8406 | 271 | 31.0 |
| November | 15994 | 860 | 18.6 | 50703 | 1404 | 36.1 | 12835 | 362 | 35.5 |
| December | 13716 | 827 | 16.6 | 22641 | 563 | 40.2 | 9273 | 305 | 30.4 |
| TOTAL | 237372 | 9987 | 23.8 | 815506 | 15342 | 53.2 | 105943 | 2813 | 37.7 |

| | WEST COAST | | | SPENCER GULF | | | ST. VINCENT GULF | | |
|---|---|---|---|---|---|---|---|---|---|
| | CATCH kg. | EFFORT hrs. | C/E kg/hr | CATCH kg | EFFORT hrs | C/E kg/hr | CATCH kg | EFFORT hrs | C/E kg/hr |
| **1971** | | | | | | | | | |
| January | 6971 | 374 | 18.6 | 35060 | 907 | 27.6 | 12755 | 400 | 31.9 |
| February | 12526 | 653 | 19.2 | 69147 | 984 | 70.3 | 14351 | 499 | 28.8 |
| March | 2136 | 131 | 16.3 | 137188 | 1580 | 86.8 | 16227 | 585 | 27.7 |
| April | 723 | 27 | 26.8 | 190851 | 3087 | 61.8 | 20128 | 676 | 29.8 |
| May | 0 | 0 | - | 198077 | 3745 | 52.9 | 20153 | 709 | 28.4 |
| June | 21734 | 523 | 41.6 | 93930 | 2282 | 41.2 | 9070 | 324 | 28.0 |
| July | 67346 | 1776 | 37.9 | 24089 | 870 | 27.7 | 9342 | 388 | 24.1 |
| August | 29815 | 1067 | 27.9 | 17816 | 581 | 30.7 | 5482 | 243 | 22.6 |
| September | 19690 | 797 | 24.7 | 23537 | 730 | 32.2 | 9407 | 418 | 22.5 |
| October | 18194 | 753 | 24.2 | 28293 | 730 | 38.8 | 16941 | 521 | 32.5 |
| November | 45431 | 1682 | 27.0 | 58085 | 1020 | 57.0 | 12154 | 443 | 27.4 |
| December | 12936 | 562 | 23.0 | 60418 | 1165 | 51.9 | 16457 | 544 | 30.3 |
| TOTAL | 237502 | 8345 | 28.5 | 936491 | 17681 | 53.0 | 162467 | 5750 | 28.3 |
| **1972** | | | | | | | | | |
| January | 22935 | 1131 | 20.3 | 92895 | 1953 | 47.6 | 20760 | 598 | 34.7 |
| February | 6261 | 342 | 18.3 | 153362 | 2300 | 66.7 | 24370 | 862 | 28.3 |
| March | 0 | 0 | - | 134646 | 1943 | 69.3 | 17207 | 713 | 24.1 |
| April | 518 | 22 | 23.6 | 197671 | 3062 | 64.6 | 18850 | 688 | 27.4 |
| May | 22357 | 817 | 27.4 | 133355 | 3027 | 44.1 | 30408 | 1017 | 29.9 |
| June | 30161 | 1091 | 27.7 | 76900 | 1973 | 39.0 | 29379 | 945 | 31.1 |
| July | 23452 | 789 | 29.7 | 25403 | 605 | 42.0 | 2676 | 111 | 24.1 |
| August | 34596 | 1490 | 23.2 | 20780 | 569 | 36.5 | 5950 | 301 | 19.8 |
| September | 27836 | 1418 | 19.6 | 14585 | 559 | 26.1 | 14511 | 689 | 21.1 |
| October | 18657 | 845 | 22.1 | 39622 | 1172 | 33.8 | 20827 | 655 | 31.8 |
| November | 6586 | 215 | 30.6 | 138308 | 3131 | 44.2 | 41663 | 947 | 44.0 |
| December | 20790 | 747 | 27.8 | 48752 | 1513 | 32.2 | 17544 | 653 | 26.9 |
| TOTAL | 214148 | 8907 | 24.0 | 1076279 | 21807 | 49.4 | 244145 | 8179 | 29.9 |
| **1973** | | | | | | | | | |
| January | 0 | 0 | - | 93393 | 1920 | 48.6 | 13261 | 540 | 24.6 |
| February | 3323 | 154 | 21.6 | 229277 | 2659 | 86.2 | 22237 | 858 | 25.9 |
| March | 5957 | 205 | 29.1 | 222547 | 2766 | 80.5 | 19285 | 708 | 27.2 |
| April | 1425 | 92 | 15.5 | 180366 | 2566 | 70.3 | 22194 | 607 | 36.6 |
| May | 51876 | 1338 | 38.8 | 167072 | 2910 | 57.4 | 24823 | 806 | 30.8 |
| June | 48365 | 1262 | 38.3 | 63362 | 1494 | 42.4 | 24418 | 704 | 34.7 |
| July | 44132 | 1703 | 25.9 | 37607 | 1034 | 36.4 | 12721 | 499 | 25.5 |
| August | 26909 | 1054 | 25.5 | 66658 | 1616 | 41.2 | 15254 | 606 | 25.2 |
| September | 16536 | 639 | 25.9 | 72372 | 1454 | 49.2 | 12270 | 396 | 31.0 |
| October | 29977 | 929 | 32.3 | 146094 | 2589 | 56.4 | 37533 | 798 | 47.0 |
| November | 29649 | 843 | 35.2 | 149368 | 2758 | 54.2 | 44754 | 799 | 56.0 |
| December | 31738 | 1057 | 30.0 | 57230 | 1379 | 41.5 | 27354 | 716 | 38.2 |
| TOTAL | 289887 | 9276 | 31.3 | 1485346 | 25145 | 59.1 | 276104 | 8037 | 34.4 |

| | WEST COAST | | | SPENCER GULF | | | ST. VINCENT GULF | | |
|---|---|---|---|---|---|---|---|---|---|
| | CATCH kg | EFFORT hrs. | C/E kg/hr | CATCH kg | EFFORT hrs. | C/E kg/hr | CATCH kg | EFFORT kg/hr | C/E kg/hr |
| 1974 | | | | | | | | | |
| January | 20415 | 483 | 42.3 | 101893 | 1938 | 52.6 | 14773 | 438 | 33.7 |
| February | 15206 | 280 | 54.3 | 306350 | 2704 | 113.3 | 19033 | 530 | 35.9 |
| March | 2725 | 284 | 9.6 | 479286 | 2892 | 165.7 | 39606 | 945 | 41.9 |
| April | 21443 | 258 | 83.1 | 410601 | 2810 | 146.1 | 43957 | 945 | 46.5 |
| May | 9245 | 192 | 48.1 | 323862 | 3753 | 86.3 | 51228 | 1103 | 46.4 |
| June | 13582 | 411 | 33.1 | 135686 | 2665 | 50.9 | 35706 | 774 | 46.1 |
| July | 20632 | 652 | 31.6 | 43807 | 912 | 48.0 | 16785 | 319 | 52.6 |
| August | 21805 | 963 | 22.6 | 75042 | 1136 | 66.1 | 13360 | 340 | 39.3 |
| September | 13589 | 691 | 19.7 | 100828 | 1470 | 68.6 | 15350 | 405 | 37.9 |
| October | 6106 | 302 | 20.2 | 156801 | 2669 | 58.8 | 29738 | 767 | 38.8 |
| November | 11296 | 352 | 32.1 | 272782 | 3611 | 75.5 | 47715 | 805 | 59.3 |
| December | 18952 | 438 | 43.3 | 114180 | 2065 | 55.3 | 42288 | 611 | 69.2 |
| TOTALS | 174996 | 5306 | 33.0 | 2521118 | 28625 | 88.7 | 369539 | 7982 | 46.3 |

