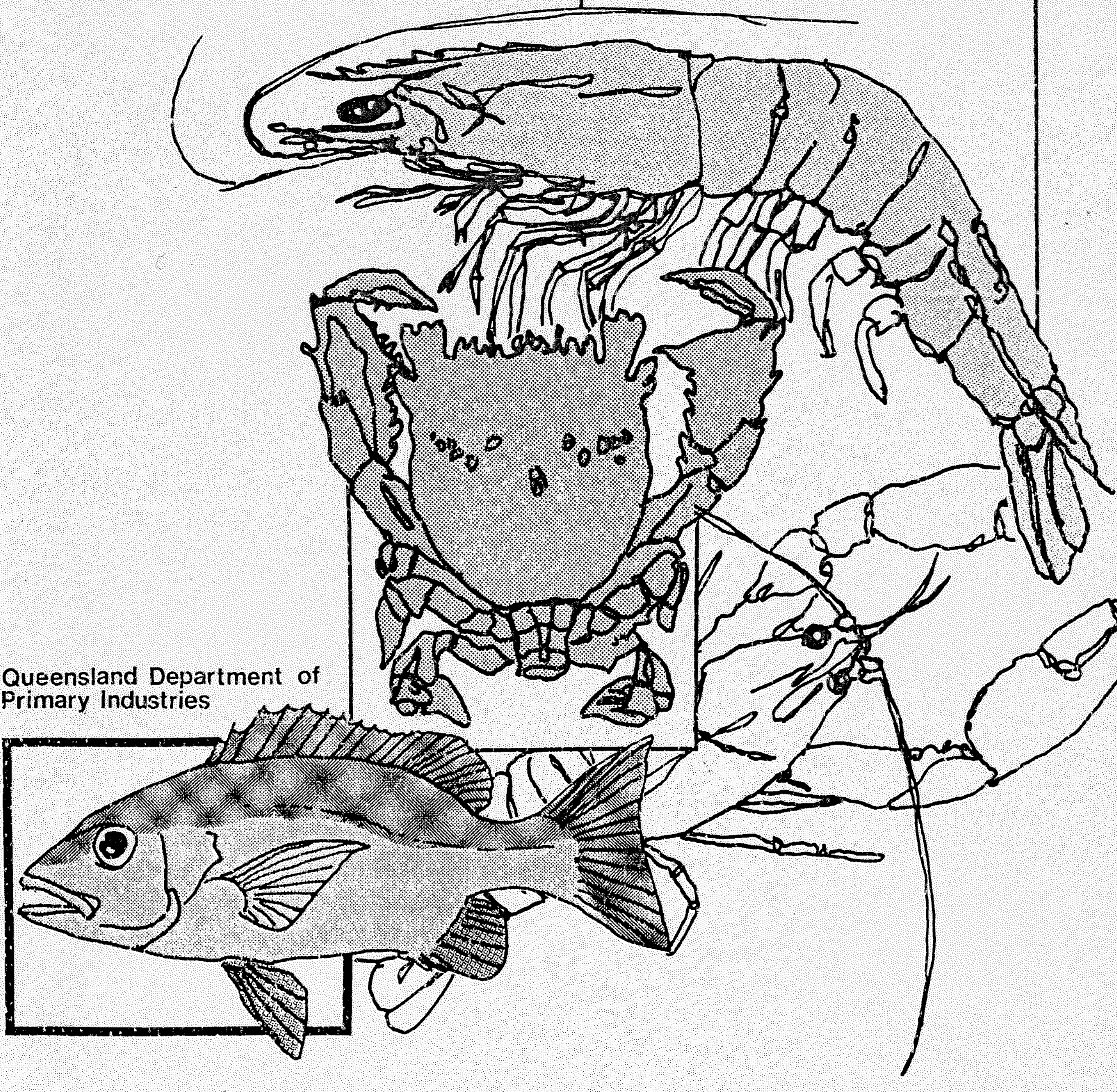
FISHERIES RESEARCH

The fishery for red spot king prawns (*Penaeus longistylus*) off the central Queensland coast

FIRTA grant 84/20



Queensland Department of
Primary Industries

The fishery for red spot king prawns (*Penaeus longistylus*) off the central Queensland coast

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Final report to the Fishing Industry Research Trust Account

Submitted February 1988

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Department of Primary Industries, Queensland Government

THE FISHERY FOR RED SPOT KING PRAWNS (*PENAEUS LONGISTYLUS*) OFF THE CENTRAL QUEENSLAND COAST

FIRTA GRANT 84/20

TITLE OF PROPOSAL

Studies on the biology of, and the fishery for, the red spot king prawn *Penaeus longistylus*

NAME OF APPLICANT

Queensland Department of Primary Industries

OBJECTIVES

1 To determine the distribution of juvenile and adult *P. longistylus* on the Queensland east coast seaboard.

2 To establish basic biological parameters of growth, movement and reproductive cycle in the species.

3 To establish a system of recording catch and effort, and processors' landing data which can be used to monitor long term changes in population levels and exploitation rates.

PERSON RESPONSIBLE FOR THE PROJECT

Mr. R. G. Pearson, Director, Fisheries Research Branch

PROJECT LEADER

Mr. M. C. L. Dredge, Senior Fisheries Biologist, Fisheries Research Branch

CONTENTS

SUMMARY

The fishery for king prawns which occurs between 18°S and 21°S has been investigated over a three year period. The fishery takes place predominantly during winter months. Availability of alternative target stocks as well as recruitment timing is responsible for the fishery's timing.

Annual catch has increased to about 2000 tonnes in 1987, from an annual catch of about 700 tonnes in 1984. This has been brought about by increased effort in the fishery, as the average annual catch rate has remained steady.

About 70% of the catch is red spot king prawn, Penaeus longistylus. The remainder is blueleg king, P. latisulcatus. Redspot kings recruit onto the main fishing grounds in the Great Barrier Reef lagoon over an extended period, whereas blueleg kings recruit over a comparatively short period.

Blue leg king prawns follow a conventional penaeid life cycle. Juveniles use coastal flats as nursery areas and move to deeper water as they mature. Red spot kings are unique in that they use coral reef lagoons as nursery areas. The species' biology is attuned to the coral reef environment.

Tagging studies conducted on red spot king prawns showed that adults were sedentary. Estimates of growth parameters and natural mortality obtained from tagging data are sufficient to use in a basic yield model.

INTRODUCTION

A stock of red spot king prawns (*Penaeus longistylus*) was rediscovered by fishermen working for scallops (*Amusium balloti*) and bugs (*Thenus spp*) in near reef waters off Townsville in the early nineteen seventies, after being first identified during the 1959 "Challenge" survey (Anon 1959). A fishery for the species began in the mid nineteen seventies. The fishery developed slowly until 1982, when effort increased rapidly. Trawlers based in Lucinda, Townsville and Bowen were the initial beneficiaries of the newly developed fishery. More recently, boats normally based between Cairns and Brisbane have worked the stock. Whilst *P. longistylus* occurs between Torres Strait (10°S) and North Reef (23°S) on the Queensland east coast, the fishery's development has largely taken place between 18°S and 21°S.

The fishery presents a series of problems (some unique) to fisheries managers. As of 1984, data on the magnitude of the fishery, its seasonality and landing variations had not been collated. The biology of the major target species (*P. longistylus*) was virtually unknown, the species having been regarded as comparatively rare until recent times (Penn 1980). Data on distribution, habitat requirements, reproductive cycle, recruitment, growth rates and mortality levels, which are a priori requirements for effective stock management, were not available. During the course of the project, the multi-species nature of the fishery became apparent. Trawlers working for red spot kings catch blueleg kings (*P. latisulcatus*), scallops (*A. balloti*) and Moreton Bay bugs (*Thenus spp*) as part of their catch. The same boats also work for tiger (*P. semisulcatus, P.esculentus*) and endeavour (*Metapenaeus endeavouri, M. ensis*) prawns on coastal grounds. Any management proposals aimed at maximizing production in the fishery must take into consideration the complex nature of the fishery.

Finally, the fishery for king prawns takes place within waters under the control of the Great Barrier Reef Marine Park Authority. There is potential for interaction between the fishery and the Marine Park Authority, whose management objectives may not coincide with those of the fishery.

In 1984 FIRTA funded a research project designed to give basic biological data on the major target species, and information on the trawl fishery for king prawns which occurs between 18°S and 21°S., off the central Queensland coast. Stated objectives for the project included

-a description of juvenile and adult red spot king prawn distribution along the continental shelf of Queensland.

-description of basic biological parameters including reproductive cycle, growth and movements of red spot king prawns

-establishment of a data base on the central Queensland king prawn fishery.

This data base was to include both estimates of total landings and continuous monitoring of catch rates and effort distribution in the fishery, sufficient to use as a basis for population studies.

The study was designed to be conducted in conjunction with a detailed investigation of trawl bycatch which was funded by the Great Barrier Reef Marine Park Authority.

In this report, a description of techniques used to obtain information on the biology of and fishery for P. longistylus, and summaries of biological and fisheries data are given.

MATERIALS AND METHODS

The Fishery

Data on monthly landings received by major processors along the Queensland coast between Lucinda and Bowen has been obtained on a voluntary basis. Many of the boats which participate in the fishery are transients which may unload at ports other than those monitored, or sell to unregistered buyers. This has induced a substantial error source into estimates of total landings. Further leakage occurs from those boats equipped with dry freezing plant which export their product directly from the wharfside. A second estimate of total catch has been made by multiplying known catch rates with estimated total effort aimed at the stock. The two estimates of catch have been interpolated to give final, order of magnitude estimates of landings from the fishery. These should be interpreted with due caution.

Data from the fishery, including effort distribution, catch rates, and catch composition has been acquired via a voluntary log book scheme operated in the fishery. Some 40-50 trawlers, most based at Townsville and Lucinda, have participated in the voluntary programme. Participating skippers completed a shot by shot record of their catches of king, tiger, endeavour and banana prawns in six by six minute grids, using NP04 (Northern prawn fishery) log books. Records of bycatch (scallop and Moreton Bay bug) are kept by some skippers. Skippers also record depth and duration of trawl shots. Log books are collected at the wharf and mailed to the Burnett Heads Fisheries Laboratory for coding. Each day's fishing is compressed into a single 80 byte record, coded and loaded onto a random access file on a micro computer, using a BASIC program. A separate file has been established for each year's data. Summaries of the data including effort distribution over space and time, catch rates by species complex and more specialized summaries on individual performance can be obtained using a suite of BASIC programs.

Biology of Red Spot King Prawns

Distribution of juveniles

Habitat requirements of juvenile red spot king prawns were unknown when this study commenced. The initial sampling programme was designed to demonstrate whether juvenile red spot kings used the estuarine or coastal nursery areas required by most Penaeidae. Seventeen sites, abutting five estuaries or coastal embayments were selected as representative of the coastal environment between 18°S and 21°S (Fig 1). These were sampled at lunar monthly intervals, using 2.5 mm, 12 mm and 28 mm mesh beam trawls, which were towed from a 5 m outboard powered dinghy. When possible sampling was conducted during day and night, during the upper half of the tide. At the completion of each 15 min trawl, all penaeid prawns were sorted, washed and frozen. They were then returned to the laboratory for identification, counting and measurement of length. The programme was continued over twelve months.

On completion of the coastal sampling programme, a second beam trawling programme was established, this time to sample prawn abundance on coral reef tops. Sampling took place during daylight hours on or about the new moon. A 1 m wide beam trawl frame was fitted to a 1.5 kwatt water pump mounted in a 5 m dinghy via 50 m of 50 mm pressure hose (Penn and Stalker 1975). The hose was set up to act both as a trawl warp and a conduit for water pumped from the dinghy to outlet jets on the beam trawl frame. These angled downwards in such a way that when the pump was operating, prawns and other lightly buried fauna were forced into the water column and became vulnerable to a towed net. Nets of 2.5 mm and 13 mm mesh were towed from the frame. Samples were taken from the reef crest and

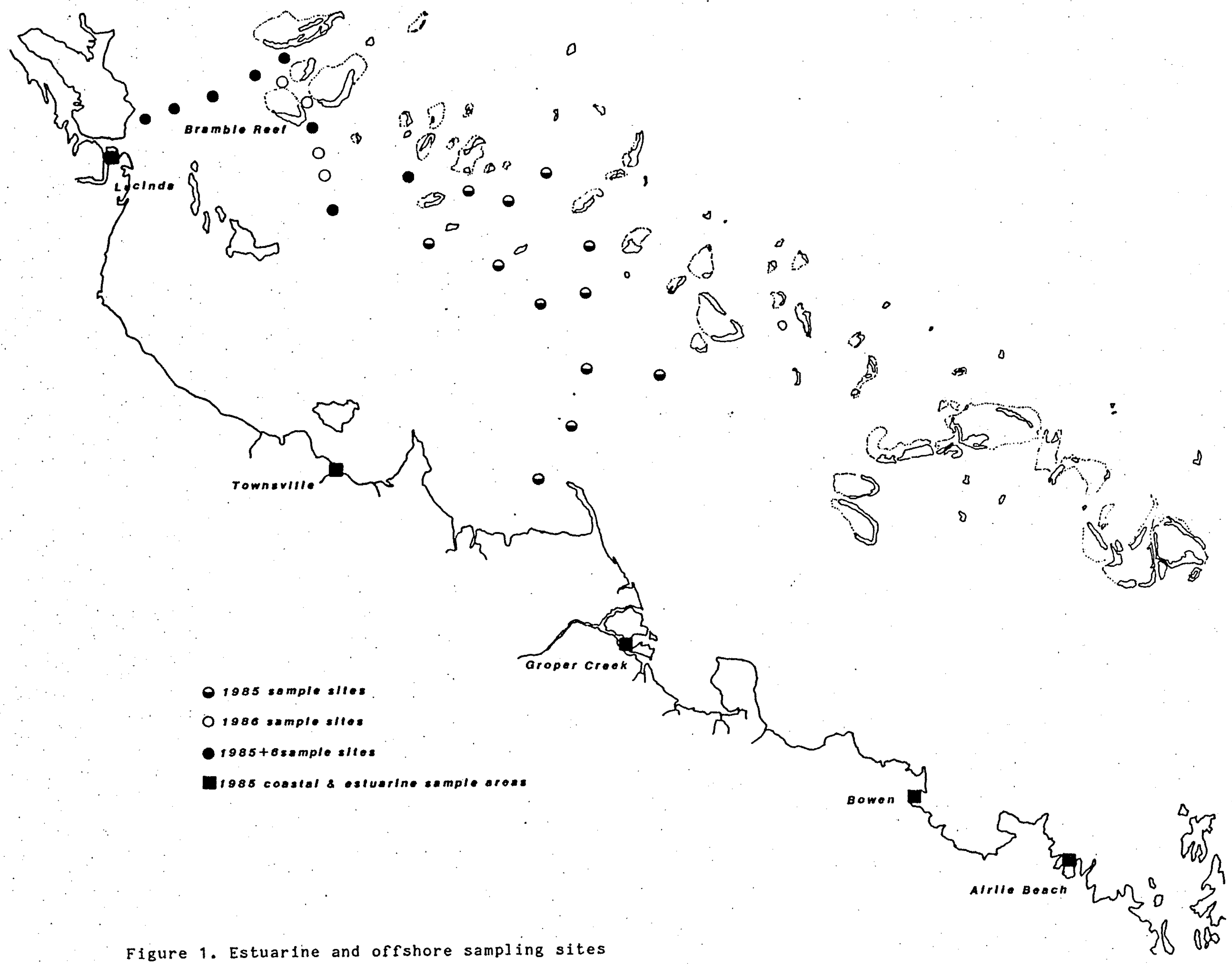

Figure 1. Estuarine and offshore sampling sites

reef lagoon of Bramble Reef (18°25′ S, 144°43′ E) for two days each lunar month for twelve months. The depth of each trawl sample was recorded, and location on the reef mapped by referring to an anchored mother ship with a hand held prismatic compass. The catch (normally a mixture of sand and invertebrates) was held in labelled plastic bags on ice prior to being sorted. All Penaeidae taken were identified and measured.

Distribution and abundance of adults

Distribution, abundance and size composition of red spot and other penaeids in offshore and inter reef areas were monitored over a two year period. Twenty four sites were selected either on the basis of their being in or adjacent to the major king prawn fishing grounds, or on transects from the shore to the Great Barrier Reef (and the major king prawn grounds), or on a transect from immediate proximity to a coral reef to waters distant to reefs (Fig 1). Eight of these sites were sampled over the full twenty four months of the programme, with the remainder being sampled over twelve months in either 1985 or 1986. Samples were taken from the 19 m research vessel "Gwendoline May" with paired 11 m head rope Florida Flyer nets. Each site was trawled for half an hour and all Penaeus spp and Metapenaeus spp were taken from the catch, counted and measured.

A sample of up to 40 female prawns from each species was snap frozen at sea, and later examined in the laboratory for reproductive development. Females were measured and dissected to demonstrate the presence or absence of a spermatophore in the thylecal cavity. The ovary of each second female was removed, weighed and ascribed to a macroscopic five stage scale of development based on criteria set down by Tuma (1967) and Yano(1984). Gonad tissue from all females was preserved for histological examination . Sections from preserved ovaries were cut at 5-7 microns, stained in haematoxylin and eosin and examined for celluar development under a compound microscope.

Growth rates, movement and natural mortality of adult red spot king prawns were described from data generated in a series of tagging experiments. In 1985, 1606 adult red spot kings were tagged with 50 mm streamer tags and released on the bottom at 7 sites. A further 2140 adults were tagged in 1986 and released at 5 sites. Most returns came from fishermen, who supplied recapture dates and positions with whole tagged prawns. Processors returned 24% of tagged prawns. The recapture date and position of these returns could be determined in only a small number of cases.

RESULTS

Distribution of *P. longistylus*

Penaeus longistylus has been recorded from Lord Howe Island, the northern Australian coast, the Arafura Sea and from near coastal areas of the eastern Indian Ocean and the South China Sea (Grey et al 1983, Anon 1981). The species is comparatively rare in Western Australian and Gulf of Carpentaria waters (Penn 1980, Somers 1987) and makes up only 5% of landings from the Torres Strait prawn fishery (Somers et al 1987). The Queensland east coast is the only area where the species is the major component of a fishery. *Penaeus longistylus* has been recorded between Torres Strait (10°S) and North Reef (23°S). A major fishery for the species exists between 18°30′ S and 21°S, offshore of Lucinda to Mackay. There are minor fisheries for the species off islands of the Capricorn Group (23°S), and survey work has shown some potential for the species in the inter reef areas of the Hardline Reef complex (Dredge and van Dyke 1987). The species also supports a minor fishery in near reef waters north of Cairns, between about 11°S and 14°S, which is still developing.

The Study Area

Between 18°S and 21°S, red spot king prawns occur in or adjacent to the most diverse coastal environment in Australia. To the north, a wet tropical climate and high coastal ranges combine to form short,high flowing rivers with open flood prone estuaries. Between about 19°S and 20°30′ S, the area is dry, the coastal plains relatively flat, and the coastal and estuarine enviroment is far less vegetated and flood prone than is the case further north. South of about 20°30′ S, the coastline features a series of oceanic bays backed by high mountains, which block the ingress of any major river system.

The Great Barrier Reef (GBR) lies some 30-60 km east of the coast. The coast and the GBR are separated by a body of water (the GBR lagoon) which grades in depth from the coast to a characteristic shelf of about 40-50 m. The GBR lagoon is protected from the prevailing south-east trades by the Reef, but is subject to strong tidal flow.

The Fishery

There are three clearly identifiable fisheries for prawns on the Queensland seaboard between 18°S and 21°S. These are

-A day time, near coastal fishery for banana prawns, <u>P. merguiensis</u>.

-A night time fishery for tiger (<u>P. esculentus</u>, <u>P. semisulcatus</u>) and endevour <u>(M. endeavouri</u>, <u>M. ensis)</u> prawns.

-A night fishery for king prawns (<u>P. longistylus</u>, <u>P. latisulcatus</u>)

-Commercial bycatches of Moreton Bay bugs (<u>Thenus spp</u>) and scallops (<u>Amusium spp</u>) are taken in the latter two fisheries.

Magnitude of the fisheries

Total landings from the king prawn fishery have varied between about 200 and 2000 tonnes in the past 6 years and catches, whilst variable, appear to be increasing (Table 1). King prawn landings are known to exceed both tiger and banana landings in this area. Records of total buy-in by processors indicate that the catch of kings are of the order of 2-3 times greater than that of the other two fisheries (Table 2).

TABLE 1. Estimates of total landings and average catch rates from the central Queensland king prawn fishery

Year	1981	1982	1983	1984	1985	1986	1987
Catch tonnes	200	750	250	650	650	1800	2000?
Catch rate kg / hour	-	-	-	-	9.82	11.07	10.61

TABLE 2. Proportion (%) of total prawns by species complex taken by buyers between Lucinda and Bowen

	1984	1985	1986	1987
Kings _P.latisulcatus_ _P.longistylus_	65.7	72.3	53.3	54.2
Tigers _P. esculentus_ _P. semisulcatus_	20.2	16.4	26.1	37.4
Endeavours _M. endeavouri_ _M. ensis_	5.9	4.9	5.3	7.2
Banana _P. merguiensis_	7.5	5.3	13.6	7.1
Corals _Metapenaeopsis_	0.8	0.1	0.2	0.7

Spatial distribution of the fished stocks

The spatial distribution of catches of king and tiger/endeavour prawns, based on log book data, is shown in Fig. 2 a, b, c. King prawns are taken over a wide area of near-reef ground, particularly to the west of the GBR. There appears to be some spatial variation in recruitment onto these grounds from year to year. In 1984, a large proportion of the the total year's landings were taken in waters north of 19°30'S. But in 1986 and 1987, the grounds adjacent to Old, Faith and Hope Reefs, south of 20°S have been the most productive. There have been minor catches of king prawns in coastal regions, particularly early in the year. The extent of overlap between king prawn and tiger prawn grounds is limited, and the generalization that tiger and endeavour prawns are taken in near-coastal waters while most kings come from near-reef, offshore grounds is reasonably accurate.

Tiger prawns are taken on far more defined grounds than are king prawns. Regional grounds can be defined to give a series of "pocket" fisheries near Lucinda, Magnetic Island, Capes Bowling Green and Upstart, and near Bowen. Tiger and endeavour prawns are taken between these areas, but not in the same quantities as are taken from the main grounds.

Effort allocation over time

An estimate of relative fishing effort allocated to the king and tiger/endeavour prawn fisheries has been made using log book data. Each record was examined and if king or tiger prawn catch exceeded 10 kg, the vessel was said to be targeting for the respective species group. Data have been summarized in Fig. 3 and Fig. 4, on a monthly and yearly basis. The fishery for king prawns

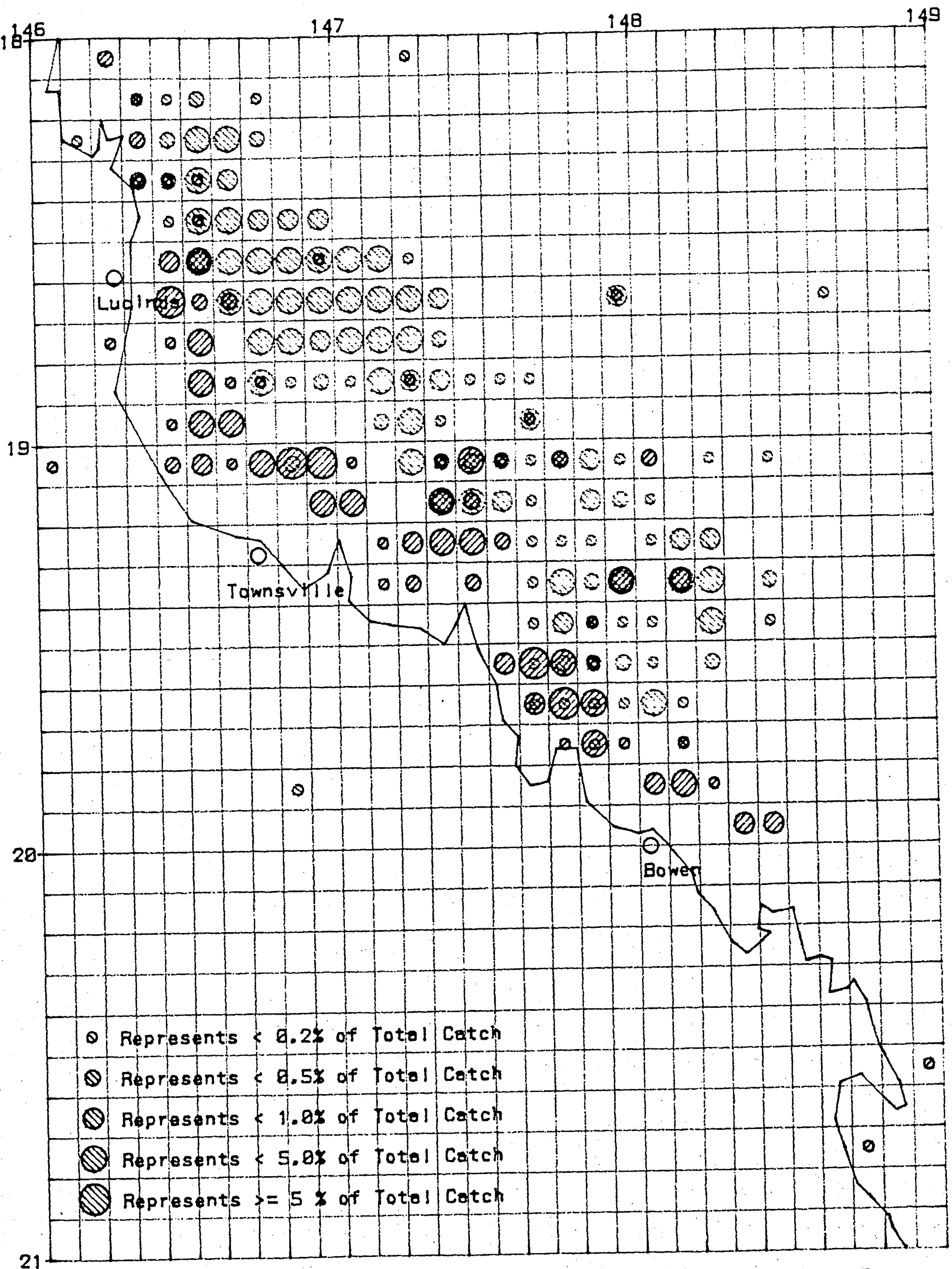

Figure 2a. Spatial distribution of catch from the king (▨) and tiger (▨) prawn fisheries-1985

