7. MOVEMENT AND GROWTH OF *PENAEUS ESCULENTUS* HASWELL, 1879 ESTIMATED FROM TAGGING IN TORRES STRAIT.

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7.1 Introduction

Some of the most important factors in managing a fishery are: an estimate of the relative abundance of the population, the age/size composition of the population, growth rates, age at maturity, and mortality rates from fishing and natural causes (Rounsefell 1975). As juvenile prawns are found in a separate habitat from that of adults, prawn movements are also important to management. Tagging of animals for later recovery is an excellent method for estimating growth rates and migration, and for separating fishing and natural mortality rates (Gulland 1983). In some instances tagging can also be used to estimate population size (Jones 1977).

Several assumptions are made concerning tagged individuals. Firstly, that the tagged individuals disperse randomly through the population to be studied before recapture, secondly that the tagged individuals are subject to the same mortality rates as untagged individuals, and thirdly that tags are not lost or overlooked when recovered (Krebs 1978). In some circumstances it is impossible not to violate one of these assumptions. Tags are known to affect speed of movement, susceptibility to predation, feeding ability and mortality (Rounsefell 1975). Despite these violations, tagging is the most reliable method for estimating growth in Penaeidae (Garcia and Le Reste 1981). Another reliable application of tagging experiments is to quantify the movement of tagged animals. A knowledge of migration patterns is an essential component in the identification of stock boundaries (Somers and Kirkwood 1984), an issue of importance for the Torres Strait Prawn Fishery which has catch sharing arrangements between two countries, Australia and Papua New Guinea.

The initial objectives of this tagging programme were to describe the movements and growth of *Penaeus esculentus*, the brown tiger prawn.

7.2 Materials and Methods

7.2.1 Study area

Two areas were used for the capture of prawns and their subsequent release after tagging: (1) west of Warrior Reef (hereafter referred to as 'West'), an area not fished for prawns since 1981, and (2) east of Warrior Reefs (hereafter referred to as 'East'), the current fishing grounds (Section 1 - Figure 1). Previous surveys had indicated that through January and February these areas would yield sufficient numbers of smaller *P. esculentus* (less than 30 mm carapace length) for tagging. Prawns were tagged at both areas during two periods: 19 January to 25 January 1987, and 18 February to 23 February 1987. The numbers of prawns tagged on each date are indicated in Table 1.

Table 1. Summary of releases of tagged prawns.

January		February	
Date	Number Tagged	Date	Number Tagged
19/01/87	1243	18/02/87	1245
20/01/87	1231	19/02/87	1625
21/01/87	1476	20/02/87	1682
22/01/87	1176	21/02/87	2017
23/01/87	1380	22/02/87	1586
24/01/87	1756	23/02/87	1334
25/01/87	1405		
TOTAL	9667		9489

7.2.2 Prawn capture

Prawns were captured using 30 min shots of twin 6-fathom wide, 48 mm mesh otter trawl gear hauled by the 18 m R.V. 'Gwendoline May'. Undamaged *P. esculentus* were quickly removed from the sorting tray and placed in buckets of fresh seawater. These were emptied within minutes into holding tanks with a continuous seawater supply. These tanks had removable plastic mesh liners to facilitate moving prawns and retrieving prawns from the bottom. The first prawns were tagged within 15 min of their removal from the trawl net.

Sites used for tagged prawn release were not fished by the 'Gwendoline May' during the month when prawns were released there.

7.2.3 Description of tags

Blue-coloured polyethylene streamer tags (Hallprint Pty Ltd, South Australia) were used. These were about 5.7 cm in length (detached from needles), 3 mm wide at their printed ends and 1.5 mm wide inthe centre (manufacture's size 7S). Each plastic tag was bonded to a sewing needle. Tags were printed with consecutive identification numbers and an abbreviated name for our organisation. Several hours before use, the base of each tag was coated with a broad spectrum antibiotic cream, Auromyecin, in an attempt to reduce the subsequent risk of infection at the site of tag penetration.

7.2.4 Tagging and prawn release

Only vigorous prawns were selected from the holding tank for tagging. The tag was passed laterally through the first abdominal segment, midway between the segmental joints below the midline so as to avoid vital organs and nerve ganglia. The tag was visible to fishermen as it protruded about 2 cm from both sides of the prawn.

Prawns were returned to another holding tank following tagging. Within one to two hours, vigorous prawns were removed from this tank for identification and measurement. Each prawn had its tag number, carapace length (CL, to nearest 0.1 mm), sex and moult stage recorded. The ovary condition and maturity of female prawns was designated to stages as described by Tuma (1967). The presence of parasites such as bopyrids, or injuries to the prawn were noted. These prawns were then returned to a holding tank.

