No 19 80 / 40 .....

- ☐ NEW PROPOSAL
- ☐ CONTINUING PROJECT
- ☒ FINAL REPORT
- ☐ PROGRESS REPORT

FISHING INDUSTRY RESEARCH TRUST ACCOUNT

TITLE OF PROPOSAL/PROJECT: POPULATION DYNAMICS OF EXPLOITED TIGER PRAWNS OFF GROOTE EYLANDT, GULF OF CARPENTARIA.

ORGANISATION: CSIRO

PERSON(S) RESPONSIBLE:

FUNDS SOUGHT/GRANTED

YEAR	SOUGHT	GRANTED
1980/81 -		$27,200 -

RELATED APPLICATIONS:

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F139-12/81

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147

FINAL REPORT (DECEMBER 1983) FOR PRO..ECT FINANCED FROM

FISHING INDUSTRY RESEARCH TRUST ACCOUNT 1980/1981

1. TITLE OF PROJECT

Population dynamics of exploited tiger prawn stocks off Groote Eylandt, Gulf of Carpentaria.

2. ORGANIZATION RESPONSIBLE: CSIRO, Division of Fisheries Research

3. PROJECT PROPOSDAL:

Conduct a series of mark recapture experiments within stocks of exploited tiger prawns in the Groote Eylandt region of the Gulf of Carpentaria.

4. PROJECT OBJECTIVE

By means of data obtained from mark recapture experiments and concurrent collection of catch and effort data, to study patterns of migration and estimate growth and mortality rates for tiger prawns in the Groote Eylandt region.

PROCEDURE UNDERTAKEN

The mark recapture experiments were carried out in two segments, separated in time by just over 3 months. During the period 21-26/2/81, 9365 tiger prawns (5011 Penaeus esculentus and 4354 P. semisulcatus) were tagged, measured and released in an area to the north of Groote Eylandt. Most releases were made in Blue Mud Bay, generally inshore of the commercial fishing grounds north of Groote Eylandt. Some releases also were made in North West Bay, Groote Eylandt. These experiments were carried out from the chartered commercial fishing vessel Xanadu 1. A total of 755 (8.1%) of these have been recaptured (492 (9.8%) P. esculentus annd 263 (6.0%) P. semisulcatus).

The second segment was conducted between 30/5/81 and 4/6/81, on board chartered fishing vessels Faysea-G and Mable-K. During this segment, tiger prawns were tagged and released in fishing grounds both south and north of Groote Eylandt. Of the 5727 prawns (5159 *P. esculentus* and 56 8 *P. semisulcatus*) released south of South Point and in the Rutland Shoal area, 971 (17%) have been recaptured; 894 (17.3%) *P. esculentus* and 77 (13.6%) *P. semisulcatus*. A further 4900 tiger prawns (3010 *P. esculentus* and 1890 *P. semisulcatus*) were tagged and released to the north of Groote Eylandt in the same general area as for the February experiments, but in the main in deeper waters within known commercial fishing grounds. A total of 872 (17.8%) of these have been recaptured; 650 (21.6%) *P. esculentus* and 222 (11.8%) *P. semisulcatus*.

Release locations for both segments of the series of mark recapture experiments are shown in figures in the accompanying manuscripts on migration and growth.

6. RESULTS

The mark recapture experiments were designed to provide data on migration, growth and mortality, three important aspects of the dynamics of the two species of tiger prawns. The first series of experiments, during which prawns were measured on release and recapture, was designed primarily to obtain growth data. To this end, releases were made in late February, the beginning of a period of low tiger prawn fishing effort, with the aim of allowing time for substantial growth before recapture. Prawns were released in areas of known abundance at that time of year. The second series of experiments was designed primarily to obtain data on mortality rates, and accordingly releases were made in commercial fishing grounds just prior to the peak months of fishing activity in the Groote Eylandt region. Both series of experiments also provided data on migrations of tiger prawns.

In addition to data on the recapture location, date and size of tagged prawns, comprehensive fishing effort data are required for proper analysis of the results of these experiments, at least in terms of assessing migration and mortality rates. Effort data were available from fishermen's daily logbook returns, but due to delays in processing these returns a reasonably complete set of data for 1981 was not available until after July 1982. Analysis of the data to determine migration patterns and to estimate growth curves has been completed. However, unfortunately, as outlined below, it has proved impossible to obtain reliable estimates of mortality rates.

Substantial progress has now been made in analysis of the data from these experiments, and results obtained to date are outlined below:

6.1 Migration

In both series of experiments conducted north of Groote Eylandt, tiger prawns of both species were captured, marked and released in Blue Mud Bay. Both species were present in each trawl catch from which prawns were selected for marking and release, but typically P. semisulcatus predominated in the more northerly release locations, and P. esculentus predominated in the more southerly release locations. However, the distribution of recaptured tagged prawns revealed marked differences in migrations between the two species.

Recaptured P. esculentus were found in deeper waters than those in which they were released, generally to the east of the release locations. There were also several individuals that were recaptured south of Groote Eylandt. Although some P. esculentus were recaptured at a considerable distance from where they were released (maximum distance 70km), only 5% of P. esculentus recaptures were made more than 30km from the release point.

P. semisulcatus showed a markedly different pattern of movement. The distribution of recapture locations for this species extended east and particularly north-east of the release area. Some 22% of P. semisulcatus recaptures were made further than 30km from the point of release, and two individuals were recaptured off Wanyanmera Point (north of Cape Grey), some 110km from the release point.

Release areas and the distribution of recaptures of both species are shown in the accompanying manuscript on migration. Fishing effort extended further to the north and south than the areas of recapture for the two species, so it is likely that the observed northerly and southerly limits of the recapture areas represent the true limits of migrations from the release locations. However, there were recaptures made right up to the easternmost limit of fishing effort, so that migrations further east cannot be ruled out.

For releases off South Point, there appeared to be little, if any, directed migration; rather there was a gradual diffusion from the release locations. However, several P. semisulcatus released near Rutland Shoal were recaptured north of Groote Eylandt.

There are several important practical implications in the results of these migration experiments. While the results helped confirm that there was geographical separation of the two tiger prawn species north of Groote Eylandt, the extent of migrations from the release locations in Blue Mud Bay was unexpected. Presumably prawns released in this area spent the juvenile phase of their life cycle in nursery grounds further inshore within Blue Mud Bay. The observed migration patterns suggest that Blue Mud Bay contains at least one of the important nursery grounds for adult tiger prawns caught in waters as far north as Wanyanmera Point, and to a minor extent even for tiger prawns caught south of Groote Eylandt.

Furthermore, it would be correct to infer that fishing pressure on stocks of small tiger prawns around the entrance to Blue Mud Bay would ultimately affect the available stocks of larger tiger prawns in the offshore fishery.

It is also interesting that there is some degree of interchange between areas north and south of Groote Eylandt.

6.2 Growth

Sufficient recaptures have been made for both species to allow fitting of a von Bertalanffy growth curve for each sex and species. The two main parameters of this growth curve are L_∞ and K, where L_∞ is the average maximum length (mm carapace length), and K is a measure of the rate of growth towards this maximum length. Estimates of these parameters, together with the growth curves, are given in the accompanying manuscript on growth of the two species.

As expected, in both species females grow to a larger size than males, and P. semisulcatus grows to a larger size than P. esculentus. The growth rates (K) of both sexes of *P. esculentus* appear similar, and this has been confirmed by statistical tests. Also, the estimated average maximum lengths (L_∞) for *P. esculentus* males and females, and *P. semisulcatus* males, are consistent with the maximum lengths observed both during these experiments and in samples from the commercial catch. This suggests that reliable growth curves have been obtained for male and female *P. esculentus* and male *P. semisulcatus*. However, the estimated maximum length for *P. semisulcatus* females is much larger than the largest observed either in these experiments or in commercial catch samples, and the estimated growth rate is much lower than the other three estimates. For this sex and species, the fitted growth curve cannot be considered reliable.

6.3 Mortality Rates

As recognized in the FIRTA Grant application for this project, it has been notoriously difficult to obtain reliable estimates of prawn mortality rates from tag recapture experiments. The principal problems associated with analysis of results of tag recapture experiments lie in the following assumptions that need to be met:

(i) The additional mortality rate suffered by a tagged prawn over an untagged prawn is either zero or small and measurable, both in respect of initial mortality (just after tagging) and long term mortality.

(ii) The area inhabited by the prawn population over time is known, and no emigration occurs from that area.

(iii) The fishing effort for the duration of the experiment is accurately known.

(iv) All tags recaptured are reported, or there must be a known non-reporting rate constant over time.

In addition, good estimates of the fishing and natural mortality rates require that the levels of fishing effort change substantially over the course of the experiment.

Specific experimental procedures were adopted to ensure as much as possible that these assumptions were warranted. To minimise tag induced mortality, a new Floy streamer tag was used, of two different sizes according to the size of prawn tagged. Marullo *et al.* (1976) have indicated that for this tag there is little, if any, initial or long term tag induced mortality. Great care was taken to select for release only undamaged individuals. This was achieved by inspections both prior to tagging after a period in a holding tank and after tagging just before release. Tagged prawns were released in batches of up to 400 on the sea bottom using a release cage at intervals throughout the night. Subsequent inspection of return rates from individual experiments revealed that prawns from dawn and dusk releases suffered significantly greater mortality than those released during darkness. Data from all such releases were ignored, but it is not certain that this eliminated initial mortality due to tagging.

As described in section 6.1 above, both tiger prawn species underwent significant migrations from release areas to the north of Groote Eylandt, especially _P. semisulcatus_. For this species, the extent of the migrations and the uneven distribution of fishing effort by themselves prevent reliable estimation of mortality rates, as it is extremely difficult to properly define the month by month extent of the stock. For _P. esculentus_ north of Groote Eylandt, this problem is not so severe, but it nevertheless is still present. It is also known that despite wide publicity about the experiments and the efforts of Mr N. Carrol, a Northern Territory Fisheries Technical Officer, stationed throughout the period on Groote Eylandt, by no means all vessels fishing in the region completed fishing logs. Thus the effort data are incomplete, and possibly misleading in some cases. No reliable estimate of the rate of non-reporting of tag recaptures could be obtained.

Data for _P. esculentus_ for the two experiments north of Groote Eylandt and the experiment south of Groote Eylandt were analysed, and preliminary estimates were obtained of the average total mortality rate Z, with components F, the fishing mortality rate and X = Z-F, which includes natural and tag induced mortality rates. Unfortunately the estimates of X (which should have been approximately constant) varied substantially between experiments, and individual estimates of Z and its components for each experiment proved to be very sensitive to values of the unknown non reporting and tag induced mortality rates. Given the above expressed doubts regarding the effort data, very reluctantly we have concluded that no reliable estimates of mortality rates could be obtained from the tag recapture data.

7. PUBLICATIONS

A popular article has been published, describing early results of this project: "Early results reveal value of tiger prawn tagging in Gulf of Carpentaria". Australian Fisheries, 41(7) July 1982, pp. 3-9.

A final draft of a scientific paper describing the analysis of migrations has been prepared for submission to Australian Journal of Marine and Freshwater Research.

A final draft of a scientific paper describing the results of the analysis of growth has also been prepared for submission to Australian Journal of Marine and Freshwater Research. The above manuscripts have been included with this report.

Movements of tagged tiger prawns in the western Gulf of Carpentaria

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Abstract

The pattern of movements of the tiger prawns Penaeus esculentus and Penaeus semisulcatus in the western Gulf of Carpentaria, is described on the basis of three tagging experiments carried out in 1981. During these experiments, 13180 P. esculentus and 6812 P. semisulcatus were tagged using streamer tags and released in waters adjacent to Groote Eylandt. By the end of 1982, there were 1433 P. esculentus and 380 P. semisulcatus recaptures which provided data usable to a study of movement patterns. Fishing effort data, which were used to interpret the geographic distribution of recaptures, were collected from fishermen's logbooks.

In experiments conducted north of Groote Eylandt, both species showed movement offshore although, as a result of different migration patterns, the two species effectively separated in the offshore fishery. The distribution of P. esculentus recaptures was generally east of the release area whereas that of P. semisulcatus was north-east.

The distribution of recaptures from releases south of Groote Eylandt showed much less movement than those to the north. With a few notable exceptions, these prawns exhibited only a gradual dispersal from the area of release.

Maximum time at liberty for tagged P. esculentus was 15 months while for P. semisulcatus it was 10 months. Both of these prawns were recaptured within 10 km of their respective release locations. The maximum distance between release and recapture locations was 82 km for P. esculentus and 110 km for P. semisulcatus.

Introduction

The tiger prawns Penaeus esculentus Haswell and Penaeus semisulcatus de Haan are important components of the commercial catch from Australia's prawn fisheries north of 18°S, these fisheries being known collectively as the northern prawn fishery. While P. semisulcatus has an Indo-west Pacific distribution, P. esculentus is endemic to Australia, and the northern prawn fishery represents the general area of overlap in their geographic distributions. The combined catch of both species has grown rapidly in the period since 1976 and currently exceeds 6000 tonnes annually.

Despite their commercial importance, there has been very little published research into either the biology of the species or the extent of the resource within this fishery.

Three tagging experiments were conducted in 1981 in waters adjacent to Groote Eylandt in the western Gulf of Carpentaria as a means of studying migration, growth and mortality of the two species of tiger prawns. Presented in this paper is a description of their migration patterns based on the release and recapture data from these experiments.

Methods

Chartered commercial fishing vessels were used to obtain specimens for tagging. Trawls were of 30 minutes duration so that a large proportion of prawns caught would be undamaged and thus be suitable for tagging. Once on board, the live prawns were transferred to a holding tank with circulating seawater. Prawns were then tagged using individually numbered blue Floy streamer tags (Marullo et al. 1976) and placed in release cages in a separate holding tank with circulating seawater. The tags were inserted through the first abdominal segment of the prawn after the needles were first smeared with antibiotic cream (aureomycin). Prior to release the tagged prawns were inspected and damaged individuals removed. With the vessel stationary, the cages, each holding up to 200 prawns, were lowered to the bottom and the prawns released. Prawns were generally released within five km of their initial capture and the proportions of the two species in each batch reflected the proportions caught in the trawls at that location.

All recaptures were made by the commercial fishing fleet and recapture details (date and location of recapture) were obtained when fishing vessels returned to port. Tagged prawns not detected on board vessels, were collected from the various processing plants which handle prawns from the fishery. A reward was paid for each tagged prawn returned. Fishing effort data used in the analysis of migration patterns were obtained through a fishermen's logbook system (Somers and Taylor 1981). The precision of recapture location is determined by the area covered by a commercial trawl, and in this region trawls are conducted typically at about three knots for two to three hours. Consequently recapture location was recorded on a six nautical mile grid square. Fleet fishing effort was recorded using the same grid and so recapture and fishing effort data were easily integrated.