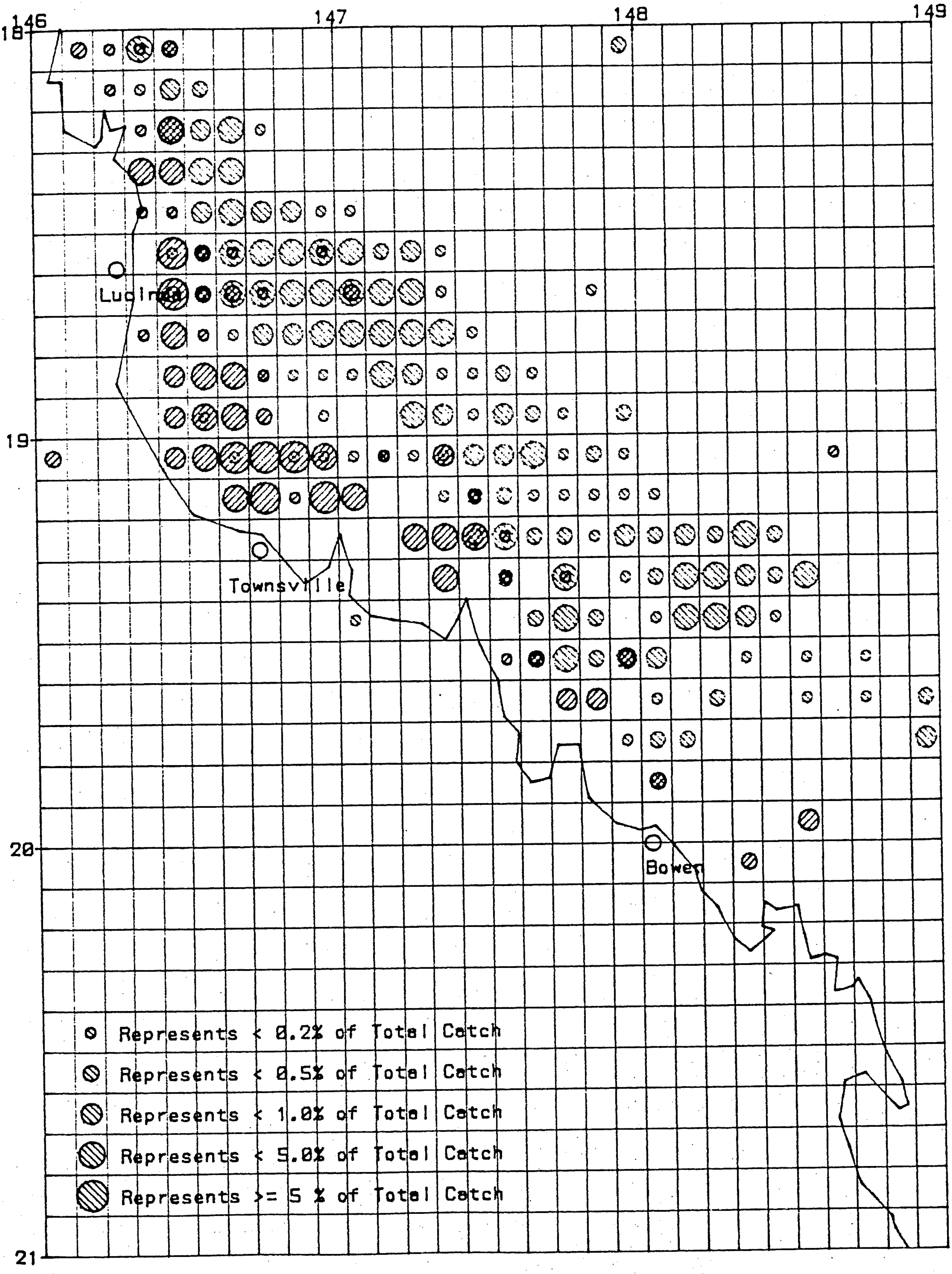

Figure 2b. Spatial distribution of catch from the king ( ) and tiger ( ) prawn fisheries-1986

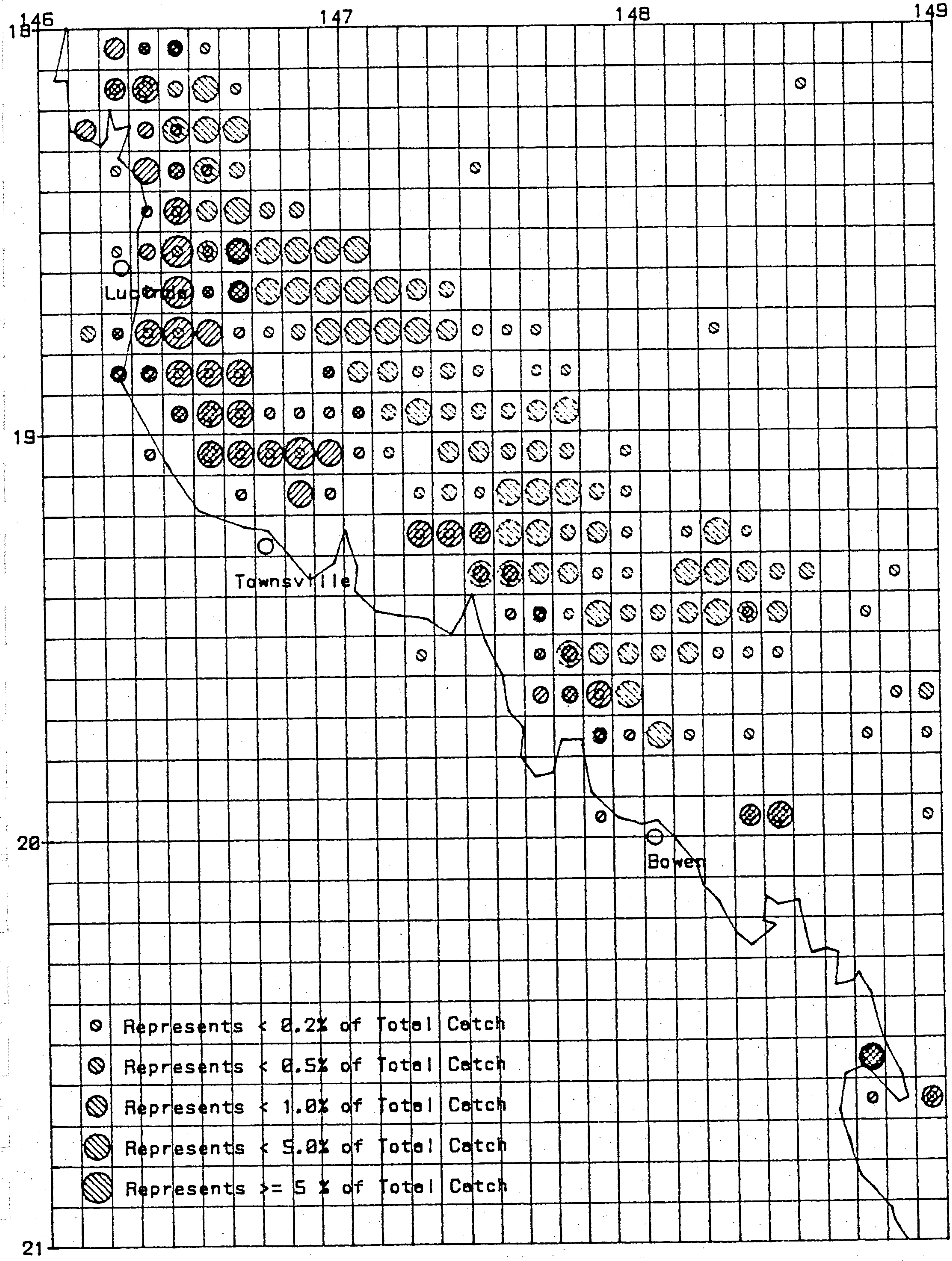

Figure 2c. Spatial distribution of catch from the king ( ) and tiger ( ) prawn fisheries-1987

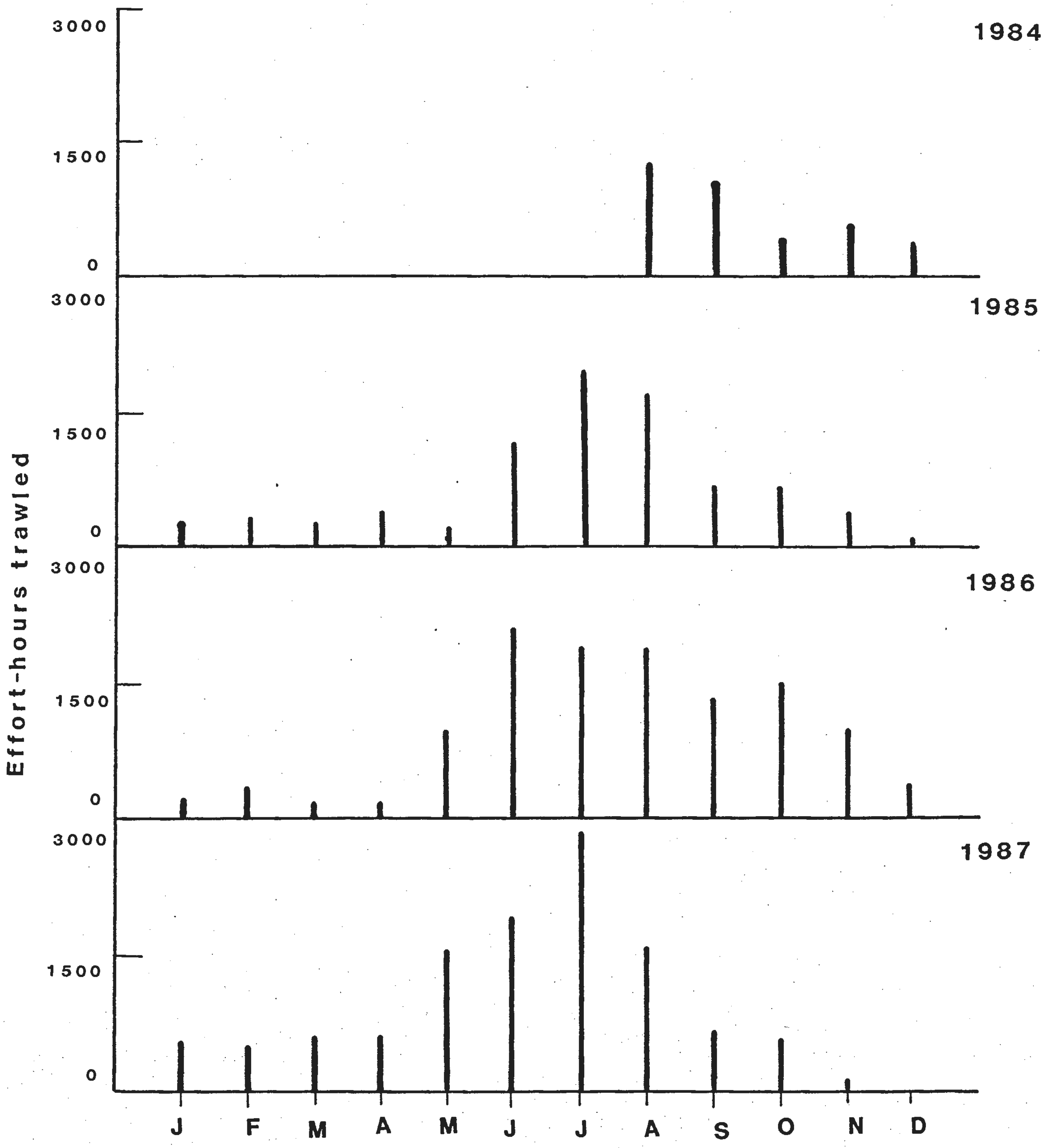

Figure 3. Effort allocated to the king prawn fishery over time

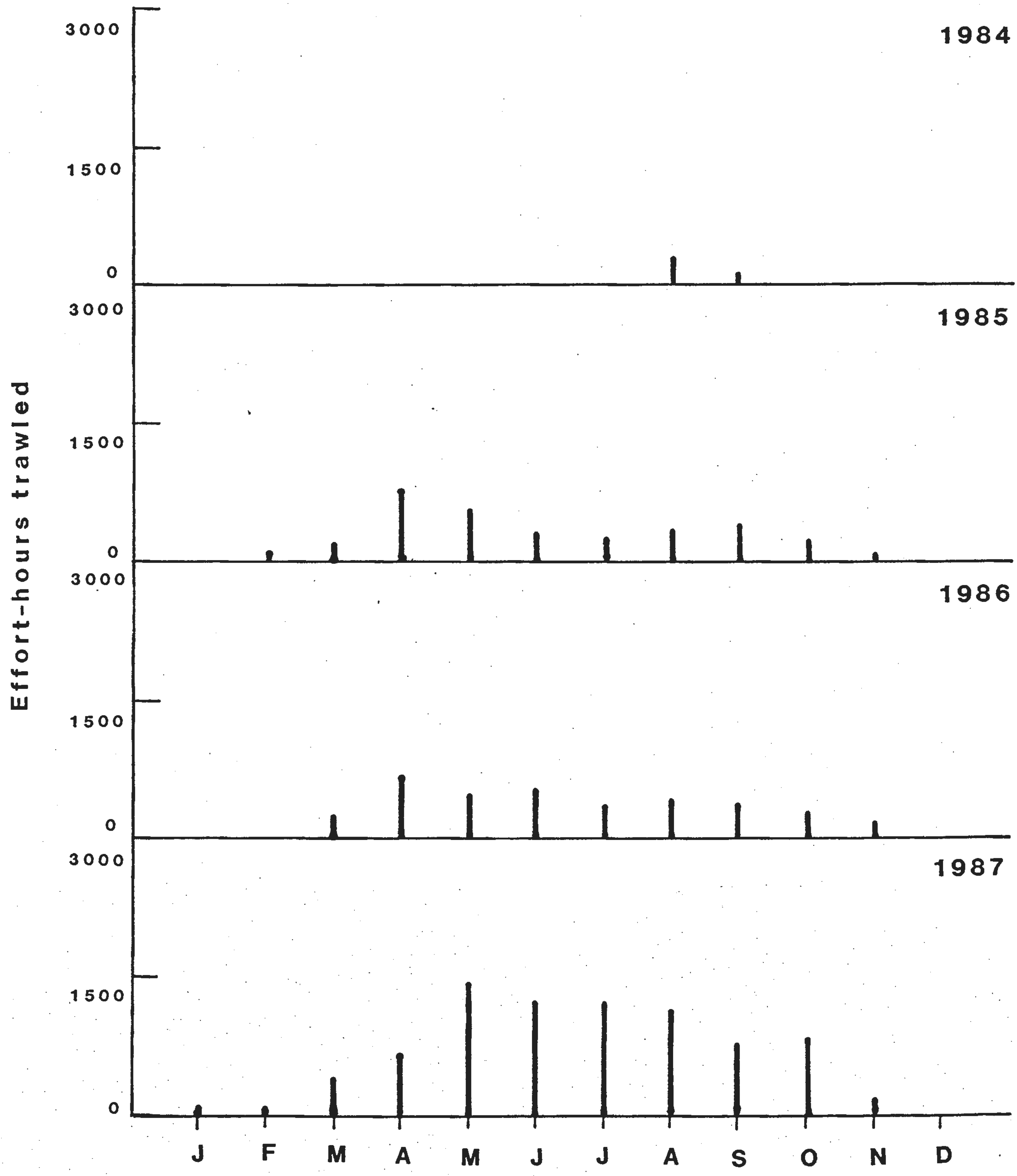

Figure 4. Effort allocated to the tiger prawn fishery over time

has extended from January-February to October in the period between 1984 and 1987. In 1985 and 1986 more than 70% of effort directed at king prawns was recorded in the period May-September. In 1987, the fishery developed a little earlier, with more than 30% of effort being recorded in the period January-May.

Interaction between vessels fishing king and tiger prawns

Trawlers can, and do, work for both king and tiger prawns. Tiger prawn abundance peaks in about March-April each year, and effort on these stocks is correspondingly at a peak at that time (Fig. 4). While a residual fishery for tiger prawns lasts until about October each year, most boats in the fishery (and others from distant ports) transfer their fishing effort to the king prawn stocks in May-June.

Short term and year to year trends in catch rates for king prawns

In the three years for which catch effort data for the full year is available, catch rates have reached maxima between May and June, and the fishery has tapered off and effectively terminated by October each year. Catch rates from the fishery show similar trends in each of the four years in which log book data was available. Catch rates increased from about 30-50% of monthly maxima in January- February to the May-June maximum (Fig. 5). A gradual tapering off of catch rates was evident until fishing operations ceased. There is good evidence of lunar catchability changes in the raw data (Fig 6. a,b,c). There are regular (28-30 day) wave formations, maxima of which can be linked to new moon phases.

Mean annual catch rates from the king prawn fishery are given in Table 1. While there has been a slight increase in annual catch rates in the period 1984-1987, the overall stability in catch rates