Prawns were usually released in groups of approximately 600 to 800 individuals. Prawns were transferred to a release cage which was quickly lowered to the bottom where an attached rope allowed the lid to be removed and the cage inverted. This operation was always completed before day break to assure that predation by fish was minimized. On the occasions when dolphins were in the vicinity of the vessel, by-catch (primarily crabs and fish) was retained on board and jettisoned rapidly as the release cage was lowered. This served to confuse and distract the dolphin pod by presenting an excess of food and sonar contacts.

7.2.5 Tag recovery system

The fishing industry was informed of the tagging programme through leaflets, newspaper and radio articles, and directly by fisheries staff prior to tagging. Plastic resealable containers were supplied to alltrawling operators, which included resealable bags, labels and instructions. A $2 reward was paid for the return of each tagged prawn with supporting documentation.

Labels supplied with tagged prawns required the trawling operator to identify the approximate recapture position on a map and/or by nominating distances and bearings measured by radar from landmarks. The date of recapture, the vessel, and the operators name were also required. Recaptured prawns were kept frozen until returned to the laboratory.

Most tags were collected from fishing vessels on the grounds by fisheries research or fisheries enforcement staff. On several occasions tagged prawns were returned directly to the laboratory. It was rare for tags to be returned without prawns or supporting documentation. A common problem was insufficient information to uniquely identify the recapture position, and frequently two recapture locations were possible. When this was observed, and when it was possible, the fishermen were asked to nominate the most likely recapture position.

7.2.6 Analysis

Information from tagged and recaptured prawns was maintained in a computer database. An index for the assessed accuracy of the recapture position was created, and prawns recaptured from uncertain locations were not included in analyses of prawn migration.

Short term growth. Frequency distributions for the observed growth of each sex were plotted, and the MIX computer program (P.D.M. Macdonald, Ichthus Data Systems) was used to determine component distributions that best fitted the histograms. This program is based on the method outlined by Macdonald and Pitcher (1979) for analysing distribution mixtures. The means of these distributions represented mean moult increments and analysis was restricted to the first three means. This technique was considered particularly applicable because the size range of the tagged population was relatively small, which indicated that prawns were from a single cohort and were expected to have similar growth rates. This type of analysis is rarely possible from tagging data, as short term return rates are usually low.

Long term growth. Prawns at liberty for less than 40 days and which had grown less than 1 mm were not included in the analysis of long term growth, as the type of model used was not suitable for predicting growth increments for prawns with short periods at liberty relative to the intermoult period (Kirkwood and Somers 1984). Residuals from nonlinear regressions were examined to identify extreme outliers, and these were subsequently omitted from the data.

Individual growth increments of prawns were used to assign growth parameters to the von Bertalanffy growth model. The form of the model used was:

$$y = (L_{\infty} - x_1)(1 - e^{-Kx})$$

y is the growth increment
x_1 is the initial size
x_2 is the time at liberty

L_∞ and K are two of the von Bertalanffy parameters.

Estimates of L_∞ and K were obtained using the minimization subroutine LMM (Osborne 1976). This model was fitted for both sexes and tagging areas, and the residual sums of squares were compared using F tests to determine which groups (sexes and tagging locations) should be considered separately. The model was refitted to calculate parameter estimates for the appropriate groups. Residuals were plotted against normal scores, time at liberty, initial size and fitted values to assess the normality of the residuals, whether there were any systematic departures from the fitted curves, and whether there were any trends in the residual variances.

Because of the generally high negative correlation between estimates of K and L_∞ (Kirkwood and Somers 1984), joint 95% confidence regions were calculated and compared graphically to determine if there were any significant differences in the estimated parameters between data sets.

7.3 Results and Discussion

7.3.1 Size

Most of the prawns tagged and released had carapace lengths greater than 27 mm (Figure 1 and Figure 2), except in the West during February, when several hundred smaller (< 27 mm CL) prawns were tagged (Fig.ure 2).

Females (average CL 33 mm) were significantly larger than males (average CL 28.6 mm) ($t = 21.301$, $p < 0.001$), (Student t-Test) and 12% more females than males were tagged and released.