The first tagging cruise was conducted north of Groote Eylandt in February 1981 to coincide with the annual recruitment of small prawns of both species to the commercial fishery. During this cruise, 9365 tagged prawns were released in areas slighlty inshore of the major commercial fishing grounds north of Groote Eylandt. It had been known from commercial catch sampling (N. Carroll, pers. comm.) that these areas contained concentrations of both tiger prawn species at that time of the year.

During May and June two further cruises were conducted which, while primarily designed to allow estimation of population mortality rates, also provided additional information on migration patterns. The first of these two cruises was conducted in a heavily fished portion of commercial fishing grounds south of Groote Eylandt, while the second cruise was conducted north of Groote Eylandt in the same general area as that of the February cruise.

Results

Of the 19992 prawns tagged and released during the three cruises, 2927 have been recovered through the commercial fishery. It was possible to obtain precise recapture date and location for 1433 of these and this subset of recaptures has been used in the following description of movement patterns.

Distribution of fishing effort

A description of the distribution of fishing effort in both time and space in the Groote Eylandt region in 1981 is given in Table 1. The monthly fishing effort data represent boat-days which had been recorded in commercial fishermen's logbooks. In 1981, the catch recorded in these logbooks accounted for just under half the total landings from the fishery.

During 1981, fishing effort on tiger prawns in the Groote Eylandt region extended as far east as 137° 6'E and in order to conveniently describe the changes in spatial patterns over time, the fishing effort data have been divided into seven smaller areas as shown in Figure 1.

Fishing effort on tiger prawns in the region as a whole was lowest in March when most of the fishing effort was being directed towards banana prawns in the eastern Gulf. As fishing for tiger prawns increased in intensity after March, it was firstly the inshore areas which received most attention. Shallow water areas such as Northwest Bay and the entrance to Blue Mud Bay, had their highest fishing intensity in April and May, after which time fishing effort gradually became more widespread. Fishing effort in the area east of Blue Mud Bay increased rapidly over the June/July/August period and extended northward into the area north of Burns Shoal in July/August/September. There was virtually no fishing effort in the area north of Cape Grey prior to August.

The areas south of Groote Eylandt around Rutland Shoal and south of South Point were subject to relatively steady fishing pressure from April through to December.

Distribution of recaptures

The number of individuals of each species released varied considerably depending on the locality of the tagging operations. In order to compare the movement patterns of each species, the individual release batches have been grouped according to the month of release, the release area and the species composition.

February releases, north of Groote Eylandt

(a) Hawknest Island - Chasm Island The prawns tagged and released in the area around Hawknest Island and between Hawknest Island and Chasm Island were predominantly *P. esculentus*. The distribution of *P. esculentus* recaptures extended generally eastwards (Figure 2) from the area of release, with the exception of five individuals caught south of Groote Eylandt. Table 2 gives some indication of the rate of dispersal from the release area. With low levels of fishing effort in March, numbers of recaptures were initially low. Recaptures from within the release area continued until July after which time the fishing effort in that area declined. Recaptures east of the release area were first made in April and continued until August corresponding with maximum fishing effort in that area. The five individuals caught south of Groote Eylandt comprised four taken in May/June near Rutland Shoal and one taken south of South Point in July.

Although the number of *P. semisulcatus* recaptures (11) is much lower, the distribution of these recaptures (Figure 2) differs markedly from that of *P. esculentus* in that almost half of the recaptures were from the area north of Burns Shoal, the remainder coming from within or to the east of the release area.

(b) East and south of Nicol Island The prawns tagged and released in this area were predominantly *P. semisulcatus*. The distribution of *P. semisulcatus* recaptures (59) from these releases, although widespread, was primarily north-east of the release area (Figure 3), extending as far north as Wanyanmera Point, some 108 km from the location of release. As can be seen from the temporal and spatial distribution of recaptures given in Table 3, the pattern of tag recaptures closely resembles the pattern of fishing effort (Table 1). *P. semisulcatus* recaptures were made within the area of release mainly in March and April, in the area to the east in July, August and September and in the area north of Burns Shoal in August, September and October. *P. semisulcatus* recaptures were first made north of Burns Shoal in April and first made north of Cape Grey in August. The relatively few recaptures in May, June and July in the area north of Burns Shoal is consistent with low fishing effort for that period.

The *P. esculentus* recaptures (21) were distributed east of the recapture area but within the range of *P. semisulcatus* recaptures.

(c) South-east of Nicol Island This release area lies between the other release area near Nichol Island and the release areas near Hawknest/Chasm Islands. In contrast with both those groups of releases, near equal numbers of each species were tagged and released. The distribution of recaptures of each species (Figure 4, Table 4) shows further evidence of marked differences in the migration patterns with a resultant separation of the two species. The *P. semisulcatus* recaptures follow the general north-easterly pattern of movement seen in the other releases around Nicol Island while the *P. esculentus* recaptures show a similar easterly pattern to those from the Hawknest/Chasm Island releases.

(d) North West Bay Prawns released in North West Bay were also in near equal proportions of each species. Of the 207 recaptures, all but two were from within North West Bay (Table 5). The two exceptions were both *P. esculentus* and were caught 10 km and 30 km north of the release area.

May/June releases, south of Groote Eylandt

(a) Rutland Shoal Near equal numbers of each species were also released in an area just south of Rutland Shoal. The distribution of recaptures for each species is given in Figure 5 and Table 6. Of the 45 *P. esculentus* recaptures, 34 were recaptured in the release area, 10 were caught south of South Point, and one was caught over 70 km north. There were 35 *P. semisulcatus* recaptured of which 10 were recaptured within the release area, 19 were recaptured south of South Point, and six were recaptured between 70 and 85 km north.

(b) South of South Point The prawns released south of South Point were predominantly *P. esculentus*. The recaptures comprised 643 *P. esculentus* and 18 *P. semisulcatus*. The distribution of recaptures for each species (Figure 6, Table 7) shows only a gradual dispersal from the release area, all recaptures being made within 30 km of the release area.

June releases, north of Groote Eylandt

(a) North-east of Hawknest Island As in the February releases near Hawknest Island, prawns released were predominantly *P. esculentus*. The distribution of *P. esculentus* recaptures (Figure 7, Table 8) is similar to that of the prawns released in February in that the general direction of movement was eastwards with only a few individuals being recaptured north of Burns Shoal. Although the extent of eastward movement is not as great as that of the Ferbruary releases, the average time at liberty for the June releases is much less as can be seen in Table 8.

(b) East of Nicol Island Although prawns released east of Nichol Island in February were predominantly *P. semisulcatus*, June releases contained near equal proportions of each species. The distribution of recaptures from these releases is given in Figure 8 and Table 9. Although distribution of *P. semisulcatus* recaptures is consistent with the same north-easterly offshore movement patterns seen in the February releases, the distribution of *P. esculentus* recaptures extends further north than the corresponding February releases.

Discussion

Interpretation of the pattern of movements indicated in the results of tagging experiments is easiest when fishing effort is uniform over both time and space, and extends over an area larger than that in which recaptures are made. In practice, these requirements are rarely fulfilled. Therefore, in the interpretation of the migration patterns within this study, the distribution of fishing effort in both time and space had to be carefully considered.

In the area north of Groote Eylandt, fishing effort early in the year was concentrated inshore in the general area of the releases. Fishing effort gradually increased and extended further offshore in an eastward direction and by July had covered the general area corresponding to the predominance of *P. esculentus* recaptures north of Groote Eylandt. It was not until August that fishing effort spread north, covering the area corresponding to predominantly *P. semisulcatus* recaptures. It follows that the pattern over time of recaptures north of Groote Eylandt is partially confounded with changes in the pattern of fishing effort. This is most noticeable for *P. semisulcatus* recaptures; the fact that no tagged *P. semisulcatus* were recaptured north of Cape Grey until August does not rule out the possibility of movement into that area before that time, as there was almost no fishing north of Cape Grey until August.

As the fishing effort south of Groote Eylandt persisted from the time of tagging in May/June until the end of the year, there is no similar problem with the interpretation of recaptures in that region.

Another potential difficulty lies in determining the limits of migration. Both to the north and south, fishing effort extended beyond the limits of the distribution of recaptures. However to the east, the limit of both fishing effort and tag recaptures was approximately 137°E. Thus the possibility of migration eastwards of this longitude cannot be ruled out on the basis of tag recapture data alone. Evidence to suggest that 137°E is close to the eastern-most limit of migration was obtained from trawls conducted by R.V. Sprightly in March, 1983. These indicated that east of 137°E, the density of tiger prawns declined rapidly, with no tiger prawns being caught beyond 137° 30'E. Thus it does appear that the limits of the distribution of tag recaptures represent the actual limits of offshore migration from the release locations.

There are several interesting features of the data worthy of further comment. Firstly, there is an indication of some degree of mixing between the prawn populations inhabiting the fishing grounds to the north and south of Groote Eylandt, with the direction of interchange generally being species specific. There were five P. esculentus recaptured south of Groote Eylandt after being released in the north, while there was only one confirmed recapture which moved in the opposite direction. In contrast, six P. semisulcatus were recaptured north of Groote Eylandt after release in the south, and there were no recorded movements from north to south.

The second feature of note is the contrast between the movement patterns for each of the two species released during February in the area around the entrance of Blue Mud Bay. Both species showed movement offshore, however the distribution of P. esculentus recaptures was generally east of the release area whereas that for P. semisulcatus was generally north-east. Indeed, even from releases containing almost equal proportions of each species in the area south-east of Nicol Island, there was almost no overlap in the distribution of recaptures of each species. The juveniles of both P. esculentus (Young 1978) and P. semisulcatus (De Freitas 1980, Mohamed et al 1981) have been shown to be dependent on the same nursery habitat type (shallow water substrates with vegetative cover). As juveniles of both species have been observed to coexist on nursery grounds in Deception Bay, Groote Eylandt, and also in nursery grounds in the eastern Gulf of Carpentaria (D. Staples, pers. comm.), it is most probable the same occurs in all nursery areas in the region. If this was the case, then the fact that either one species or the other was completely dominant for most of the area worked during the tagging, would suggest that the separation commences immediately after leaving the nursery area.

As the migration of juvenile prawns from inshore nursery areas to offshore spawning grounds is a characteristic of Penaeids in general, one possible explanation for this species separation might be that each species has different temporal and spatial spawning strategies associated with transport of larvae to nursery grounds. Another hypothesis is that, as adults, the two species have different habitat preferences. Both of these hypotheses are currently being investigated.

The prawns tagged in June in similar areas to those in February showed less extensive movement and less distinct separation (Figures 7 and 8). The prawns tagged were on average much larger and because they were released at a time of heavy fishing pressure, were at liberty for much less time.

The prawns released south of Groote Eylandt in May/June were of a similar size to those released in the same period north of Groote Eylandt, however the extent of any movement was even less (Figures 5 and 6). It is possible therefore, that tagging south of Groote Eylandt was carried out in areas which are the end points of migrations which occurs earlier in the year.

Acknowledgements

We thank those members of the fishing industry who have participated in the study through the return of tagged prawns and the completion of fishing logbooks. We also acknowledge the cooperation and assistance of staff from Fisheries Departments in Queensland, Northern Territory, Western Australia and South Australia, during both the tagging program and the subsequent collection of tagged prawn recaptures. This study was funded in part by a grant from the Australian Fishing Industry Research Trust Account.

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TABLE 1. Fishing Effort (boat days) in the Groote Eylandt region for the period February to December, 1981.

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North of Cape Grey	7	0	0	0	2	3	116	54	77	63	14
Burns Shoal to Cape Grey	54	1	37	19	29	63	266	126	73	76	48
Entrance of Blue Mud Bay	68	7	111	95	30	78	20	26	48	29	62
East of Blue Mud Bay	3	9	13	8	62	90	107	64	49	49	38
Northwest Bay	4	13	42	13	3	2	0	1	1	0	3
Rutland Shoal	7	17	23	76	42	60	15	34	37	70	27
South of South Point	45	4	79	158	66	173	141	88	185	155	83
Total effort	188	51	305	369	234	469	665	393	470	442	275

TABLE 2. Temporal and spatial distribution of tag returns from February releases in the Hawknest Island to Chasm Island area.

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<u>P. esculentus</u> (3284 released)											
Burns Shoal to Cape Grey	0	0	2	0	2	0	0	0	0	0	0
Entrance of Blue Mud Bay	1	6	51	14	9	4	0	0	0	0	0
East of Blue Mud Bay	0	0	5	4	13	4	6	0	0	0	0
Rutland Shoal	0	0	0	2	2	0	0	0	0	0	0
South of South Point	0	0	0	0	0	1	0	0	0	0	0
<u>P. semisulcatus</u> (547 released)											
Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	0	0	0	0	0	0	4	1	0	0	0
Entrance of Blue Mud Bay	0	0	0	0	0	0	0	0	0	0	1
East of Blue Mud Bay	0	0	1	0	2	0	0	1	0	0	0

TABLE 3. Temporal and spatial distribution of tag returns from February releases in the area east and south of Nicol Island.

P. esculentus (738 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	0	0	1	0	0	0	0	0	1	0	0
Entrance of Blue Mud Bay	0	0	6	5	2	2	0	0	0	0	0
East of Blue Mud Bay	0	0	2	0	1	1	0	0	0	0	0

P. semisulcatus (2957 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North of Cape Grey	0	0	0	0	0	0	3	0	3	0	0
Burns Shoal to Cape Grey	0	0	6	0	1	1	13	6	3	0	0
Entrance of Blue Mud Bay	0	3	6	1	0	0	0	0	0	0	0
East of Blue Mud Bay	0	0	0	1	0	3	4	3	0	0	0

TABLE 4. Temporal and spatial distribution of tag returns from February releases in the area south-east of Nicol Island.

P. esculentus (604 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entrance of Blue Mud Bay	0	1	10	3	0	2	0	0	0	0	0
East of Blue Mud Bay	0	0	0	1	5	0	0	2	0	0	0
Rutland Shoal	0	0	0	1	0	0	0	0	0	0	0

P. semisulcatus (486 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	0	0	0	0	1	0	2	2	0	0	0
Entrance of Blue Mud Bay	0	1	5	0	0	0	0	0	0	0	0
East of Blue Mud Bay	0	0	0	1	0	0	0	0	0	0	0

TABLE 5. Temporal and spatial distribution of tag returns from February releases in Northwest Bay.

P. esculentus (385 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	0	0	1	0	0	0	0	0	0	0	0
Northwest Bay	16	80	25	3	0	0	0	0	0	0	0
East of Blue Mud Bay	0	0	0	0	1	0	0	0	0	0	0

P. semisulcatus (364 released)

Area	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northwest Bay	13	53	13	0	0	0	0	0	0	0	0

TABLE 6. Temporal and spatial distribution of tag returns from May releases in the Rutland Shoal area.