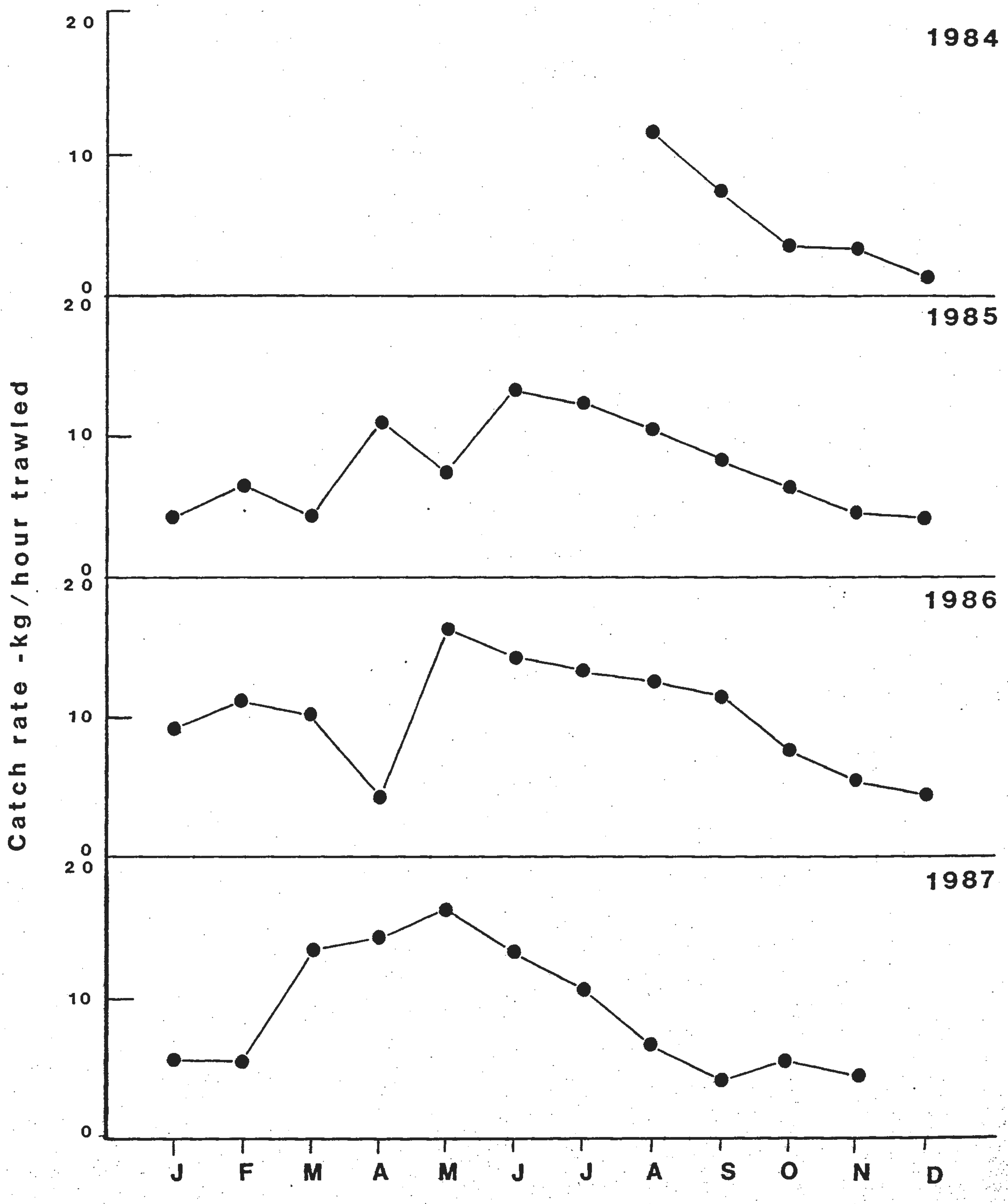

Figure 5. Monthly average catch rates monitored from the king prawn fishery

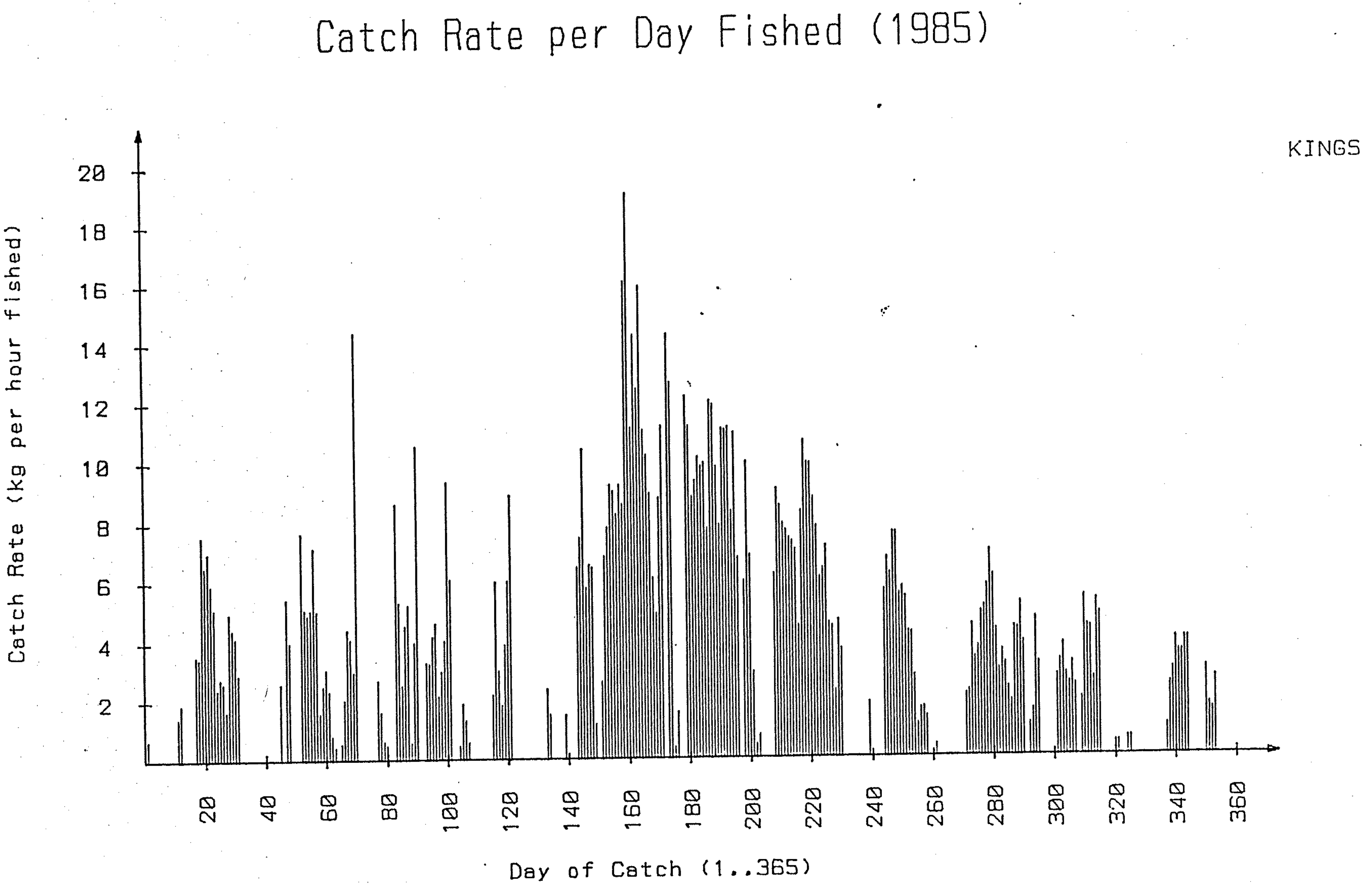

Figure 6a. Daily average catch rates from the king prawn fishery-1985

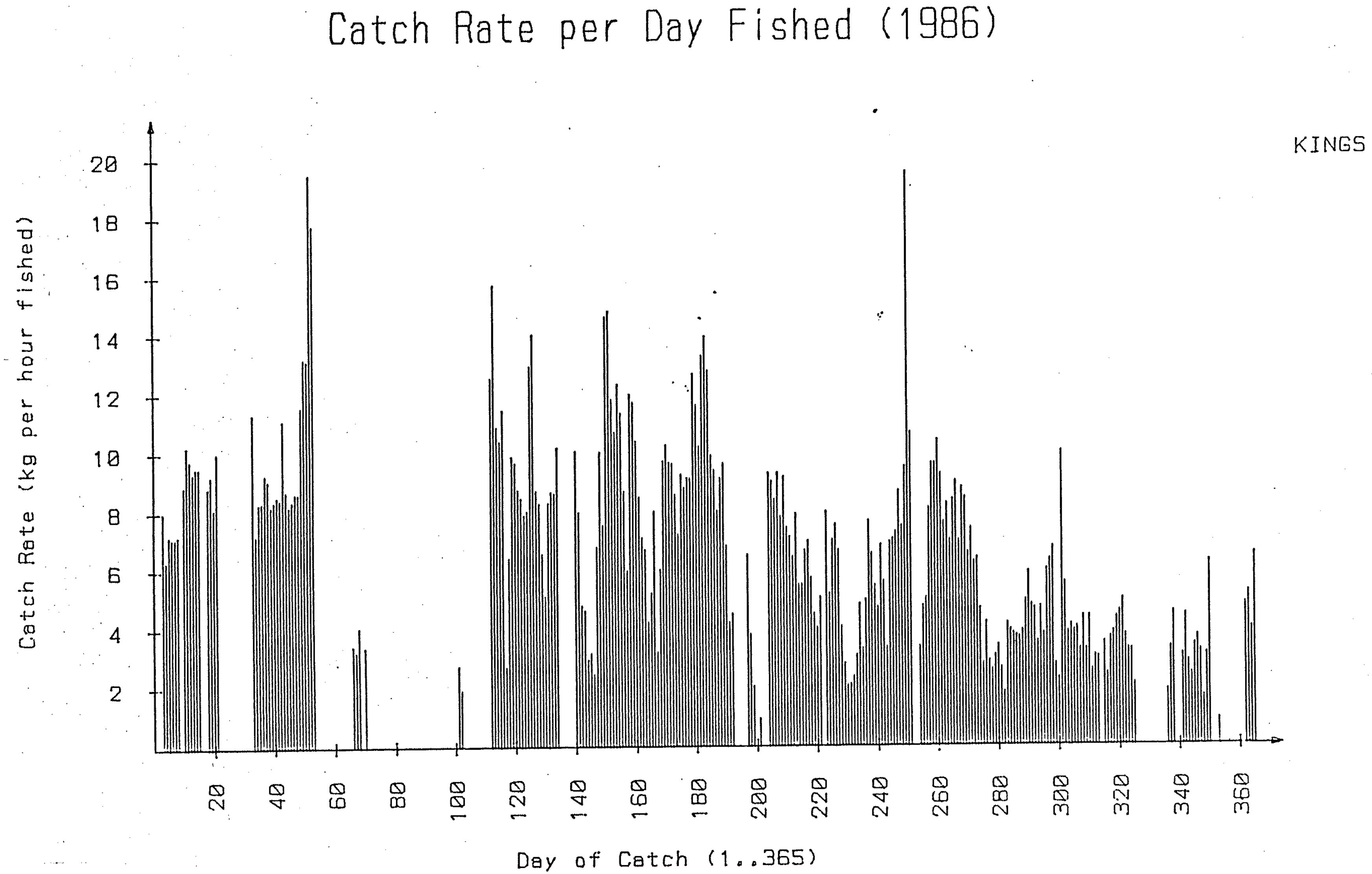

Figure 6b. Daily average catch rates from the king prawn fishery-1986

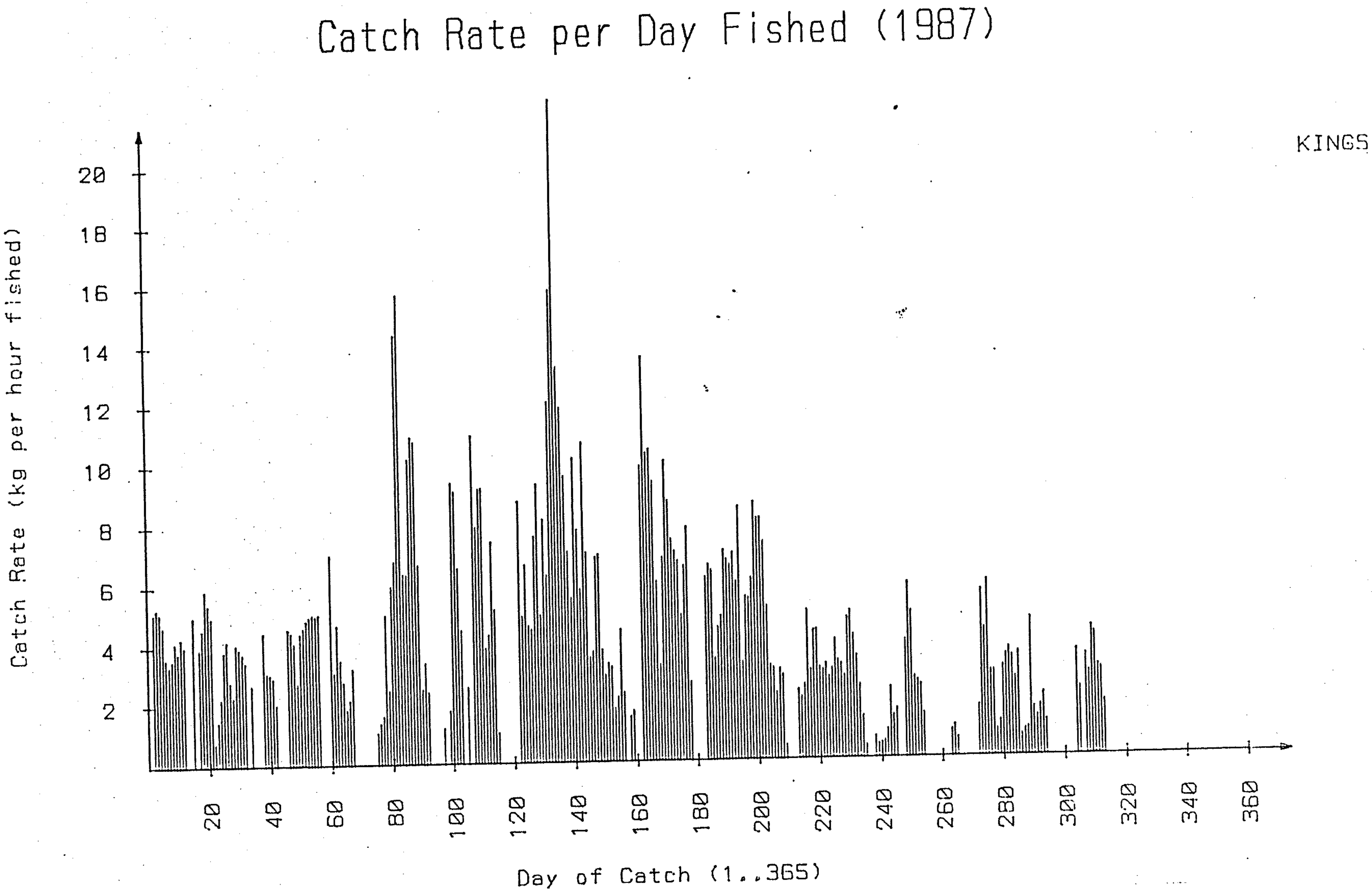

Figure 6c. Daily average catch rates from the king prawn fishery-1987

is notable. An upward shift in short term (monthly) catch rates in the early (March-May) part of the season was observed between between 1985 and 1986-7.

Tiger prawn catch rates also followed a relatively uniform pattern between 1984 and 1987. Catch rates increased from the commencement of the fishery in about February to a maximum in March-April. The catch then declined slowly through winter (Fig. 7). The catch rate variation associated with moon phase observed in the king prawn fishery was not as noticeable in the tiger prawn fishery (Fig. 8 a,b,c).

King prawn species composition

In the absence of a regular commercial catch monitoring programme, data from the monthly offshore sampling programme has been used to estimate species composition, in terms of numbers and weight, in the fishery between January 1985 and December 1986. Numbers of P. latisulcatus and P. longistylus recorded from all monthly samples were converted to weight estimates using an empirically derived length-weight function. The estimated breakdown of P. longistylus: P. latisulcatus was 73%:27% in both 1985 and 1986.

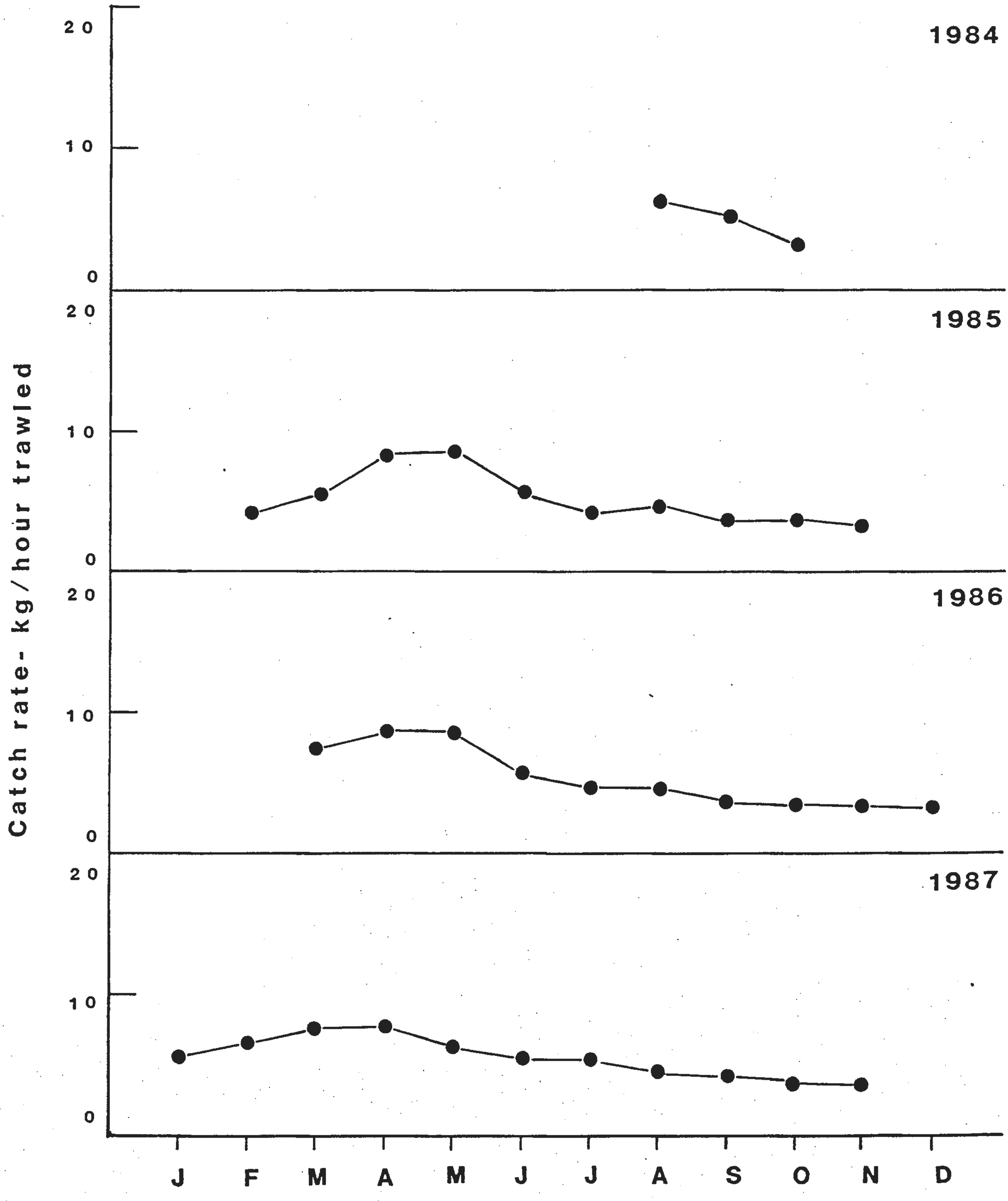

Figure 7 Monthly average catch rates monitored from the tiger prawn fishery

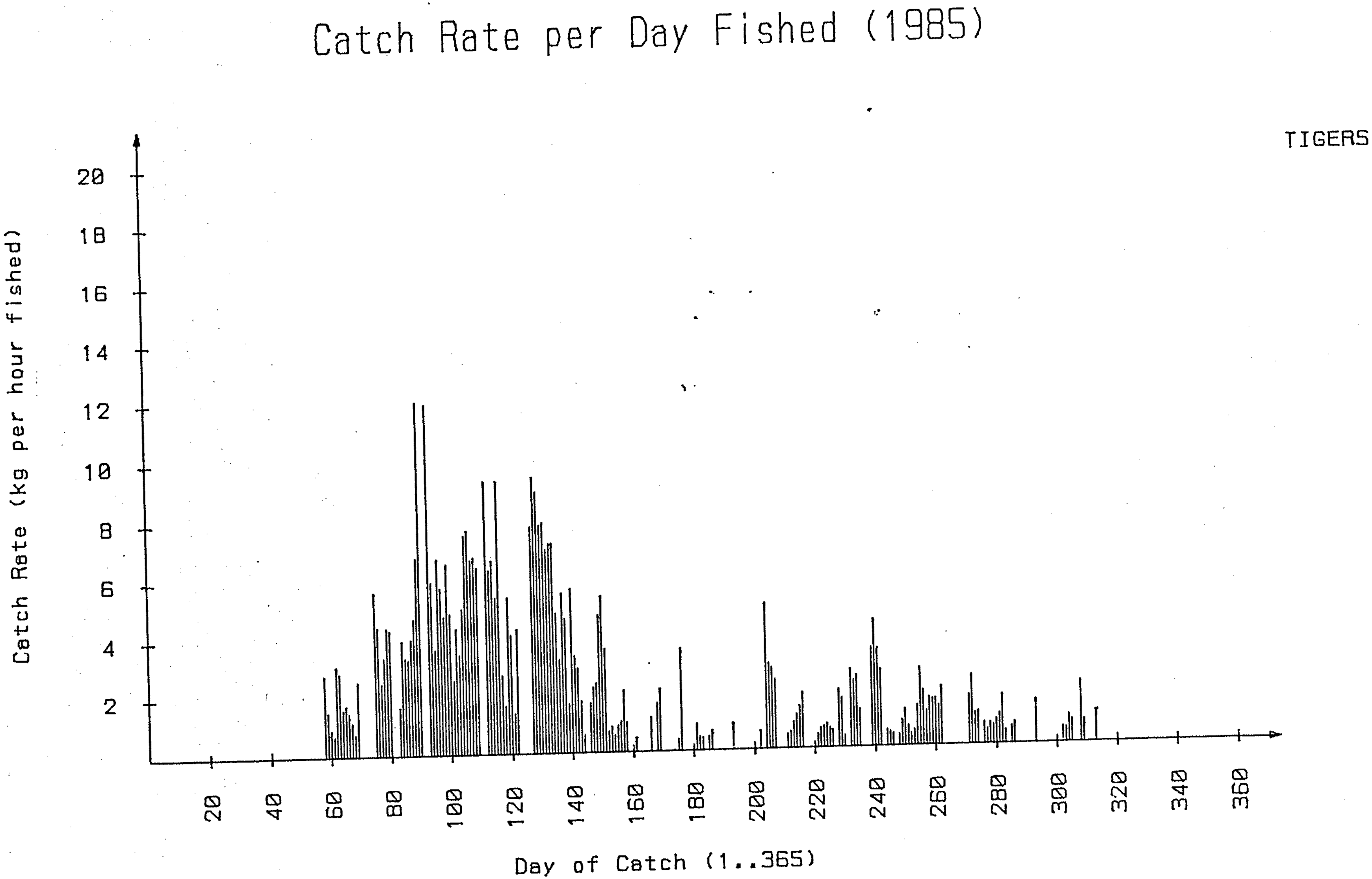

Figure 8a. Daily average catch rates from the tiger prawn fishery-1985

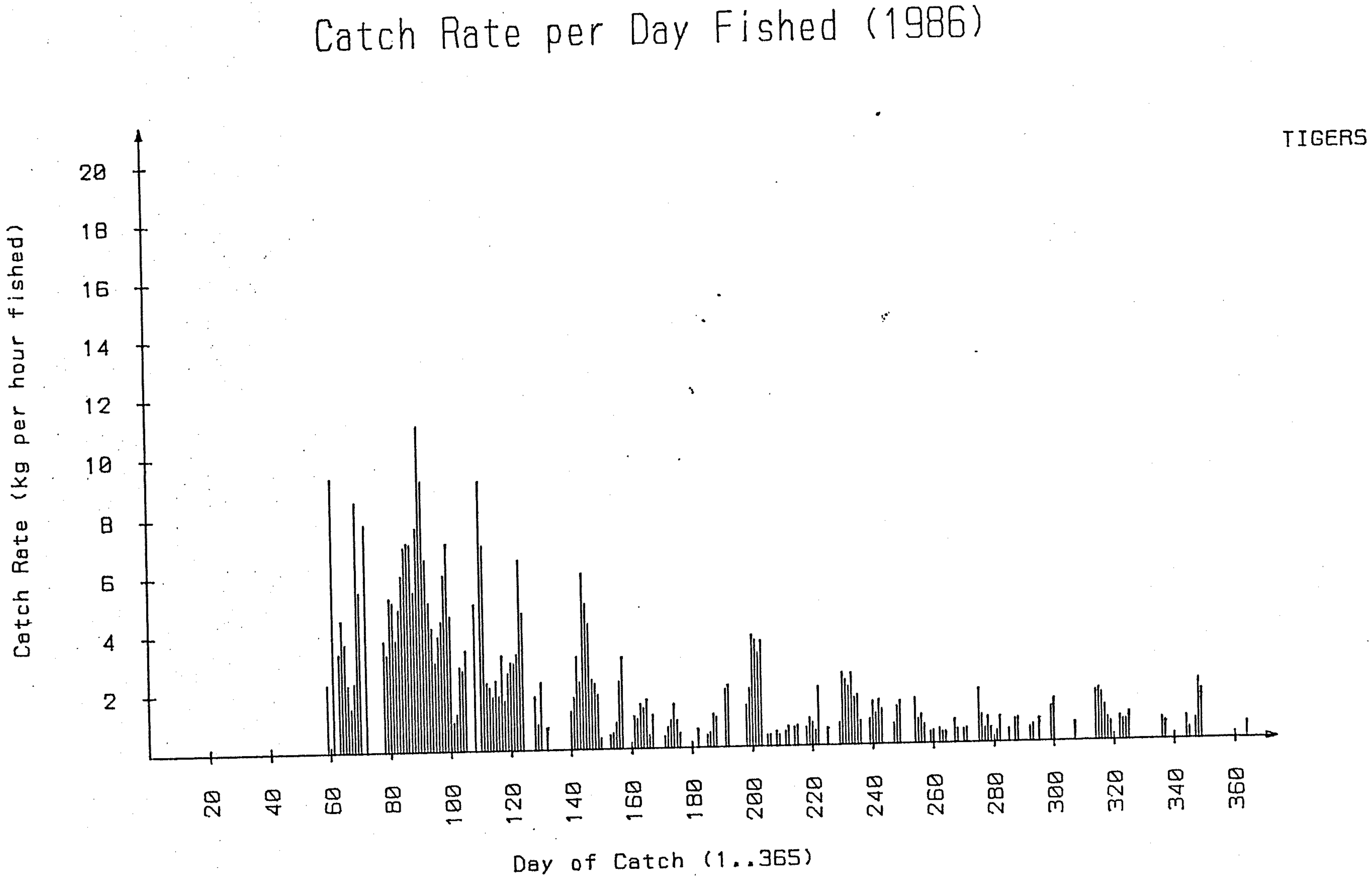

Figure 8b. Daily average catch rates from the tiger prawn fishery-1986

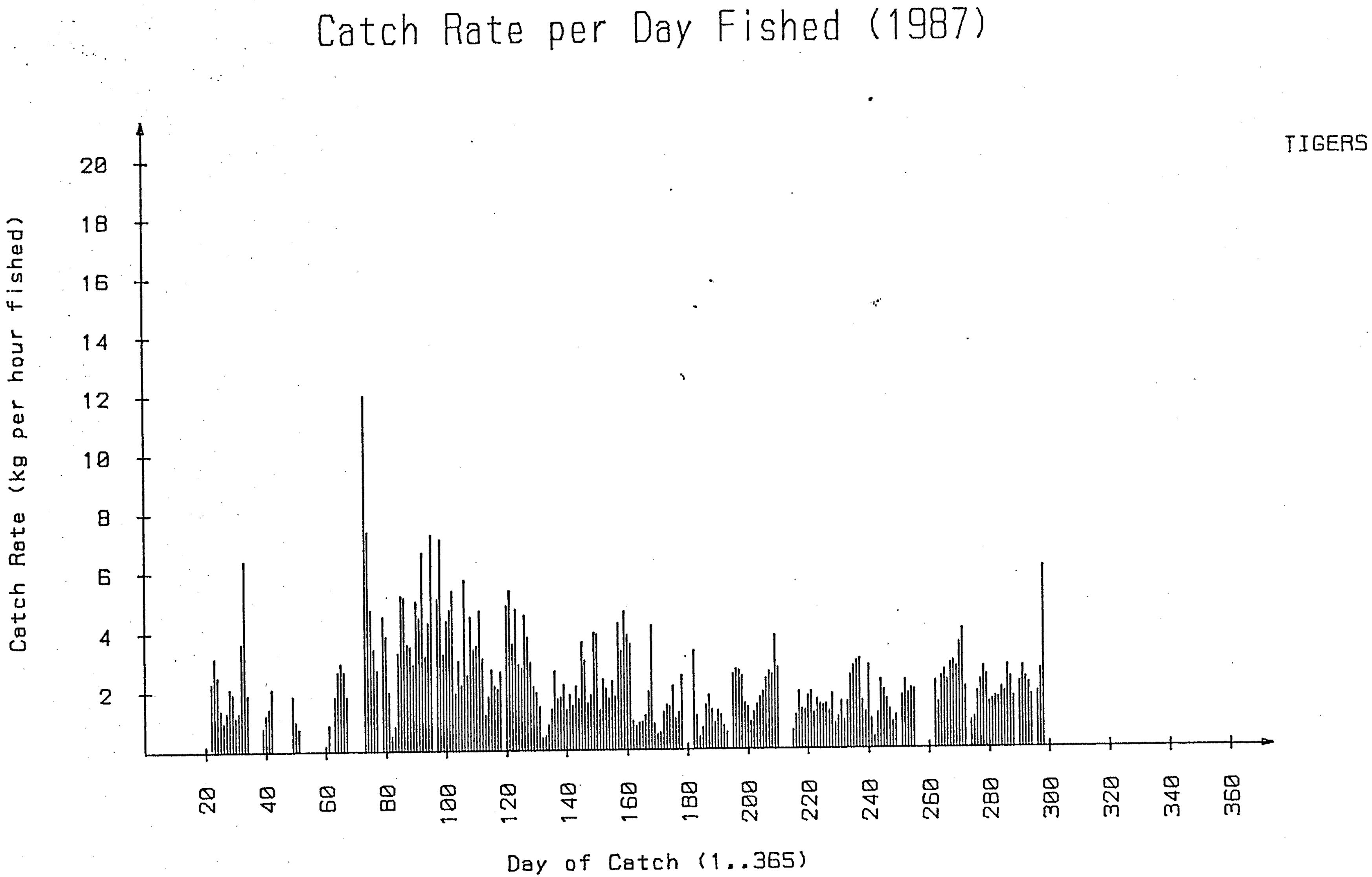

Figure 8c. Daily average catch rates from the tiger prawn fishery-1987

Biology of P. longistylus and P. latisulcatus

Coastal and estuarine studies on distribution

In the period between January and December 1985, 204 of a projected 221 coastal stations (Fig. 1) were sampled. A total of 4006 Penaeid prawns from 18 species were taken (Table 3). All but Penaeus monodon and Metapenaeus eboracensis were taken as sexually immature animals. Penaeus longistylus was not recorded at all. Species and species groups could be related to both seasonal and site characteristics. There was a characteristic group of prawns, including banana prawns (P. merguiensis), M. ensis and M. eboracensis which were found only in the near mangrove environment. The two tiger prawn species, P. semisulcatus and P. esculentus were found in some (but not all) seagrass sites, and P. latisulcatus was characteristically found on open sand flats. P. latisulcatus juveniles were taken in the period February to November, which offers a contrast to the strongly pulsed recruitment of animals to offshore grounds.

Table 3 Abundance of penaeids from all estuarine and coastal samples

Species	Numbers taken
Penaeus esculentus	41
Penaeus semisulcatus	93
Penaeus monodon	7
Penaeus merguiensis	732
Penaeus latisulcatus	219
Metapenaeus endeavouri	163
Metapenaeus ensis	634
Metapenaeus sinuosus	32
Metapenaeus eboracensis	696
Metapenaeus bennettae	349
Metapenaeus insolitus	1
Trachypenaeus fulvus	134
Trachypenaeus anchoralis	3
Trachypenaeus granulosus	2
Metapenaeopsis palmensis	661
Metapenaeopsis novaeguineae	33
Metapenaeopsis stridulans	2
Parapenaeopsis cornuta	57

Studies on the penaeid fauna of a reef lagoon

The reef crest and lagoon of Bramble Reef is representative of coral reef formations between 18°S and 21°S in that there is no supra tidal area and no seagrass community in the lagoon. The reef face falls almost vertically from the reef crest to the south and east of the reef but slopes more gently to the north and west. The lagoon is scattered with bombies but has an underlying sand substrate which slopes from a mean depth of about 1m on the south and east to a maximum of about 15 m. A somewhat atypical feature of the reef is the extensive opening to the lagoon. The northern reef face is very open and deep, leaving an almost U-shaped reef, rather than the more normal oval shape (Fig. 9).

Sampling was concentrated on the eastern, southern and western periphery of the lagoon in depths of 1-6 m. Preliminary sampling had shown that prawns were rare in the central and northern parts of the lagoon, and sampling in these areas was destructive on equipment.

A total slightly in excess of 2000 penaeid prawns were collected from 113 samples taken in 10 months between February 1986 and January 1987. Samples could not be obtained in June and November, 1986. Of the prawns sampled, 1557 were P. longistylus in the size range 3-18 mm carapace length (C.L.). The remainder were from the genera Trachypenaeopsis and Metapeneopsis. A list of species taken from the reef lagoon, ranked by abundance, is given in Table 4.

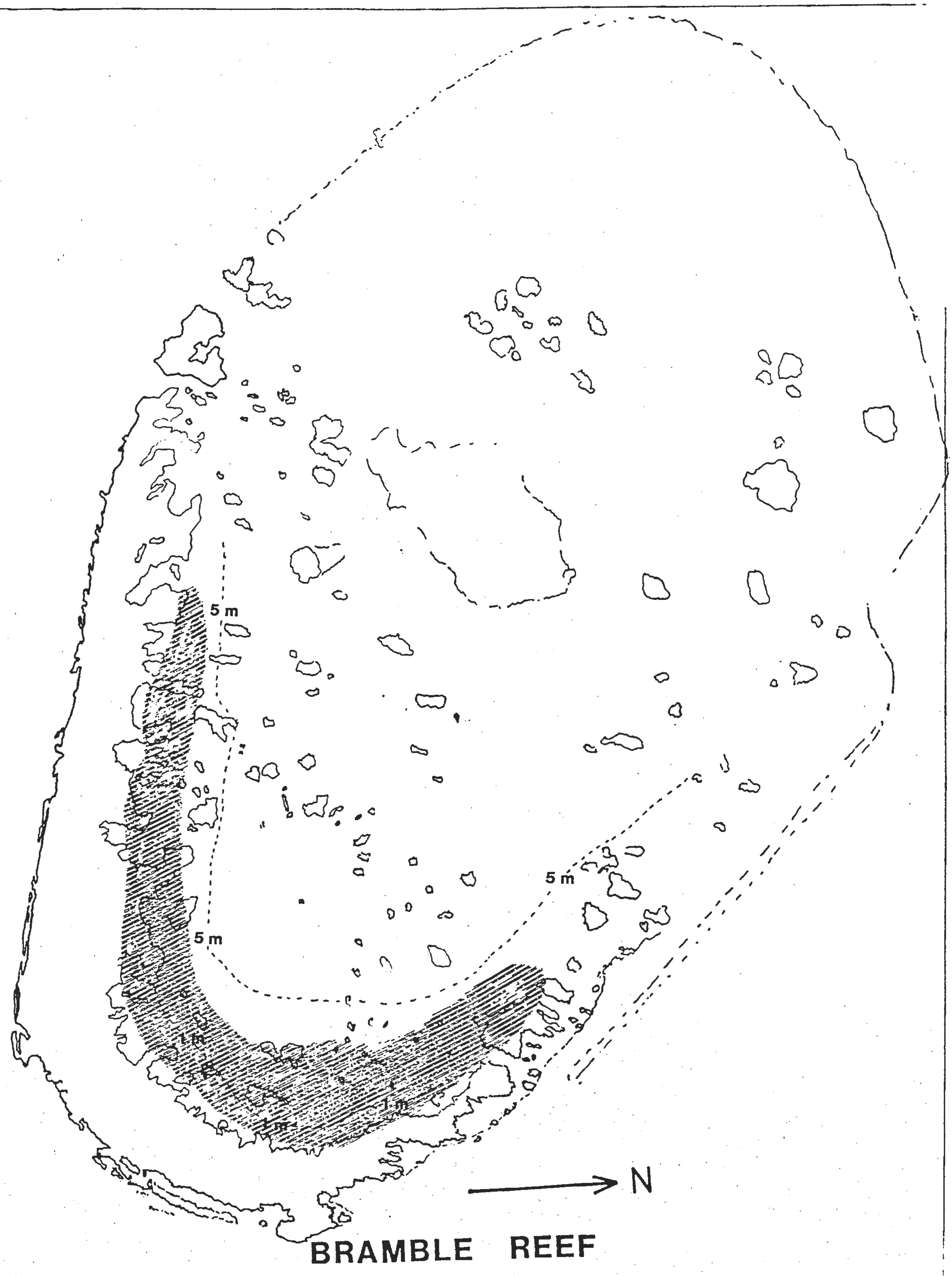

Figure 9. Bramble Reef. The main sampling areas are hatched

TABLE 4. Penaeid species taken from Bramble Reef lagoon in order of abundance

Penaeus longistylus
Metapenaeopsis spp
Metapenaeopsis mogiensis
Metapenaeopsis mannarensis
Metapenaeopsis hilarula
Trachypenaeopsis richtersii

Juvenile _P. longistylus_ were found to be very patchily distributed in space, although most abundant in depths of 1-3 m. Of the total of 1557 which were identified, 733 (47%) were taken from 9 of the 113 samples completed. The areas on which _P. longistylus_ were most abundant were not consistent from month to month. Seasonal abundance can be demonstated by plotting numbers from the most abundant sample in each month over time (Fig. 10). Juvenile prawns could be taken at most times of the year, but there is some suggestion of a reduction in numbers in May-July and possibly in October to December.

