

Female Reproductive Biology and Spawning Periodicity of Two Species of King Prawns, *Penaeus longistylus* Kubo and *Penaeus latisulcatus* Kishinouye, from Queensland's East Coast Fishery

A. J. Courtney^A and M. C. L. Dredge^B

^A Queensland Department of Primary Industries, Southern Fisheries Research Centre, Deception Bay, Qld 4508.

^B Queensland Department of Primary Industries, Fisheries Research Station, Burnett Heads, Qld 4670.

Abstract

In the coastal region of central Queensland female red-spot king prawns, *P. longistylus*, and the western or blue-leg king prawns, *P. latisulcatus*, had high mean ovary weights and high proportions of advanced ovary development during the winter months of July and August of 1985 and 1986. On the basis of insemination, both species began copulating at the size of 26–27 mm CL, but *P. longistylus* matured and spawned at a smaller size than *P. latisulcatus*. Abundance of *P. longistylus* was generally three to four times greater than that of *P. latisulcatus* but the latter was subject to greater variation in abundance. Low mean ovary weight and low proportions of females with advanced ovaries were associated with the maximum mean bottom sea-water temperature (28.5°C) for both species. Population fecundity indices indicated that peaks in yolk or egg production (a) displayed a similar pattern for both species, (b) varied in timing from year to year for both species and (c) were strongly influenced by abundance. Generally, sample estimates of abundance and commercial catch rates (CPUE) showed similar trends. Differences between the two may have been due to changes in targeted commercial effort in this multi-species fishery.

Introduction

The red-spot king prawn (*Penaeus longistylus*) and the western or blue leg king prawn (*P. latisulcatus*) have been fished by trawlers off the central Queensland coast between 18°S. and 21°S. for the past 12 years. Log-book data for this fishery indicate considerable annual landing variation (Robertson and Dredge 1986).

Little biological information has been generated on either species in its eastern geographic distribution; however, growth, reproduction (Penn 1975, 1980a) and mortality (Penn 1976) of *P. latisulcatus* have been investigated in Western Australia. Penn (1980b) has also described length-weight relationships and possible habitats of *P. longistylus* in Western Australia. Rothlisberg *et al.* (1987) assessed the reproductive activity of various prawn species from the distribution and abundance of their zoeal stages in the Gulf of Carpentaria. However, the larval abundance, as noted by Rothlisberg *et al.* (1987), for these two king prawns was rare. Somers *et al.* (1987) investigated abundance, distribution, recruitment and reproductive activity of *P. longistylus* over a period of 10 months within Torres Strait; interpretation of the seasonal reproductive biology in their study was restricted because of the 3-month interval between surveys.

The present study was carried out in the context of future management plans, and particular emphasis has been placed on quantifying periods of spawning potential. This paper differs from previous studies in that it provides a detailed seasonal study of reproduction in *P. longistylus*, as well as information on the reproductive biology of both species in their eastern Australian range. It also differs from other studies of these species in the

Gulf of Carpentaria (Rothlisberg *et al.* 1987) and Torres Strait (Somers *et al.* 1987) because the sampling was more frequent and extended for a greater period, thus providing a more detailed account of reproduction.

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

Population fecundity indices have been determined for other prawns sampled from the Gulf of Carpentaria including the banana prawn, *P. merguensis* (Crocos and Kerr 1983), and the two tiger prawns, *P. semisulcatus* (Crocos 1987a) and *P. esculentus* (Crocos 1987b). Population fecundity indices have also been determined for the western or blue-leg king prawn, *P. latisulcatus* in Western Australia (Penn 1980a) and comparisons have been made in this study between western and eastern populations of this species.