| | WEST COAST | | | SPENCER GULF | | | GULF ST. VINCENT | | | INVESTGATOR STRAIT* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CATCH (KG) | EFFORT (HR) | C/E | CATCH (KG) | EFFORT (HR) | C/E | CATCH (KG) | EFFORT (HR) | C/E | CATCH (KG) | EFFORT (HR) | C/E |
| 1975 | | | | | | | | | | | | |
| January | 19151 | 577 | 33.2 | 169058 | 3068 | 55.1 | 16123 | 613 | 26.3 | | | |
| February | 2701 | 110 | 24.6 | 252871 | 4738 | 53.4 | 24516 | 776 | 31.6 | | | |
| March | 2579 | 153 | 16.9 | 298630 | 4146 | 72.0 | 20740 | 681 | 30.5 | | | |
| April | 4596 | 191 | 24.1 | 314236 | 5171 | 60.8 | 50480 | 1259 | 40.1 | | | |
| May | 19537 | 570 | 34.3 | 173899 | 3974 | 43.8 | 23600 | 652 | 36.2 | | | |
| June | 38505 | 1256 | 30.7 | 79538 | 2388 | 33.3 | 41376 | 1115 | 37.1 | | | |
| July | 23635 | 958 | 24.7 | 45792 | 1693 | 27.1 | 8686 | 499 | 17.4 | | | |
| August | 16053 | 790 | 20.3 | 45770 | 1858 | 24.6 | 14189 | 683 | 20.8 | | | |
| September | 5834 | 329 | 17.7 | 62531 | 2383 | 26.2 | 18910 | 897 | 21.1 | 1914 | 141 | 13.6 |
| October | 6766 | 354 | 19.1 | 69357 | 2738 | 25.3 | 22994 | 1024 | 22.5 | 2737 | 116 | 23.6 |
| November | 11009 | 474 | 23.2 | 164668 | 4431 | 37.2 | 68668 | 1502 | 45.7 | 6817 | 248 | 27.5 |
| December | 6169 | 319 | 19.3 | 59753 | 2024 | 29.5 | 30324 | 605 | 50.1 | 4965 | 165 | 30.1 |
| TOTALS | 156535 | 6081 | 25.7 | 1736103 | 38612 | 45.0 | 340606 | 10306 | 33.0 | 16433 | 670 | 24.5 |
| 1976 | | | | | | | | | | | | |
| January | 6930 | 303 | 22.9 | 164928 | 3585 | 46.0 | 32702 | 802 | 40.8 | 5919 | 202 | 29.3 |
| February | 4617 | 207 | 22.3 | 288539 | 5087 | 56.7 | 31881 | 977 | 32.6 | 8221 | 284 | 29.0 |
| March | 2925 | 241 | 12.1 | 455739 | 6276 | 72.6 | 69680 | 1475 | 47.2 | 14044 | 402 | 34.9 |
| April | 5582 | 470 | 11.9 | 283985 | 4853 | 58.5 | 54649 | 1144 | 47.8 | 17943 | 384 | 46.7 |
| May | 6864 | 541 | 12.7 | 206179 | 4190 | 49.2 | 57098 | 1213 | 47.1 | 18919 | 396 | 47.8 |
| June | 7063 | 547 | 12.9 | 107563 | 2819 | 38.2 | 40969 | 939 | 43.6 | 24390 | 558 | 43.7 |
| July | 3785 | 308 | 12.3 | 73303 | 2437 | 30.1 | 29278 | 932 | 31.4 | 13636 | 365 | 37.4 |
| August | 2680 | 234 | 11.5 | 76793 | 2186 | 35.1 | 16311 | 653 | 25.0 | 8973 | 439 | 20.4 |
| September | 905 | 100 | 9.1 | 68938 | 2256 | 30.6 | 19021 | 597 | 31.9 | 5100 | 286 | 17.8 |
| October | 3136 | 256 | 12.3 | 113600 | 2855 | 39.8 | 45406 | 1066 | 42.6 | 5686 | 317 | 17.9 |
| November | 2532 | 134 | 18.9 | 171200 | 3378 | 50.7 | 77714 | 1201 | 64.7 | 8924 | 335 | 26.6 |
| December | 3970 | 221 | 18.0 | 119397 | 2804 | 42.6 | 36295 | 759 | 47.8 | 14735 | 365 | 40.4 |
| TOTALS | 50989 | 3562 | 14.3 | 2130164 | 42726 | 49.9 | 511004 | 11758 | 43.5 | 146490 | 4333 | 33.8 |

* Catch statistics from Investigator Strait include those of permit holders only.

## APPENDIX 3: MESH SELECTIVITY

The action of trawling gear is such that it can be assumed that prawns of all sizes in the population are equally likely to enter the mouth of the trawl net. However, all sizes of prawns are not equally likely to be retained in the net as smaller individuals may be able to pass through the open meshes of the netting.

The selectivity of trawls has been the subject of study for two basic purposes. Firstly, from a scientific viewpoint, it is necessary to have information on what effect the sampling gear (trawls) is having in biassing the sample towards the larger individuals in the population. Secondly, from a management viewpoint, mesh selectivity may be able to be used as a method of conserving small prawns.

Using minimum mesh sizes as a method of conserving small prawns has been a matter of some controversy in penaeid fisheries. It has been argued (J.A. Gulland pers. comm.) that mesh regulations are ineffective for the following reasons -

(1) The distortion of the net under pressure of trawling tends to close the meshes, thus preventing the escape of small prawns.

(2) If small prawns do pass through the net they are too damaged to survive.

However, in most prawn fisheries minimum mesh sizes in the trawl nets are imposed in the hope that small prawns will escape uninjured. This conservation measure has been largely based on the practice followed in scale fisheries where there is a great deal of data available (Boerema 1956, Pope 1966, etc.). In South Australia the mesh size of nets at present is limited to a minimum of 4.5 cm* in the cod end and to 5.0 cm* in the wings (See Fig.1-1 in section II-1).

During the course of this present study mesh selectivity experiments were conducted for -

(a) juvenile prawns - in relation to the beam trawl used in the nursery areas;

(b) adult prawns - in relation to otter trawl nets used by commercial fishing vessels.

The method used involved attaching a cover of fine mesh netting over the cod-ends of the main nets to retain the prawns which escape through the cod end itself. The method is described by Pope (1966).

a. Juvenile *P. latisulcatus*

Cover net experiments for juvenile *P. latisulcatus* were conducted in Barkers Inlet over the period when it was known that very small prawns were present in the population. The net, beam trawl and towing vessel are fully described in the section on methods.

The results of an experiment on 13 April 1976 are given in Table 3.1 The catches of 2 separate trawls were combined to give these data during which the subsurface water temperature was 20.5°C and approximately 3½ kg of other material (mainly seagrass, algae, small crustacea and fish) was caught in each trawl.

---

* with net stretched and measured from inside the two knots.

TABLE 3.1 Mesh selection data for juvenile *Penaeus latisulcatus* caught by beam trawl in Barker Inlet, 13 April 1976.

| Carapace Length (mm) | Nos. in main net | Nos. in cover net | Total | Percentage retained |
|---|---|---|---|---|
| 1 | | 4 | 4 | 0 |
| 2 | | 19 | 19 | 0 |
| 3 | | 21 | 21 | 0 |
| 4 | | 9 | 9 | 0 |
| 5 | | 8 | 8 | 0 |
| 6 | 6 | 16 | 22 | 27 |
| 7 | 17 | 16 | 33 | 52 |
| 8 | 25 | 9 | 34 | 63 |
| 9 | 30 | 3 | 33 | 87 |
| 10 | 39 | 2 | 41 | 95 |
| 11 | 42 | 0 | 42 | 100 |
| 12 | 22 | 1 | 23 | 96 |
| 13 | 29 | | 29 | 100 |
| 14 | 18 | | 18 | 100 |
| 15 | 8 | | 8 | 100 |
| 16 | 5 | | 5 | 100 |
| 17 | 3 | | 3 | 100 |
| 18 | 1 | | 1 | 100 |
| Totals | 245 | 108 | 353 | |

CH/

No prawns less than 6 mm C.L. were retained in the main net and all juvenile prawns over 12 mm C.L. were vulnerable to the trawl. Figure 3.1 shows the selection curve for these data. A linear regression line fitted through points between 10 and 90 per cent retained length has been used to estimate the 50 per cent length as i.e. the size of prawn at which half are retained and half escape.