Distribution of king prawns in the Great Barrier Reef Lagoon

In 1985, 212 of a proposed 240 stations in and east of the Great Barrier Reef Lagoon were sampled and in 1986, 138 of the proposed 144 samples were obtained.

Spatial distribution and abundance of _P. longistylus_

The ratio of relative abundance at each sample site to total abundance from all sites remained relatively stable over the full 24 months of sampling. On this basis, a comparison of abundance between sites has been made for 1985 and 1986 (Fig. 11). The most conspicuous feature of the data was the absence of _P. longistylus_

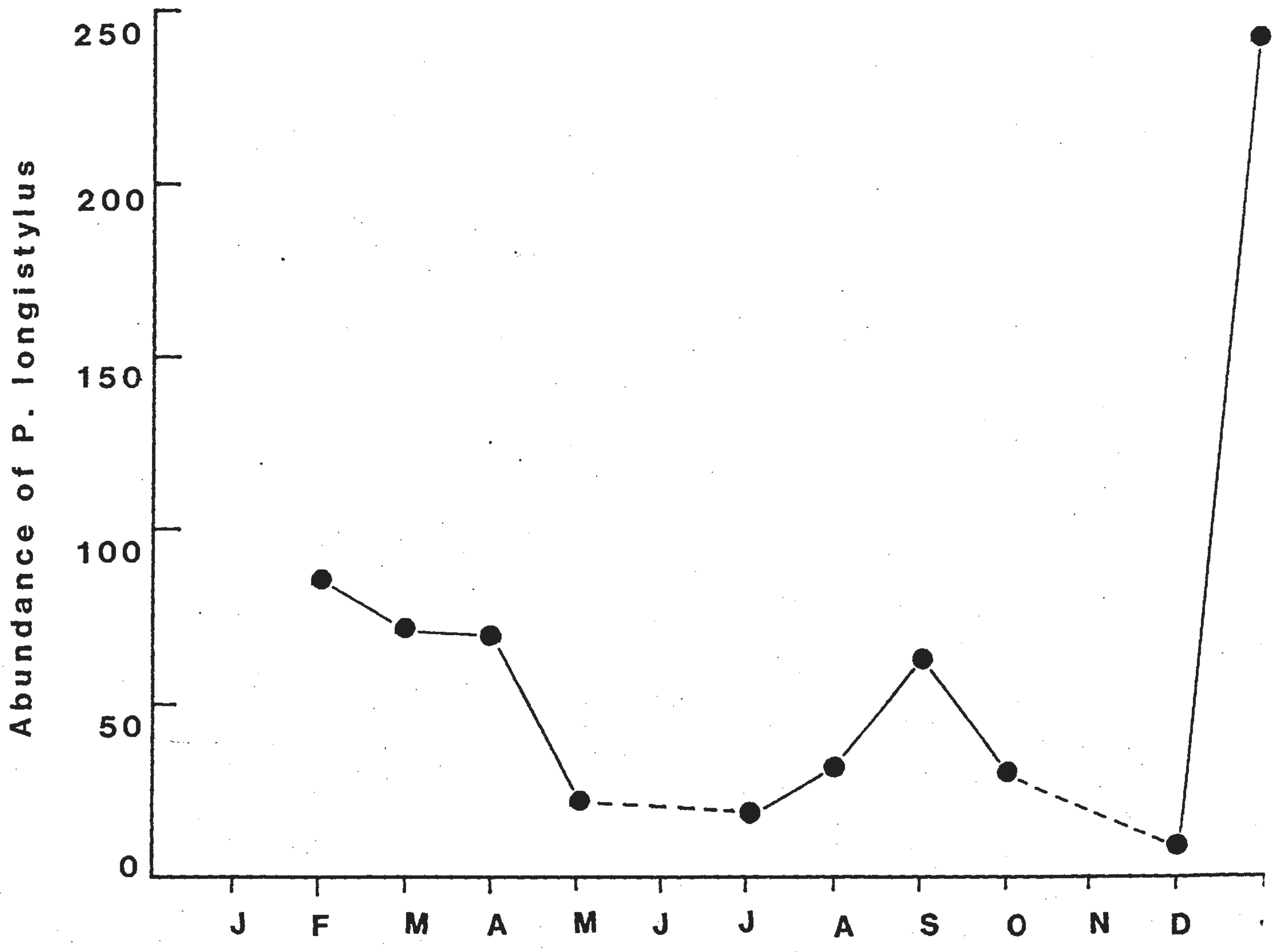

Figure 10. Maximum number of P. longistylus per monthly sample at Bramble Reef

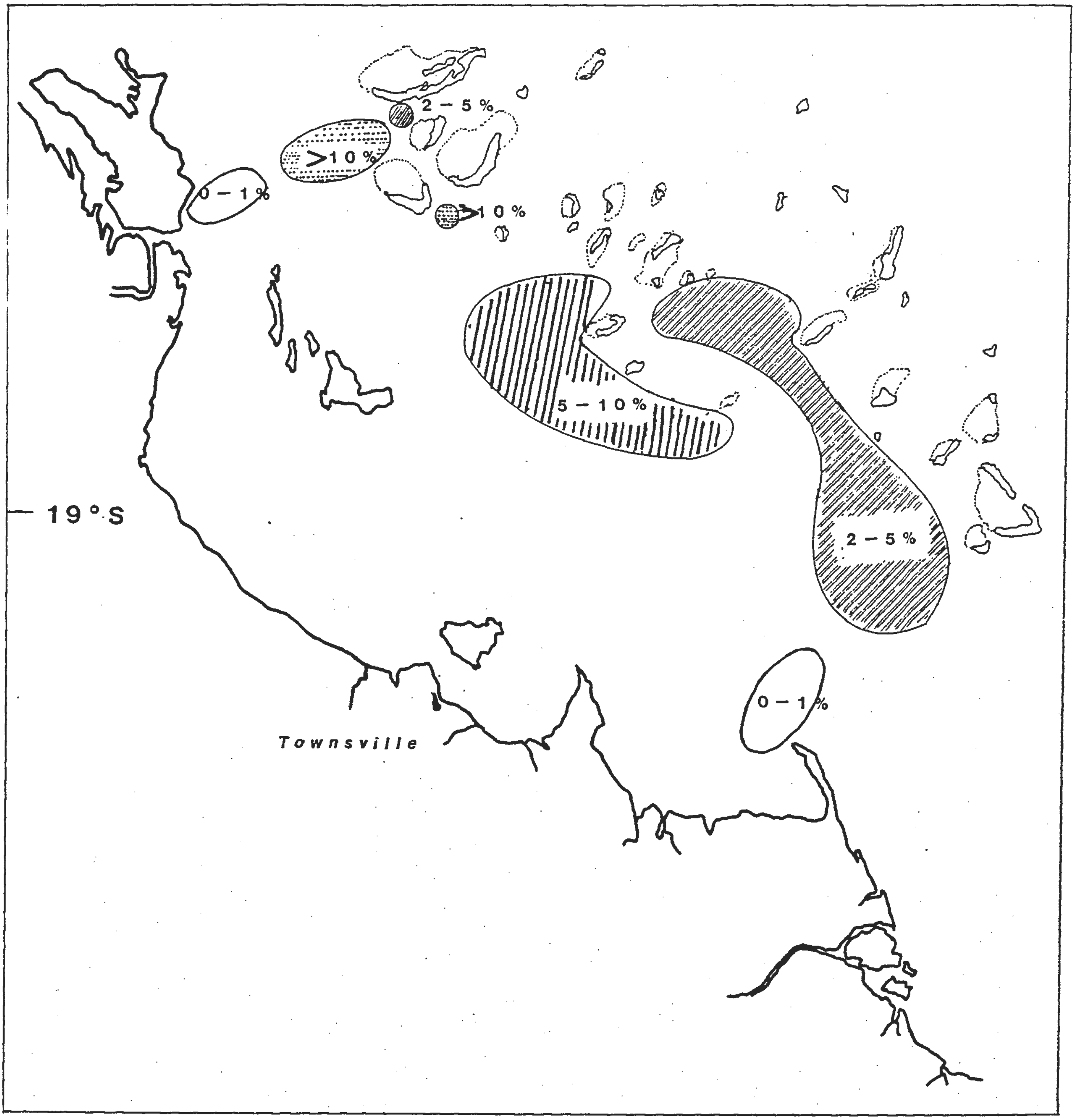

Figure 11. Relative abundance, expressed as proportion (%), of all *P. longistylus* taken from 1985 samples

from the shallow inshore stations. Data from these four stations were then discarded. Preliminary analysis (Table 5a,5b) indicated that P. longistylus were most abundant in depths of 40-44m and 55-59 m. Site effects may be responsible for this apparent irregularity. Penaeus longistylus was most abundant at distances of 3-7 km from the nearest coral reef in both 1986 and 1987. The species was less abundant in true inter reef waters (stations 8,9,10 and 11) than in waters of the Great Barrier Reef Lagoon, despite the similarity in depths between the two areas.

Table 5a Abundance of Penaeus longistylus as a function of depth and distance from coral reefs in 1985. Column and row summaries give mean, standard error and number of samples.

Depth(m)	Distance from coral reefs (km) 0-2	3-7	8-12	13-17	18-22	>22	Mean	S.E.	n
15-19							0	0	21
20-24							0.4	0.3	12
25-29							no data		
30-34							54.6	12.6	23
35-39							no data		
40-44							66.9	4.9	50
45-49							15.6	5.0	9
50-54							41.9	5.9	42
55-59							49.2	7.7	44
60-65							31.2	9.6	11
Mean	42.8	62.5	43.6	no data	35.2	2.7			
S.E.	6.7	5.1	5.8		7.9	1.3			
n	11	86	61		11	43			

Table 5b Abundance of <u>Penaeus longistylus</u> as a function of depth and distance from coral reefs in 1986. Column and row summaries give mean, standard error and number of samples.

	Distance from coral reefs (km)								
	0-2	3-7	8-12	13-17	18-22	>22	Mean	S.E.	n
Depth(m)									
15-19							0	0	12
20-24							1.8	1.7	12
25-29							no data		
30-34							100.3	17.7	12
35-39							no data		
40-44							88.8	6.4	35
45-49							45.3	8.1	22
50-54							63.4	10.7	22
55-59							69.7	6.8	22
60-65								no data	
Mean	43.8	77.3	81.3	no data		0.9			
S.E.	7.1	5.5	7.8			0.9			
n	23	57	34			24			

Spatial distribution and abundance of P. latisulcatus

Unlike *P. longistylus*, the abundance data of *P. latisulcatus* for sites and times were confounded, and the two effects could not be isolated. In both 1985 and 1986, *P. latisulcatus* was most abundant at inshore and mid Great Barrier Reef Lagoon sites early in the year (January-May). Later in the year, sample numbers suggested a wide dispersal by the species over the Great Barrier Reef Lagoon.

Abundance as a function of time- P. longistylus and P. latisulcatus

Abundance of *P. longistylus* and *P. latisulcatus* taken from stations 3,4,5,6,7 and 20 in 1985 and 1986 are given in Fig 12. These stations were sampled with a minimum number of missed samples and cover both years of the project. Where abundance data are missing from any of these sites, estimates made from the surrounding station abundance matrix have been used.

In both 1985 and 1986, *P. longistylus* abundance remained at a fairly steady level in the period April-July before falling away to a minimum in December-January.

Penaeus latisulcatus appeared in samples in November-December each year and attained maximum numbers by about March. There was a rapid decrease in abundance after this time.

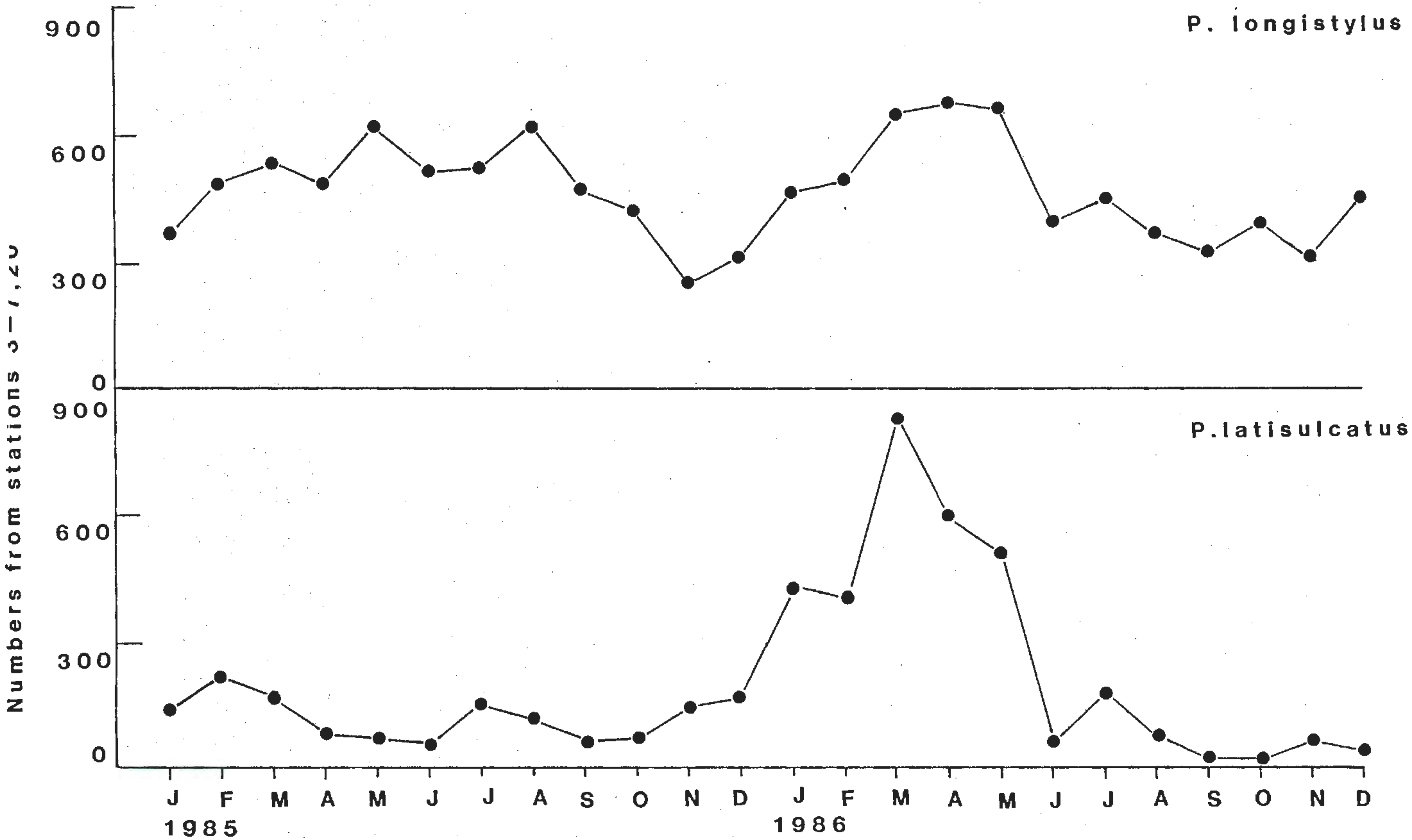

Figure 12. Abundance of P. longistylus and P. latisulcatus from monthly sampling programme

Size composition and timing of recruitment

Size frequency data for P. longistylus and P. latisulcatus have been expressed in terms of percentage of each month's catch of the respective species in 1 mm C.L. clases (Fig 13.a,b, 14.a,b).

There was little difference in 1985 and 1986 size frequency plots for P. longistylus. A mode between 30 and 40 mm C.L. was evident in every month's data and, while the modal size increased between April and December each year, the increase in average size of prawns was partially masked by the variability around the mode. Size frequency data from June to November were bimodal in the size range 30-55 mm C.L. This reflects the growth variation between genders.

There was no clear pulse of recruits coming onto the sampled areas over time. But by comparing the proportion of P. longistylus smaller than 25 mm C.L. with the total numbers taken over time (Fig. 15), some evidence that recruitment onto the fishing grounds takes place mainly in the period November-May is given. There appears to have been a lower rate of recruitment throughout the rest of the year.

Size frequency data for P. latisulcatus was similar to that of P. longistylus in its year to year consistency. There was clear evidence for time pulsed recruitment of juveniles onto the fishing grounds (Fig. 15) in October to February. The tightly grouped size frequency data and progression in size of the mode over time is further indicative of a population which has recruited over a relatively short time. Bimodality in the size frequency data from larger (>35 mm C.L.) animals was again indicative of the difference in growth rates between males and females. The maximum average size of the two modes (42 and 51 mm C.L.) correspond with Penn's (1975)

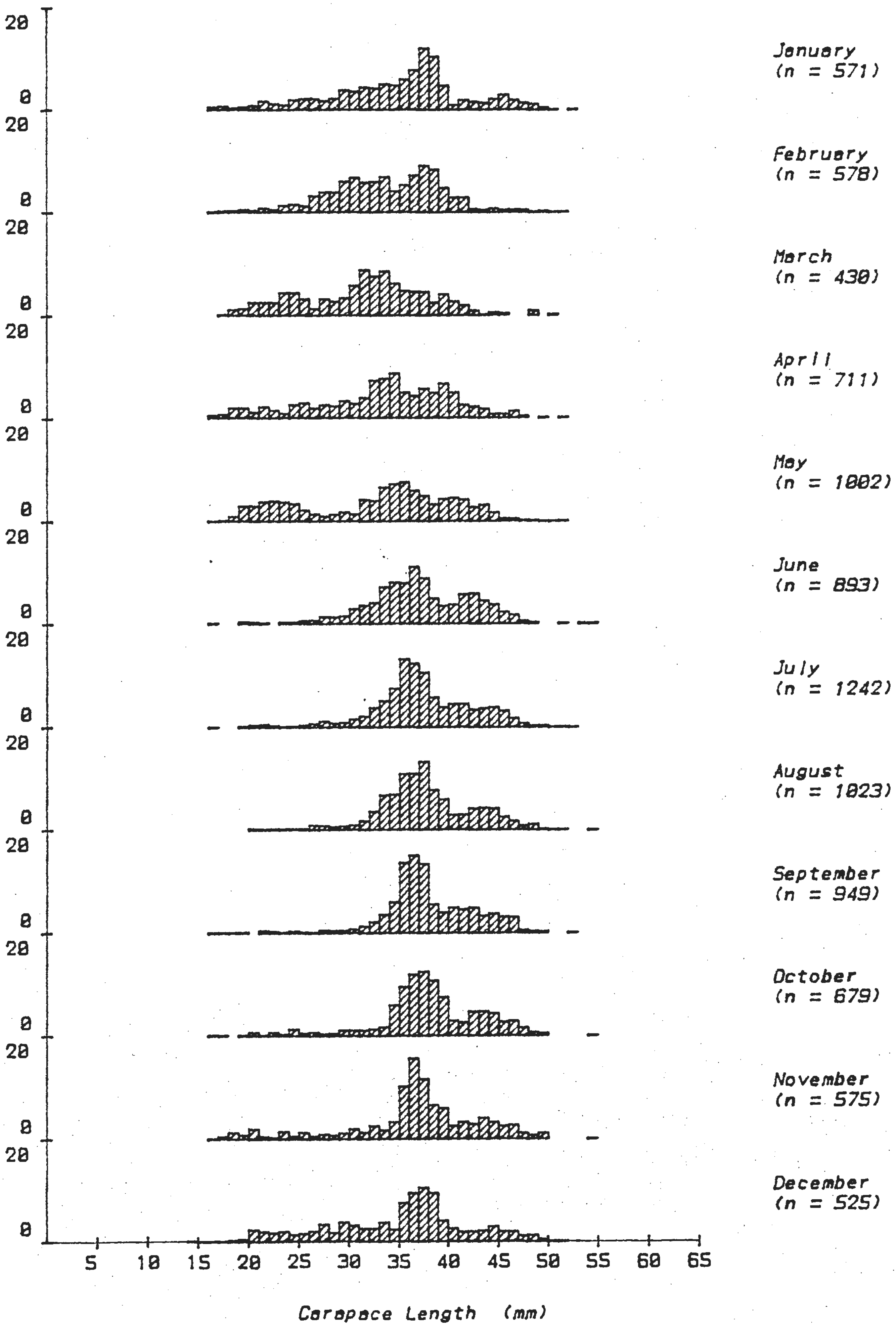

Figure 13a. Monthly size frequency distribution of P. longistylus from 1985 samples

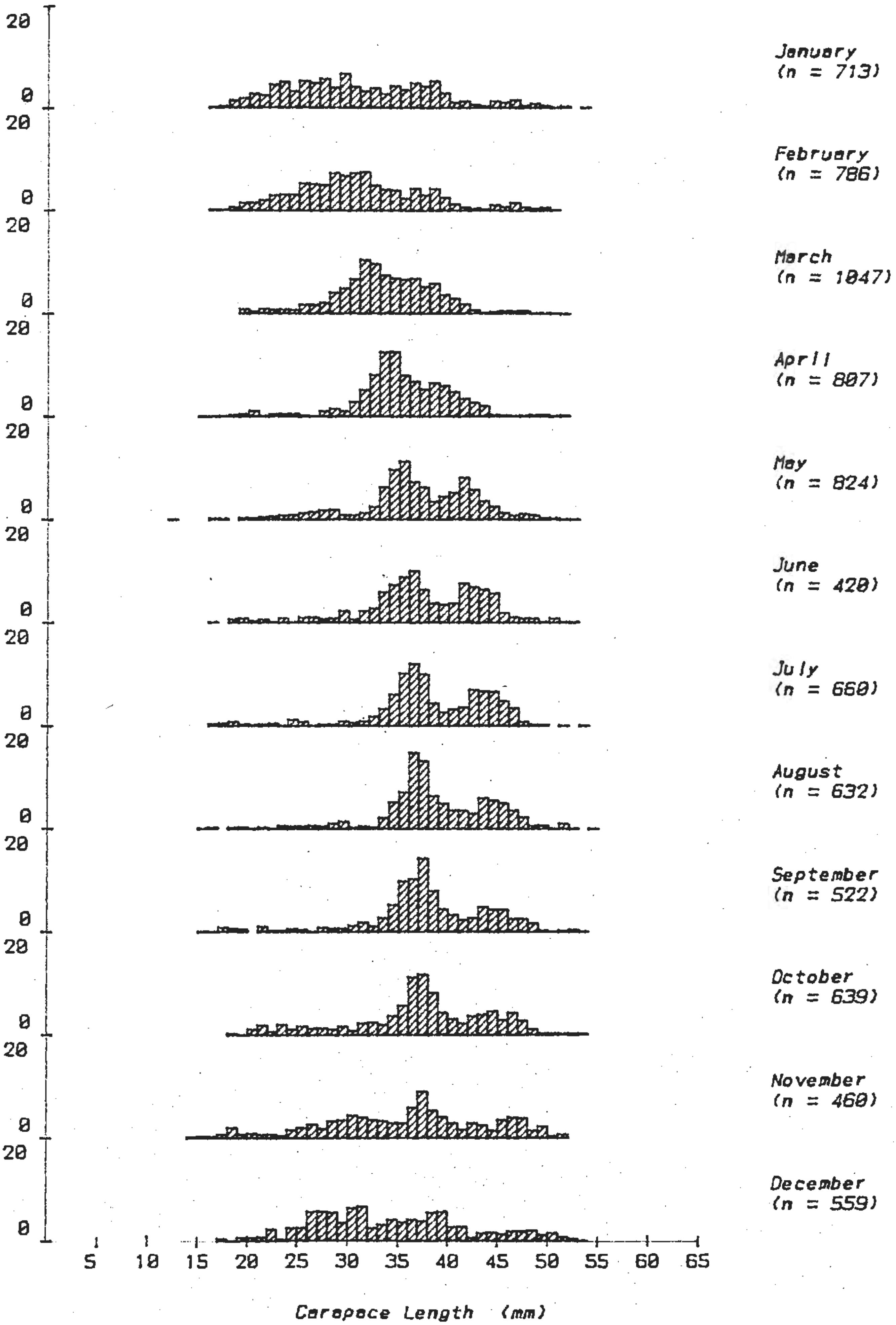

Figure 13b. Monthly size frequency distribution of P. longistylus from 1986 samples