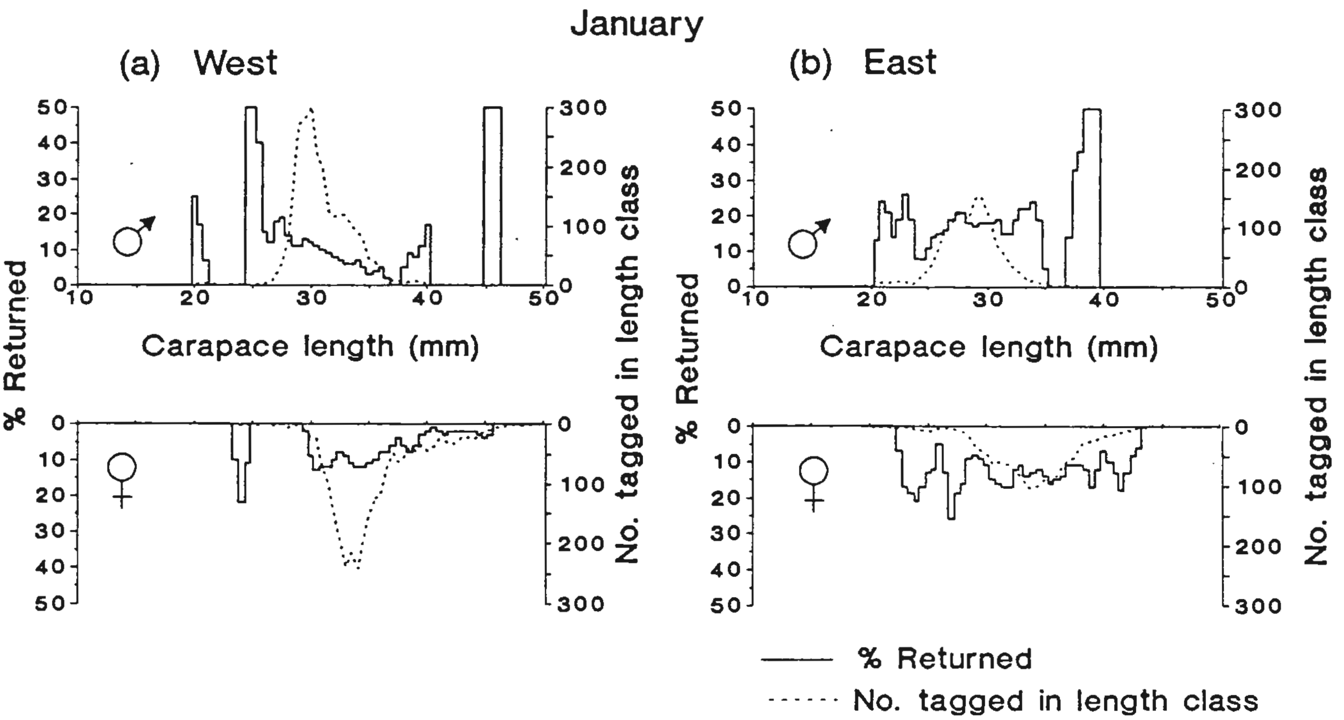

Figure 1. Length frequency distribution of males and females, and return rates for prawns tagged and released to the (a) West and (b) East during January 1987.