For juvenile Penaeus latisulcatus under the conditions described the selection curve is steep (slope = 19) with a 50 per cent length of 7 mm carapace length.

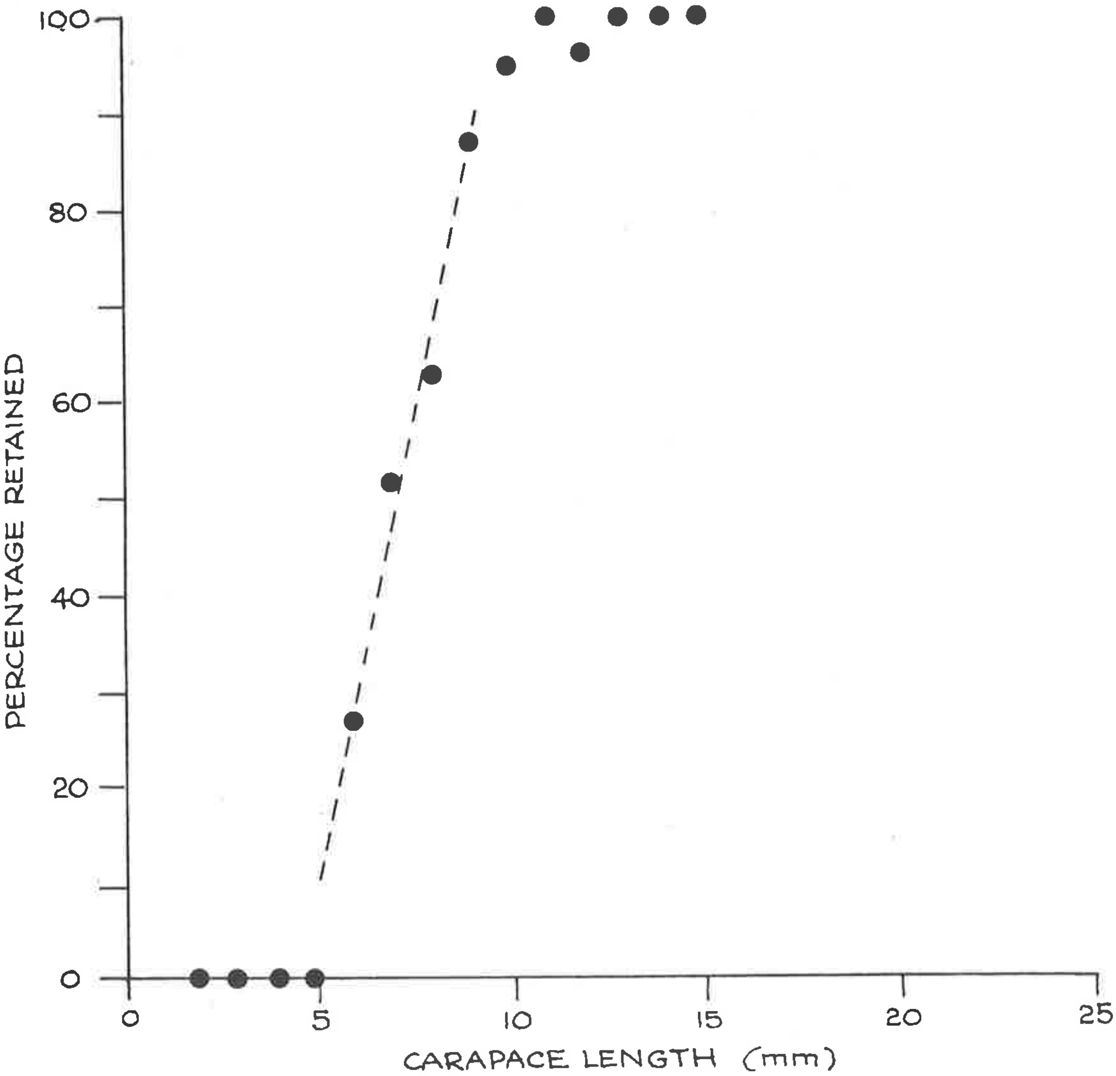



FIGURE 3-1: Mesh selection data for juvenile Penaeus latisulcatus using the beam trawl. The regression line (fitted by least squares) through points between the range 10% to 90% has the formula $Y=19.1x - 86.0$

b. Adult *P. latisulcatus*

One of the double rigged commercial vessels was found to have 2 different sized nets, one on each of the starboard and port arms and the opportunity was taken to conduct mesh selectivity experiments. The cod end of the port and starboard nets of the trawler were originally purchased as 2" and 1 3/4" respectively; the actual sizes are given in the following table.

| | Nominal size* | | Measured mean size (mm) | |
|---|---|---|---|---|
| | Inches | mm | Inside of knots + | Centres of knots ++ |
| Cover net | ½ | 12.7 | 12.8 | |
| Starboard net | 1¾ | 44.4 | 34.5 | 43.5 |
| Port net | 2 | 50.8 | 41.0 | 50.0 |

* Size given by manufacturer or supplier

\+ Actual measured size (mean) of stretched dry mesh from inside of each knot.

++ Actual measured size (mean) of stretched dry mesh between centres of each knot.

The experiment was conducted at Douglas Bank in Northern Spencer Gulf, on 28 January 1976 when it was known that small, newly recruited prawns were in the area. The subsurface water temperature was 22°C.

Two trawls were made with both nets, totalling 85 minutes trawling time. Approximately 50 kg of other material (mainly sponge, algae and small fish) were caught in each net during each trawl. All prawns caught in the cover nets were measured and samples representing approximately 1/12th and 1/9th of the total catch were measured from the main nets of 34.5 mm and 41.0 mm mesh size respectively.

Data from the experiment are given in Table 3.2 and are inconclusive in showing significant differences between the 2 different size nets. The catch from each main net were compared in Table 3.3 (adapted from the alternate-haul method - Pope, 1966). A fitted regression line through these data provided an estimate of 24.5 mm as the 50% carapace length (fig. 3-2).

Although it was not possible to run adequate experiments on mesh selection without the use of a research vessel, indications are that minimum mesh sizes may be an effective means of conserving small prawns. Small prawns in general passed through the mesh undamaged and survived well when returned to seawater holding tanks.

However, the effectiveness of having minimum mesh sizes in the cod ends of nets may be negated or reduced by -

1. large quantities of 'trash' (e.g. sponge, 'coral' etc.) blocking the meshes.
2. The fishermen deliberately setting the otter boards to stretch the nets and so distort mesh sizes. Underwater films made during the course of the study have shown that, in a properly set net, the meshes remain virtually square while being towed.