P. esculentus (468 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East of Blue Mud Bay	0	1	0	0	0	0	0
Rutland Shoal	15	17	2	0	0	0	0
South of South Point	2	8	0	0	0	0	0

P. semisulcatus (367 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	0	1	0	0	0	0	0
East of Blue Mud Bay	0	0	1	1	1	1	0
Rutland Shoal	8	2	0	0	0	0	0
South of South Point	2	12	3	0	0	0	0

TABLE 7. Temporal and spatial distribution of tag returns from May/June releases in the area south of South Point.

P. esculentus (4691 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rutland Shoal	0	3	1	0	0	1	0
South of South Point	185	329	64	18	13	7	2

P. semisulcatus (201 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South of South Point	4	12	1	1	0	0	0

TABLE 8. Temporal and spatial distribution of tag returns from June releases in the area north-east of Hawknest Island.

P. esculentus (1913 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	1	9	2	1	0	0	0
Entrance of Blue Mud Bay	104	95	1	3	4	0	2
East of Blue Mud Bay	71	49	6	3	1	0	3

P. semisulcatus (69 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entrance of Blue Mud Bay	2	3	0	0	1	0	0
East of Blue Mud Bay	1	2	0	0	0	0	0

TABLE 9. Temporal and spatial distribution of tag returns from June releases in the area east of Nicol Island.

P. esculentus (1097 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	6	7	3	0	0	0	0
Entrance of Blue Mud Bay	35	30	1	2	3	0	0
East of Blue Mud Bay	0	12	1	2	1	0	1

P. semisulcatus (1821 released)

Area	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Burns Shoal to Cape Grey	9	10	15	6	10	3	0
Entrance of Blue Mud Bay	59	23	2	0	6	2	2
East of Blue Mud Bay	0	2	1	3	2	1	0

Figure Captions

Figure 1. Map of the study area in the western Gulf of Carpentaria. The fishing effort data have been divided into the subareas shown.

Figure 2. Map of the distribution of recaptures from the prawns released in February in the area around Hawknest Island and between Hawknest Island and Chasm Island. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

Figure 3. Map of the distribution of recaptures from the prawns released in February in the areas east and south of Nicol Island. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

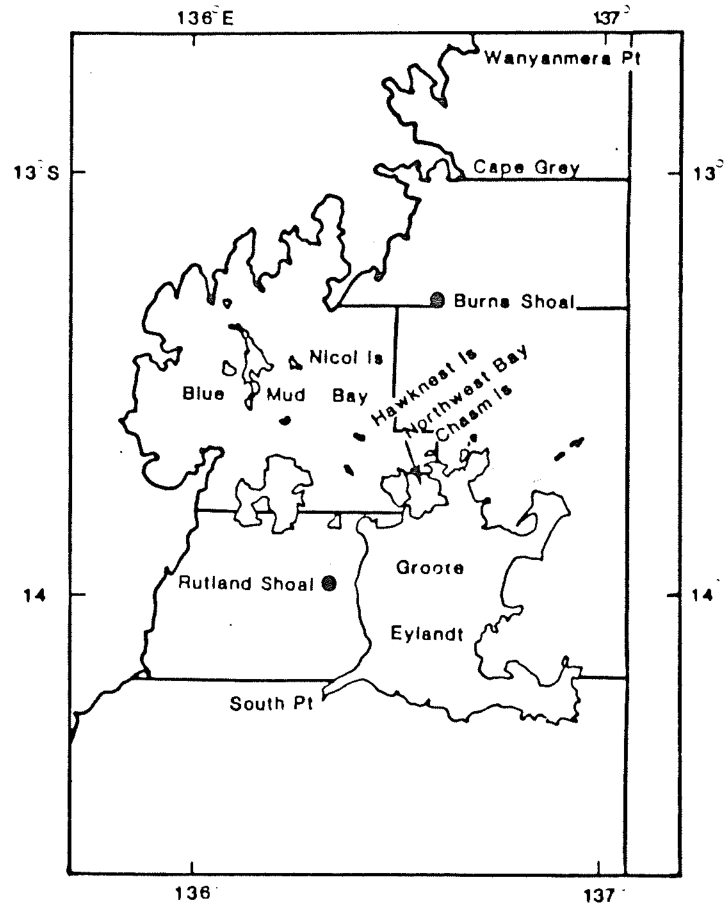
Figure 4. Map of the distribution of recaptures from the prawns released in February in the area south-east of Nicol Island. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

Figure 5. Map of the distribution of recaptures from the prawns released in May/June in the area around Rutland Shoal. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

Figure 6. Map of the distribution of recaptures from the prawns released in May/June in the area south of South Point. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

Figure 7. Map of the distribution of recaptures from the prawns released in June in the area north-east of Hawknest Island. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .

Figure 8. Map of the distribution of recaptures from the prawns released in June in the area east of Nicol Island. The release area is shaded. The recapture locations are denoted by ■ for P. esculentus and by □ for P. semisulcatus .:



136°E
137°
Wanyanmera Pt
13°S
13°
Cape Grey
Burns Shoal
Nicol Is
Hawknest Is
Northwest Bay
Chasm Is
NE
Blue
Mud
Bay
Groote
Eylandt
Rutland Shoal
14
14
South Pt
136
137

Fig 1

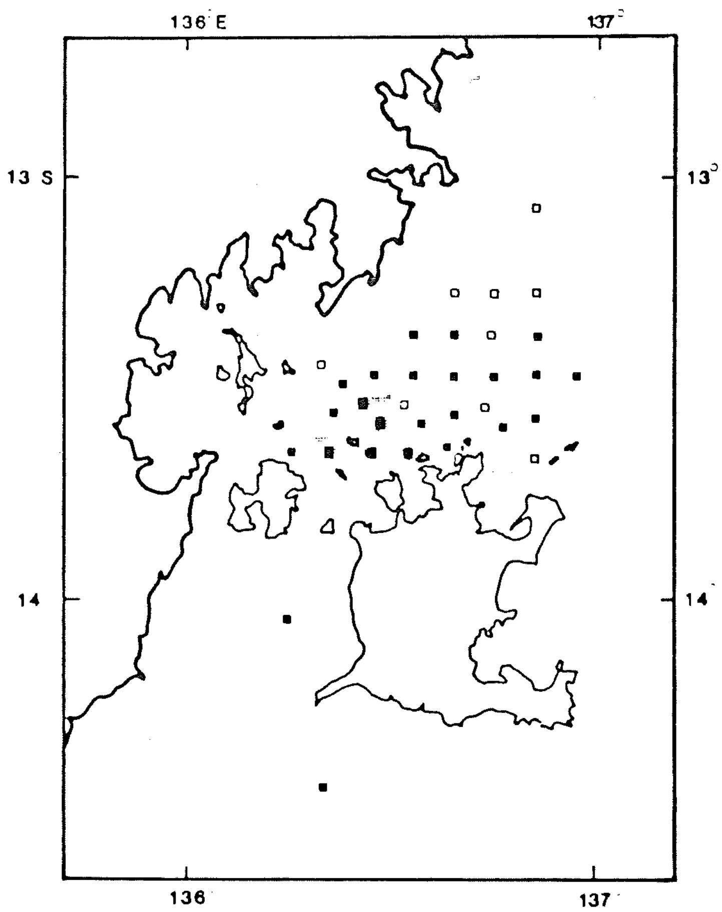


Fig 2

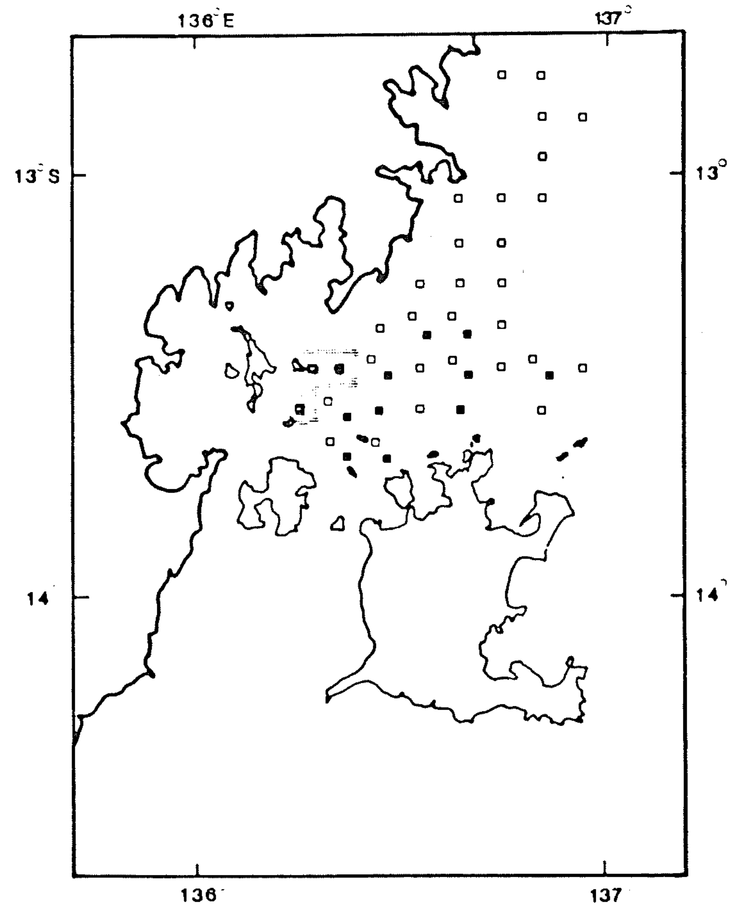


Fig 3

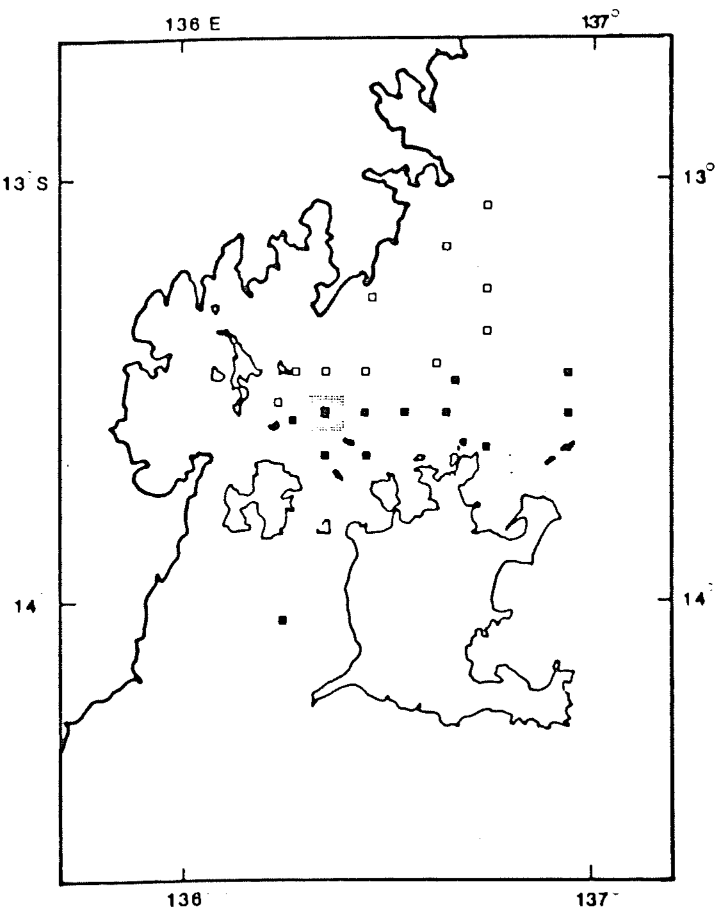


Fig 4

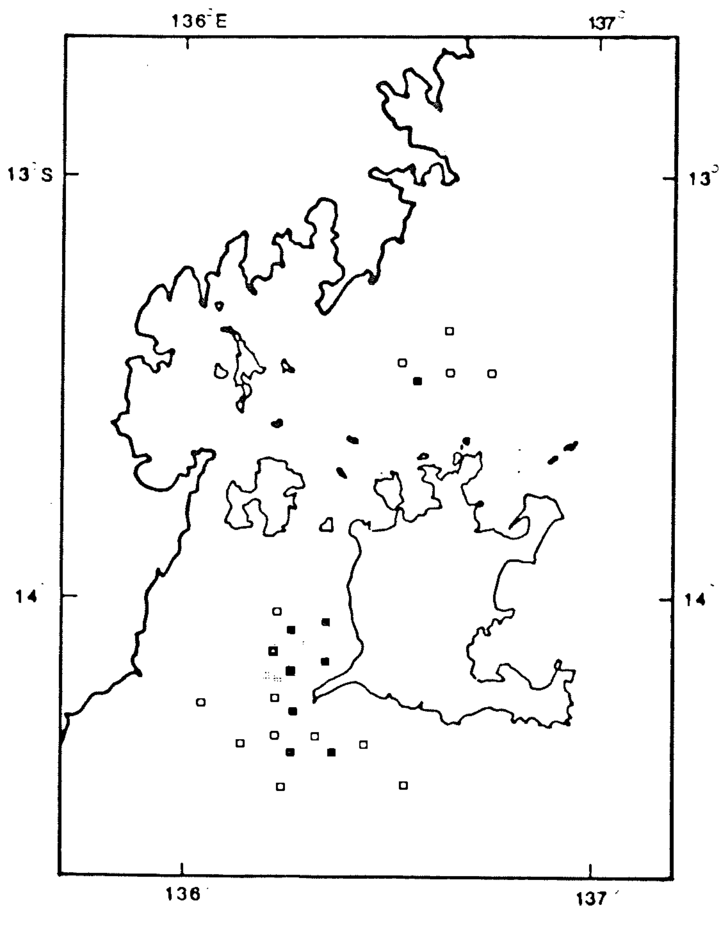


Fig 5

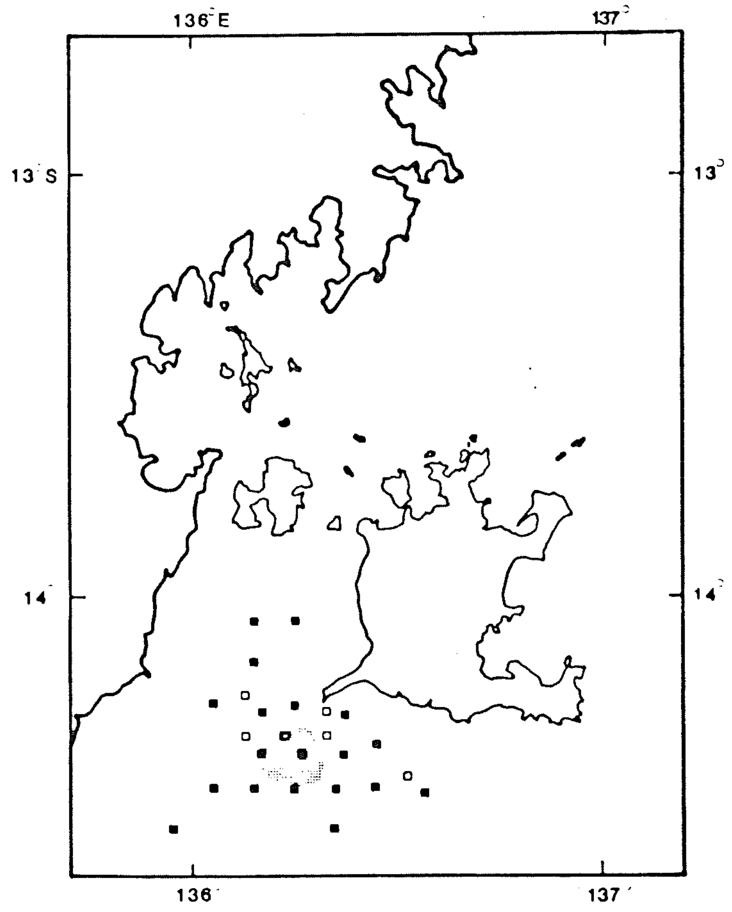


Fig 6.