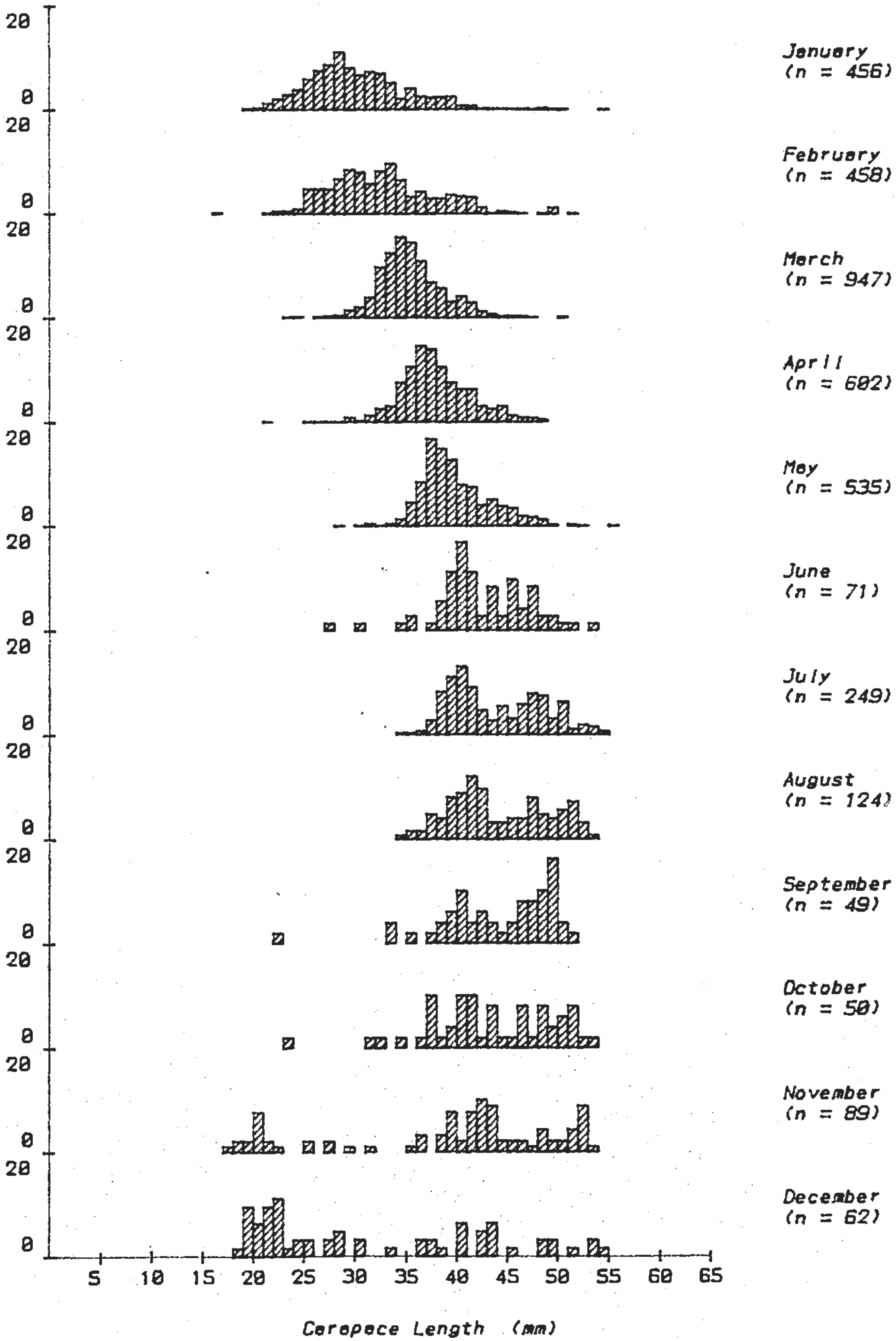

Figure 14a. Monthly size frequency distribution of <u>P. latisulcatus</u> from 1985 samples

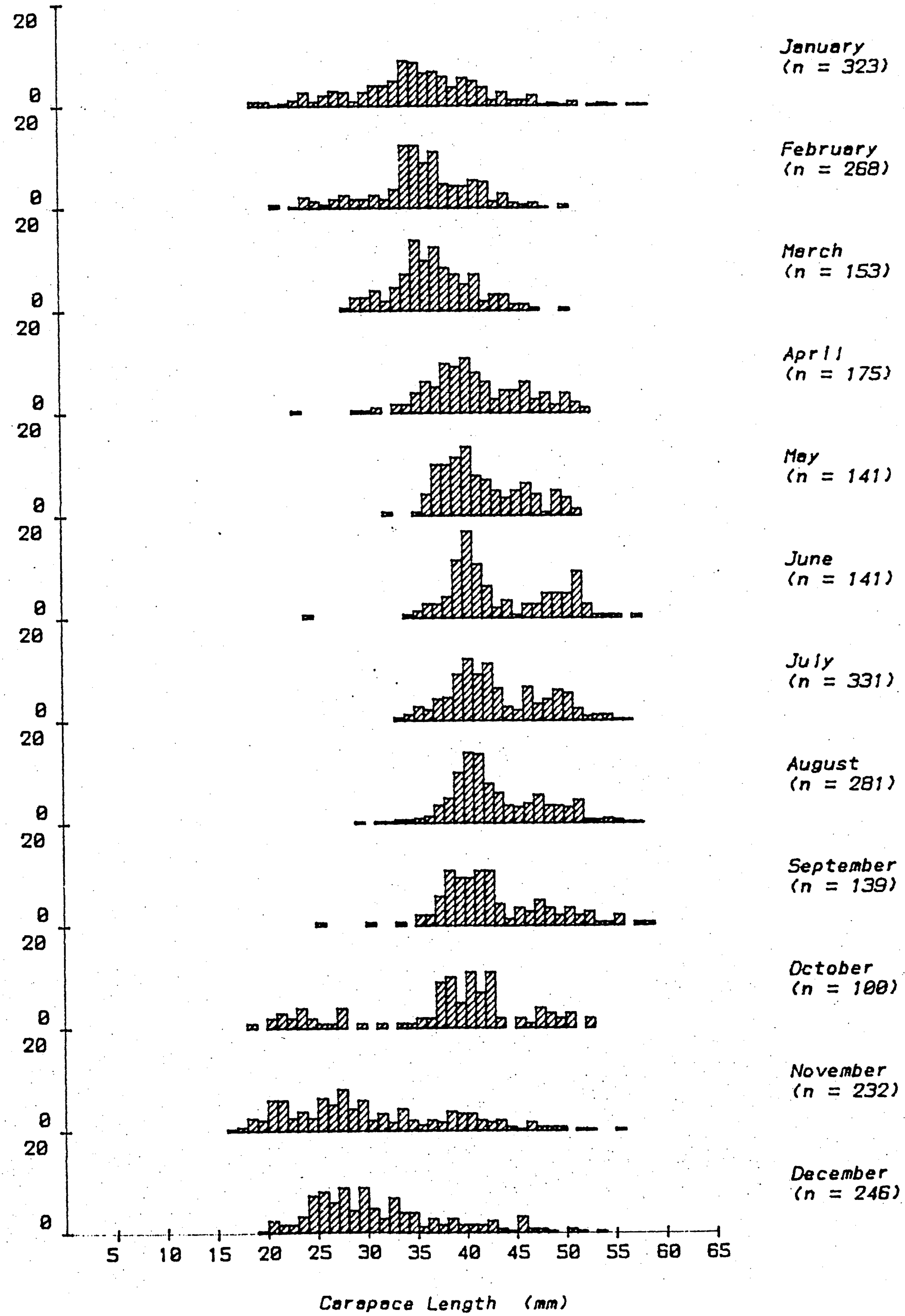

Figure 14b. Monthly size frequency distribution of _P. latisulcatus_ from 1986 samples

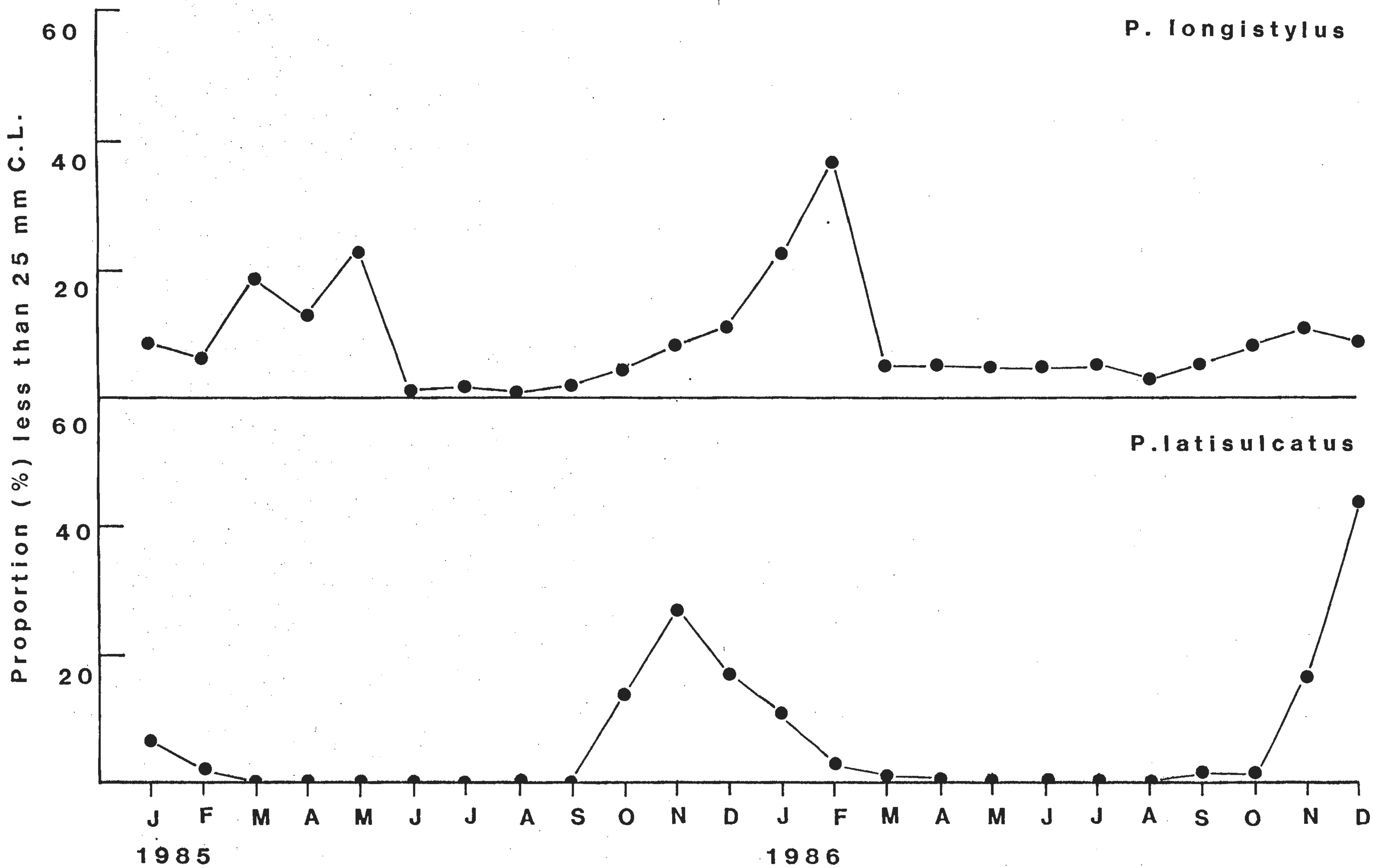

Figure 15. Percentage of P. longistylus and P. latisulcatus smaller than 25 mm C.L. over time.

estimates of L_∞ for P. latisulcatus.

Reproductive behaviour and periodicity in stocks of P. longistulus and P. latisulcatus

Details of size at first maturity, development of genitalia using histological examination and population fecundity over time for P. longistylus and P. latisulcatus are given in the (draft) paper in Appendix 1. The smallest female P. longistylus found to be inseminated were 26 mm (C.L.) and the corresponding size for P. latisulcatus was 27 mm C.L. Population fecundity indices based on number of females with gonads sufficently developed to spawn and size of these females were developed for the two species (Appendix 1). Two estimates of population numbers, based on log book data and our own sampling data, were used as a co-variate of female population size. These gave reasonably consistent results. The population of P. longistylus showed an extended peak of spawning potential between May to September each year, with a lower level for spawning potential being evident throughout the year. The population fecundity index for P. latisulcatus was not consistent between 1985 and 1986, with a peak in spawning potential being evident in July-September in 1985 and a much stronger peak occuring between March and July in 1986. The 1986 peak reflects the very strong recruitment of P. latisulcatus observed in 1986.

Growth, movement and natural mortality rate of P. longistylus

Data obtained from tagging estimates have been used to estimate growth rate parameters and an estimate of natural mortality for P. longistylus. The tag data were also used to describe movement of adult P. longistylus. Details of the tagging studies are given in the draft paper in Appendix 2.

The major findings from the study were

-Low recovery rates of P. longistylus smaller than 30 mm C.L. were indicative of size differential mortality induced by tagging.

-Few tagged male or female P. longistylus moved a discernable distance from their point of release. There was no increase in average distance moved as a function of time, and there was no evidence for anything but random movement by prawns which did move from the release point.

-The growth parameters for male and female P. longistylus varied significantly, and there was evidence for year to year growth variation.

-An estimate of the natural mortality rate of P. longistylus using tagging data gave a rate (0.085 $week^{-1}$), which was higher than estimates for other Penaeus species.

DISCUSSION

In 1984, when the present study was commenced, the central Queensland king prawn fishery was one of the state's less important fisheries. Since that time, effort directed at the king prawn stocks have increased 3-4 fold and the fishery has become an important revenue source.

The study was originally conceived as a means of obtaining base line data on the fishery, in terms of catch, catch rate and effort distribution. The need for biological data (habitat requirements, recruitment times, and growth and mortality estimates) on the major target species (P. longistylus) was evident. And because the fishery took place in waters under the control of the Great Barrier Reef Marine Park Authority, there was justification in examining bycatch from the fishery and comparing it with true reefal faunas.

The complexity of fisheries in the area between 18°S and 21°S only became apparent after the study had been underway for some time. The existence of a coastal fishery for tiger and endeavour prawns has a considerable effect on the king prawn fishery. Tiger prawns (two species) recruit onto the coastal grounds in February-March (Coles et al. 1985) and appear to be a more favoured target than king prawns. Consequently maximum effort is not directed at the king prawn stocks until May-June each year. By this time most king prawns have recruited onto the grounds. Changes in price differentials between tiger and king prawns could change the timing of the two fisheries in the future.

Further complexity in the fishery comes from its bi-specific target. Blue-leg king prawns make up about 20-30% of the king prawn catch. The species has a typical penaeid lifestyle, using coastal sand flats as nursery areas. Recruitment from nursery grounds to the main fishing grounds occurs over a relatively short time, in October to February. And there was strong evidence of variation in recruitment levels between 1985 and 1986, which could be expected in a species whose juvenile phase was subject to considerable environmental variation.

The red spot king prawn has been shown to have unique habitat requirements and a most unusual lifecycle. Juveniles appear to rely on coral reef lagoons as nursery areas, although Coles et al (1987) reported finding juveniles of the species in coastal areas on the Queensland far north coast. Such a habitat requirement has not been previously described for a member of the genus <u>Penaeus</u>, and suggests that the species has evolved a life cycle attuned to a coral reef environment. Juveniles appear to move from the reef to surrounding inter reef areas and complete their life cycle there. The recruitment and spawning phases were far more extended over time than is the case for many other penaeid species. The absence of the marked changes in salinity and temperature which are typical of coastal environments in central Queensland may be responsible for this extended spawning and recruitment.

There was a relative scarcity of prawns in the size range 20-30 mm C.L. in the research programme's sampling regime. These small prawns are apparently taken only intermittently in the commercial catch, and their absence, while probably beneficial to the fishery, reflect a phase of the species' life history which could benefit from further study.

A more detailed study of the species' juvenile (reef top) phase in terms of abundance variation as a factor of time of year and small scale geographic variation would also be of value. The apparent variation in density over small areas on the reef top environment and difficulty in obtaining reliable replicate samples means that any such programme would need to be far more intensive than the preliminary survey carried out during this study.

A further unusual feature of the species' life history is the apparent absence of movement or migration by adults. Most penaeid species incorporate some degree of migratory behaviour into their life cycle, but in becoming attuned to a near-reef environment, P.longistylus appears to have lost the need for migration. This characteristic enabled us to estimate the natural mortality rate of the species using a sequential tagging experiment.

Sufficient data on the fishery has been collected, or can be obtained from other sources, to carry out a basic yield per recruit assessment. This can be extended to an assessment of the effects of seasonal closures which are a feature of Queensland's fisheries management strategy at this time. There has been considerable discussion on the necessity of a seasonal (January-February) closure, designed to maximize tiger prawn yield per recruit, which covers king prawn grounds. An evaluation incorporating growth, recruitment and mortality estimates will give some basic factual information to this debate.

It is important that the central Queensland king prawn fishery be seen in the context of it being one of many fisheries which are worked by the Queensland trawl fleet. Its viability in part depends on the contribution coming from Moreton Bay bugs and scallops, as well as from blue-leg king prawns. All three of these species are subject to recruitment variability between 18°S and 21°S. The present very high level of effort directed towards the fishery between 18°S and 21°S may not be maintained in the future, and other stocks may be subject to further fishing effort as effort is transferred from the king prawn fishery.

There is, however, some scope for development of the fishery for red spot king prawns. Near reef areas between 21°S and 23°S and north of about 13°S are not fished extensively at this time. Given that the habitats required by red spot king prawns (coral reef formations and sand-mud substate in the inter and near reef area) are extensive in these areas, it seems likely that fisheries for the species will develop both north and south of the present fishery between 18°S and 21°S.

DISSEMINATION OF RESULTS

Interim results from this project were published in a series of three articles in June, July and August, 1986 issues of 'Australian Fisheries as follows

Robertson J and M. Dredge. Red spot king prawn research off central Queensland
Aust Fish 45, 6, 18-20

Lupton C. Qld estuarine and coastal prawn studies
Aust Fish 45, 7, 22-23

Jones C. King prawn bycatch and the Great Barrier Reef
Aust Fish 45, 8, 31-32

A conscious effort has been made to inform fishermen who work the central Queensland king prawn stocks of the aims and results of the project. A series of irregular newsletters (10 so far) incorporating results from tagging, trawl sampling, log books and other information have been circulated to fishermen who complete log books, returned tagged prawns or who are known to work in the fishery. The print run for these newsletters is 250, and most people who get the newsletters appear to be reading them. A series of public meetings, at which we tried to discuss research findings with fishermen had mixed results. Audiences varied between 2 and 30. As a means of discussing a fisheries project, I'd no longer put public meetings high on my priority list.

Two scientific papers, included as appendices to this report, have been submitted to refereed journals, as have two papers dealing with bycatch. A further three papers are in varying stages of preparation. They should be completed by mid 1988.

More general discussions of research findings will also be prepared as internal reports to the Queensland Fish Management Authority, and as 'Australian Fisheries' articles. Log book data summaries have been used by the Queensland Fish Management Authority as general background information, and as a reference source when discussing Great Barrier Reef Marine Park zonation plans.

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Somers I, I Poiner and A. Harris (1987) A study of the species composition and distribution of commercial penaeid prawns of Torres Strait.
Aust. J. Mar. Freshwater Res. 38, 47-62

Yano I. (1984) Rematuration of spent kurama prawn Penaeus japonicus.
Aquaculture 42, 179-183

Appendix 1

Draft paper, submitted to Aust. J. Mar. Freshw. Res.
Not to be cited

Female reproductive biology and spawning periodicity of two species of king prawns, *Penaeus longistylus* Kubo and *Penaeus latisulcatus* Kishinouye from Queensland's east coast fishery.

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Abstract

The reproductive biology of two commercially important king prawn species, *Penaeus longistylus* and *P. latisulcatus*, in their eastern geographic distribution has been investigated. Emphasis has been placed on determining spawning magnitude and periodicity by calculating monthly population fecundity indices. Spawning of these two species was found to coincide with periods of high population fecundity occurring in July-August for both years. Two different estimates of female abundance, based on the sampling program and fishermens' log books, were incorporated into the population fecundity indices. Size class frequencies of adult females has also been considered in the formulation of the indices. The influence of the fishery

on the population fecundity indices has resulted in clearly defined peaks rather than extended periods of high population fecundity.

Introduction

The red spot king prawn (Penaeus longistylus) and the western or blue leg king prawn (P. latisulcatus) have been fished by trawlers off the central Queensland coast between $18^{o}S$ and $21^{o}S$ for the past 12 years. Logbook data for this fishery indicate considerable annual landing variation (Robertson and Dredge 1986). Although little biological information is available on these two species in central Queensland, growth, reproduction (Penn 1975, 1980a) and mortality (Penn 1976) of P. latisulcatus have been investigated in Western Australia. Penn (1980b) has also described length-weight relationships and possible habitats of P. longistylus in Western Australia.

The reproductive behaviour of these species has been investigated in this study in the context of future management plans. Particular emphasis has been placed on quantifying periods of spawning potential. Information on the spawning periodicity and nature of the species' reproductive behaviour may also offer some insight into the variations in landings.

Descriptions of penaeid spawning periodicity have frequently been based either on a gonad index or on the percentage of females with ripe ovaries (Cummings 1961, Badawi 1975, O'Connor 1979, Chong 1980, Tseng and Cheng 1981, Kulkarni and Nagabhushanam 1982 and Anderson et al 1985). These investigations have not considered the influence that abundance of adult females has upon the magnitude of the spawning. Population fecundity indices incorporate the abundance of female prawns and have been generated for P. longistylus and P. latisulcatus in the present study.

Similar population fecundity studies have been carried out on the western or blue leg king prawn, P. latisulcatus (Penn 1980a), the banana prawn, P. merguiensis (Crocos and Kerr 1983) and the two tiger prawns, P. semisulcatus (Crocos 1987a) and P. esculentus (Crocos 1987b).

Materials and Methods

Sampling Methods

Sampling of prawns commenced in January 1985. In addition to collecting information on reproduction the program was also designed to give information on prawn abundance over space and time, size composition of prawns and by-catch composition. During 1985, trawl samples were taken from 20 sites between 18°S and 20°S, in Barrier Reef waters. In the following year 12 of the original sites were abandoned and four others were established (Figure 1). Sampling was carried out at night over a period of 4-5 nights and synchronized to coincide with the new moon each month. Samples taken in May 1985 were delayed for eight days due to adverse weather conditions.

Thirty-minute trawl shots with two trawl nets (50.0 mm and 37.0 mm mesh) were undertaken at each station. All Penaeus and Metapenaeus species were sorted, sexed and had their carapace length (CL) measured on board. Female P. longistylus and P. latisulcatus (as well as some less abundant Penaeidae) were snap frozen on board for later analysis. In the laboratory a maximum of 40 female prawns from each station were examined each month. About half of all females caught were examined. Data recorded for each female included a measure of CL and total wet weight. Carapace was classified as either soft or hard shelled and the thelycal cavity was examined to ascertain whether a spermatophore had been implanted. The ovary of every second female prawn was dissected out and weighed on an electronic scale after being dried with tissue paper.

A histological section of the ovary of each female was prepared. Ovarian tissue from the first abdominal segment was either cut directly from the dissected ovary or taken by a transverse section through the undissected prawns. The tissue was preserved in 10% (v/v) formalin. Haematoxylin and eosin were used to stain the tissue which was sectioned in paraffin at a thickness of 6 μm. The stage of development of the ovary was determined by a combination of criteria describing primary development (Tuma 1967) and absorption and rematuration (Yano 1984).

A number of authors (Cummings 1961, Brown and Patlan 1974, and Kulkarni and Nagabhushanam 1982) have used the frequency of certain colours associated with mature stage ovaries as an index of maturation. A PANTONE colour picker by Letraset was used to classify the colour of each ovary in the present study.

Population Fecundity Index

Monthly population fecundity indices were based on abundance of adult females, the proportion of potential spawners (i.e. adult females with early mature (stage 3) and ripe (stage 4) ovaries) and an estimate of ovary weight in potential spawners for each species. The relationship between ovary weight and carapace length for these early mature (stage 3) and ripe (stage 4) females was calculated for each month from the formula

$$\text{Ovary Weight} = a \times (\text{Carapace length})^b$$

The relative contribution to total ovary weight from different size classes of spawners was estimated each month. Calculation of monthly population fecundity indices was carried out on a computer spreadsheet using the formula

$$PFI = n \times p \times \sum_{fm}^{ms} [s \times (a \times CL^b)]$$

where "n" represents the relative abundance (number of adult females sampled and/or catch per unit effort from fishery [CPUE]) of adult females;

"p" represents the proportion of early mature (stage 3) and ripe (stage 4) adult females from the sampling program;

"s" represents the proportion of adult females in size classes between first maturing (fm) and maximum size ⟷ (ms) encountered in the population;

"a" and "b" were coefficients in the relationship between ovary weight and carapace length.

Two estimates of female abundance were used to generate population fecundity indices. The first was derived from the sampling program which also provided monthly sets of size class frequencies for female prawns. The second estimate of female abundance was obtained from logbook records covering the same two year period. Information on effort distribution and hourly catch rate of kings, tigers and other prawns in 6 min x 6 min grids was collected for between 10-15% of fishermen working in the fishery in the same two year period. The data were loaded into a series of random access files on computer and catch rates for unit effort were accessed through a series of Basic programs.

Logbook catches were assumed to consist of prawns in similar size class frequencies as those obtained from the sampling program. Since the logbook records consisted of only pooled species king prawn catch, average monthly catches were broken down into proportions, by weight, attributable to each species. This was estimated by establishing carapace length - total weight relationships for both species and converting monthly size frequency data to estimates of weight for each species taken in the sampling program. The relative contributions to the weight of the catch from each species were then applied to the logbook catches.

Results

Spermatophore Insemination

Over the two year sampling period a total of 4,043 female P. longistylus and 1,132 female P. latisulcatus were examined. The smallest female P. longistylus found inseminated with a spermatophore was 26.0 mm CL (Figure 2). The frequency of insemination increased sharply over the size class range 26.0-33.0 mm CL. Approximately 95% of all female P. longistylus over 34.0 mm CL were found inseminated. The smallest female P. latisulcatus found inseminated was 27.0 mm CL. The frequency of inseminated females increases up to 42.0 mm CL (Figure 2). Approximately 95% of all female P. latisulcatus over 42.0 mm CL were inseminated.

The proportion of inseminated adult females in the population provides an indication of mating activity. The lowest incidence of inseminated adult females of both species occurred in both years in the summer months (January, February and March) (Figure 3).

Ovary Colour

A detailed analysis of ovary colour changes through time is not provided because it was not possible to distinguish ripe (stage 4) ovaries from early mature (stage 3) on the basis of colour alone. The onset of vitellogenesis (yolk production) results in ovaries of both
king prawns taking on a golden-yellow appearance. Somers et al (1987) used this colour to identify ripe ovaries of P. longistylus. Early stages of ovary development (previtellogenic stages 1 and 2) were clear to very pale

grey. Resorbed ovaries, ovaries from soft shelled females and spent ovaries were a dull grey colour.

Seasonal Changes in Ovary Weight

For both years and for both species mean ovary weight increased from the summer months (January, February, March) to the winter months (July and August). Consistent peaks in ovary weight occurred for both species during July and August. Mean ovary weight also increased in the summer months (November and December) but, this increase was not as consistent as the winter peak and was not apparent for P. latisulcatus in 1985 (Figure 4).

Histological Development of Ovaries

In order to study only the adult female population, younger, less mature females were distinguished from the older adult females. Females greater than the minimum size at which vitellogenesis or yolk production (early mature stage 3, Tuma 1967) first occurred were classed as adult. The minimum size of adult female P. longistylus and P. latisulcatus were 33.0 mm and 34.0 mm respectively (Figure 5).

Less than 3.0% of the adult female P. longistylus were histologically classed as ripe (stage 4, Tuma 1967). Ripe (stage 4) females ranged in size from 33.3 mm to 54.5 mm CL. Most spawners sampled were between 44.0 mm and 46.0 mm CL (Figure 6). A slightly greater proportion (3.4%) of the adult female P. latisulcatus were classed as ripe (stage 4); they ranged from 43.1 mm and 55.6 mm CL respectively (Figure 6).

The frequency of P. longistylus and P. latisulcatus females with ripe ovaries was relatively low (Figure 7). Crocos and Kerr (1983) have shown that the frequency of ripe banana prawns (P. merguiensis) can exceed 30% at certain times of the year. The proportion of adult female P. longistylus with ripe ovaries never exceeded 10% in any particular month. The combined proportion of early mature (stage 3) and ripe (stage 4) adult females of both species peaked simultaneously in July 1985 and August 1986 (Figure 7). These peaks in the frequency of advanced histological stages coincided with the increase in ovary weight (Figure 4).