TABLE 3.2 Mesh selection data for adult *Penaeus latisulcatus* caught by commercial trawler, Douglas Bank, 28 January 1976 using main nets of 34.5 mm mesh (A) and 41.0 mm mesh (B). The main net sample represents approximately 1/12th and 1/9th respectively of the total catch.

| Carapace Length (mm) | A | | B | |
|---|---|---|---|---|
| | Nos. in main net sample | Nos. in cover net | Nos. in main net sample | Nos. in cover net |
| 15 | | | | 1 |
| 16 | | 2 | | 0 |
| 17 | | 1 | | 2 |
| 18 | | 0 | | 1 |
| 19 | | 2 | | 0 |
| 20 | 1 | 4 | | 3 |
| 21 | 1 | 8 | | 6 |
| 22 | 5 | 12 | 1 | 13 |
| 23 | 5 | 19 | 4 | 25 |
| 24 | 11 | 34 | 8 | 27 |
| 25 | 23 | 46 | 19 | 61 |
| 26 | 31 | 55 | 17 | 64 |
| 27 | 32 | 66 | 46 | 92 |
| 28 | 38 | 64 | 40 | 58 |
| 29 | 34 | 20 | 34 | 46 |
| 30 | 21 | 14 | 30 | 32 |
| 31 | 16 | 9 | 17 | 20 |
| 32 | 14 | 3 | 11 | 15 |
| 33 | 8 | 4 | 14 | 8 |
| 34 | 7 | 3 | 8 | 2 |
| 35 | 6 | 1 | 8 | 3 |
| 36 | 4 | | 7 | 0 |
| 37 | 6 | | 7 | 2 |
| 38 | 4 | | 5 | |
| 39 | 1 | | 3 | |
| 40 | 0 | | 0 | |
| 41 | 1 | | 0 | |
| 42 | 0 | | 0 | |
| 43 | 0 | | 1 | |
| 44 | 1 | | 0 | |
| 45 | 0 | | 1 | |
| 46 | 0 | | | |
| 47 | 0 | | | |
| 48 | 1 | | | |

TABLE 3.3 Mesh selection data for *Penaeus latisulcatus* applying adaption of alternate haul experiment. Data processed for frequencies greater than 10 individuals (prawns less than 33 mm carapace length).

| Carapace Length (mm) | (A) nos. in 34.5 mm cod end | (B) nos. in 41.0 mm cod end | B/A |
|---|---|---|---|
| 20 | 1 | | 0 |
| 21 | 1 | | 0 |
| 22 | 5 | 1 | 0 |
| 23 | 5 | 4 | 0.80 |
| 24 | 11 | 8 | 0.73 |
| 25 | 23 | 19 | 0.83 |
| 26 | 31 | 17 | 0.55 |
| 27 | 32 | 46 | 1.44 |
| 28 | 38 | 40 | 1.05 |
| 29 | 34 | 34 | 1.00 |
| 30 | 21 | 30 | 1.43 |
| 31 | 16 | 17 | 1.06 |
| 32 | 14 | 11 | 0.79 |
| 33 | 8 | 14 | |
| 34 | 7 | 8 | |
| 35 | 6 | 8 | |
| 36 | 4 | 7 | |
| 37 | 6 | 7 | |
| 38 | 4 | 5 | |
| 39 | 1 | 3 | |
| 40 | 0 | 0 | |
| 41 | 1 | 0 | |
| 42 | 0 | 0 | |
| 43 | 0 | 1 | |
| 44 | 1 | 0 | |
| 45 | 0 | 1 | |
| 46 | 0 | | |
| 47 | 0 | | |
| 48 | 1 | | |
| 49 | | | |
| 50 | | | |

CH ✓

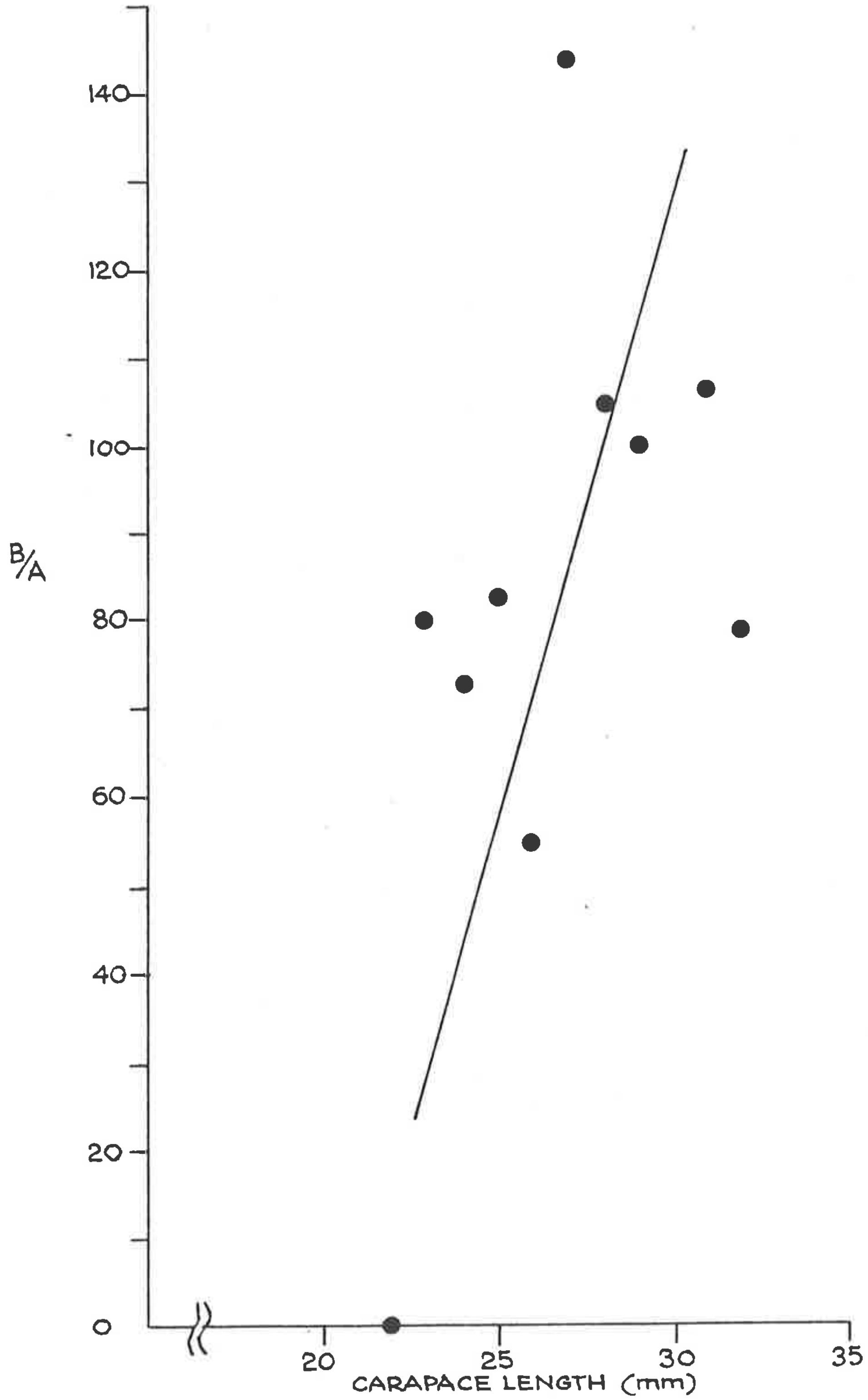



Fig. 3-2: Mesh selection data for adult *Penaeus latisulcatus* for a 41.0 mm mesh cod end. The regression line (fitted by least squares) indicates a 50% point of 24.5 mm carapace length.

APPENDIX 4.

## RELATIVE FISHING POWER

As mentioned in Section II-1. effective effort in the prawn fishery has increased dramatically over the years since the beginning of the industry; reasons for this increase have been discussed. There is, at present, a tendency to seek larger vessels in the fleet and to increase engine-power. It is essential to the management of the fishery that the effects of such changes are known or can be predicted.

In order to provide such information, the data in Tables 1 to 5 (at end of Appendix 4) were used to test the following hypotheses -

1) that annual trawling time (effort) increases with vessel length;
2) that the catch rates of double rigged vessels are greater than single rigged vessels;
3) that catch rate increases with engine horsepower;
4) that catch rate increases with boat length;
5) that annual catch increases with boat length:

These hypotheses were tested in the following manner -

| Hyp. | Data Used | Method and Test Used |
|---|---|---|
| 1 | Tables 1 and 2 | Regression line by least squares (length vs. effort) and analysis of variance. |
| 2 | Tables 3,4 and 6 | Difference between means (single rig vs. double rig) and student's t-test. |
| 3 | Tables 3 and 4 | Regression line by least squares (h.p. vs. effort) and analysis of variance. |
| 4 | Table 5 | Regression line by least squares (length vs. catch rate) and analysis of variance. |
| 5 | Table 5 | Regression line by least squares (length vs. catch) and analysis of variance. |

Results:

Hypothesis 1: The relation between vessel length and time spent trawling is shown by the regression line in Figure 1. The value of the correlation coefficient is positive but low (p = 0.19).