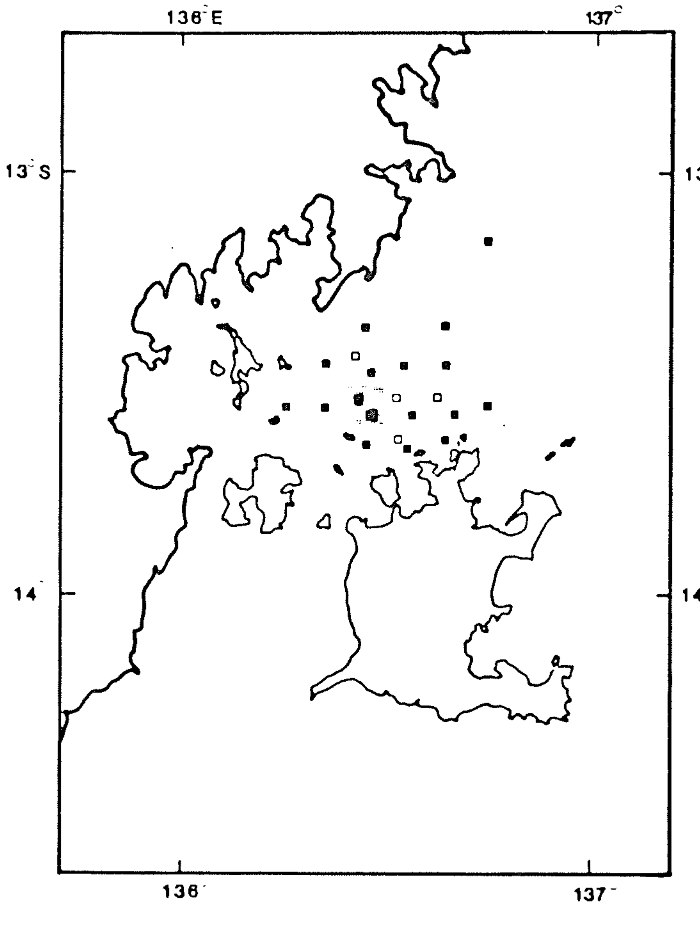


Fig 7

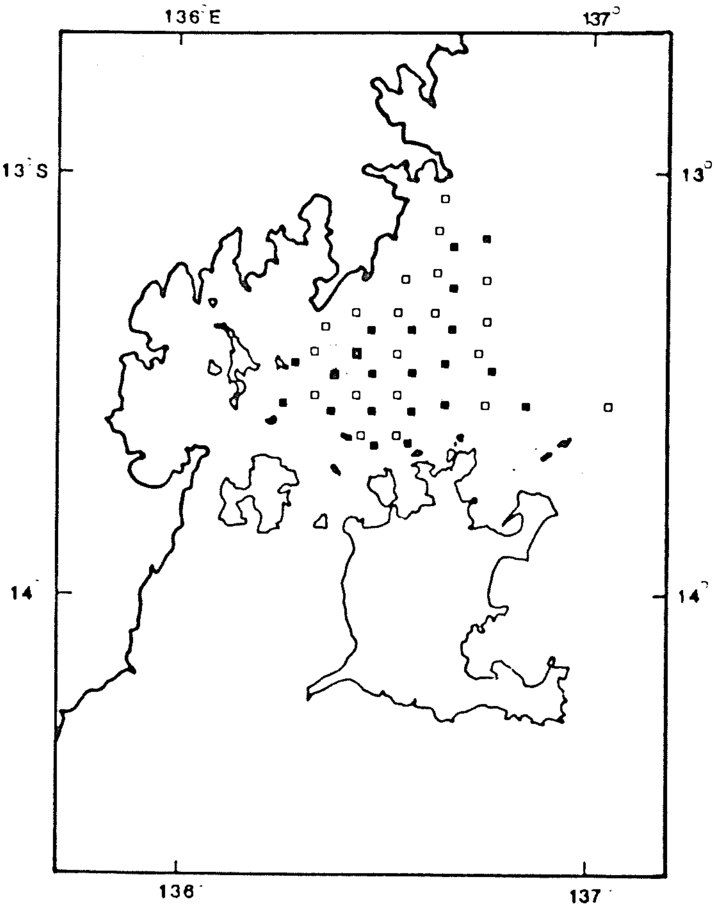


Fig 8

Early results reveal value of tiger prawn tagging in Gulf of Carpentaria

With the help of commercial fishermen, biologists are increasing their knowledge of tiger prawn stocks in the Gulf of Carpentaria, knowledge that will be used in management of the fishery. Here biologists I. F. Somers, G. P. Kirkwood, B. R. Taylor (CSIRO Division of Fisheries Research) and N. Carroll (Fisheries Division, NT Department of Primary Production) detail some of the early results from tagging experiments in the Gulf.

WHEN the prawn fishery of the Gulf of Carpentaria commenced in the late 1960s it was based mainly on the banana prawn. However in recent years this has changed because of the large increase in fishing effort for other species, mainly tiger prawns. Tiger prawn catches now constitute the major part of the annual landings from the fishery. Despite the importance of tiger prawns to the fishery, there has been very little research into either the biology of the species or the extent of the resource.

As part of a preliminary research program on tiger prawns, scientific and technical staff from CSIRO, Northern Territory Fisheries Division and Queensland Fisheries Service tagged and released 20 000 tiger prawns in the western Gulf of Carpentaria near Groote Eylandt in 1981. To date almost 3 000 tagged prawns have been recaptured.

The tagging experiments had three main aims:

- estimate tiger prawn growth rates;
- study tiger prawn migration patterns; and
- estimate mortality rates in the fishery under different levels of fishing effort, and thereby estimate the current level of exploitation.

The tagging experiments were in two parts. The first tagging cruise was completed in February 1981, using the commercial fishing vessel *Xanadu I*, skippered by Marcus Westlake. The second was completed in June 1981 using two vessels — *Faysea-G* skippered by Jeff Hutley, and *Mable-K* skippered by Warwick Smyth.

The first series of experiments was at a time of the year when fishing effort was concentrated on banana prawns in the eastern Gulf, with minimum fishing effort on tiger prawns. This potentially allowed the tagged tiger prawns a longer time at liberty before recapture and thus was likely to provide better information on growth rates and migration patterns. The second series in June was timed to coincide with the increased fishing effort on tiger prawns (highest around July and August). In this way fishing mortality estimates could be made from experiments conducted during periods of different fishing intensities.

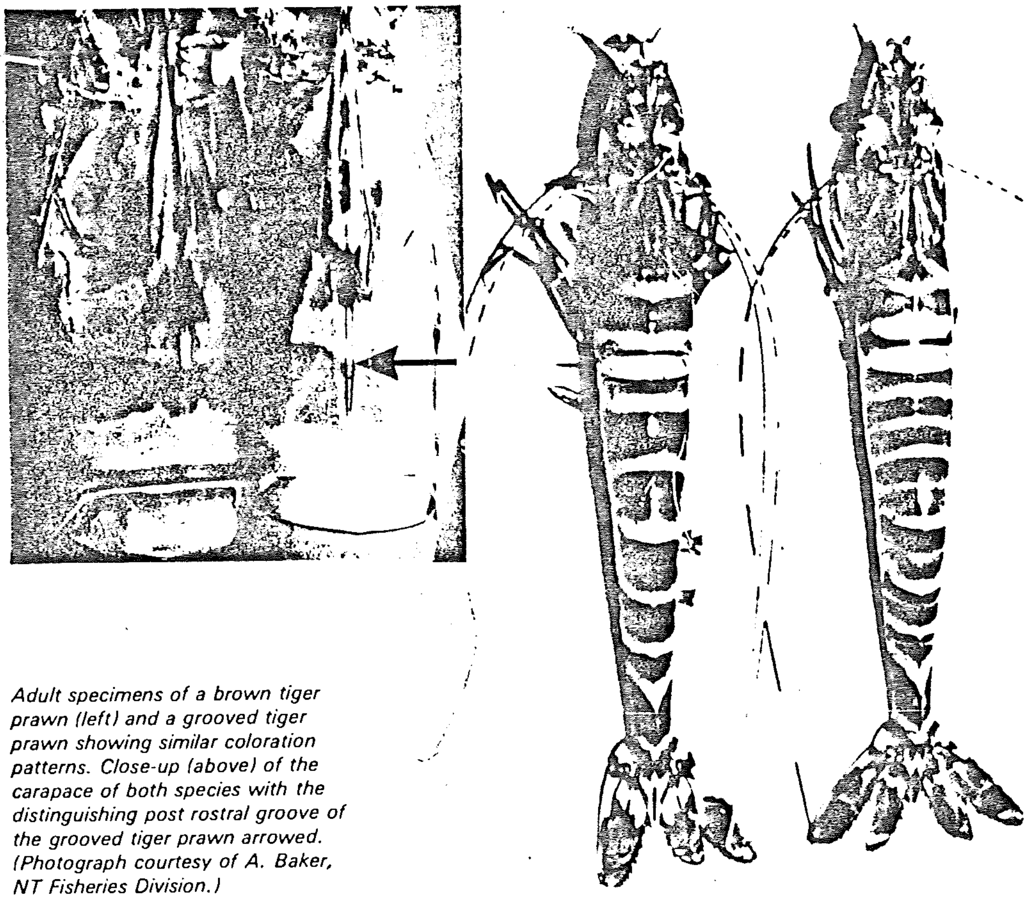
There are two species of prawns commonly referred to as 'tiger prawns' in the Gulf of Carpentaria. They are the brown and the grooved tiger prawn.

The brown tiger prawn (*Penaeus esculentus* Haswell) has only ever been recorded in Australian prawn fisheries. It is caught in northern waters from Shark Bay on the west coast to Moreton Bay on the east coast.

The grooved tiger prawn (*Penaeus semisulcatus* de Haan) sometimes referred to as the green tiger prawn, has a wider distribution than the brown tiger prawn. Although it does not extend as far south as the brown tiger prawn in Australia's northern prawn fisheries, this species is a major component of prawn fisheries of New Guinea, Indonesia, India, the Persian Gulf and East Africa.

The two species have very similar color patterns and are not easily distinguished. (Commercial fishermen record catches of both species grouped as tiger prawns.) The simplest way to separate the two species is to look for the very small groove in the ridge at the rearmost part of the rostrum of the grooved tiger prawn (see photograph). It also seems the grooved tiger prawn is more vulnerable than the brown tiger prawn to the infestation of a crustacean parasite (bopyrid isopod) that attaches itself to the gills of the prawn. Its presence is seen as a swelling on the side of the prawn's carapace. During the tagging period about 15 per cent of grooved tiger prawns carried the parasite but none of the brown tigers.

To obtain undamaged prawns suitable for tagging, trawls were kept to about 30 minutes. Once on board, the live prawns were immediately transferred to holding tanks with circulating seawater. The size, sex and species of each prawn was recorded alongside the number of the tag. The tagged prawn was then placed in a release cage in a separate holding tank before release. With the vessel stationary the release cages, each holding up to 200 prawns, were lowered to he bottom and the prawns set free.



Adult specimens of a brown tiger prawn (left) and a grooved tiger prawn showing similar coloration patterns. Close-up (above) of the carapace of both species with the distinguishing post rostral groove of the grooved tiger prawn arrowed. (Photograph courtesy of A. Baker, NT Fisheries Division.)

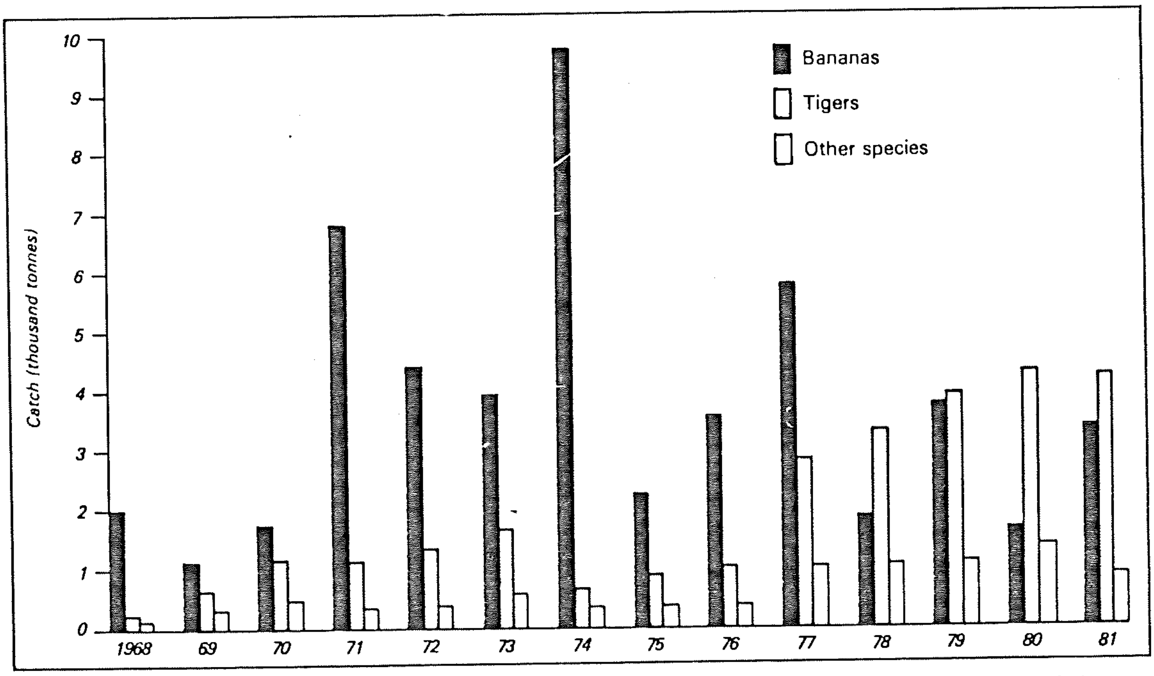


Figure 1: Annual prawn catches from the Gulf of Carpentaria for the years 1968 to 1981, showing the variation in banana prawn catches but steadily increasing tiger prawn catches.