Spent (stage 5) ovaries were difficult to distinguish histologically from rematuring and resorbed ovaries for both species. Ovaries that were redeveloping after a spawning, or after being resorbed were also difficult to distinguish from ovaries in younger females that were maturing for the first time. Penn (1980a) also had difficulty in identifying spent ovaries (stage 5) in P. latisulcatus. The ovaries of soft shelled prawns were all at a low level of sexual development. This was reflected in ovary weight and colour as well as histology.

To test whether the prawns move into different depth zones as they mature, an analysis of variance of depth for the maturity stages was carried out. There was no significant difference ($p > 0.05$) between depths for the first three stages of ovarian development (immature stage 1, developing stage 2, and early mature, stage 3) for P. longistylus. However, there was

significant difference ($p < 0.01$) between depths for the first four stages of development. In eight of the 12 months during 1985 the mean depth for ripe (stage 4) females was greater than the depths associated with the less mature stages. Mean
depths for ripe (stage 4) females differed significantly ($p < 0.05$) from each of the three less mature stages. This analysis was carried out for 1985 data which included a greater range of depths and a larger database as a result of more stations being sampled in 1985 than 1986 (Figure 1).

There was no significant difference between depths ($p > 0.05$) for immature, developing and early mature *P. latisulcatus*. Nor was there significant difference ($p > 0.05$) between depths of immature, developing, early mature and ripe stages either. Mean depths for immature *P. latisulcatus* differed significantly from those of early mature and ripe females. There were no significant differences between depths for early mature and ripe females, developing and early mature or developing and ripe females.

Spawning stock estimation

Abundance of adult females for both species of king prawns was determined from five stations which were consistently sampled over the
full two year program, and from which prawns of both species were normally present. Estimates of abundance for *P. longistylus* from the sampling program (the number of adult females per five stations) and the logbook data (CPUE) show similar trends over the two years (Figure 8). A discrepancy between sampling program and logbook estimates of female abundance occurred in April, 1986. Both estimates indicated

that abundance peaked during the winter months (June to August) in 1985, then decreased to a minimum in summer, (November to February).

Abundance of adult female P. latisulcatus showed a similar pattern to P. longistylus in 1985, however, the peak in abundance of P. latisulcatus occurred earlier in 1986 than in 1985.

Population Fecundity

Indices of P. longistylus population fecundity, which incorporated sampling program abundance peaked during July in both years (Figure 9). Similar trends were evident when the estimates for female abundance were derived from logbook data where population fecundity indices peaked in July 1985 and August 1986.

A peak in the population fecundity index for P. latisulcatus (estimated from sampling program data) occurred in July 1985, while there was no clear peak in 1986, between March and August when the index was relatively high. When the abundance estimate derived from logbooks is incorporated into the population fecundity indices, peaks occurred in July in both 1985 and 1986.

Discussion

Spermatophore Insemination

Female P. longistylus and P. latisulcatus both start mating at approximately the same size (26-27 mm CL). However the plateau of high insemination frequency is attained at a much smaller size for P. longistylus than P. latisulcatus (34.0 mm and 42.0 mm CL respectively). This suggests that P. longistylus mate and mature at a smaller size than P. latisulcatus. Results from the histological analysis of the ovaries support this finding. Minimum spawning size was found to be 33.3 mm CL and 43.1 mm CL for P. longistylus and P. latisulcatus respectively.

Histological Ovarian Development

The proportion of ripe P. longistylus in the monthly samples never exceeded 10%. This is low compared with P. merguiensis in the south eastern Gulf of Carpentaria (Crocos and Kerr 1983). The ripe (stage 4) condition, determined by the presence of the cortical specialization at the oocyte cortex, is only present for a few days and is indicative of spawning occurring within a week (Anderson 1985). The low frequency of ripe female P. longistylus in the present study may have been due to the onset of maturity and spawning occurring within the lunar month, but outside the sampling period, which coincided with the new moon.

Analysis of ovary stage and depth support the general concept for the life cycle of P. longistylus. This species has an atypical juvenile stage which utilizes coral lagoons as nursery grounds (Racek and Dall 1965, Lupton 1986). Crocos and Kerr (1983) found significant differences between mean depths of developing stages 1 and 2 for female P. merguiensis, which would be expected for penaeids that migrate seaward as they mature sexually. However, immature P. longistylus appear to move from shallow (< 3 m) coral lagoons directly into deeper (> 25 m) water and develop sexually through immature, developing and early mature stages in similar depths.

Juvenile P. latisulcatus utilize shoreline nursery habitats (Penn 1980a). The significant differences between depths for immature and the older stages, early ripe and ripe suggests that this prawn migrates seaward as it matures.

The greater mean depths associated with ripe female P. longistylus cannot be explained by tag-return data (Dredge per. comm.) which indicate no adult migratory phase in the life cycle. The deeper stations sampled were true inter-reef sites subject to less trawling than the shallower stations, west of the Great Barrier Reef which were in the major fishing grounds. The geographic distribution of fishing pressure may give rise to enhanced survival of ripe females in these deeper waters. Alternatively, there may be a depth related specific migration not detected through tagging experiments.

Population Fecundity

Penn (1980a) calculated population fecundity indices for P. latisulcatus from three different latitudes on the western coast of Australia and concluded that in the northern latitudes (22^{o}-26^{o}S) the species spawns throughout the year. In more temperate latitudes near Cockburn Sound (32^{o}S), he concluded that spawning peaks were reduced to only the warmer summer months, December to March. The present study indicates that seasonal spawning activity for P. latisulcatus on the east coast of Australia between 18^{o} and 20^{o} differs markedly from spawning activity on the west coast.

Garcia (1984) concluded that a double peaked spawning pattern is the most common seasonal pattern found for penaeids. However, P. longistylus and P. latisulcatus appear to have a single reasonably well defined annual spawning peak in winter (July-August). Abundance of P. latisculcatus was more variable than that of P. longistylus. Penaeus latisculcatus appear to be more than twice as abundant during early 1986 than 1985. Populations of both species would probably remain high for longer if these stocks were not fished commercially. The near reef fishery was seasonal with little effort being directed at either king prawn species until May in each year. As catch rates decreased monitored effort directed at the stocks also reduced and fishing effort ceased in August/September each year. The influence of the fishery on the population fecundity indices has resulted in clearly defined single annual peaks rather than extended periods of high population fecundity.

The reason for the simultaneous nature of the population fecundity peaks is largely due to several reproductive features of these two king prawns' reproductive biology that coincide. Spermatophore insemination frequency, change in ovary weight, histological development and abundance of prawns for both species appear to have similar seasonal fluctuations.

Given their spawning synchrony but dissimilar nursery areas it is unlikely that the postlarvae rely only on prevailing seasonal currents for dispersal. Early developmental stages may display behavioural patterns which influence the direction in which they move. Different migratory modes may also be utilized if spawning times differ within lunar months, outside the monthly sampling period.

Acknowledgements

The authors would like to thank Mr. Millan Curtis, Mr. Malcolm Pearce and Mr. Graham Low for their assistance. Doctor P. Crocos (C.S.I.R.O.) provided advice on the histological staging of ovaries. The project was funded by the Australian Fishing Industry Research Trust Account (F.I.R.T.A.).

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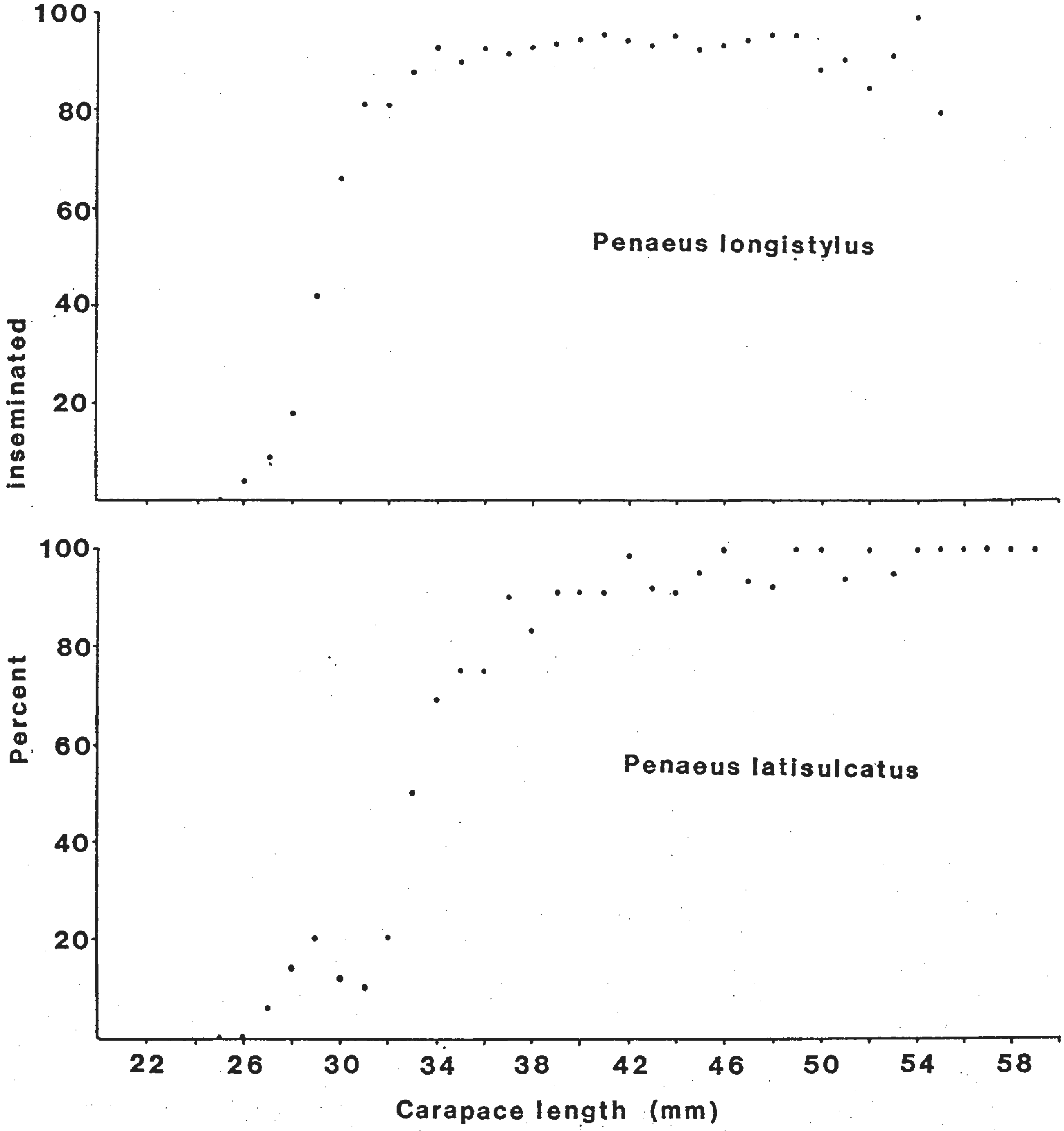
List of Figures

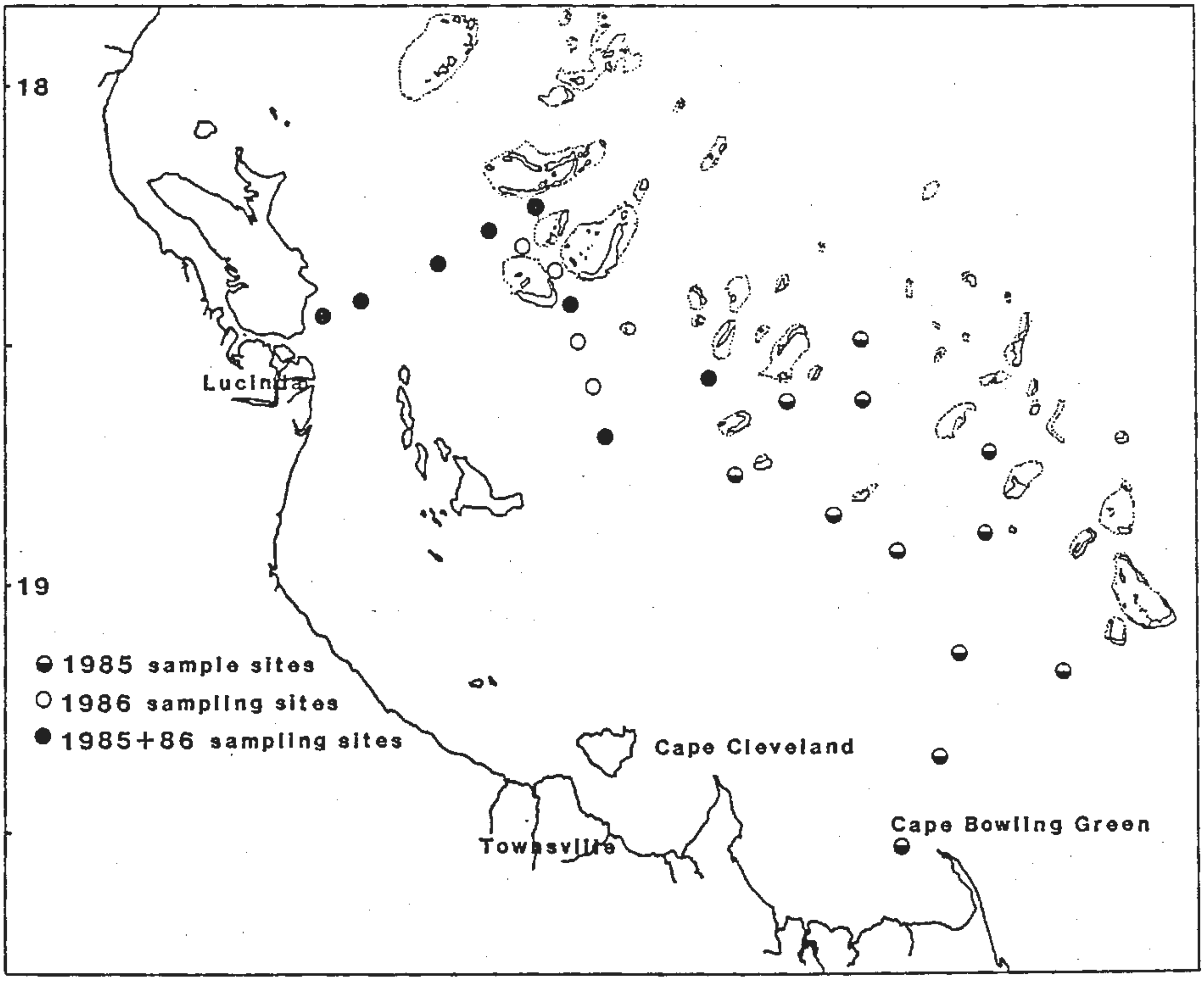
7 Relationship between the proportion of potential spawners in the population of adult females and time.

8 Abundance of female king prawns for both species estimated from two sources as a function of time.

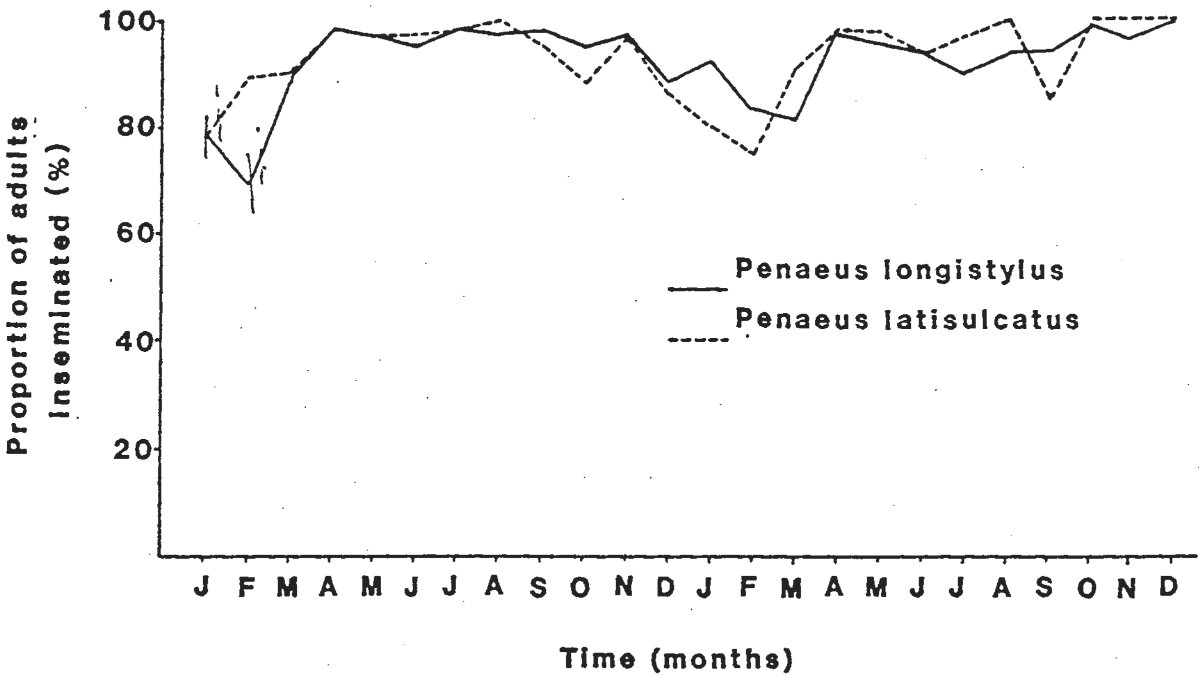
9 Monthly population fecundity indices. Two sets of monthly P.F.I.s have been calculated for each king prawn species.



Percent Inseminated
100
80
60
40
20
Penaeus longistylus
Penaeus latisulcatus
22
26
30
34
38
42
46
50
54
58
Carapace length (mm)

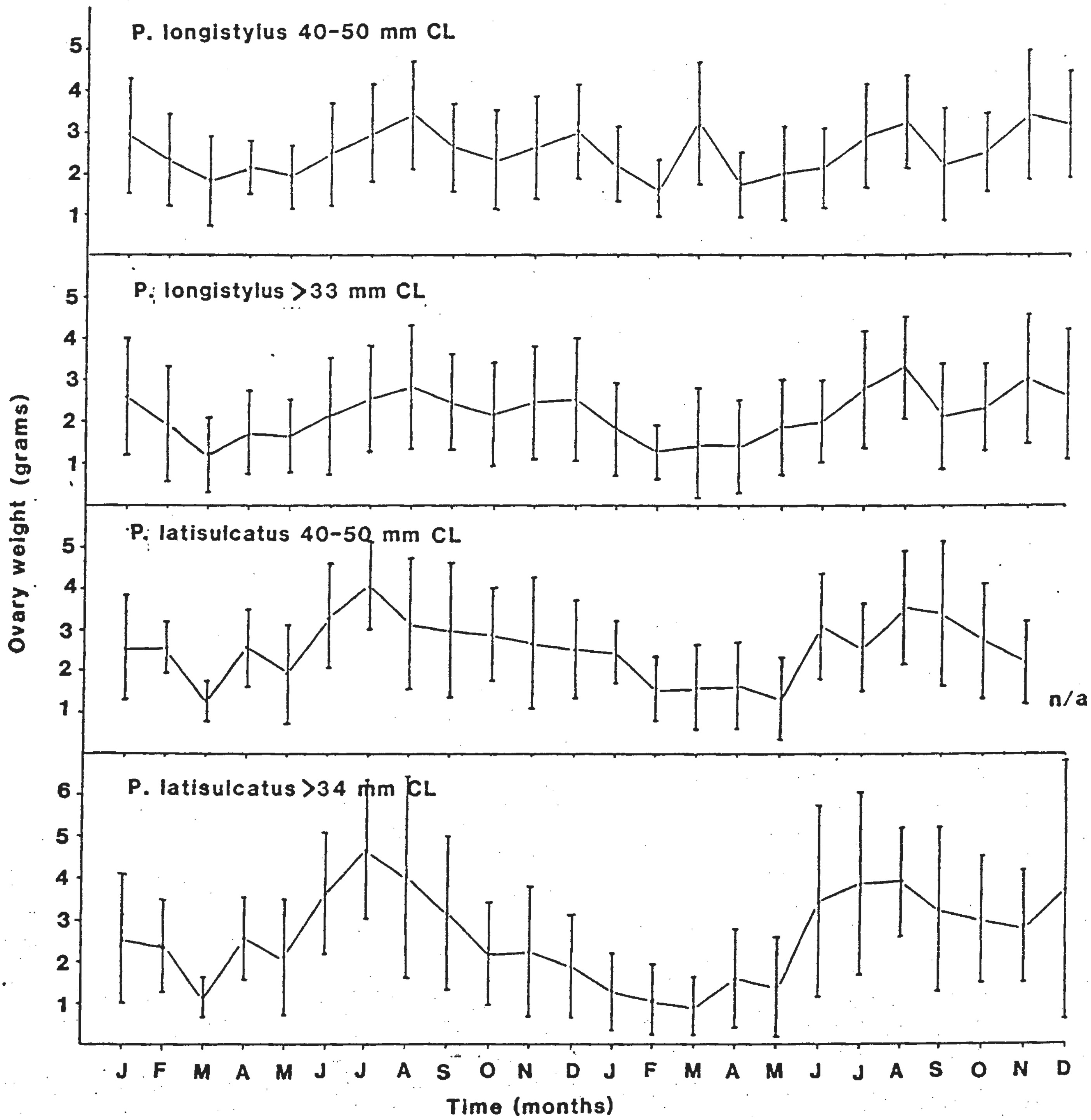


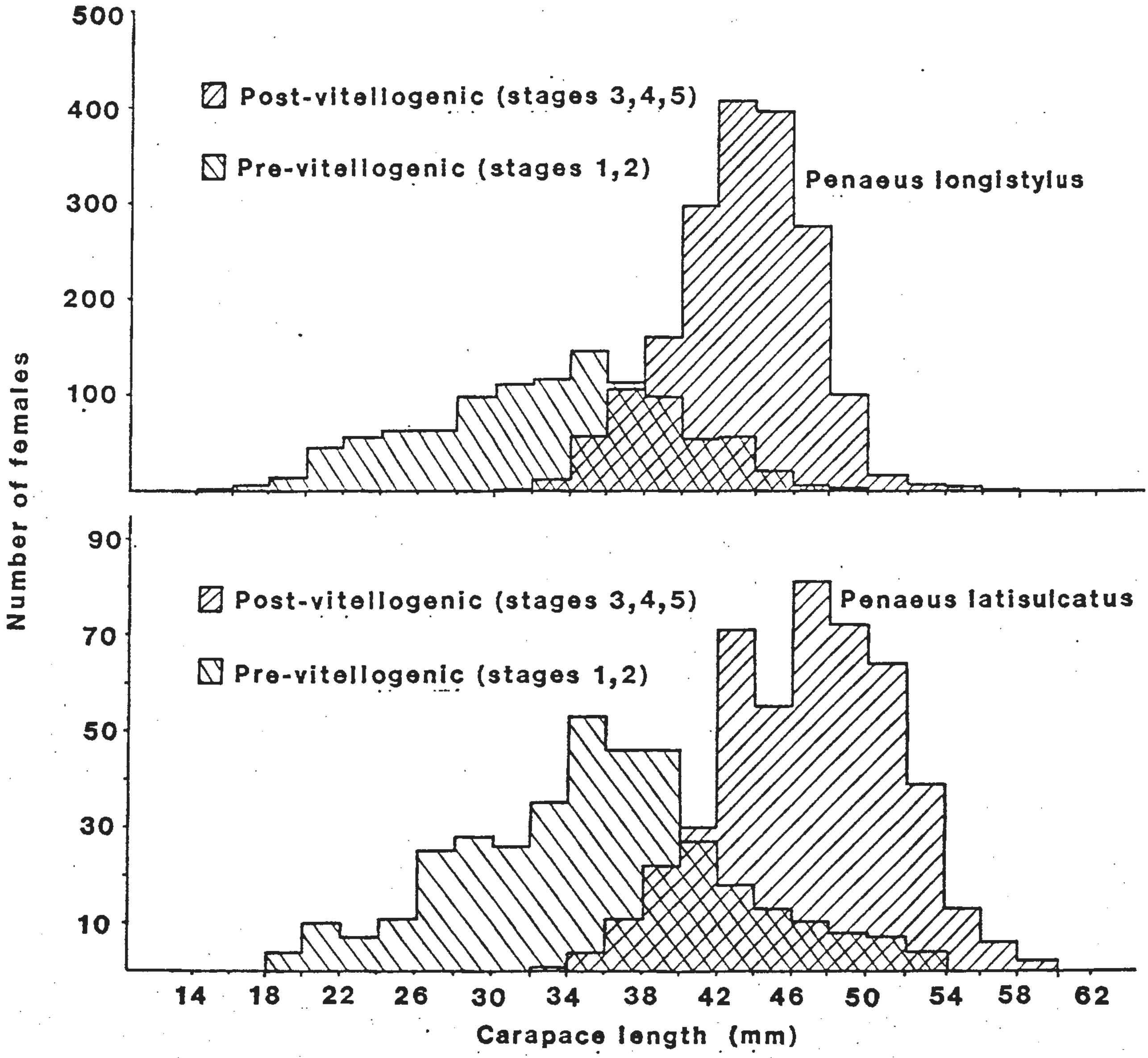
18
19
Lucinda
1985 sample sites
1986 sampling sites
1985+86 sampling sites
Cape Cleveland
Townsville
Cape Bowling Green