The analysis of variance for these data is as follows:

| Variation | DF | SS | MS | F |
|---|---|---|---|---|
| Regression | 1 | 228033.00 | 228033.00 | 1.02 N.S. |
| Error | 26 | 5805947.68 | 223305.68 | |
| Total | 27 | 6033980.68. | | |

The low value of F indicates that the slope b in the equation of the line $y = a + bx$ is not significantly different from zero - i.e. time spent trawling does not significantly increase with vessel length.

Hypothesis 2: Using catch data from Spencer Gulf (1973), table 6 shows the mean catch rates of single and double rigged vessels of similar sizes.

Using Student's t-tests the difference between the mean catch rates for each group was significant at the 0.1% level. It can be concluded that the catch rates of double rigged vessels are greater than those of single rigged vessels. From the above data the relation of catch rates of double to single rigged vessels is as follows -

$$C.E.(d) = C.E.(s) \times 1.56$$

where C.E.(d) and C.E.(s) represent the catch per effort in double and single rigged vessels respectively.

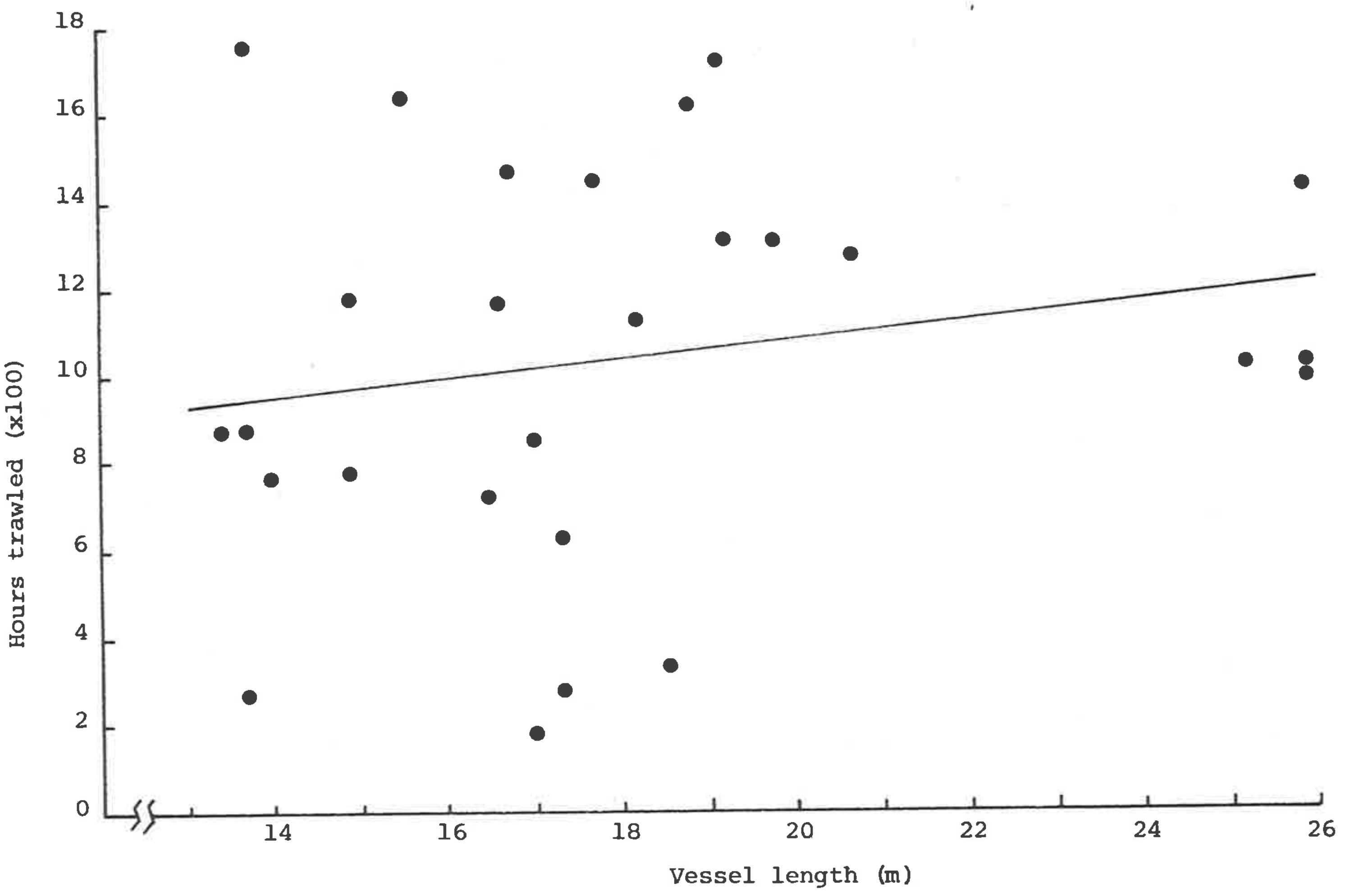



FIGURE 1 Total hours trawled per year for individual vessels of various lengths (m) both single and double rigged. The regression line best fitting these data (by least squares method) is also shown.

Hypothesis 3: The relation between the engine horsepower and catch rates for vessels fishing in Spencer Gulf (1973 data) are shown in Figure 2. The regression line of best fit using data from both single and double rigged boats combined has a ~~positive~~ correlation coefficient of 0.605.