Migration patterns

In general the movement of tagged prawns was as fishermen would expect from shallow to deeper water. The main release area for the experiments in February was around the entrance to Blue Mud Bay in depths between 20 and 25 metres. Within six months, recaptures of these prawns were mainly in depths of 30 to 45 metres.

Of more interest, however, was the different general direction of movement shown by the two species from these releases. Recaptures of grooved tiger prawns were widely distributed north-east of the release area, with at least eight recaptures north of Cape Grey, more than 100 kilometres from the release area. In contrast, brown tiger prawns were recaptured east and south of the release area (see Figure 2).

During the series of experiments conducted in June 1981, tagged prawns were released in two main areas. One area was basically the same as for the February series, north of Groote Eylandt, while the other was south of the island. The average size of prawns released was larger than in the February experiments and, as might be expected, the patterns of movement slightly different. In the case of the releases north of Groote Eylandt, the prawns did not seem to move as far and the overlap in the distribution of each species seemed to be greater than in the earlier experiment.

The prawns tagged in June, south of Groote Eylandt, were mainly brown tigers. These showed much less movement than those to the north of the island, with only a gradual dispersal and shift to marginally deeper water. Of the grooved tiger prawns released in this area, five of the 70 recovered were recaptured to the north of Groote Eylandt, suggesting some intermixing of stocks throughout the region (see Figure 3).

Although we have a large amount of recapture information, tagged prawns can not be recaptured from areas in which there is no fishing effort. The full analysis of migration patterns can only be undertaken when the pattern of fishing effort is taken into account. This will be possible when all of the relevant fishermen's logbook information has been collected and processed.

Growth rates

Because prawns were measured individually before release and because fishermen were very cooperative in returning the recaptured prawns and tags, it has been possible to measure rates of growth for both males and

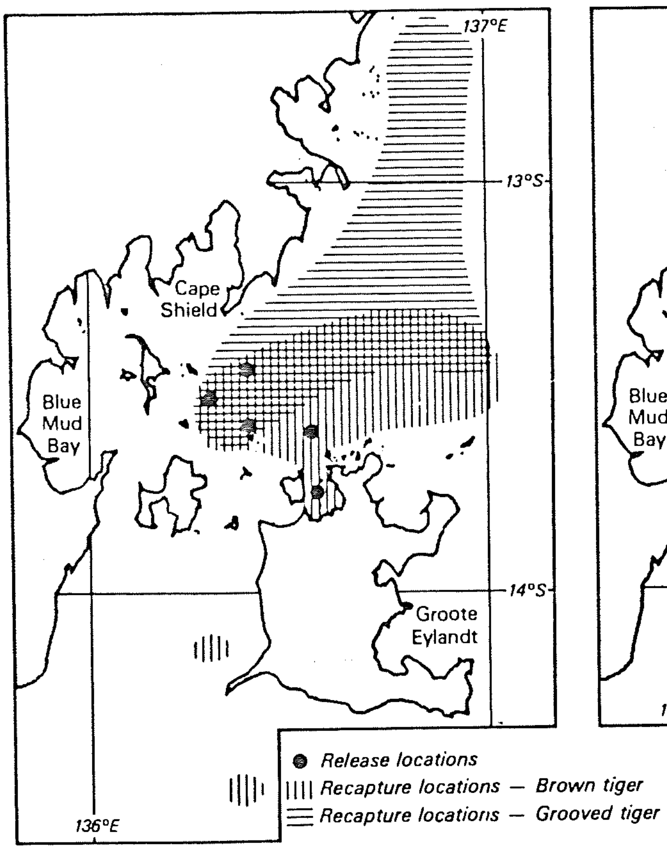


Figure 2: The tagging area around Groote Eylandt in the Gulf of Carpentaria, with the release and recapture areas for prawns released in February 1981.

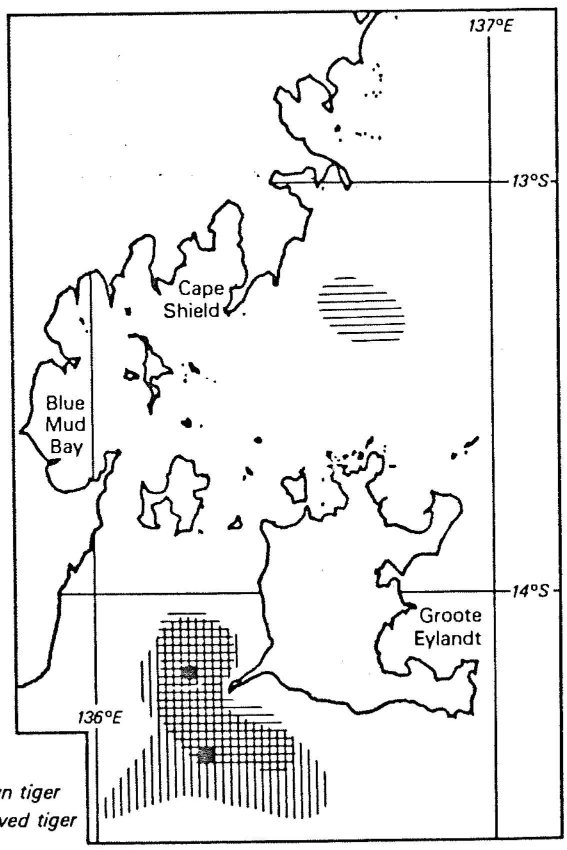


Figure 3: This map shows the location of release and area of recapture for prawns released in June 1981 in the tagging area south of Groote Eylandt.

females of each tiger prawn species.

As with most prawns, the females grew faster and to a larger maximum size. But more significant was the marked difference between the species. The rate of growth is faster and the maximum size attained is larger for the grooved tiger prawn than for the brown. This can be demonstrated easily by applying the growth models obtained from the tagging experiments to a hypothetical situation where prawns of each sex and each species are the same size (equivalent to 150 prawns a kilogram) in December of any year. The sizes that each prawn would attain over the subsequent year are given in the table.

A knowledge of these rates of growth is important when assessing the effects of closing areas (temporarily or permanently) on total yields.

Mortality rates

Estimates of mortality rates are based on the rate of decline over time in the number of tags returned. However, because the numbers returned must first be adjusted according to the varying level of fishing effort, such an analysis must await final collection and processing of all the relevant logbook information.

Fishing industry role

The success of prawn-tagging experiments depends heavily on the degree of interest and cooperation by the fishing industry. The amount of useful information obtained is greatest when recaptured tagged prawns, together with the relevant details regarding time and place of recapture, are returned directly from fishing vessels.

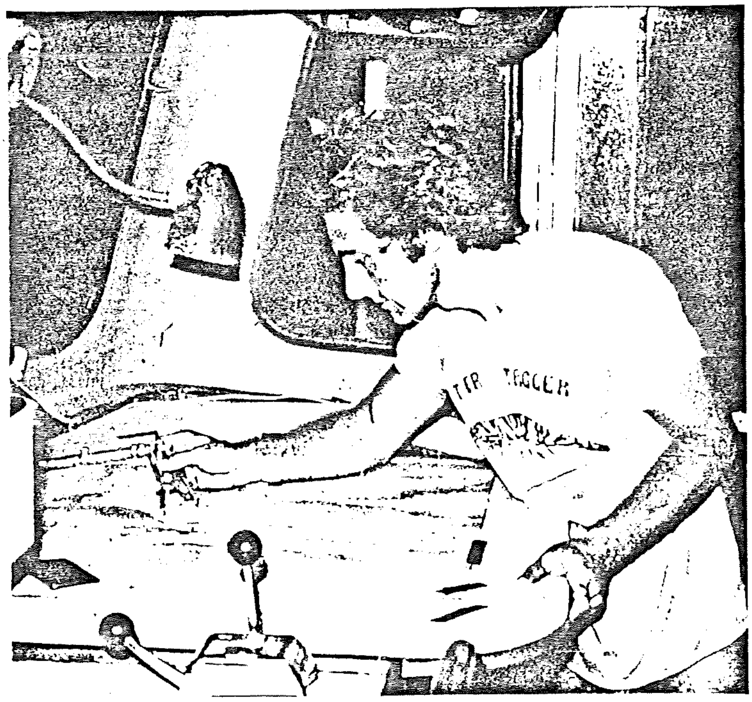
Previous tagging experiments in the Gulf have not been as successful because most of the prawns recaptured were not found until they had reached a processing plant. Although tag returns from processing plants are still important in estimating mortality rates, without accurate information on date and location of recapture they add nothing to our knowledge of growth and migration of the species.

In this present series of experiments there has been a marked improvement in data quality, with almost 90 per cent of recaptures coming directly from the fishing fleet.

Two contributing factors are the use of blue streamer tags, which seem to be more noticeable than red tags previously used, and an increase in the amount of onboard processing of the commercial catch.

An equally important contribution by fishermen to the research project is the completion of logbook records. As mentioned earlier, the pattern of tagged prawn recaptures is not meaningful unless the pattern of fishing effort is taken into account. The fact that no tagged prawns were recaptured in any area may simply be a result of no fishing effort there at that time.

We hope that fishermen have gained an appreciation of the importance of fishing effort data to the experiments. By continuing to maintain accurate logbooks they can help provide a more precise and detailed understanding of the fishery.



Jeff Hutley, skipper of Faysea-G, *recording the vessel position during the release of a batch of tagged prawns.*

Growth of tiger prawns over one year. Size is given in terms of the number of prawns to the kilogram

	Brown tiger prawn		*Grooved tiger prawn*	
	Male	*Female*	*Male*	*Female*
December	150	150	150	150
February	95	62	73	61
April	52	38	48	35
June	41	29	37	24
August	35	23	31	18
October	32	20	28	15
December	29	18	26	13

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Growth of two species of tiger prawns (Penaeus esculentus and Penaeus semisulcatus) in the western Gulf of Carpentaria

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Abstract

Growth data were obtained for the two tiger prawn species Penaeus esculentus and P. semisulcatus from a tagging experiment carried out in February 1981 in waters adjacent to Groote Eylandt in the western Gulf of Carpentaria. A von Bertalanffy growth curve was fitted to these data and least squares estimates of the parameters L_∞ and K and joint 95% confidence regions were calculated for males and females of both species. Tests on the residuals from the fitted curve were carried out to check the adequacy of the fit of the von Bertalanffy model, and likelihood ratio tests were used to test equality of the parameters between sexes and species. An alternative von Bertalanffy-type model was used to test the consistency between the estimated L_∞ values and the carapace lengths of the largest individuals observed in samples from the populations.

For males of each species, the fit of the von Bertalanffy was satisfactory, and the estimates of L_∞ were consistent with the largest observed carapace lengths in catch samples. For females, however, the fit of the von Bertalanffy was not entirely satisfactory, especially for P. semisulcatus, for which additionally the estimated L_∞ was much higher than the largest carapace length in catch samples. Possible reasons for this lack of fit are discussed. Estimates of L_∞ all differed significantly, but

there was no significant difference found in estimates of K for P. esculentus males and females, and only a marginally significant difference in K between P. esculentus males and females and P. semisulcatus males. Presence in P. semisulcatus of a bopyrid parasite did not affect growth.

Introduction

The tiger prawns Penaeus esculentus Haswell and Penaeus semisulcatus de Haan are caught commercially throughout Australia's prawn fisheries north of approximately 29° S. Most of the catch is exported, the annual export value being more than $50 million.

The two species have similar life cycles. After a planktonic larval stage of approximately three weeks, postlavae settle on inshore nursery grounds. After several months, the juvenile tiger prawns commence an offshore spawning migration. This offshore migration occurs in late summer in the Gulf of Carpentaria and the prawns immediately become vulnerable to the commercial fishing fleet. These adolescent prawns entering the fishery are approximately 20 mm carapace length.

The object of this study was to describe the growth of each species of tiger prawn from this adolescent stage through to their maximum age. Previous studies of growth of these species have been made by White (1975, P. esculentus , Shark Bay, Western Australia), Thomas (1975, P. semisulcatus, Mandapam, India) and by Jones and van Zalinge (1981, P. semisulcatus, Kuwait). In each case the authors have based their estimates of growth parameters on analysis of modal progressions in length frequency data from the respective fisheries. Garcia and Le Reste (1981) have outlined the main difficulties associated with such an approach and concluded that tagging, despite constraints relating to the effect of tags, is currently the most reliable method for estimating growth of Penaeidae.

A tagging program was undertaken in February 1981, as part of a study of the population dynamics of the two tiger prawn species in the western Gulf of Carpentaria. In this paper, von Bertalanffy growth curves were fitted to data on growth increment and time at liberty, with separate curves being fitted for each sex and species. Several tests of residuals from the fitted curves are used to test the reliability of the growth curves obtained. Also, an alternative von Bertalanffy-type model is proposed that allows a further reliability test through direct comparison of the estimated L_∞ values with the largest individuals found in length frequency data. Joint 95% confidence regions are calculated for the parameters estimated for each sex and species and likelihood ratio tests are used to test whether the parameters differ significantly between sexes and species.

Experimental Methods

Live prawns for tagging were obtained using a chartered commercial fishing vessel. Prawns were tagged using individually numbered Floy streamer tags (Marullo et al. 1976) and carapace lengths (from the rear of the carapace to the posterior edge of the orbital space) were measured to the nearest 0.1 mm. Details of the tagging procedure were given in Somers and Kirkwood (submitted). The tagging experiment was conducted in February in order to coincide with the annual recruitment of small prawns of both species to the commercial fishery and thus provide maximum growth information. Tagging was carried out slightly inshore of the major fishing grounds north of Groote Eylandt in an area where it was known from previous commercial catch sampling (N. Carroll, pers. comm.) that sufficient quantities of both tiger prawn species could be obtained at that time of year. The prawns tagged ranged in size from 20 mm to 40 mm carapace length.

All recaptures were made by the commercial fleet and recapture details (date and location of recapture, species, sex and recapture length) were obtained when fishing vessels returned to port. The data on species, sex and recapture lengths were then assessed and stored. Of 9,365 prawns tagged, 755 were recaptured, although not all were used in the subsequent analysis. Omitting those tag recaptures for which full recapture details were not available, as well as those which had been at liberty for less than 14 days, data from 400 tag recaptures were used to obtain estimates of growth curve parameters.