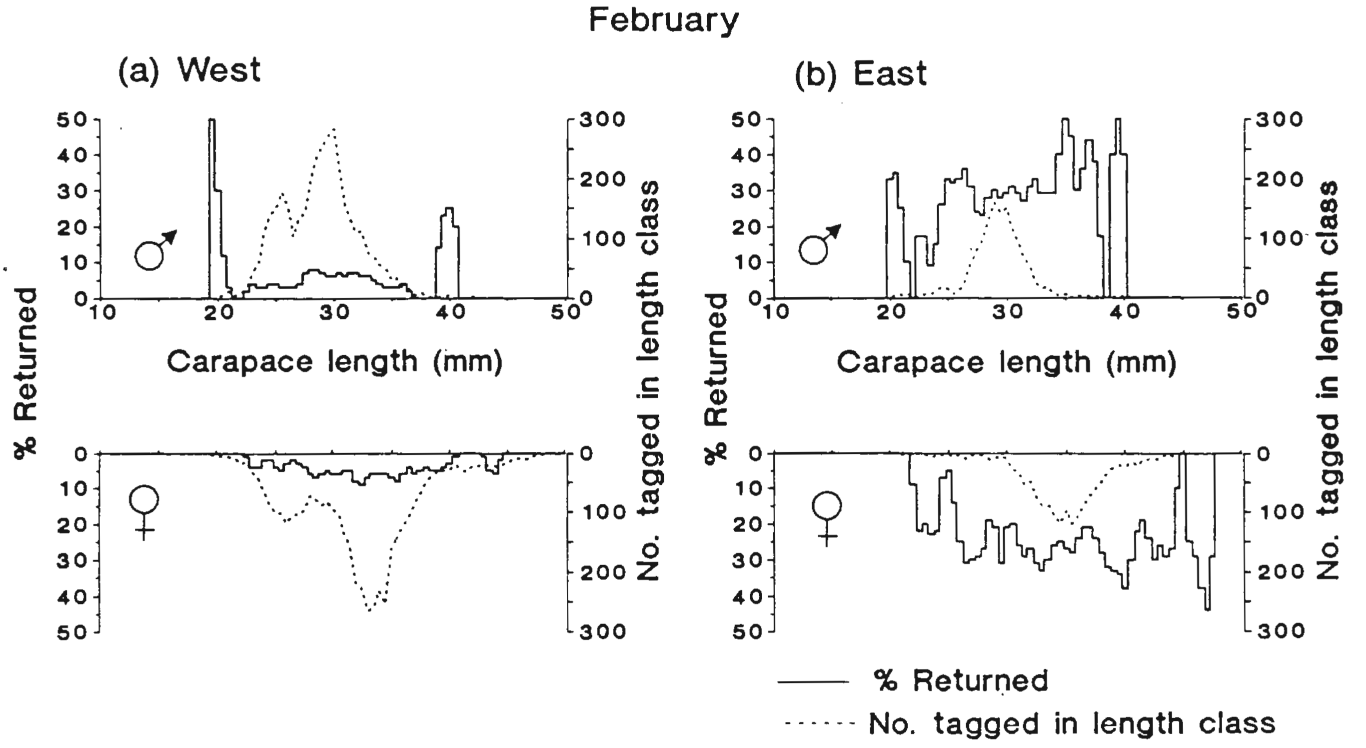

Figure 2. Length frequency distribution of males and females, and return rates for prawns tagged and released to the (a) West and (b) East during February 1987.

7.3.2 Return rates

Of the 19 156 tagged prawns released, 2085 were returned. The return rate for prawns released in the East (20%) was higher than for prawns released in the West (6.8%), due to differences in the level of fishing effort between the two areas. There was no fishing effort in the West, so prawns released there could not be recaptured by the fleet unless they migrated to the East. Most recaptures of prawns released in the East were made within 20 days after release, as there was a pulse of fishing effort at the beginning of the fishing season, which opened soon after tagging in February.

Return rates for males and females were similar, except for those prawns released in the East during January, of which 11.8% and 15.4% respectively were returned (Table 2). Prawns released in the East had relatively constant return rates across the range of carapace lengths tagged (Figure 1 and Figure 2). Return rates for prawns released in the West during January declined with increasing carapace length, especially for males (Figure 1).

Table 2. Return rates (%) for female and male prawns released east and west of Warrior Reefs.

	Females	Males
West January	8.3	9.0
West February	4.5	5.4
East January	11.8	15.4
East February	27.0	26.6

Return rates for small (< 27 mm CL) prawns released in the West during February were lower than for larger prawns (Figure 2). This may have been caused by greater tag induced mortality for these smaller-prawns. Hill and Wassenberg (1985) demonstrated in laboratory studies that tag induced mortality was greater in *P. esculentus* smaller than 19 mm CL. The prawns tagged in the present study were larger than this (Figure 1 and Figure 2). Return rates may also be influenced by size dependent natural mortality, as marine invertebrates typically have higher natural mortality earlier in life (Krebs 1978).

7.3.3 Movement

West. Apart from six prawns recaptured in the West by the 'Gwendoline May', all of the returns from prawns released in the West were recaptured in the East (Figure 3). Even though prawns could not be recaptured by the fleet in the West as the area is closed to commercial fishing, it is evident that there was a major movement of prawns to the East. Recaptures were concentrated south of Warrior Reef and around Yorke Islands and probably reflect the distribution of effort of the fishing fleet (Section 3).