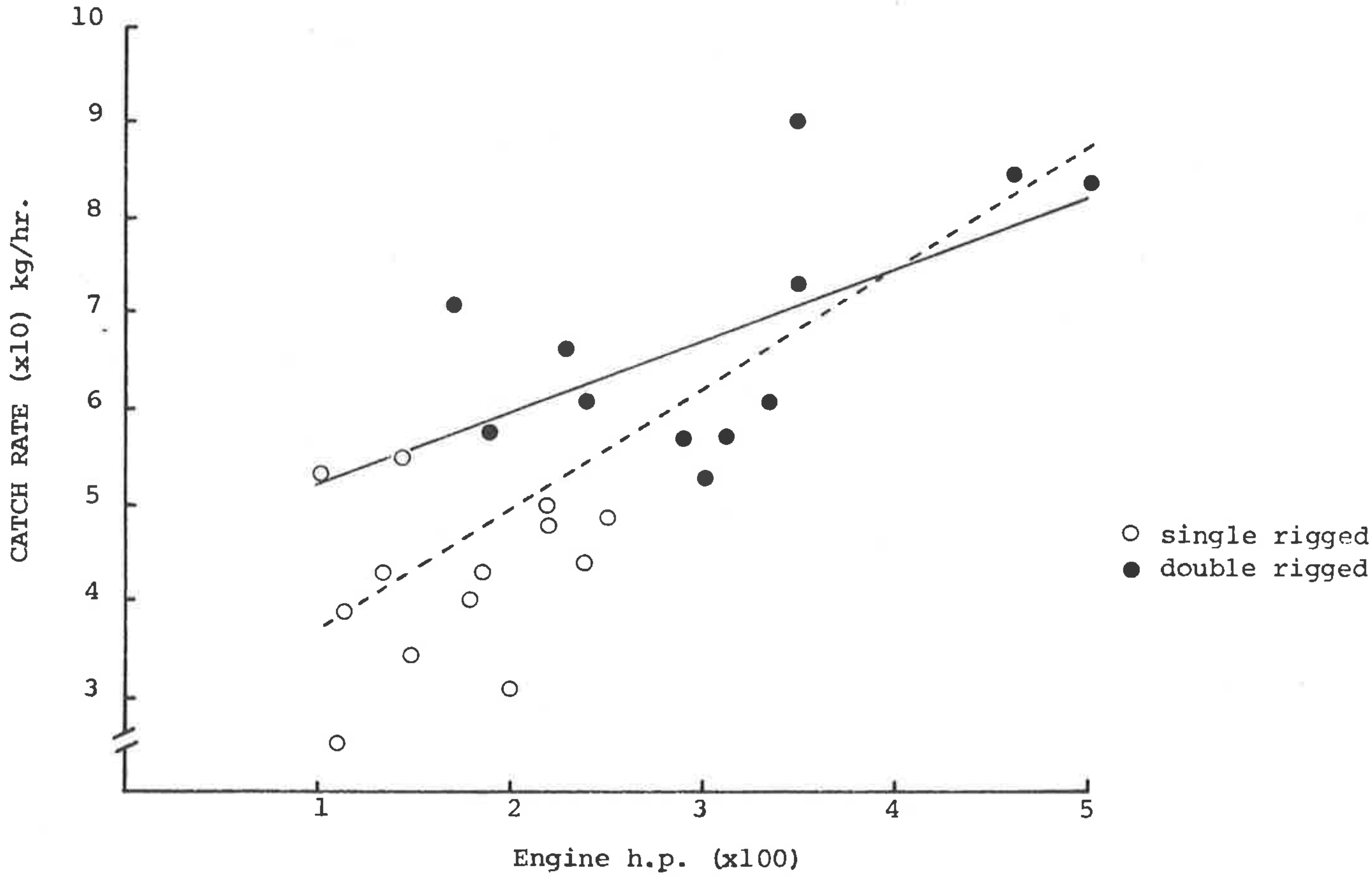



FIGURE 2. Mean annual catch rates (kg per hour) for individual vessels of various horsepowers. Regression lines are for single and double rigged vessels (broken line) and double rigged vessels only (solid line).

The analysis of variance for all vessels combined is as follows

| Variation | DF | SS | MS | F |
|---|---|---|---|---|
| Regression | 1 | 3868.97 | 3868.97 | 29.57*** |
| Error | 25 | 3270.77 | 130.83 | |
| Total | 26 | 7139.73 | | |

*** denotes significance at the 0.1% level.

The large F value is highly significant showing that the slope (b) in the equation of line y = a + bx is significantly greater than zero - i.e. that the catch rate of vessels increases with horsepower.

However, as it was shown that -

(1) the catch rates of double rigged vessels are, in general, greater than single rigged vessels, and

(2) double rigged vessels are usually larger with more powerful engines,

it was decided to examine double rig vessels separately.

The analysis of variance for double rigged vessels only is as follows -

| Variation | DF | SS | MS | F |
|---|---|---|---|---|
| Regression | 1 | 643.66 | 643.65 | 6.33* |
| Error | 11 | 1117.73 | 101.61 | |
| Total | 12 | 1761.38 | | |

*denotes significance at the 5% level.

The value of F is significant at the 5% level showing that the slope (b) of the regression line in Figure 2 is significantly different from zero. Catch rates of similarly rigged vessels can therefore be said to increase with horsepower.

Hypothesis 4: The catch statistics of all trawlers in the Spencer Gulf fishery for 1975 were examined to determine relationships between vessel length and mean annual catch rate. The data used are shown in Table 1 and Figure 3 shows the regression line of best fit by least squares. As the catch rates of double rigged vessels were shown to be greater than those of single rigged vessels, the data for double rigged was examined separately (line B) and analysed as follows -

| Variation | DF | SS | MS | F |
|---|---|---|---|---|
| Regression | 1 | 220.11 | 240.12 | 3.00 N.S. |
| Error | 31 | 2275.48 | 73.40 | |
| Total | 32 | 2495.60 | | |

The slope of the regression line does not significantly differ from zero indicating that catch rates in similarly rigged vessels do not significantly increase with boat length.

Hypothesis 5: The relation between vessel length and boat catch rate and effort (hours trawled) were shown to be positive but non-significant. As total annual catch is affected by both catch rate and effort, the data in Table 5 were used to test whether the relation between vessel length and annual catch was significant.

The lines of best fit through the data is shown in Figure 4 and the analysis of variance is given below -

| Variation | DF | SS | MS | F |
|---|---|---|---|---|
| Regression | 1 | 3347.89 | 3347.89 | 9.94** |
| Error | 36 | 12124.00 | 336.78 | |
| Total | 37 | 15471.89 | | |

** denotes significant at the 5% level.

The slope of the line in Figure 4 is significantly different from zero indicating that annual catch increases with vessel length.

At present, there is a large variation in sizes of vessels in the Spencer Gulf fishery (Table 1). Vessels being replaced in the industry must be replaced by one of the same or smaller size. During the study period there was pressure from fishermen to be allowed to change their vessels for larger ones. The above relationship was then used to estimate the increase in 'effective effort' which would result from owners of smaller vessels purchasing new ones at the maximum size of 55 feet (16.8 m). As shown in Table 5 it was estimated that, providing -

(1) all owners chose to purchase vessels of the maximum size (16.8 m)

(2) fishing patterns and tactics do not alter (other than the ability of larger boats to spend longer at sea).

the total 'effective effort' in Spencer Gulf may be increased by 12.2% by the increase in vessel size. That is, an increase approximately equal to the addition of 5 new vessels into the fishery under the present conditions.

TABLES 1 AND 2. VESSEL AND CATCH DATA (1973) FOR THE SPENCER GULF FISHERY (INCLUDING CATCH AND EFFORT FROM THE WEST COAST).

| | LENGTH (m) | ENGINE H.P. | CATCH (TONNES) | EFFORT (HOURS) | CATCH PER EFFORT. KG/HR |
|---|---|---|---|---|---|
| 1. DOUBLE RIGGED VESSELS (*indicates also fished on West Coast) | | | | | |
| | 25.2 | 500 | 86.3 | 1034 | 83.5 |
| | * 25.9 | 300 | 43.9 | 1027 | 42.7 |
| | * 25.9 | 350 | 96.5 | 1428 | 67.6 |
| | 25.9 | 290 | 58.4 | 1021 | 57.2 |
| | 14.9 | 170 | 84.9 | 1189 | 71.4 |
| | * 19.8 | 240 | 76.2 | 1304 | 58.4 |
| | 18.5 | 240 | 20.2 | 336 | 60.1 |
| | 20.7 | ? | 67.7 | 1266 | 53.5 |
| | * 15.5 | 228 | 83.9 | 1643 | 51.1 |
| | * 18.2 | 335 | 67.7 | 1128 | 60.0 |
| | * 19.2 | 2 @ 155 | 72.6 | 1318 | 55.1 |
| | 19.1 | 350 | 126.7 | 1725 | 73.5 |
| | * 16.6 | 190 | 68.5 | 1183 | 57.9 |
| | 18.8 | 460 | 136.9 | 1624 | 84.3 |
| 2. SINGLE RIGGED VESSELS (*indicates also fished on West Coast) | | | | | |
| | 14.9 | 147 | 43.0 | 785 | 54.8 |
| | 17.0 | 180 | 7.8 | 195 | 40.2 |
| | * 17.7 | 240 | 49.1 | 1446 | 34.0 |
| | * 16.9 | 150 | 5.2 | 168 | 31.0 |
| | * 17.3 | 200 | 17.1 | 626 | 27.3 |
| | 13.7 | 100 | 15.6 | 289 | 54.0 |
| | * 13.7 | 185 | 60.6 | 1781 | 34.0 |
| | 14.0 | 110 | 19.5 | 785 | 24.8 |
| | 17.3 | 200 | 9.2 | 294 | 31.3 |
| | 17.0 | 240 | 42.3 | 845 | 50.1 |
| | 16.7 | 135 | 63.3 | 1474 | 42.9 |
| | 13.7 | 220 | 41.8 | 869 | 48.1 |
| | * 16.5 | 250 | 34.0 | 723 | 47.0 |
| | * 13.4 | 117 | 27.6 | 868 | 31.8 |