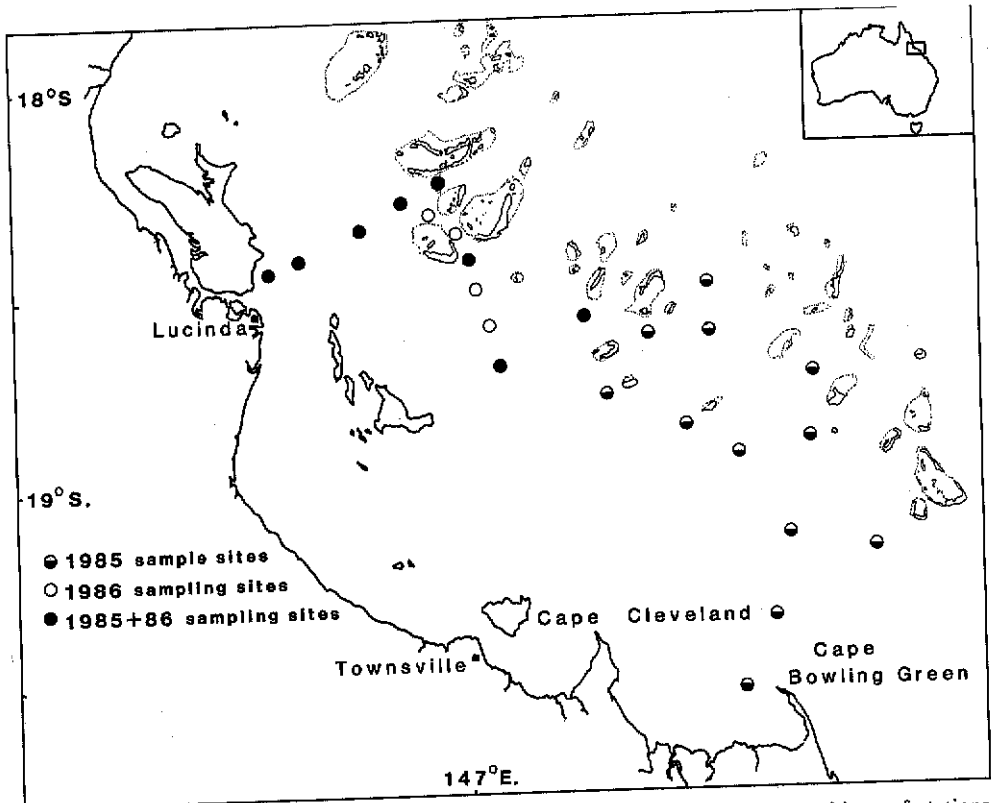


Fig. 1. Study area in the region of the central Queensland coast showing the positions of stations sampled during 1985 and 1986.

Materials and Methods

Sampling Methods

Sampling of prawns began in January 1985 and lasted for 24 lunar months. In addition to collecting information on reproduction, the programme was also designed to give information on prawn abundance over space and time, size composition of prawns and by-catch composition. During

1985, trawl samples were taken from 20 sites between 18°S. and 20°S., in Barrier Reef waters. In the following year, 12 of the original sites were abandoned and four others were established (Fig. 1). Sampling was planned to be carried out at night over a period of 2–4 nights beginning 2 nights prior to the new moon each month. Samples taken in May 1985 were delayed for 8 days by adverse weather, but all other samples were taken within 6 days of the planned date.

Thirty-minute (bottom time) trawl shots with two trawl nets (50-mm and 40-mm mesh cod ends), each with 11-m head-rope length, were undertaken at each station. Bottom sea-water temperature was measured at each station. All *Penaeus* and *Metapenaeus* species were sorted, sexed and had their carapace length (CL) measured on board. Female *P. longistylus* and *P. latisulcatus* (as well as some less abundant Penaeidae) were snap frozen on board for later examination. In the laboratory, a sub-sample of females (with a mean of 25 individuals and a maximum limited to 40) was randomly selected from each station and examined. The total number of prawns examined from these sub-samples represented approximately half of all female prawns landed. Data recorded for each female included a measure of CL and total wet weight. The carapace was classified as either soft or hard, and the thelycal cavity was examined to ascertain whether a spermatophore had been implanted. The ovary of every second female prawn was dissected out and weighed on an electronic scale after being dried with tissue paper.

A histological section of the ovary of each female was prepared. Ovarian tissue from the first abdominal segment was either cut directly from the dissected ovary or taken by a transverse section through the undissected prawns. The tissue was preserved in 4% (v/v) formaldehyde. Haematoxylin and eosin were used to stain the tissue which was sectioned in paraffin at a thickness of 6 μ m. The stage of development of the ovary was determined by a combination of criteria describing primary development (Tuma 1967) and absorption and rematuration (Yano 1984).

The minimum size of adult females was defined by the CL (to the nearest millimetre) of the smallest prawn with ovaries in the post-vitellogenic state. Abundance of adult females each month was standardized by being determined from the five stations which were consistently sampled over the full 2-year programme and from which prawns of both species were normally present. Commercial catch rates also provided information on abundance of king prawns. Effort distribution and hourly catch rates of king, tiger and other prawns in 6 min \times 6 min grids were collected for between 10–15% of fishermen who worked in the same region as the sampling programme (within the Great Barrier Reef Lagoon between Lucinda and Cape Bowling Green, Fig. 1) during the same 2-year period.