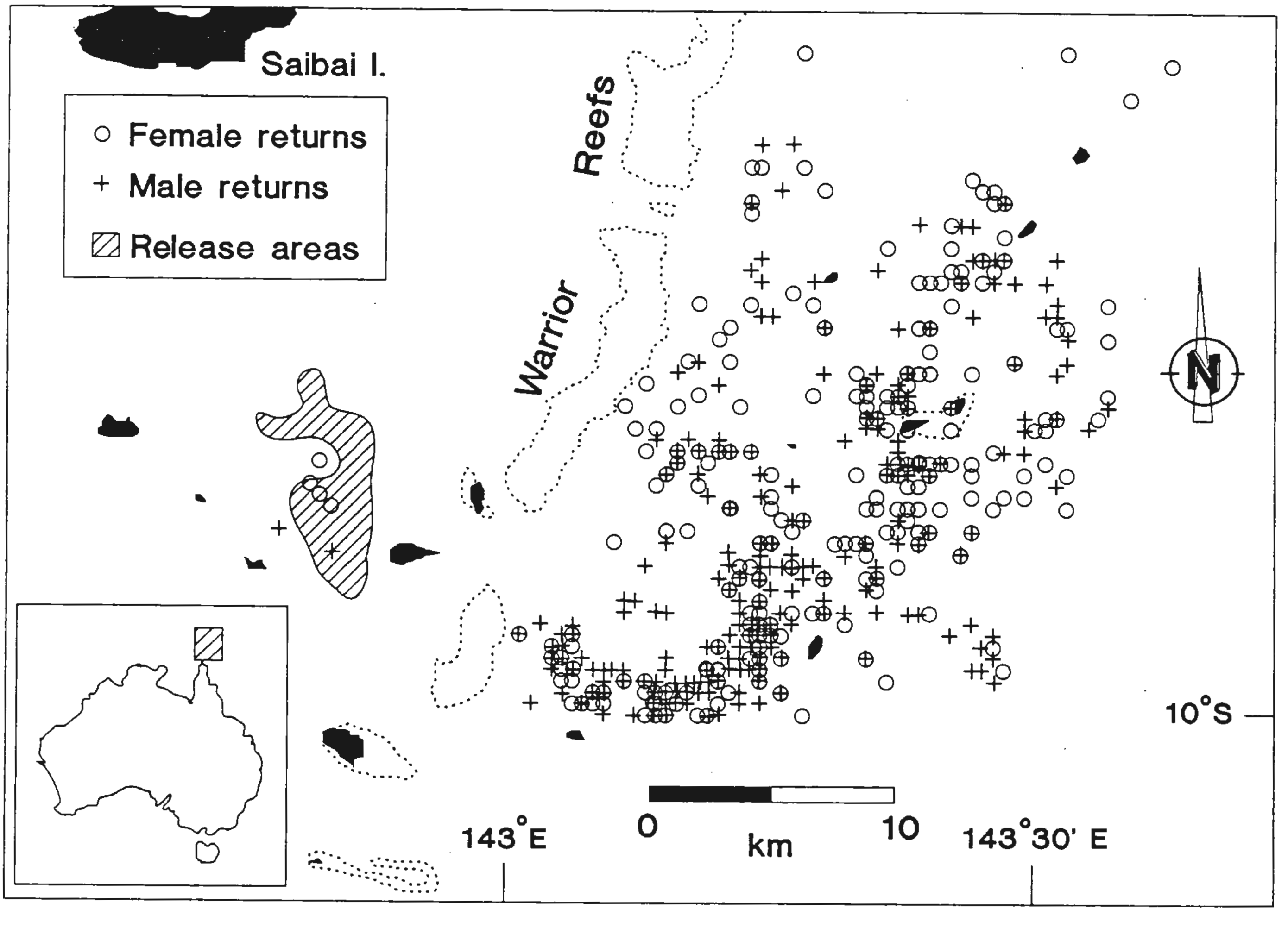

Figure 3. Release areas and recapture positions for prawns tagged and released to the West.

The average distance moved by males (24.9 n mile) was significantly less than that moved by females (27.5 n mile) ($t = 3.448$, $p < 0.001$)(Student t-Test). The greatest distance travelled was 69 n mile by a female released during February.

The average time at liberty was 72.7 days (s.d. = 44.8) and the greatest time at liberty recorded was 297 days for a male released during January. There was no significant difference in time at liberty between sexes ($t = 1.304$, $p > 0.05$)(Student t-Test) which, as males travelled smaller distances than females, indicates that males generally moved more slowly than females. There was no evidence of different migration routes for males and females (Figure 3).

Analysis of variance revealed that the distance moved significantly increased with time at liberty ($F = 193$, $p < 0.001$)(F Test), which was probably a result of the shift in effort of the fishing fleet from the Warrior Reef area towards Yorke Islands (Section 3). If the assumption that the fleet follows prawn movement is made, then the trend shown by the ANOVA can be attributed to prawn movement.

East. Most of the returns from prawns released in the East were recaptured close to the release areas (Figure 4). Other recaptures were scattered throughout the East (Figure 4). Concentrations of recaptures south of Warrior Reefs and around Yorke Islands such as occurred for prawns from the West(Figure 3) were not evident. The average time at liberty for prawns from the East was significantly less than that for prawns from the West ($t = 20.907$, $p < 0.001$)(Student t-Test), which indicates that the high fishing effort in the release areas of the East around the time of release may have prevented large numbers of prawns from migrating from these areas.