Parameter Estimation

Standard von Bertalanffy Model

As outlined originally by Fabens (1965), the appropriate form of the von Bertalanffy growth equation when data are available from a mark recapture experiment in the form length at release (r), length at recapture (c) and time at liberty (t) is

$$d = (L_\infty - r) (1 - e^{-Kt}) \tag{1}$$

where d=c-r is the growth increment, and L_∞ and K are two of the von Bertalanffy parameters. With the added assumption that departures from (1) are independent, with zero mean and constant variance, estimates of L_∞ and K may be obtained by unweighted nonlinear least squares. The estimates reported in this paper for model (1) were obtained using the minimization subroutine LMM1 (Osborne 1976, program modified by Dr. A.J. Miller). For both sexes and species of tiger prawns, this model was fitted and the set of residuals was examined for extreme and influential outliers. If any were detected, they were omitted and new parameter estimates were calculated for the revised data set.

Once influential outliers had been removed, the residuals were examined further to determine whether there was any evidence of lack of fit or departures from the assumptions of the regression model. Two specific tests were carried out, in which the residuals were regressed linearly against both length at release and time at liberty. A significant trend in residuals with either of these variables indicates failure of some of the assumptions and may indicate substantial bias in the parameter estimates (Draper and Smith 1981, Ch 3).

Although it is a simple matter to obtain standard errors of the estimates of L_∞ and K, the generally high negative correlation between the parameter estimates implies that correct interpretation of these standard errors by themselves is difficult. A much clearer picture is given by joint confidence regions for L_∞ and K. Asymptotic likelihood based confidence regions were calculated using a procedure described by Gallant (1976). If, given n data points

$$S(L_\infty,K) = \sum_{i=1}^{n} [d_i - (L_\infty - r_i)(1 - e^{-Kt_i})]^2$$

with $S(\hat{L}_\infty,\hat{K})$ being the minimized sum of squares at the least squares estimates $\hat{L}_\infty$ and $\hat{K}$, then

$$\frac{(n-2)(S(L_\infty,K) - S(\hat{L}_\infty,\hat{K}))}{2S(\hat{L}_\infty,\hat{K})} = F_{2,n-2,0.05}$$

defines the boundary of an approximate 95% confidence region for L_∞ and K, where $F_{2,n-2,0.05}$ is the upper 5% point of an F distribution on 2 and n-2 degrees of freedom. For each data set, 95% confidence regions for L_∞ and K were derived using this procedure.

While it is common for the values of L_∞ to differ between sexes and species, the same is not necessarily true for the parameter K. Tests for differences in K between sexes and species were carried out using a procedure similar to that outlined for length at age data by Kimura (1980). These tests require the additional assumption that departures from (1) are independent between data sets, and are normally distributed. Then, in the case of comparisons across all four data sets for example, maximum likelihood estimates of a common K and a differing L_∞ for each species-sex combination were calculated, and a likelihood ratio test was used to test the null hypothesis that K was the same for each data set against the alternative that at least one K was different (Kimura 1980).

An alternative model

Subject to satisfactory performance on the residual checks, the above procedure produces a von Bertalanffy growth curve that fits adequately over the range of the available data. While this is a useful endpoint in itself, it was also intended that the fitted growth curves be used in subsequent yield per recruit analyses. These analyses may well require an adequate description of growth over a wider range of lengths. Indeed, it is common practice simply to substitute the estimated L_∞ and K into a Beverton and Holt (1957) yield per recruit equation, in which case it is desirable that the estimated L_∞ should be similar to the true average maximum length. However even if independent data on maximum lengths are available, a quantitative comparison of these with an L_∞ calculated using the standard model is not possible, since that model assumes that all animals grow to the same maximum length.

Von Bertalanffy-type models that incorporate explicit recognition of individual variability in growth were described by Sainsbury (1980), who in fact allowed for variability in both L_∞ and K. Unfortunately, the number of parameters then required to be estimated is large, and the estimation procedure is both extremely time-consuming and fraught with difficulties with data sets of the size considered here. A simpler model of this type assumes that only the maximum length L_∞ varies between individuals. Specifically, L_∞ is taken to be normally distributed with mean μ and variance σ^2, so that for each individual, the growth increment d is a random sample from a normal distribution with mean $(\mu-r)(1-e^{-Kt})$ and variance $\sigma^2(1-e^{-Kt})^2$. Note that this is equivalent to the model

$$d = (\mu - r)(1 - e^{-Kt}) + w \qquad (2)$$

where w is normally distributed with zero mean and variance $\sigma^2(1-e^{-Kt})^2$. This is very similar to (1), the principal difference being that the error variance now is assumed to increase with time at liberty.

For each sex and species, maximum likelihood estimates of μ, σ^2 and K were calculated using model (2). Then with estimates μ and σ^2 of the mean and variance of L_∞, it is a simple matter to draw comparisons with observed data on maximum lengths. Also, the consistency of the model (2) estimates of μ and K can be compared with the model (1) estimates of L_∞, but in this paper we shall be treating the model(1) estimates as the primary parameter estimates.

Results

Estimates from model (1)

For each sex and species, least squares estimates of L_∞ and K were calculated using model (1) and the estimates are shown in Table 1, along with their standard errors. For P. esculentus males and P. semisulcatus males and females, initial fits revealed the presence in each case of one extreme outlier. The absolute standardized residuals (actual residual divided by residual standard error) for these were respectively 4.1, 4.8 and 4.4. The corresponding observations were omitted and revised parameter estimates calculated. These revised estimates are shown in Table 1. Further, to aid comparisons of growth between both sexes and species, von Bertalanffy growth curves with parameters given in Table 1 are shown in Fig. 1, under the assumption that both sexes and species have zero length at time zero.

The residual tests carried out suggest that model (1) provided an adequate fit to the data for males of both P. esculentus and P. semisulcatus . However there was a significant trend in residuals with time at liberty for P. esculentus females, and significant trends with both time at liberty an length at release for P. semisulcatus females. Residual plots illustrating the trends against time at liberty for females of each species are given in Fig. 2. For each data set, Fig. 2 indicates that there is a period during which no tag recoveries were made. The residuals for long times at liberty tended to be substantially higher than those for shorter times at liberty. With the previously identified outliers removed, two data sets were split into two groups at the natural break-points; for P. esculentus the groups corresponded to $t \leq 14$ weeks and $t > 14$ weeks, while the P. semisulcatus data were split at $t = 17$ weeks. Model (1) then was fitted to each subset, and the resulting parameter estimates and residual tests are shown in Table 2. In each case, splitting the data in the indicated manner led to satisfactory residual patterns for each subset. For P. semisulcatus females, the large differences between estimates of L_∞ and K indicated clearly that model (1) does not fit the entire range of data at all well. The Table 2 estimates for P. esculentus females are much more similar, and they also do not differ greatly from the corresponding estimates in Table 1.

Joint 95% confidence regions corresponding to the estimates shown in Table 1 were calculated and they are given in Fig. 3. It is clear from this figure that there are significant differences in L_∞ between data sets, as expected, but that at least some of the estimates of K may not differ significantly. Parameter estimates assuming a common K and likelihood ratio test statistics for testing equality between K values are given in Table 3. The statistical tests point to significant differences in K between P. esculentus and P. semisulcatus , but no significant difference in K between male and female P. esculentus .

Estimates from model (2)

Estimates of the parameters μ, σ^2 and K from model (2) were obtained for each species and sex using the data sets (with outliers removed) used to calculate the model (1) estimates in Table 1. The estimates obtained using model (2) are given in Table 4.

As outlined earlier, the purpose of introducing model (2) was to allow meaningful comparisons of the estimated L_∞ with the carapace lengths of the largest individuals recorded in samples of each sex and species. For such comparisons, the critical parameters are μ and σ^2. Since by assumption L_∞ is normally distributed, one would expect the largest observed carapace length in a large sample to be roughly comparable with an upper percentage point of a $N(\mu,\sigma^2)$ distribution, say $\mu+3\sigma$, although such a comparison can be only approximate. To this end, also shown in Table 4 are the carapace lengths of the largest individuals of each species and sex recorded in commercial catch samples taken throughout the year and in the recaptured tagged individuals. Note that in the latter data source,the sample sizes are substantially larger than those for data used elsewhere in this paper to estimate growth parameters. This was possible because additional tagging experiments were carried out in which tagged prawns were measured only on recapture, and these data have also been used to determine maximum carapace lengths.

Table 4 indicates that for P. esculentus males and females and for P. semisulcatus males, the maximum observed carapace lengths are compatible with the corresponding estimates of μ and σ^2. However for P. semisulcatus females, as in Table 1, the estimated mean L_∞ exceeds the length of the largest observed individuals. Although the estimate of μ in this case has a coefficient of variation in excess of 10%, the comparison suggests a considerable anomaly.

Since the underlying models differ, it is to be expected that the estimates of K and of L_∞ and μ for corresponding data sets in Tables 1 and 4 will differ. In each case however, the differences are small, and we therefore can infer that for *P. esculentus* males and females and for *P. semisulcatus* males, the Table 1 estimates of L_∞ are compatible with the observed maximum lengths.

Discussion

As with all Crustacea, growth in tiger prawns occurs only at the time of moulting, with the carapace length remaining constant between moults. Consequently a model such as the von Bertalanffy which assumes continuous growth gives an inadequate description of the detailed growth process. Predictions of growth increments using (1) are particularly poor for prawns with short times at liberty relative to the inter-moult period. The normal inter-moult period for *P. esculentus* is of the order of two weeks (Barclay *et al*. 1983), although strictly this estimate applies only to untagged prawns. In this study, growth data for tagged prawns recaptured less than two weeks after release were omitted in order to eliminate at least the potentially gross discrepancies between predicted and observed growth increments for prawns with short times at liberty.

The general properties of model (1) and the statistical properties of the parameter estimates obtained using this model are both well known, but the same is not true of model (2). While the advantage of model (2) over model (1) is explicit incorporation of individual variability in L_∞, model (2) has the disadvantage that the only source of "error" allowed for lies in this variability in L_∞. Specifically, model (2) assumes that there are no measurement errors, and each individual is assumed to grow exactly according to a von Bertalanffy curve with a common K between individuals. This raises two potential problems, both associated with the assumption that individuals cannot shrink. Especially for short term recoveries, it is not uncommon for the recorded recapture length to exceed the recorded release length. The L_∞ for such an individual will be predicted by model (2) to be much less than its release or recapture lengths, and this is absurd. A more subtle problem arises for individuals with a large release length. Conditional on this release length, the distribution of L_∞ properly should be truncated below at that release length, and the estimation procedure should take that truncation into account. While it is possible in principle to allow for measurement error and for the truncation effect, in practice the estimation procedure again becomes cumbersome and time-consuming. Fortunately, in none of the data sets examined here did the release length exceed the recapture length, and all prawns were released at lengths well below their estimated L_∞. Thus in this sense model (2) was adequate, but it still remains true that the behaviour of model (2) is much less well understood than that of model (1). It was for this reason, and partly for reasons of tradition, that we preferred to treat the model (1) estimates of L_∞ and K as the primary estimates of those parameters. Essentially, model (2) was used only for comparison of estimated mean L_∞ with observed length frequency data. However, we feel that potentially model (2) may be extremely useful for estimation purposes as well, and its general properties deserve further study.

Synthesizing the results obtained using both models (1) and (2), for males of both tiger prawn species, there were no indications that the von Bertalanffy curve failed to fit the data satisfactorily, and the estimated L_∞ values were consistent with the largest males found in observed length frequency data. However, for females there were indications that the fit of the von Bertalanffy curve was unsatisfactory. For female *P. esculentus* , there was a significant trend in residual growth increments with time at liberty. When the data were split into two groups by time at liberty and a von Bertalanffy curve fitted to each group, no such trend was found. Naturally parameter estimates differed between groups, but the differences were relatively small. Also, in each case the estimated L_∞ was consistent with the maximum observed length. Thus, despite the warning signal of the significant residual trend, the estimated curve for *P. esculentus* females may be satisfactory. For *P. semisulcatus* females however, the fit obtained was extremely poor. Highly significant trends in residuals were found with both time at liberty and length at release, and the estimated L_∞ exceeded by a considerable margin the carapace length of the largest observed specimen. Also, when the data were split into two groups by time at liberty, markedly different estimates of L_∞ and K were obtained between groups. In this case, no reliable growth curve has been obtained. To indicate its likely unreliability, the growth curve shown in Fig 1 for *P. semisulcatus* females is shown as a dashed, rather than a solid line.

In both species, it was for females that evidence of a possibly unsatisfactory fit was found, and it is interesting to speculate on the reasons for this. Since the von Bertalanffy curve appeared to fit data for males of each species quite satisfactorily, over length ranges comparable with those for females relative to the estimated L_∞, it does not seem fruitful simply to search for an alternative growth curve for females. The most obvious possible explanation is that the females, which become sexually mature at around 30 mm carapace length (Mohammed *et al.* 1981; O'Conner 1979; White 1975), divert energy from growth to reproduction at the onset of the breeding season. If so, one may well expect the von Bertalanffy curve to provide a poor fit. Data on the reproductive cycles of *P. esculentus* and *P. semisulcatus* in this region are sketchy at best, but available evidence from postlarval settlement on nursery areas near Groote Eylandt suggests that spawning takes place around September/October (D. Staples, pers. comm.), which is well within the period over which recaptures were made in these experiments.

The remaining statistical tests carried out were designed to test equality of the parameter K between species and between sexes. Of the tests performed, only that between *P. esculentus* males and females proved not significant, although any test involving *P. semisulcatus* females is meaningless given the extremely poor fit attained to these data. Since males and females of both species are found together throughout their life cycles, it perhaps should not be surprising that *P. esculentus* males and females have similar K values. Thus it may not be merely coincidental that, for *P. semisulcatus* females, the estimate of L_∞ assuming a common K between sexes and species is similar to that obtained for long term *P. semisulcatus* female recoveries, and that an L_∞ of 53-54 mm is much more consistent with observed length frequency data. In fact, since the test for equality of K between *P. esculentus* males and females and *P. semisulcatus* males was only just statistically significant, it may even turn out that the common K estimates in the first row of Table 3 are much closer to the mark than might originally have been expected. This, however, is drawing a rather long bow and clearly more work is needed to obtain demonstrably reliable descriptions of growth, at least for female *P. semisulcatus*. It seems unlikely that further tagging experiments will provide the necessary data. Instead, the most promising approach may be to follow carefully the growth of a cohort of females, simultaneously monitoring their reproductive condition and other important biological parameters.

There have been few published estimates of von Bertalanffy parameters for tiger prawns. For *P. esculentus* in Shark Bay, Western Australia, White (1975) estimated growth parameters for three successive years (1969-71). The mean parameter values were for males, K=0.05 per week and L_∞=32.6 mm carapace length. For females these were K=0.05 and L_∞=40.9 mm carapace length. For *P. semisulcatus* in Kuwait waters, Jones and van Zalinge (1981) obtained estimates of L_∞=47.7 mm carapace length and K=0.05 per week for females, and L_∞=42.5, K=0.04 for males from analyses of modal size progressions. Thomas (1975) reported a carapace length after two years of 41.08 mm for *P. semisulcatus* females and 29.36 mm for *P. semisulcatus* males, but the method by which these estimates were calculated is unclear. No standard errors are available for any of these estimates.