TABLES 3 AND 4. VESSEL AND CATCH DATA (1973) FOR THE SPENCER GULF FISHERY (EXCLUDING CATCH AND EFFORT FROM THE WEST COAST).

| | LENGTH (m) | ENGINE H.P. | CATCH (TONNES) | EFFORT (HOURS) | CATCH PER EFFORT. KG/HR |
|---|---|---|---|---|---|
| 3. DOUBLE RIGGED VESSELS | | | | | |
| | 25.2 | 500 | 86.3 | 1034 | 83.5 |
| | 25.9 | 300 | 10.5 | 199 | 52.8 |
| | 25.9 | 350 | 70.2 | 779 | 90.1 |
| | 25.9 | 290 | 58.4 | 1021 | 57.2 |
| | 14.9 | 170 | 84.9 | 1189 | 71.4 |
| | 19.8 | 240 | 74.6 | 1230 | 60.7 |
| | 18.5 | 240 | 20.2 | 336 | 60.1 |
| | 20.7 | ? | 67.7 | 1266 | 53.5 |
| | 15.5 | 228 | 60.5 | 910 | 66.5 |
| | 18.2 | 335 | 66.9 | 1104 | 60.6 |
| | 19.2 | 2 @ 155 | 55.7 | 969 | 57.5 |
| | 19.1 | 350 | 126.7 | 1725 | 73.4 |
| | 16.6 | 190 | 68.0 | 1171 | 58.1 |
| | 18.8 | 460 | 136.9 | 1624 | 84.3 |
| 4. SINGLE RIGGED VESSELS | | | | | |
| | 14.9 | 147 | 43.0 | 785 | 54.8 |
| | 17.0 | 180 | 7.8 | 195 | 40.0 |
| | 17.7 | 240 | 24.0 | 542 | 44.3 |
| | 16.9 | 150 | 3.2 | 92 | 34.8 |
| | 17.3 | 200 | 16.4 | 519 | 31.6 |
| | 13.7 | 100 | 15.6 | 289 | 54.6 |
| | 13.7 | 185 | 40.5 | 935 | 43.3 |
| | 14.0 | 110 | 19.5 | 785 | 24.8 |
| | 17.3 | 200 | 9.2 | 294 | 31.3 |
| | 17.0 | 240 | 42.3 | 845 | 50.1 |
| | 16.7 | 135 | 63.3 | 1474 | 42.9 |
| | 13.7 | 220 | 41.8 | 869 | 48.1 |
| | 16.5 | 250 | 20.8 | 418 | 49.8 |
| | 13.4 | 117 | 19.8 | 504 | 39.3 |

TABLE 5. Catch statistics for vessels in Spencer Gulf Fishery (1975 data) right hand column shows the projected increase in 'effective effort' if authorities were transferred to 16.8 m vessels. (Increases calculated using regression line in Figure 1 - i.e. vessels to catch an extra 3 t per year for each increase of 1 m in length).

| VESSEL | LENGTH (m) | RIG | EFFORT (HOURS) | CATCH (kg) | C/E (kg/hr) | PROJECTED INCREASE % |
|---|---|---|---|---|---|---|
| | 12.5 | D* | 872 | 36 141 | 41.4 | 36 |
| | 12.2 | S** | 639 | 11 837 | 18.5 | 117 |
| | 17.3 | D | 1 258 | 44 327 | 35.2 | 0 |
| | 16.7 | D | 958 | 52 579 | 54.9 | 0 |
| | 19.7 | D | 1 602 | 91 181 | 56.9 | 0 |
| | 16.5 | D | 1 122 | 69 932 | 62.3 | 1 |
| | 16.6 | D | 823 | 32 937 | 40.0 | 2 |
| | 16.6 | D | 1 625 | 75 250 | 46.3 | 1 |
| | 19.2 | D | 1 355 | 38 539 | 28.4 | 0 |
| | 14.9 | D | 921 | 33 969 | 36.9 | 17 |
| | 14.9 | D | 986 | 49 528 | 50.2 | 12 |
| | 25.7 | D | 1 164 | 52 546 | 45.1 | 0 |
| | 15.1 | D | 1 254 | 43 307 | 34.5 | 12 |
| | 17.3 | D | 1 455 | 67 959 | 46.7 | 0 |
| | 18.8 | D | 1 039 | 62 598 | 60.2 | 0 |
| | 15.5 | D | 1 400 | 70 494 | 50.4 | 6 |
| | 14.8 | D | 1 054 | 37 241 | 35.3 | 16 |
| | 14.0 | S | 1 091 | 22 326 | 20.5 | 38 |
| | 17.0 | D | 1 692 | 65 251 | 38.6 | 0 |
| | 14.6 | D | 588 | 20 506 | 34.9 | 32 |
| | 16.9 | D | 1 322 | 45 837 | 34.7 | 0 |
| | 16.7 | D | 929 | 33 971 | 36.6 | 1 |
| | 15.3 | D | 1 024 | 37 021 | 36.2 | 12 |
| | 17.0 | S | 156 | 5 439 | 34.9 | 0 |
| | 13.6 | S | 429 | 10 009 | 23.3 | 96 |
| | 15.8 | D | 1 223 | 51 345 | 42.0 | 6 |
| | 16.5 | D | 905 | 49 853 | 55.1 | 2 |
| | 19.2 | D | 1 451 | 60 882 | 42.0 | 0 |
| | 18.5 | D | 1 288 | 62 685 | 48.7 | 0 |
| | 20.7 | D | 1 746 | 82 146 | 47.0 | 0 |
| | 13.7 | S | 1 442 | 55 207 | 38.3 | 17 |
| | 18.2 | D | 1 582 | 74 763 | 47.3 | 0 |
| | 17.0 | D | 664 | 33 056 | 49.8 | 0 |
| | 17.3 | D | 1 207 | 62 121 | 51.5 | 0 |
| | 25.2 | D | 1 126 | 62 928 | 55.9 | 0 |
| | 19.1 | D | 1 419 | 72 711 | 51.2 | 0 |
| | 25.6 | D | 1 182 | 51 225 | 43.3 | 0 |
| | 14.0 | D | 1 061 | 31 876 | 30.0 | 26 |
| | | | | | | 12.2% |

* Double rig
** Single rig

| Single Rig | | Double rig | |
|---|---|---|---|
| Length (m) | Catch rate (kg/hr) | Length (m) | Catch rate (kg/hr) |
| 14.9 | 54.8 | 14.9 | 71.4 |
| 17.0 | 40.0 | 19.8 | 60.7 |
| 17.7 | 44.8 | 18.5 | 60.1 |
| 16.9 | 34.8 | 15.5 | 66.5 |
| 17.3 | 31.6 | 18.2 | 60.6 |
| 17.3 | 31.3 | 19.2 | 57.5 |
| 17.0 | 50.1 | 19.1 | 73.5 |
| 16.7 | 42.9 | 16.6 | 58.1 |
| 16.5 | 49.8 | 18.8 | 84.3 |
| 15.1 | 42.2 | 17.8 | 65.9 = $\overline{X}$ |

TABLE 6 : Mean catch rates of single and double rigged vessels in the size range 14 to 20 m during 1973, Spencer Gulf.