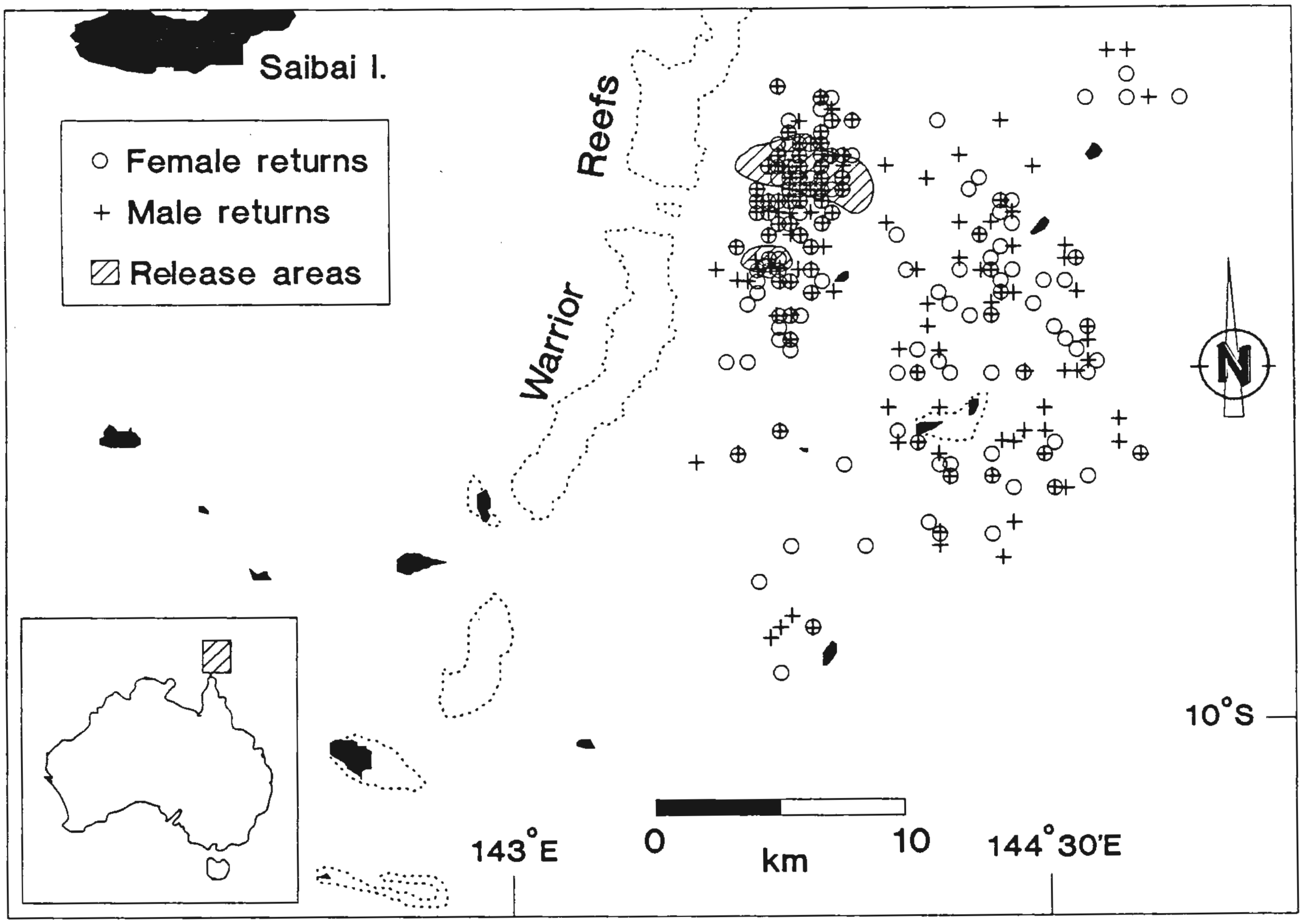

Figure 4. Release areas and recapture positions for prawns tagged and released to the East.

The average distance travelled by females (4.3 n mile) was not significantly different to that moved by males (4.8 n mile) ($t = 1.229$, $p > 0.05$)(Student t-Test). The average distance travelled by prawns from the East was significantly less than for prawns from the West ($t = 55.014$, $p < 0.001$)(Student t-Test), which is at least partially attributable to the unequal distribution of fishing effort. The greatest distance travelled was 58 n mile by a male released during January.

The average time at liberty was 27.9 days (s.d. = 34.5) and the greatest time at liberty recorded was 243 days for a male released during January. There was no significant difference in time at liberty between sexes ($t = 1.401$, $p > 0.05$)(Student t-Test).

As for the West, there was a significant positive relationship between the distance moved and time at liberty ($F = 629$, $p < 0.001$)(F Test).

7.3.4 Growth

Short term. Data on short term growth was restricted to prawns released in the East because of insufficient returns of prawns released in the West with small (< 20 days) periods at liberty.

The first three peaks of growth increments, identified for both sexes using the MIX program, were interpreted as representing prawns prior to ecdysis, those which had moulted once, and those which had moulted twice following tagging (Figure 5). The estimated means for these peaks and their standard errors are given in Table 3, and the computed chi-squared statistics indicate a good fit for both sexes (Table 4).