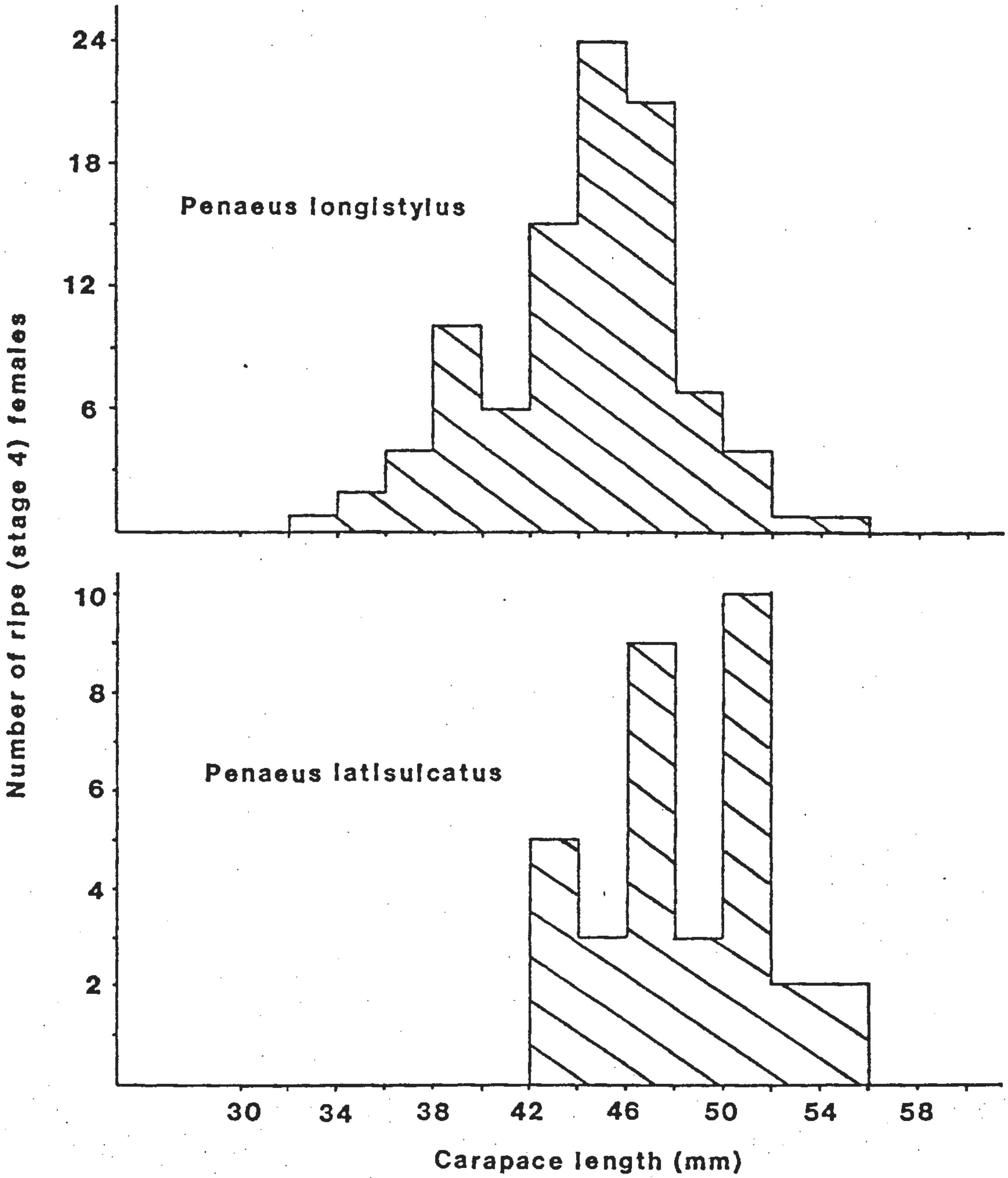
100
80
60
40
20
Proportion of adults
Inseminated (%)
Penaeus longistylus
Penaeus latisulcatus
J F M A M J J A S O N D J F M A M J J A S O N D
Time (months)

4

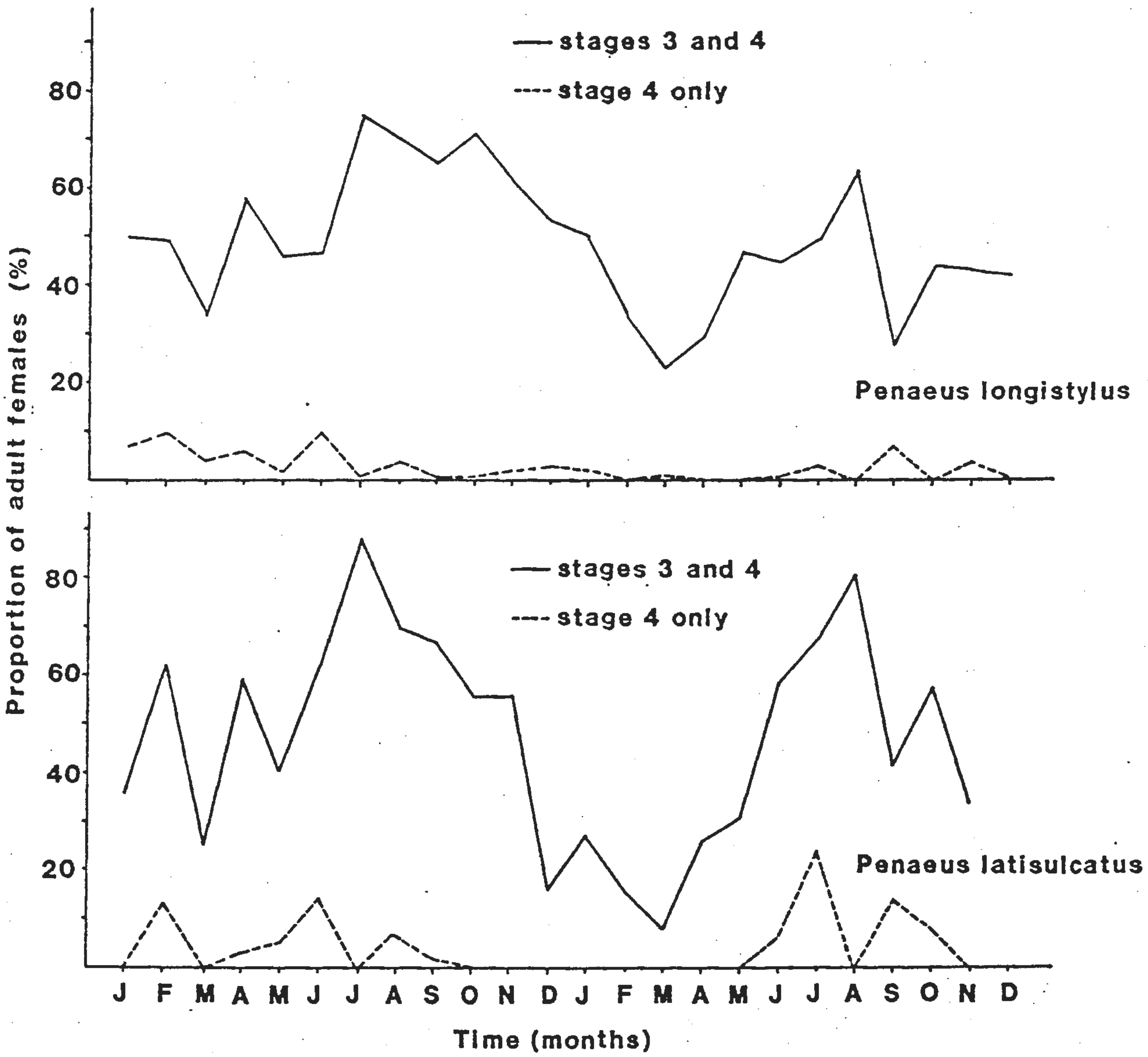

P. longistylus 40-50 mm CL
P. longistylus >33 mm CL
P. latisulcatus 40-50 mm CL
P. latisulcatus >34 mm CL
n/a
Ovary weight (grams)
J F M A M J J A S O N D J F M A M J J A S O N D
Time (months)



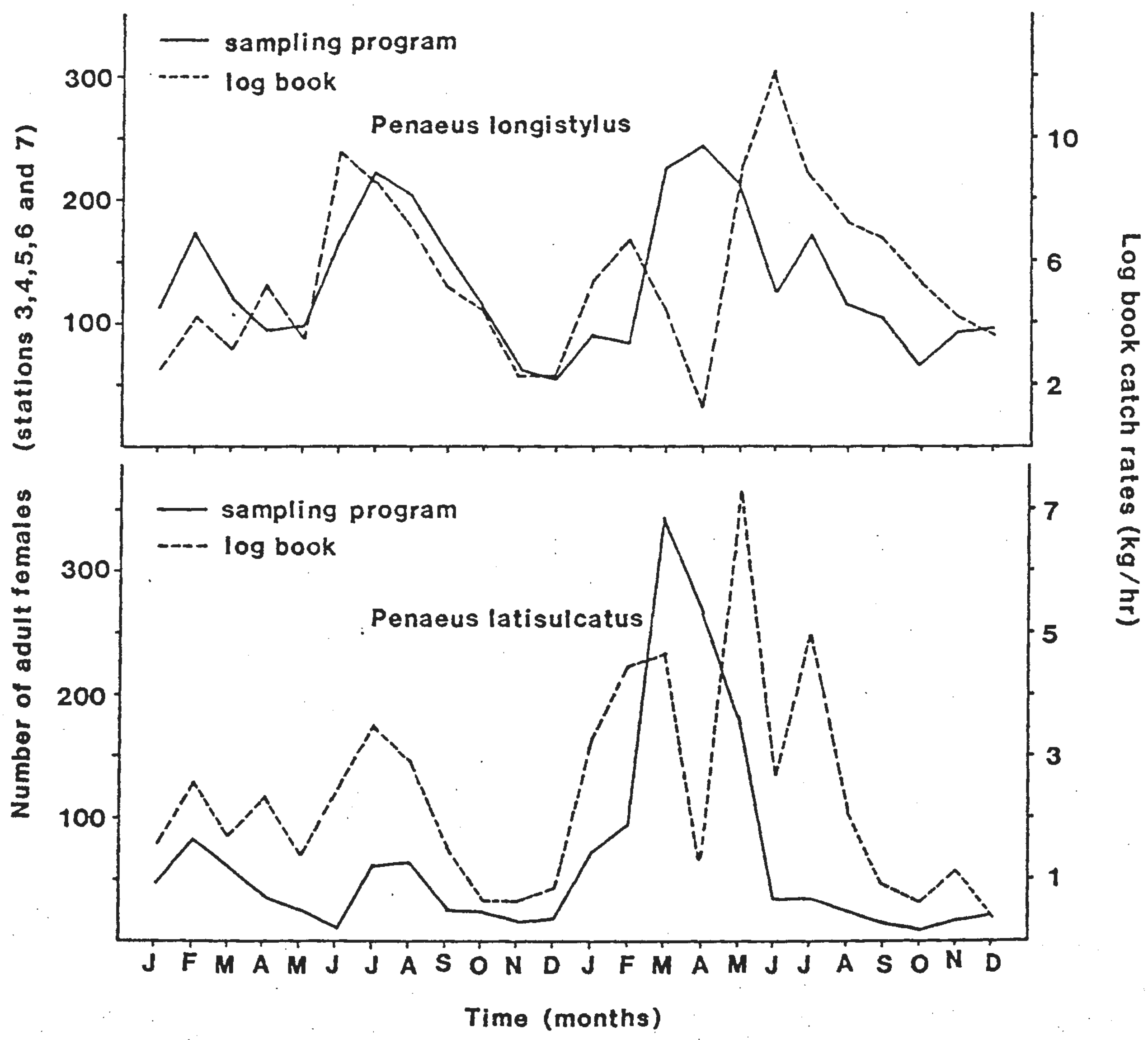
500
400
300
200
100
Post-vitellogenic (stages 3,4,5)
Pre-vitellogenic (stages 1,2)
Penaeus longistylus
Number of females
90
70
50
30
10
Post-vitellogenic (stages 3,4,5)
Pre-vitellogenic (stages 1,2)
Penaeus latisulcatus
14 18 22 26 30 34 38 42 46 50 54 58 62
Carapace length (mm)



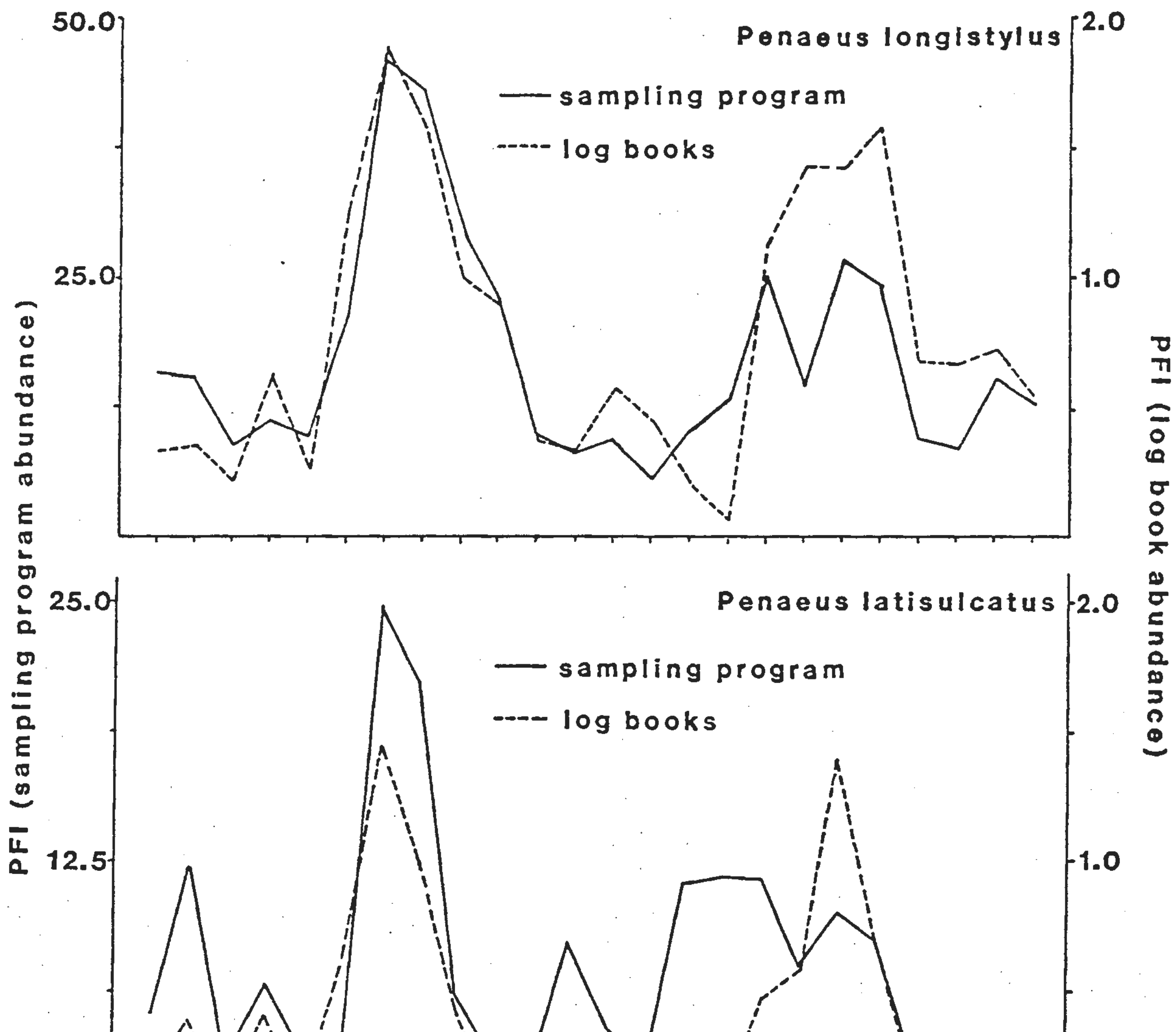
24
18
12
6
Penaeus longistylus
10
8
6
4
2
Penaeus latisulcatus
Number of ripe (stage 4) females
30
34
38
42
46
50
54
58
Carapace length (mm)



stages 3 and 4
stage 4 only
80
60
40
20
Penaeus longistylus
stages 3 and 4
stage 4 only
80
60
40
20
Penaeus latisulcatus
Proportion of adult females (%)
J F M A M J J A S O N D J F M A M J J A S O N D
Time (months)



sampling program
log book
Penaeus longistylus
sampling program
log book
Penaeus latisulcatus
300
200
100
10
6
2
7
5
3
1
Number of adult females (stations 3,4,5,6 and 7)
Log book catch rates (kg/hr)
J F M A M J J A S O N D J F M A M J J A S O N D
Time (months)



50.0
25.0
Penaeus longistylus
2.0
1.0
sampling program
log books
25.0
12.5
Penaeus latisulcatus
2.0
1.0
sampling program
log books
PFI (sampling program abundance)
PFI (log book abundance)
J F M A M J J A S O N D J F M A M J J A S O N D
Time (months)

ESTIMATES OF MOVEMENT, GROWTH PARAMETERS AND NATURAL MORTALITY FOR THE RED SPOT KING PRAWN, PENAEUS LONGISTYLUS KUBO, FROM TAGGING DATA.

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Abstract

Movement, growth and natural mortality rate of the red spot king prawn, _Penaeus longistylus_, have been investigated in a series of tagging experiments. Adult _P. longistylus_ move little after leaving nursery areas. Their winter growth rate was slower than the conspecific species _P. plebejus_ and _P. latisulcatus_. Their natural mortality rate was assessed using a technique which eliminated the possibility of confounding with the rate of fishing mortality. The rate of natural mortality so estimated was between .073 and .085 ($week^{-1}$), which is a higher rate than has been estimated for other species of the genus Penaeus.

Appendix 2

Draft paper, submitted to Aust. J. Mar. Freshw. Res.
Not to be cited

Introduction

A trawl fishery for two species of king prawn, *Penaeus longistylus* Kubo (red spot king) and *Penaeus latisulcatus* Kishinouye (blueleg king) has existed in waters between the Queensland coast and the Great Barrier Reef between 18°S and 21°S since the mid 1970s. Annual landings from what is a predominantly winter fishery have ranged between 200 and 650 tonnes in the period 1980 to 1985 (Robertson and Dredge 1986). *Penaeus longistylus* comprises more than 70% of the catch by weight.

Penaeus longistylus has been recorded from Lord Howe Island, the northern Australian coast, the Arafura Sea and from the coastal fringe of the eastern Indian Ocean to South China Sea (Racek and Dall 1965, Grey et al. 1983). The species is relatively uncommon in Western Australian waters (Penn 1980), contributes little to fisheries in south east Asia (Anon 1981) and constituted less than 5% of total landings from the Torres Strait prawn fishery in 1985 (Somers et al. 1987). Information on its biology is fragmented. Racek and Dall (1965) noted that the species occurred in the vicinity of reef areas, and that juveniles had been taken from coral reef lagoons at Heron Island (23°25′S, 151°55′E), on the Great Barrier Reef. By contrast, Coles et al. (1987) recorded juveniles at two coastal sites as well as on reef platforms in far north Queensland waters. Penn (1980) published length weight convertions for the species and suggested that adults may require a habitat in which the dominant fauna were large sessile invertebrates. Somers et al. (1987) gave quarterly size frequency data and infered from them that recruitment of *P. longistylus* to the Torres Strait fishing grounds peaked in December.

More detailed information on seasonal abundance, reproduction, habitat requirements, movement, growth and mortality is required for effective management of the Queensland stock or stocks. In the present study, tagging techniques have been used to obtain data on movement, growth and natural mortality rates of P. longistylus. Tagging has been widely used to study growth and movement of prawns, particularly since streamer tags (Murrello et al 1976) have become readily available.

Growth of prawns has been studied either through analysis of size frequency data or from tagging studies. Despite the occurence of abnormal growth moults following tagging (Penn 1975, Hill and Wassenberg 1985), Garcia and Le Reste (1981) concluded that growth parameters derived from tagging data were less susceptible to error than those from size frequency analysis.

Data obtained from tagging experiments have been used with a variety of analytical techniques to estimate fishing and total mortality for prawn stocks (Lucas 1974, Penn 1976, Garcia and Le Reste 1981). Validity of the estimates is dependent on the assumption that tagged animals are equally vulnerable to recapture as untagged ones. To meet this requirement, the density of tagged animals should be proportional to stock density over the area occupied by the stock. In situations where this condition is not met, but where tagged animals are sedentary, the natural mortality component of total mortality can be estimated from tag returns using sequential releases. Differences in returns from releases spaced over time, but not location, reflect survival of tagged animals to the time they are recaptured. If there is no fishing mortality in the period between the sequential releases, assumptions associated with the estimatiom of natural mortality are minimimized. The limitations of the technique have invalidated its use for any species of prawn to the present time.

Methods

In 1985 tagging operations were conducted in and immediately adjacent to areas which had been consistently fished for king prawns in the Great Barrier Reef lagoon (Fig. 1). *Penaeus longistylus* taken by trawl were sorted and apparently healthy animals were held in flowing seawater prior to being tagged. Each tagged animal was sexed, its carapace length (C.L.) measured to the nearest 0.1 mm and tagged through the first abdominal segment with a Floy streamer tag which had been smeared with a broad spectrum antibiotic ointment. Tagged animals were returned to a second container of fresh, flowing seawater prior to release. Releases of between 90 and 290 prawns were made after each batch was inspected and damaged or obviously distressed prawns were removed. Prawns were released on the bottom, via a mesh cage with a manual releasing mechanism. Tagging experiments designed to give data on growth, movement and recovery rates as functions of size at release and gender were conducted between May and August, 1985. A total of 1606 tagged prawns were released at 7 sites in this period.

Data from the 1985 releases indicated that *P. longistylus* moved relatively short distances, if at all, once they moved from nursery areas to the near-reef areas in which they are fished. In 1986, sequential tag releases were made at four sites to assess the natural mortality rate of adult *P. longistylus.* The tagging procedure used in 1985 was followed. Tagged prawns were released in April (833 tagged animals released) and May (1034 tagged animals released), prior to the commencement of the fishery for king prawns off central Queensland. A further 273 prawns were tagged and released in April 1986 to obtain further growth data.

Natural mortality in a sedentary population can be estimated by considering the number of animals (N1) tagged at the time of the first release (T1) which survive until the time at which the second release of N2 animals occurred (T2). Call the number of survivors N1′. Let the number of animals recaptured from release 1 and release 2 be Re1 and Re2 respectively. If fishing commences some time after T2, Re1 is proportional to N1′ and Re2 proportional to N2. Therefore

$Re1/N1' = Re2/N2$ and the instantaneous mortality coeffient M is estimated from

$$M_{(T1-T2)} = \ln(N1'/N1)$$ using N2*Re1/Re2 as an estimator of N1′.

Prior to tagged prawns being released in 1985 and 1986, skippers of trawlers who had participated in the fishery were contacted personally. They were notified of the tagging programme and issued with pre printed tag recapture labels. Processors were also made aware of the tagging programme and requested to return tagged prawns. In addition to payment of a small reward, details of growth and movement for each recaptured prawn were given to the person returning tagged prawns.

A voluntary log book return scheme for the central Queensland prawn fishery was commenced in 1984. The data required from fishermen included details of king prawn catch on a shot by shot basis in grids of six by six minutes. Between 10 and 15 per cent of annual landings from the king prawn fishery have been monitored in this programme. The composition of the sample fleet is such that effort distribution in the entire fishery is thought to be reasonably represented by this sample fleet.

Results

Of the 1606 tagged prawns released in 1985, 345 were returned. The maximum period between release and recapture for any one prawn was 330 days and the mean period at liberty was 51 days (s.d.= 41.0 days). In 1986, 271 of the 2140 tagged prawns released were recaptured. Average period at liberty for these prawns was 64 days (s.d.= 34.1), and maximum period between release and recapture was 251 days.

Variation in recovery rate as a function of gender and size at release.

Released and recaptured prawns have been classified by gender and size at release (C.L., grouped in 5mm size classes) in Table 1. There was no significant variation in the sex ratio of recaptured prawns compared with the sex ratio at release (1985- χ^2=3.00, P>.05, 1986- χ^2=2.36, P>.05). A comparison of recovery rate as a function of size at release was carried out using data pooled into 5 mm size classifications for each year's tag returns. Expected versus observed returns generate values which were significant in both data sets (1985- χ^2=17.39, P<.05, 1986- χ^2=21.74, P<.01). Both sets of tag return data show that the return rate of prawns tagged at a size of 30 mm C.L. or less was significantly lower than for prawns larger than this size.

Movement of tagged animals

Any attempt to relate movements of tagged animals to movement or migratory patterns of the population as a whole should be considered bearing in mind the availability of effort to recapture tagged prawns. Effort distribution in the 4 month periods after tagged prawns were first released in 1985 and 1986 is shown in Fig. 2 a,b. More than 90% of returned tags had been recaptured in this period. In both 1985 and 1986, fishing effort was distributed along an area with a north-west to southeast axis, largely to the west of the Great Barrier Reef. To the west of the major king prawn grounds, the coastal tiger prawn grounds were lightly fished during winters of 1985 and 1986. Red spot king prawns are rarely taken in water depths of less than 30 m in the coastal area between Cape Bowling Green and Lucinda. There is little trawling in the inter-reef area to the east of the tag release sites. Red spot kings are appreciably less abundant in these areas then on the eastern edge of the Great Barrier Reef lagoon (Robertson and Dredge unpublished data).

Tag recaptures from 1985 and 1986 releases are summarized in terms of distance and direction moved in Table 2. Movement of any prawn recaptured within a 12 km radius of the release point could not be distinguished from zero movement. Trawlers in this fishery normally cover a distance of approximately 12 km during each shot and skippers could not identify where in a shot they had picked up a tagged prawn. Of the 269 recaptured prawns taken from 1985 releases and 177 recaptures from 1986 releases for which recapture position could be reliably located, 242 and 162 respectively were recaptured within 12 km of the release point.

The greatest recorded distance travelled by a recaptured prawn was 55 km. To determine if the distance moved by tagged *P. longistylus* increased with time at liberty, distance moved by those tagged prawns which had recorded movements of more than 12 km has been compared with time at liberty. The slope of the regression of distance moved on time out did not vary significantly from zero for both year's data (1985-b =.017, t =1.89, P>.05, 1986-b =.0034, t =.107, P>.05).

The sex ratio of tagged P. longistylus which moved more than 12 km was compared with the ratio at release.

The male to female ratios in 1985 and 1986 were 1.5 and 2.0 respectively. These ratios did not differ significantly from the overall sex ratios of returned prawns (χ^2=0.20, P>.05 and χ^2=2.45,P>.05 in 1985 and 1986).

Direction moved by tagged prawns recaptured more than 12 km from their release site has been considered in terms of the proportion of recaptures made in 45° sectors radiating from the release site. (Table 2). Because expected numbers in each sector were low, returns made in each of the four 90° sectors radiating from 0° , and from the four 90° sectors originating at 045° were compared against expected returns in a single chi square test. There was significant heterogeneity in the proportion of animals recaptured from each sector (1985- χ^2=13.85, P<.05, 1986- χ^2=23.87, P<.001) but no year to year consistency of observed directional movement. Prawns tagged and recaptured more than 12 km from the release point in 1985 were more likely to have been recaptured to the south west and north west than in other sectors, whilst in 1986 there were more recaptures made to the east and south east of release points.

Growth

Growth of redspot king prawns in the size range 25-55 mm CL has been modelled using the Marquardt algorithm to derive estimates of the Brody-von Bertallanffy parameters K and L_∞ (Conway et al 1970). Data from 1985 and 1986 have been segregated, and growth parameters for males and females have also been estimated separately, as there is ample evidence that growth rates and assymptotes in the Peneaidea can be differentiated by gender (Garcia and LeReste 1981). Because estimates for K and L_∞ have been shown to be interdependent for other species of Penaeidea, confidence estimates around point estimates for K and L_∞ were estimated in terms of joint confidence areas. These are more readily comprehended in diagramatic form (Kirkwood and Somers 1984). Growth parameters were derived from data obtained from 427 tagged prawns (218 in 1985, 209 in 1986). These prawns had been returned with meaningful information on time at liberty and size at recapture, and had been at liberty for more than 10 days. Data from a further two prawns which met these criteria were removed from subsequent analyses as they were considered to be extreme outliers, possibly as a result of measurement error. Estimates of the growth parameters, their standard errors and results from analyses of variance on residuals against time at liberty and size at release are given in Tables 3 a, b and c. Whilst there was no sigificance in the comparison with residuals against size at release, both years' data sets indicate significant variation of residuals with time at liberty for female (but not male) P. longistylus. Joint confidence limits for K and L_∞ from the two year's data are shown in Fig. 3. The degree of distortion from circularity in these diagrams demonstrates interdependence of the two parameters. Comparisons of year to year consistency between both K and L for males and females indicated that there was significant variation in the value of K (the Brody-von Bertallanfy growth rate parameter) for both males and females, and for female (but not male) length assymotes (Table 3, Fig 3). Calculated growth curves for prawns in the size range 25 to 50 mm CL is shown in Fig 4. In the absence of estimates for the value of t , there is no justification for relating size to biological age.