A distinguishing feature of *P. semisulcatus* over *P. esculentus* was the occasional presence in the former of a bopyrid parasite (*Epipenaeon* sp.), which occurred in approximately 15% of specimens captured for tagging and later released. Data for parasitized *P. semisulcatus* were included when estimating the von Bertalanffy parameters. Inspection of individual residuals from the fitted curves revealed that in no case was a parasitized individual associated with a high residual. The presence of the parasite therefore does not appear to affect growth.

Acknowledgements

We thank Mr. D. Grey and Mr. N. Carrol of the Northern Territory Fisheries Division for providing access to unpublished data on commercial catch samples from the tiger prawn fisheries in the Gulf of Carpentaria, which were extremely valuable both in the planning of the tagging experiments and in determining maximum carapace lengths. The analyses reported here would not have been possible without the cooperation of the fishing industry and the assistance of staff of Fisheries Dapartments in Queensland, Northern Territory, Western Australia and South Australia, during both the tagging program and subsequent collection of tagged prawn recaptures. This study was funded in part by a grant from the Australian Fishing Industry Research Trust Account.

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Figure captions

Figure 1. Fitted von Bertalanffy growth curves for male and female P. esculentus and P. semisulcatus, using parameter estimates in Table 1 and assuming zero length at time zero. The curve for P.semisulcatus females is shown as a dashed line to indicate its probable unreliability.

Figure 2.(a) Plots of residuals from model (1) against time at liberty for P. esculentus females. (b) Plot of residuals from model (1) against time at liberty for P. semisulcatus females.

Figure 3.Joint 95% confidence regions for L_∞ and K for males and females of P. esculentus and P. semisulcatus, obtained using model (1).

TABLE 1. Parameter estimates calculated using model (1), together with their standard parameter estimates calculated using model (1), together with their standard errors (se), number of data (n), and results of tests of residuals for significant trend with length at release (length) or time at liberty (time).

	L_∞ (se)	K (se)	n	Residual tests[2] length	Residual tests[2] time
P. esculentus					
Males[1]	37.49 (0.54)	0.034 (0.003)	154	ns	ns
Females	44.80 (1.00)	0.041 (0.004)	94	ns	P<0.05
P. semisulcatus					
Males[1]	38.09 (1.54)	0.061 (0.009)	42	ns	ns
Females[1]	62.22 (5.04)	0.025 (0.005)	70	P<0.01	P<0.01

1 One extreme outlier omitted

2 ns = not significant at 5% level.

TABLE 2. Results of fitting model (1) to subsets of data for *P. esculentus* females and *P. semisulcatus* females. Parameter estimates and their standard errors (se), number of data in subset (n), and results of tests of residuals for significant trend with length at release (length) and time at liberty (time, t); ns=not significant at 5% level.

	L_∞ (se)	K (se)	n	Residual tests length	Residual tests time
P. esculentus females					
$t \leq 14$	42.44 (0.89)	0.046 (0.005)	76	ns	ns
$t > 14$	45.05 (1.34)	0.054 (0.009)	18	ns	ns
P. semisulcatus females					
$t \leq 17$	41.11 (2.71)	0.073 (0.024)	29	ns	ns
$t > 17$	53.92 (3.19)	0.040 (0.009)	41	ns	ns

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TABLE 3. Parameter estimates and their standard errors (se) assuming a common K and differing L_∞, together with likelihood ratio test statistics, which are asymptotically distributed as χ^2 with df degrees of freedom. Column 1 shows results of testing for a common K between *P. esculentus* males and females and *P.semisulcatus* males and females; column 2 covers tests between *P. esculentus* males and females and *P. semisulcatus* males; column 3 covers tests between *P. esculentus* males and females.

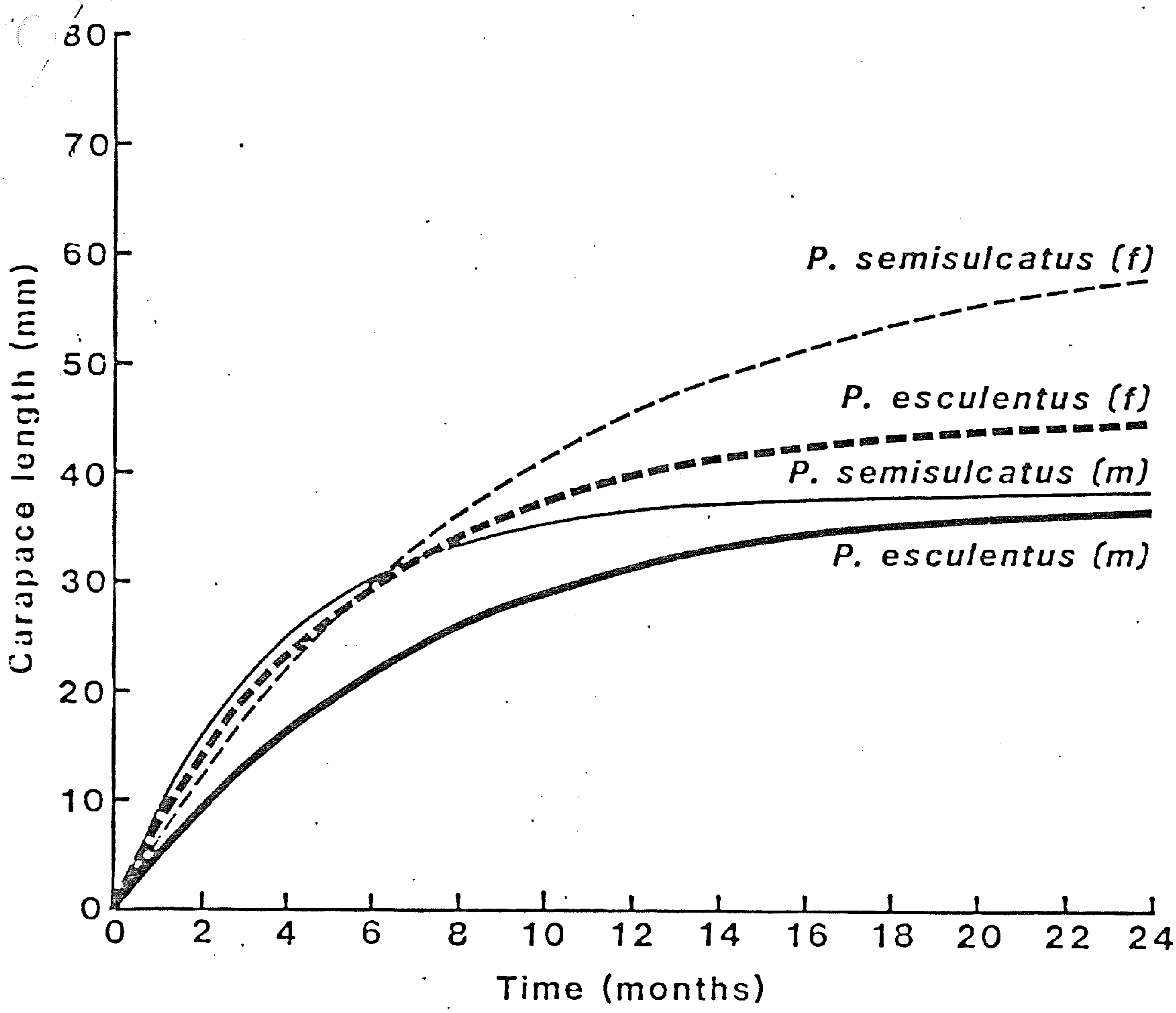
	Test 1	Test 2	Test 3
P. esculentus			
L_∞, (se) - males	36.77 (0.83)	36.43 (0.72)	36.45 (0.84)
L_∞, (se) - females	45.08 (1.02)	44.53 (0.88)	44.60 (1.02)
P. semisulcatus			
L_∞, (se) - males	40.72 (0.69)	40.13 (0.58)	
L_∞, (se) - females	53.10 (0.68)		
Common K, (se)	0.040 (0.002)	0.043 (0.002)	0.042 (0.002)
χ^2 (df)[1]	26.49 (3) **	7.67 (2) *	2.96 (1)

1 * denotes significant at 5% level, ** denotes significant at 1% level.

95

TABLE 4. Parameter estimates for model (2), in which L_∞ has a normal distribution with mean μ and variance σ^2. Data sets are the same as those used to calculate Table 1 estimates. Also shown are observed maximum carapace lengths and sample sizes (n) for recaptured tagged prawns (tags) and from catch samples.

	μ	σ^2	K	Maximum carapace length	
				tags (n)	samples (n)
P. esculentus					
Males	36.14	3.74	0.044	41.8 (1068)	42.0 (3113)
Females	42.33	10.88	0.054	49.6 (969)	52.0 (3004)
P. semisulcatus					
Males	38.30	2.53	0.059	44.9 (244)	43.0 (2097)
Females	60.72	65.32	0.024	45.5 (300)	56.0 (2639)



80
70
60
50
40
30
20
10
0
Carapace length (mm)
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (months)
P. semisulcatus (f)
P. esculentus (f)
P. semisulcatus (m)
P. esculentus (m)

Fig 1

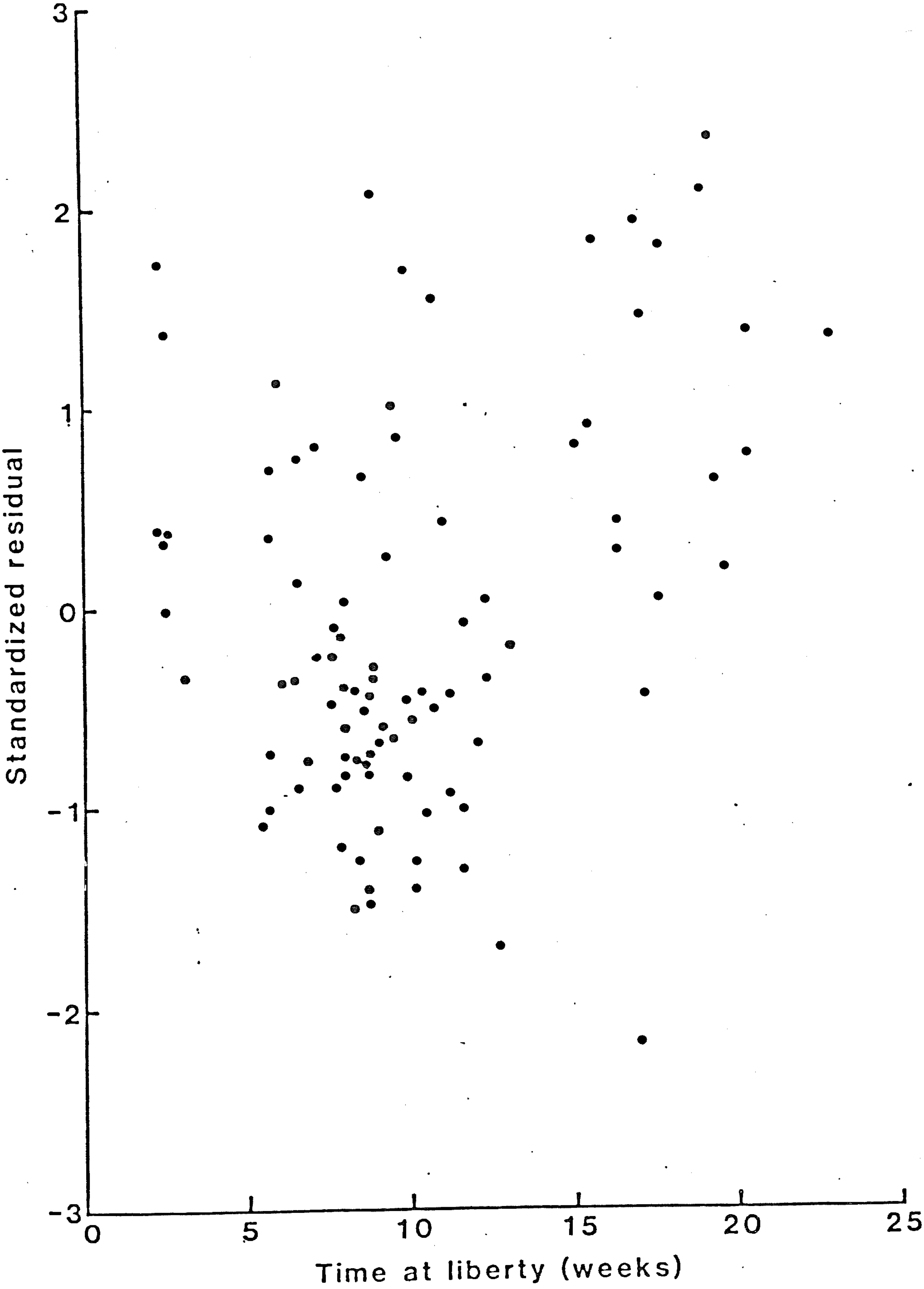
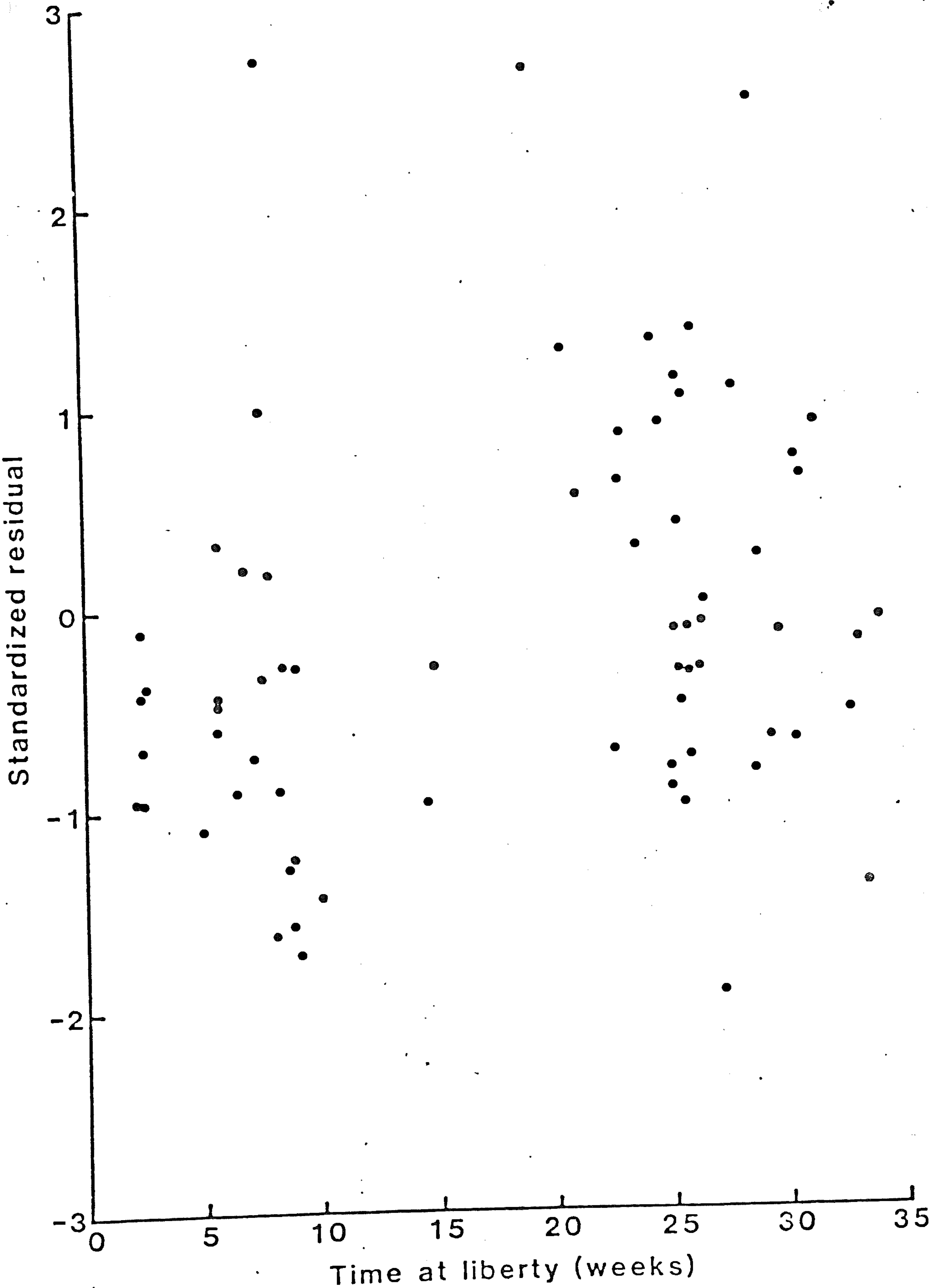