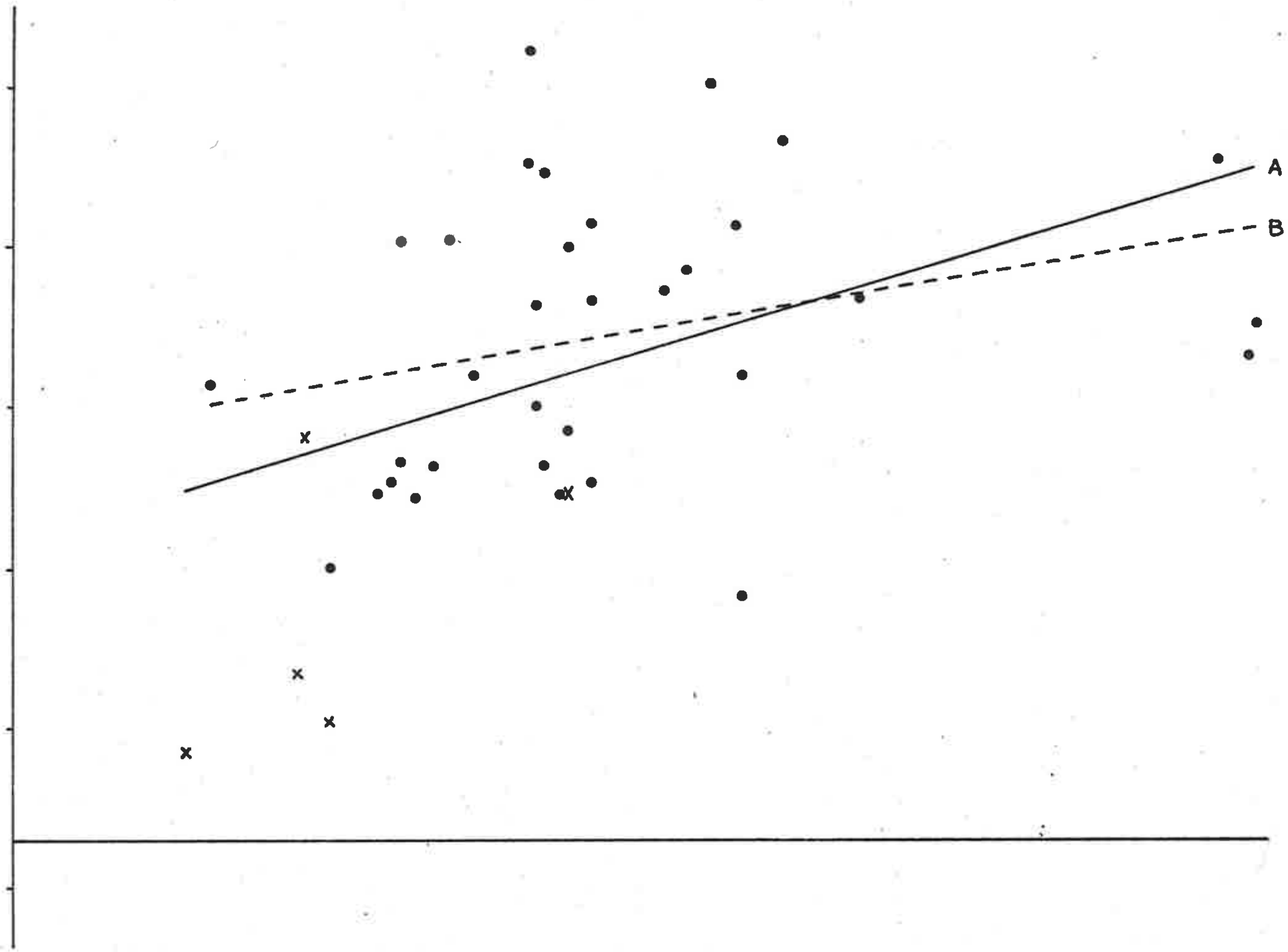



Fig. 3: Relation of annual catch rate to vessel length; catch rates of single and double rigged vessels are indicated by crosses and points respectively. Regression lines are for all vessels (solid line) and double rigged vessels only (broken line) - data from Spencer Gulf 1975.

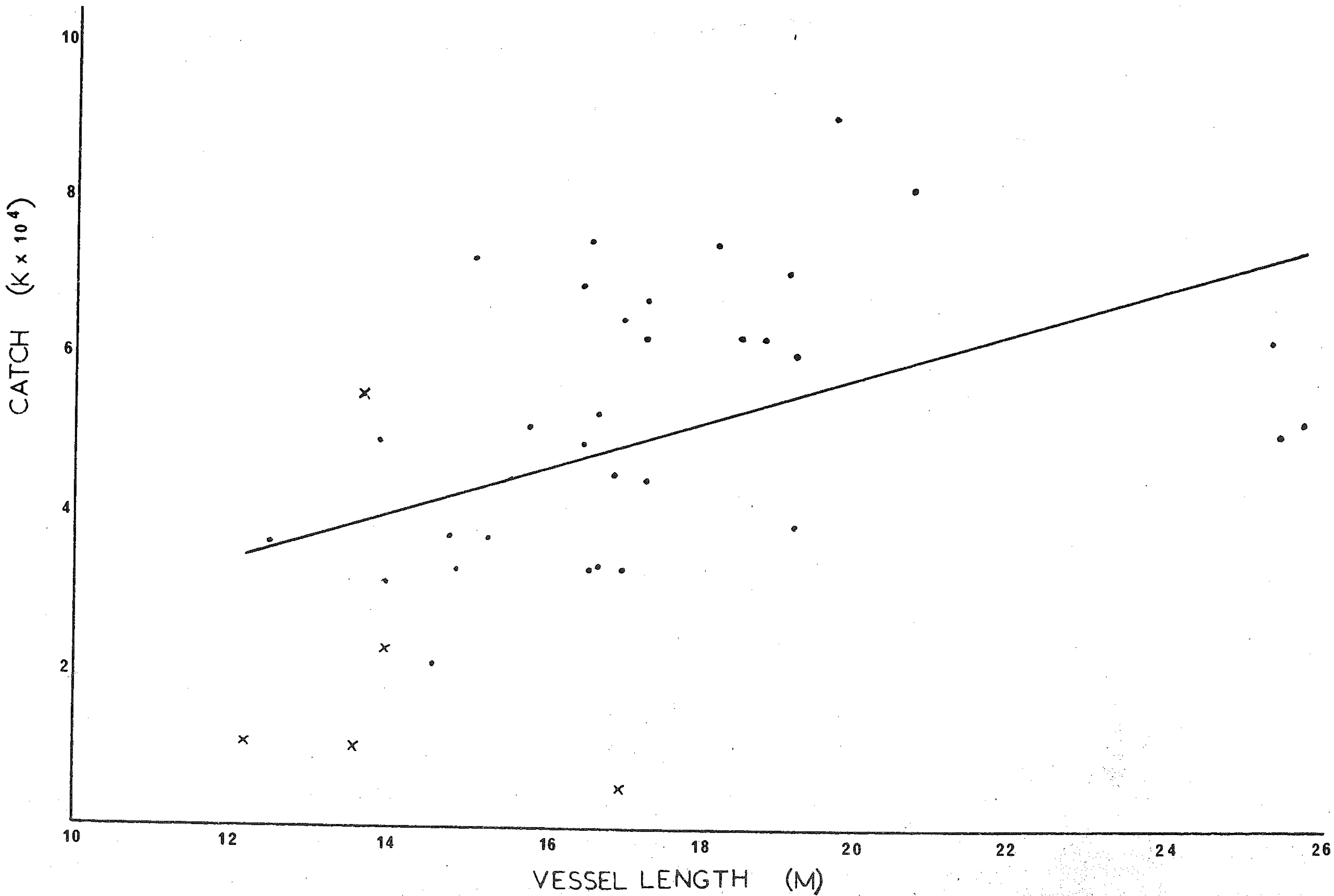



Fig. 4: Relation of annual catch to vessel length; catches of single and double rig vessels are indicated by crosses and points respectively. The regression line fitting these data (by least squares method) is also shown (data from Spencer Gulf 1975).