Natural Mortality

Four sets of data derived from sequential releases of tagged prawns were available for estimating the natural mortality rate of adult P. longistylus.

A series of estimates for M can be calculated, using data from the four sites, and also by considering recaptures from release 1 and release 2 over a series of time intervals after T2. Recaptures considered in this manner can be laid out in matrix form (Table 4) and estimates of M made from each cell's data. The mean and standard error of M so estimated from the four sites was M = 0.073 (week^{-1}), with s.e.= 0.043. If the data are treated as a single sequential release over time, with recoveries being made in three 28 day time periods (required to give similar numbers of returns in each period) , the resultant estimate for M (week) is 0.085, with s.e. = 0.026.

DISCUSSION

Penaeus longistylus is one of three morphologically similiar species which support important fisheries off the Australian coast, the others being P. plebejus Hess and P. latisulcatus Kishinouye. Migration patterns and growth parameters of P. plebejus have been described from tagging studies (Lucas 1974, Potter 1975, Ruello 1975, Glaister 1987). The species offers a remarkable contrast in migratory behaviour with P. longistylus, undertaking extensive northward migrations after leaving an estuarine nursery areas. The limited information published on movements of P. latisulcatus (Penn 1976) suggest that the species follows a more convention life cycle (sensu Garcia and Le Reste 1981), moving from inshore nursery to offshore spawning sites in deeper water without undertaking extensive movement along the axis of the coastline. Whilst P. longistylus moves from a specific nursery habitat to deeper water (Dredge unpub data), the absence of migratory behaviour after individuals attain a size of about 25 mm (C.L.) offers a marked contrast to P. latisulcatus and P. plebejus. The lack of directional movement by the small proportion of P. longistylus which did move measurable distances has been interpreted as random movement from release sites rather than directed or migrational movement. There was sufficient fishing effort to the north, south, west and immediately to the east of the tagging sites to take tagged prawns had they moved in those directions.

Growth parameters estimated for P. longistylus suggest that the species has a slightly slower growth rate than both P. plebejus and P. latisulcatus, and attains a smaller maximum size. The sexual dimorphism in growth parameters which appears to be a feature of the Penaeidea was again observed to occur in P. longistylus. The estimated growth parameters show significant variation between the two years in which tagging data was obtained. Williams and Dredge (1981) showed similar year to year growth variation in a sedentary scallop Amusium japonicum balloti Bernardi. The growth parameter estimates should be considered with some reservation. Not only are the growth paramaters derived from prawns tagged only in half of their overall size regime, but they come from animals which were tagged in a two to four month period during autumn and winter. The majority were recaptured within four months of release. Growth rate parameters therefore reflect winter growth. Given seasonal behavioural changes noted by White (1975) for P. esculentus and temperature induced variation in emergence noted by Hill (1985), seasonal variation in growth parameters may occur. These, in turn, may explain why there was significant variation between residuals of estimated against observed growth of the slightly faster and larger growing females prawns with time at liberty.

The growth data were further limited by the low recapture rates of small (<30 mm C.L.) prawns. Hill and Wassenberg (1985) reported that tag induced mortality on P. esculentus larger than 24 mm C.L. was not measurable in aquarium experiments, and Glaister et al (1987) were unable to detect size differential mortality in field tagged P. plebejus. The present data indicate that under some circumstances, small prawns may be more vulnerable to tag induced mortality than larger ones, and due regard for this phenomenon should be given if tag data is to be used to study mortality parameters.

Estimates of the natural mortality rate using data obtained from tagging experiments have been made for P. plebejus (Lucas 1974) and P. latisulcatus (Penn 1976). Both of these estimates were derived in conjunction with estimates of total and fishing mortality and offer the possibility of confounded results. In the present study, the unusual behaviour of P. longistylus lent itself to obtaining information on natural mortality independant of fishing mortality. The resultant estimate of M was higher than those obtained for P. plebejus and P. latisulcatus. Whilst this apparent rapid rate of natural mortality may be a feature of the species, it should be born in mind that the period over which natural mortality was estimated covered five weeks. Some care on extrapolating such data to a full life span should be taken. The estimate of natural mortality also bypasses the problem of long term tag induced mortality. Whilst Hill and Wassenberg (1985) were not able to detect such mortality in experimental conditions, the possibility for such mortality exists in the field. When prawns tagged with streamer tags bury, the tips of the tags can remain above the substrate (Wassenberg pers com) and may act as a signal or attractor to potential predators. The estimate of the natural mortality coeffient M given in this study should therefore be treated with some reservation. However, the technique of sequential tagging in populations of sedentary animals which suffer low, zero or measurable tag induced mortality is one which could be investigated further.

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Table 1 Comparative recoveries of tagged P. longistylus as functions of size at release and gender.

Year of release			Size Class (Carapace length, mm)								
			15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-5	55-9
1985	Males	No.rel.	0	15	46	262	629	28	0	0	0
		No.recapt.	-	0	5	55	153	5	-	-	-
	Females	No.rel.	0	14	24	81	121	277	99	7	3
		No.recapt.	-	0	1	14	24	51	24	0	0
		% recapt.	-	0	8.6	20.1	23.6	18.4	24.2	0	0
1986	Males	No.rel.	2	14	48	515	592	52	0	0	0
		No.recapt.	0	0	3	46	8	5	-	-	-
	Females	No.rel.	8	10	31	44	237	474	101	11	1
		No.recapt.	0	0	3	4	38	70	8	3	0
		% Recapt.	0	0	7.6	11.2	14.8	14.3	7.9	27.3	0

Table 2. Distance and direction of movement for tagged <u>P. longistylus</u> recaptured more than 12 km from their release point.

	1985			1986		
	Distance moved (km)			Distance moved (km)		
Direction moved from release point (degrees)	13-18	19-24	>25	13-18	19-24	>25
0-44	3					
45-89						
90-134	1		2	2	2	
135-179	3			6		0
180-224	1	3	1			2
225-269						
270-314	5	5	3		1	2
315-359			2			

Table 3a Estimates of growth parameters for <u>P. longistylus</u>

Year	Gender	Number of prawns	L_∞ (s.e.) (mm)	K (s.e) (day^{-1})
1985	Male	145	42.76 (0.61)	0.00339 (0.00035)
	Female	73	48.51 (0.73)	0.00566 (0.00060)
1986	Male	107	41.62 (0.78)	0.00563 (0.00086)
	Female	102	54.83 (1.19)	0.00309 (0.00048)

Table 3b Comparisons of year to year estimates for L and K (values of d)

Male		Female	
L_∞	K	L_∞	K
1.15(N.S.)	2.41(*)	4.53(**)	3.37(**)

Table 3c Analyses of variance between residuals and time at liberty, size at release

Year	Gender	F values	
		residuals vs time out	residuals vs C.L. at release
1985	Males	0.001 (N.S.)	1.57 (N.S.)
	Females	9.17 (**)	0.11 (N.S.)
1986	Males	3.64 (N.S)	0.75 (N.S.)
	Females	5.53 (*)	1.75 (N.S.)

note: *-significant at .05 probability level
**-significant at .01 probability level

Table 4 Recaptures from sequential release of tagged prawns on 11-4-86 (T1) and 15-5-86 (T2).

Sites	Number released		Time out (days) from T2: 0-28	29-56	>56		N1´	M(week^{-1})
			Number recaptured					
1	T1	236	0	16	7	23	158.4	0.079
	T2	179	0	14	12	26		
2		234	5	12	13	30	145.3	0.095
		276	15	31	11	57		
3		172	7	4	9	20	213.9	-0.044
		246	1	8	14	23		
4		170	10	5	1	16	75.6	0.162
		255	15	28	11			
		812	22	37	30	89		
		956	31	81	48	160		
	N1´		678.5	436.7	597.5			
	M(week^{-1})		0.036	0.124	0.094			

Figure Captions

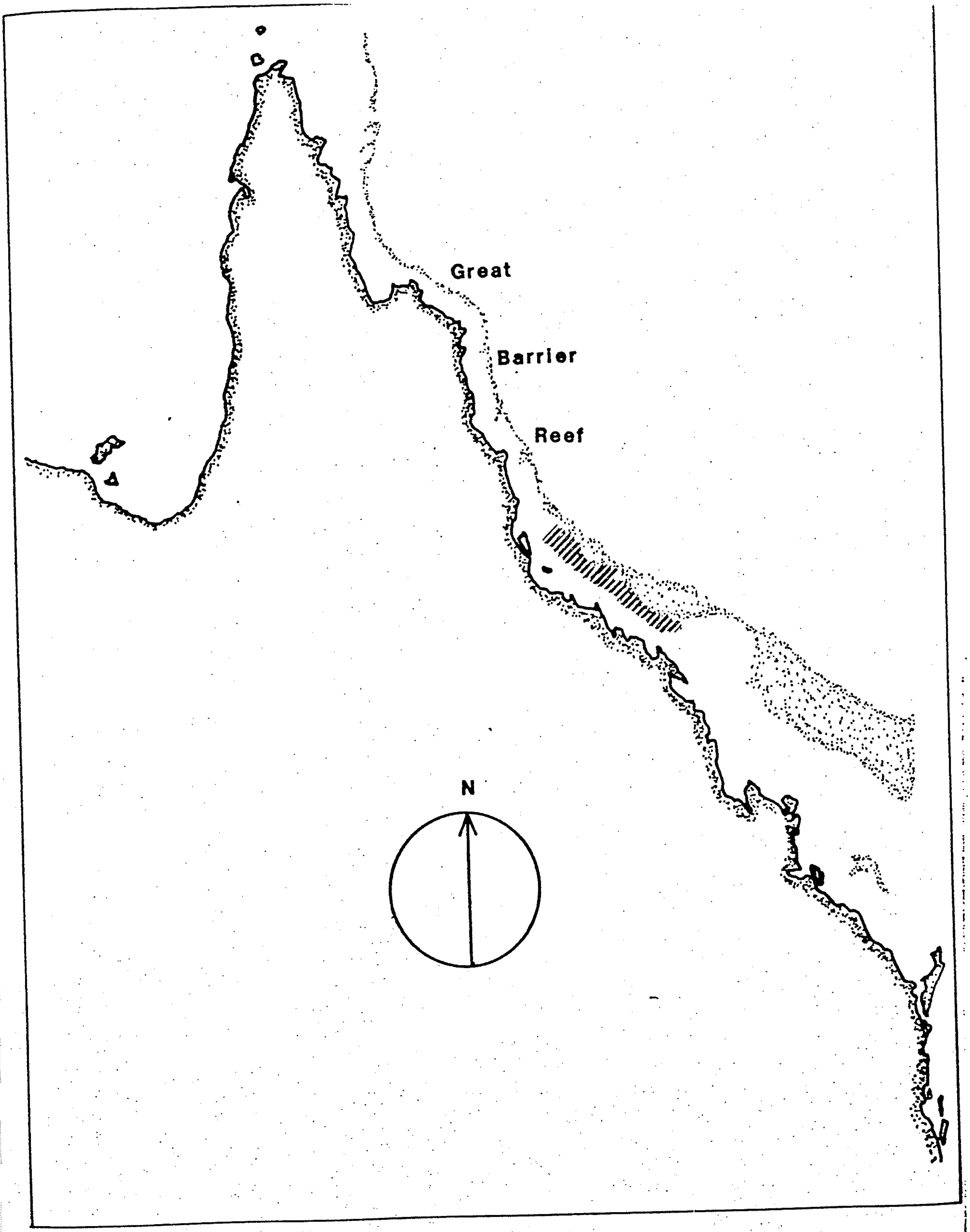
Figure 1. The Queensland coast line, showing major redspot king prawn fishing grounds (hatched) in 1984-1986.

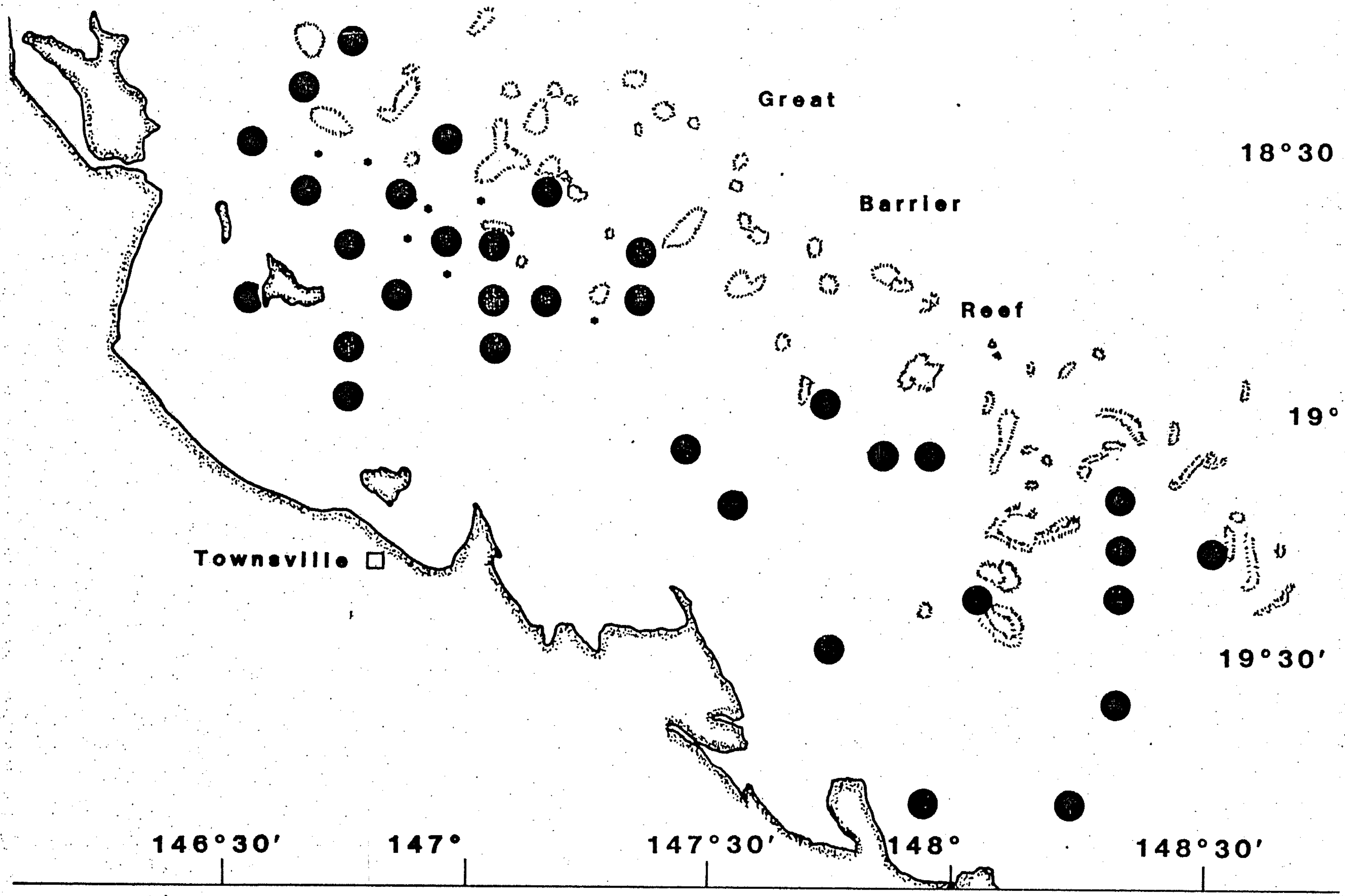
Figure 2a. Effort distribution for boats fishing king prawns in the four months following first release of tags in 1985, from log book data. Solid circles represent more than 1% of monitored king prawn catch in 6 by 6 minute grids. Asterisks show tag release sites.

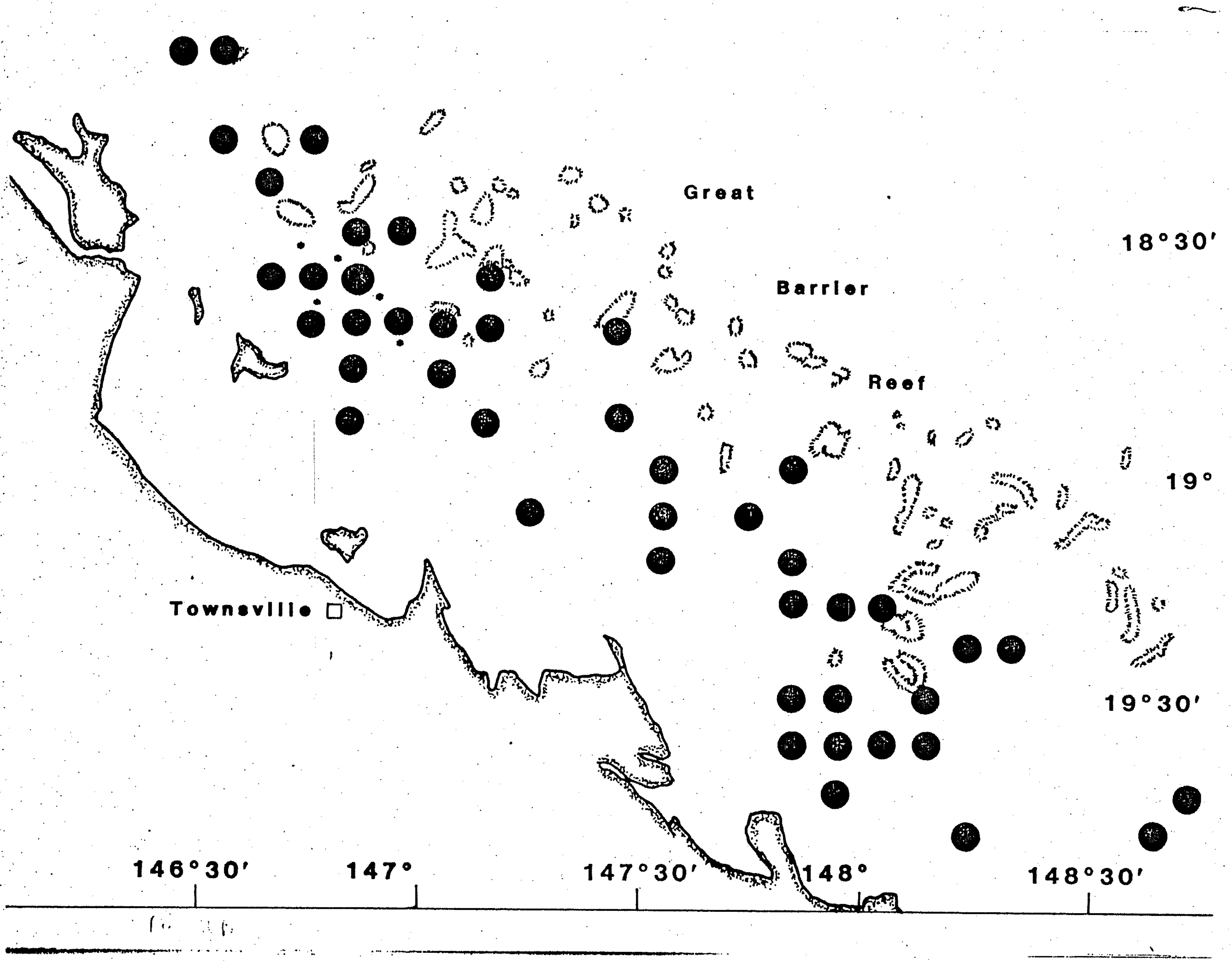
Figure 2b. Effort distribution for boats fishing king prawns in the four months following first release of tags in 1986, from log book data. Solid circles represent more than 1% of monitored king prawn catch in 6 by 6 minute grids. Asterisks show tag release sites.

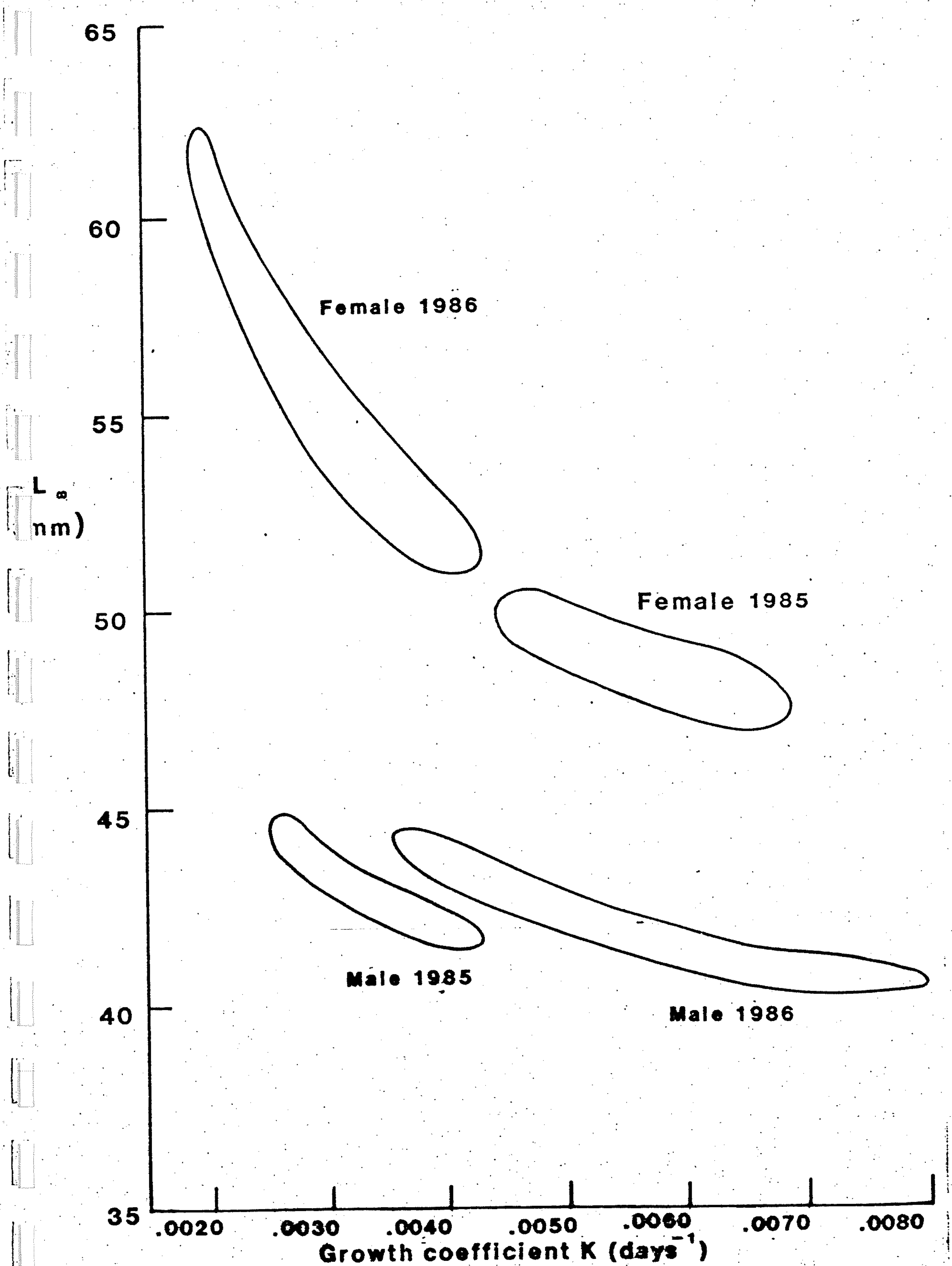
Figure 3. Joint confidence limits for k and L from 1985 and 1986 tag recapture data.

Figure 4. Growth of P. longistylus from estimates of growth rate parameters.

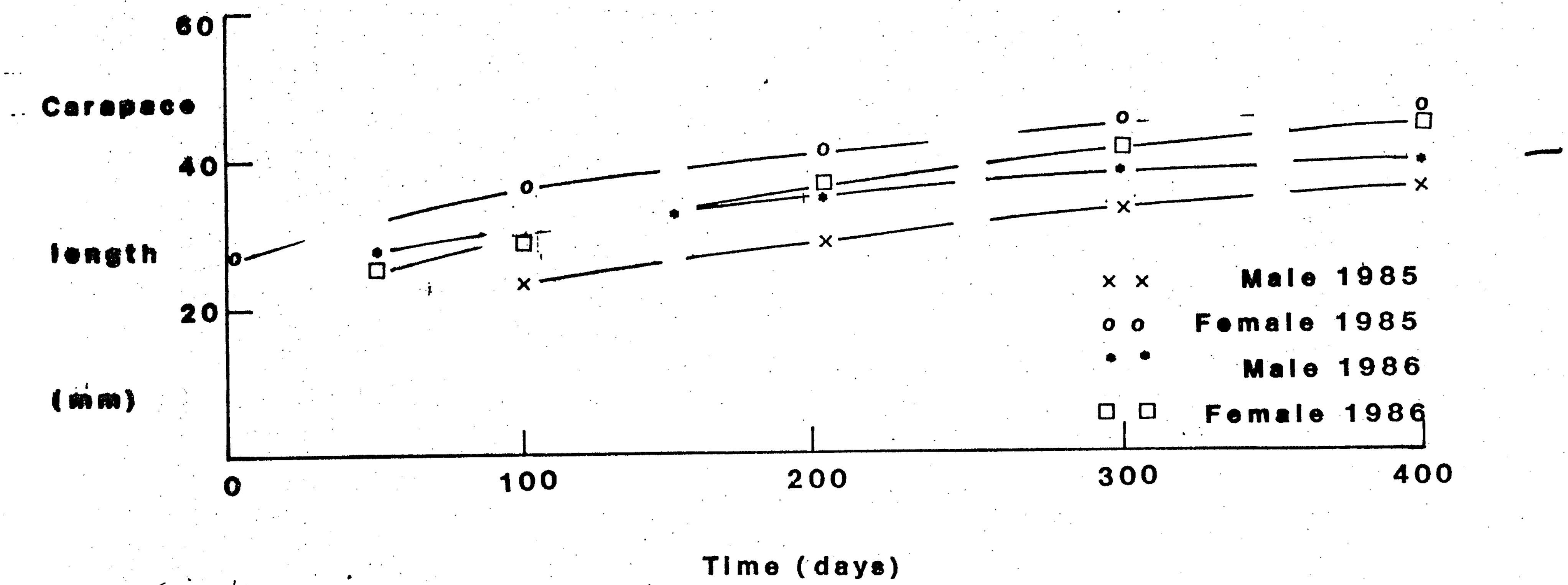

Great
Barrier
Reef
N


Great
Barrier
Reef
18°30
19°
19°30′
Townsville
146°30′
147°
147°30′
148°
148°30′


Great
Barrier
Reef
18°30′
19°
19°30′
Townsville
146°30′
147°
147°30′
148°
148°30′



65
60
55
50
45
40
35
L ∞
(mm)
Female 1986
Female 1985
Male 1985
Male 1986
.0020
.0030
.0040
.0050
.0060
.0070
.0080
Growth coefficient K (days⁻¹)



Carapace
length
(mm)
60
40
20
0
100
200
300
400
Time (days)
Male 1985
Female 1985
Male 1986
Female 1986

Fig 4