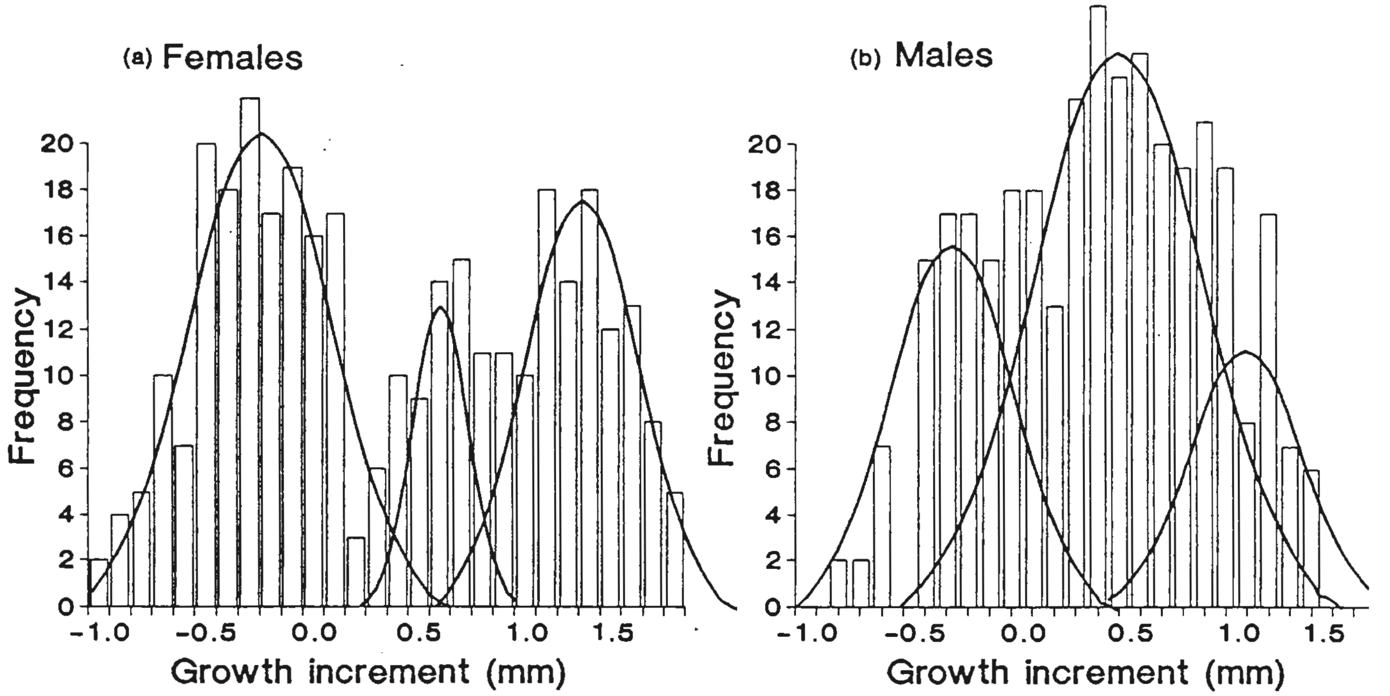

Figure 5. Component distribution for short-term growth of (a) females and (b) males.

Table 3. Means (mm) and their standard errors estimated by the MIX computer program for peaks of short term growth.

Moult	Means (s.e.) Females	Males
0	-0.3069 (0.0279)	-0.3275 (0.0307)
1	0.5891 (0.0355)	0.4482 (0.0353)
2	1.2052 (0.0289)	1.0417 (0.0391)

Table 4. Goodness of fit statistics computed by MIX for the analysis of short term growth.

Sex	df	χ^2	p
Females	24	16.128	0.883
Males	19	10.347	0.944

There was no significant difference between the means of females and males which had not moulted between release and recapture ($t = 0.496$, $p > 0.05$)(Student t-Test). The mean growthincrement of females which had moulted once since release was significantly larger than that for males of the same moult ($t = 2.812$, $p < 0.05$)(Student t-Test), as was the increment for females which had moulted twice ($t = 3.364$, $p < 0.05$). This indicates that females grew more than males during the period of the first two moults after release.

Subtracting the mean growth increment for one ecdysis from the following increment reveals that carapace lengths increased by between 0.6 mm and 0.9 mm with each moult. This is similar to the size increments found by Hill and Wassenberg (1985) for tagged *P. esculentus* in the laboratory.

The mean of the peak representing no ecdysis for both sexes was about -0.3 mm, which may indicate that shrinkage of the carapace occurred since release. This value is approximately 1% of the average carapace length, an insignificant amount when measuring longer term growth, but important when measuring a moult increment of between 0.6 mm and 0.9 mm. Since the prawns were returned to the laboratory frozen and measured at a lower temperature than when they were tagged (around 25°C difference), it is possible that thermal contraction caused the apparent negative growth. Measurement of carapace lengths in the laboratory over temperatures which ranged from 0°C to 25°C produced no obvious trend, so if freezing caused contraction it appears to be non-reversible.

Long term. Comparison of the residual sums of squares for females indicated that prawns from the East and West were significantly different ($F = 20.94$, $p < 0.001$)(F Test), hence growth parameters and joint 95% confidence regions for these prawns were estimated separately. Males from the East and West were not significantly different ($F = 0.23$, $p > 0.05$)(F Test), and were combined for estimation of growth parameters and joint 95% confidence regions. Estimates of growth parameters are given in Table 5, and joint 95% confidence regions corresponding to these estimates are shown in Figure 6. Residual diagnostic plots did not indicate any unusual departures from the fitted model.

Table 5. Estimates of growth parameters for females and males tagged and released in the East and West.