3
2
1
0
-1
-2
-3
Standardized residual
0
5
10
15
20
25
Time at liberty (weeks)

Fig 2a



Standardized residual
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
35
Time at liberty (weeks)

Fig 2b

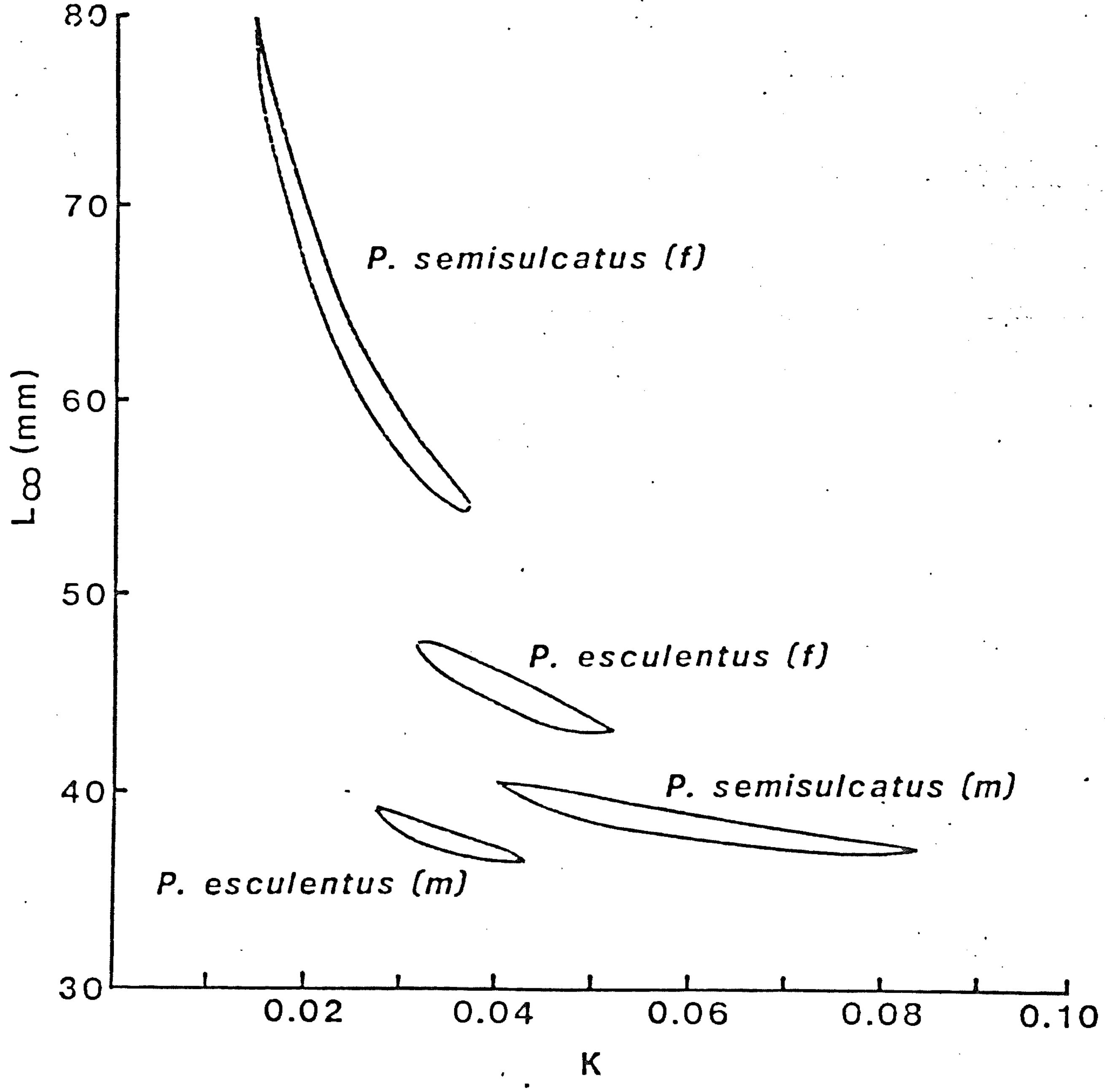

80
70
60
50
40
30
L∞ (mm)
P. semisulcatus (f)
P. esculentus (f)
P. semisulcatus (m)
P. esculentus (m)
0.02
0.04
0.06
0.08
0.10
K

Fig 3

Tiger prawn tagging program in Gulf of Carpentaria

by I. F. Somers

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Tiger prawn tagging program in Gulf of Carpentaria

by I. F. Somers*

A SERIES of experiments which involve the tagging and release of more than 20 000 tiger prawns is to be carried out near Groote Eylandt in the Gulf of Carpentaria this year.

The program will be a co-operative exercise: partly funded by the Commonwealth Government's Fishing Industry Research Trust Account, and with officers from the CSIRO, Northern Territory Fisheries and the Queensland Fisheries Service taking part.

It is designed to estimate growth and mortality rates for tiger prawns, as well as to help trace their migrations.

A better understanding of these aspects of tiger prawn population dynamics will enable an assessment to be made of the impact of fishing on the stocks, and thus provide a basis for industry's most efficient utilisation of this resource.

Estimates of growth will be obtained by measuring individual prawns both before release and after recapture. In this respect, it is imperative that fishermen who catch tagged prawns return the whole prawn for subsequent measurement. Migration patterns will be studied if the precise location of recapture is also reported.

The estimation of mortality rates and the impact of fishing on the population is not quite as straightforward. It is based on the rate of decline over time in the number of tag returns, which must first be adjusted according to the corresponding level of fishing effort. Therefore, to achieve these objectives, it is critical that accurate logbooks be completed by all fishermen, whether they recapture tagged prawns or not.

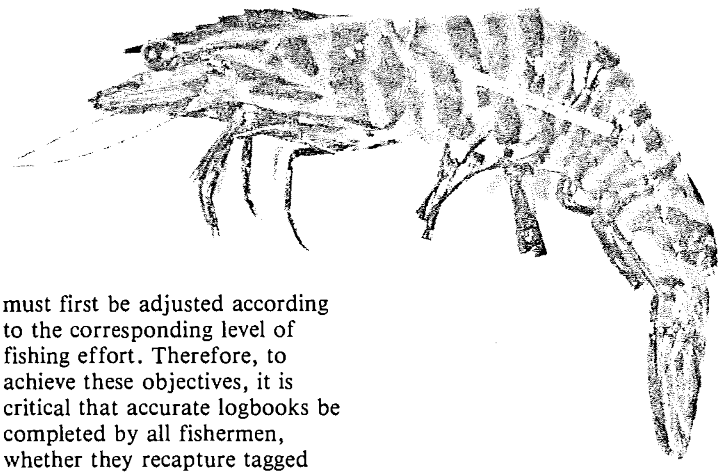
Many management decisions concerning the industry are based, at least in part, on the information gained from such experiments, so it is very important that the estimates be as reliable as possible.

As the effect of the tag on the prawn will also affect the number that are ultimately recaptured — and consequently the reliability of mortality estimates — much time has been spent in designing prawn tags which cause minimal damage to the prawn.

New tags

The latest development in prawn tag design is that of a plastic streamer, inserted through the first abdominal segment of the prawn with the aid of a needle.

These tags, when tested in the United States using the three main commercial prawn species from the Gulf of Mexico and holding the tagged individuals in laboratory tanks, proved much better than the previously used Petersen tags: initial mortality due to tagging was much less.



A tiger prawn with a (blue) streamer tag, the type to be used in the Gulf of Carpentaria this year.

Field trials of the streamer tags were conducted by CSIRO's Division of Fisheries and Oceanography in 1977-78 using two of Australia's commercial prawn species, the eastern king prawn (*Penaeus plebejus*) and the brown tiger prawn (*Penaeus esculentus*).

During the initial trials conducted in Moreton Bay (southern Queensland), more than 7 500 king prawns were tagged with the conventional Petersen tags and the new streamer tags in approximately equal numbers. The results were anything but startling with a recovery of streamer tags (20.7 per cent) only marginally better than that of Petersen tags (18.3

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per cent).

However in similar trials near Mornington Island in the Gulf of Carpentaria using almost 8 000 tiger prawns, the result was substantially different. The total return of streamers (19 per cent) was more than double that of Petersen tags (8 per cent). (The total monthly returns for each tag type is shown in Figure 1.)

Was this merely because the streamer tags were easier to detect in the catch? It seems not, because the percentage of tags recovered that were returned from fishing vessels was exactly 30 per cent for both tag types, the remainder coming from processing establishments. There is, therefore, sufficient evidence to conclude that in the case of tiger prawns, streamer tags cause significantly less initial tag-induced mortality. The use of streamer tags in tiger prawn tagging experiments should therefore make a more precise analysis of the results of these experiments possible.

The tagging trials also highlighted another important prerequisite for precise analysis of tagging results — accurate recording of fishing effort details. The tagged king prawns of Moreton Bay dispersed very rapidly after release, with general migrations offshore and northwards along the east coast of Queensland for up to one hundred miles. But the tiger prawns at Mornington Island, even those recaptured more than six months after release, were all caught within 12 miles of the point of release.

Therefore it is extremely important that not only fishing effort should be recorded in fishermen's logbooks but also precise location of fishing activities.

How can the industry assist the tiger-tagging program?

1. Watch out for tagged tiger prawns

At least two out of every three tagged prawns recaptured were not seen when sorting the catch on board fishing vessels during the 1978 Gulf of Carpentaria experiments.

2. Return the tagged prawn intact

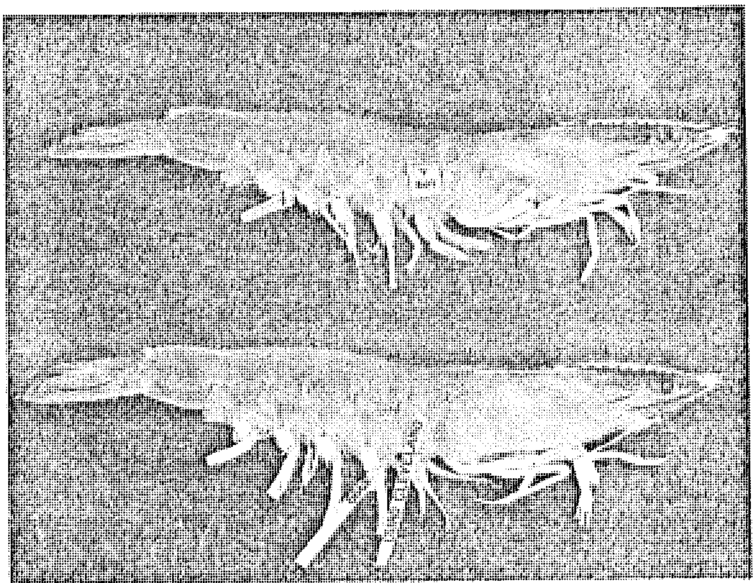
Representatives of the various fisheries research organisations are stationed in Darwin, Groote Eylandt, Karumba and Cairns. A reward of $1 will be paid for the return of each tagged prawn.

3. Record and report the following details after catching a tagged tiger prawn:

- tag number;
- date of capture;
- precise location of capture; and
- depth.

4. Complete accurate and comprehensive fishing logs

Include both the hours of trawling and the precise location of each day's fishing activities.



Two eastern king prawns showing the streamer and Petersen tags.

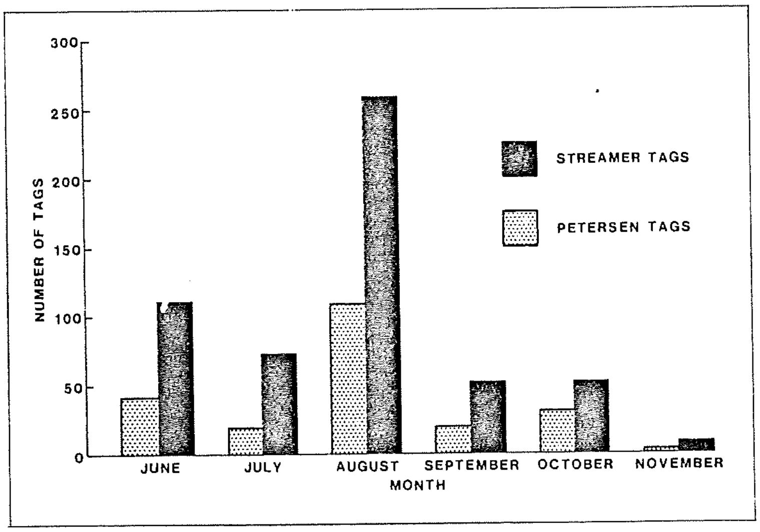


Figure 1: Monthly returns of streamer and Petersen tags from tiger prawns released near Mornington Island (Gulf of Carpentaria) in June, 1978.