Area	Sex	No. of Prawns	L_∞ (s.e.) (mm)	K (s.e.) (day^{-1})
East	Female	112	42.4 (0.9)	0.0091 (0.0013)
	Male	104	37.2 (1.2)	0.0057 (0.001)
West	Female	281	52.6 (2.1)	0.0035 (0.0005)
	Male	237	36.6 (0.6)	0.0063 (0.0007)

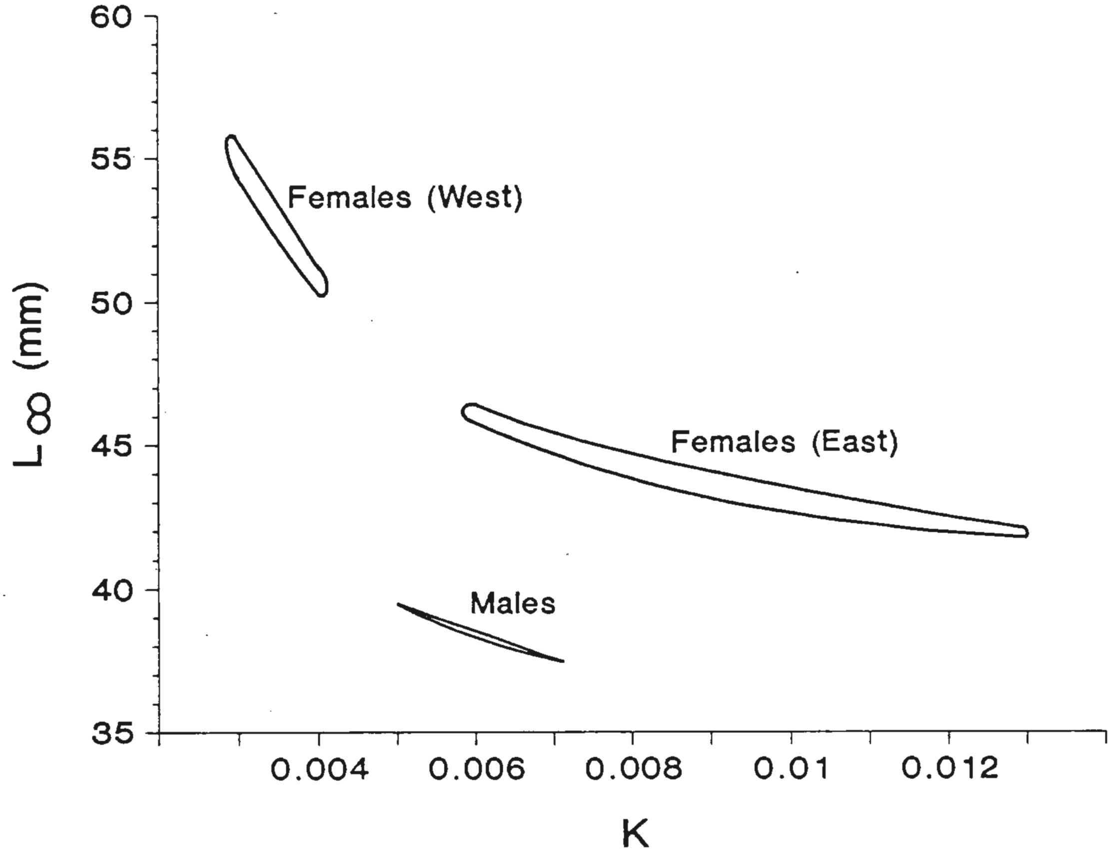

Figure 6. Joint 95% confidence regions for L_∞ and K for females tagged and released to the West and the East, and for males (West and East combined).nt 95% confidence regions for L

There were highly significant differences in both K and L_∞ between females from each area (Figure 6). There is some overlap of K between females from the East and males, otherwise the estimated parameters for males were significantly different from those for females from both areas.

The greater L_∞ estimated for females from the West compared to those from the East may be related to differences in the timing of spawning events for the two groups. Prawns from the different areas originate from different spawning periods (Section 5). Those from the West, which mature at a larger size, may be older when external cues stimulate biological changes such as ovary development (Section 6).

Using a similar analysis of *P. esculentus* for the Gulf of Carpentaria, Kirkwood and Somers (1984) obtained estimates of L_∞ = 42.4 mm (s.e. = 0.9) and K = 0.0066 day^{-1} (s.e. = 0.0007) for females, and L_∞ = 37.5 mm (s.e. = 0.5) and K = 0.0049 day^{-1} (s.e. = 0.0004) for males. The joint 95% confidence regions corresponding to these estimates generally overlap with those shown in Figure 6, except for females from the West. Kirkwood and Somers found no significant difference in K between sexes for *P. esculentus,* unlike the difference found between females from the West and males in Torres Strait (Figure 6). The differences in growth parameters for *P. esculentus* between the Gulf of Carpentaria and Torres Strait may be due to differences in the timing of life history events such as spawning and maturation.

7.4 Acknowledgments

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