Population Fecundity Index

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

$$\text{Ovary weight} = a(\text{Carapace length})^b,$$

where $a = 5.6 \times 10^{-5}$ and $b = 2.92$ for *P. longistylus* ($n = 604$); and $a = 4.8 \times 10^{-6}$ and $b = 3.52$ for *P. latisulcatus* ($n = 180$). Calculation of monthly population fecundity indices was carried out using the formula

$$\text{PFI} = n \sum_{fm}^{ms} s_{CL} p_{CL} o_{CL},$$

where n is the number of adult females sampled (standardized from five stations), s_{CL} is the proportion of adult females in a particular size class, p_{CL} is the proportion of early mature (stage 3) and ripe (stage 4) adult females within a particular size class, o_{CL} is the weight of the ovary in females from a particular size class, fm is size at first maturing and ms is maximum size found in the population.

Results

Post-vitellogenic females (adults) were separated from pre-vitellogenic females (sub-adults) histologically (Figs 2a, 2b). The minimum sizes of adult female *P. longistylus* and *P. latisulcatus* were 33.0 mm and 34.0 mm, respectively; females less than these respective sizes were not included in the population fecundity indices as they were not yet contributing to the population fecundity.

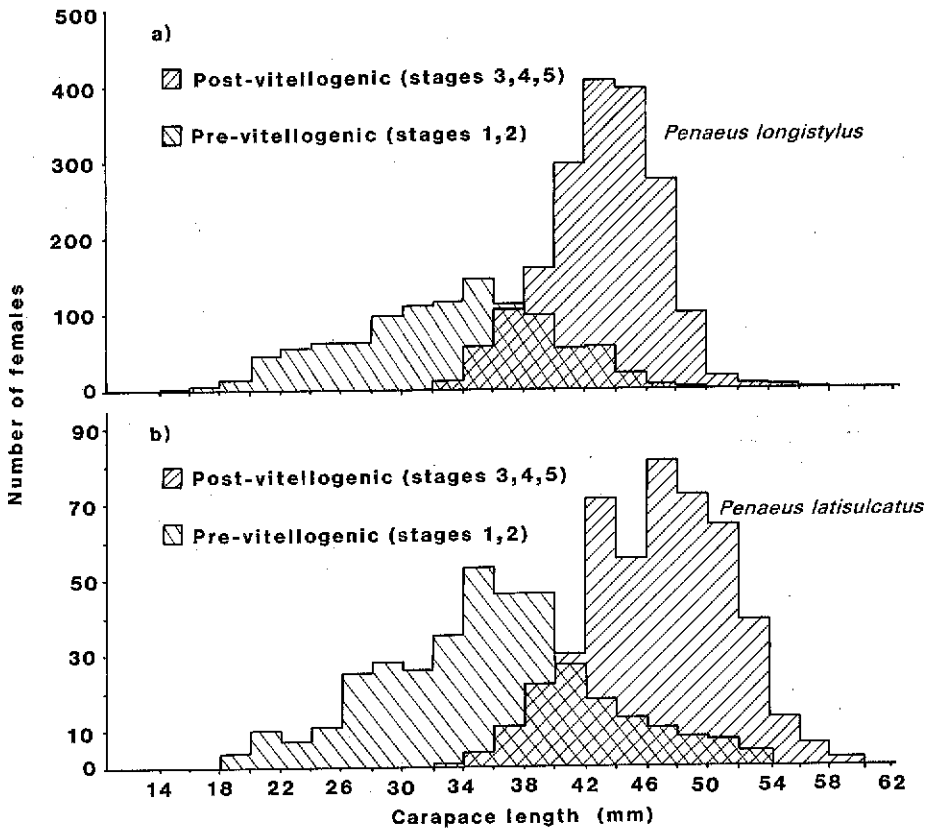


Fig. 2. Size-frequency distribution for pre-vitellogenic and post-vitellogenic ovarian developmental stages for (a) *Penaeus longistylus* and (b) *Penaeus latisulcatus*.

Insemination

Over the 2-year sampling period, 4043 *P. longistylus* females and 1132 *P. latisulcatus* females were examined. The smallest *P. longistylus* female found inseminated was 26.0 mm CL (Fig. 3a). The frequency of insemination increased sharply over the size class range 26.0–33.0 mm CL. Approximately 95% of all female *P. longistylus* over 34.0 mm CL were found to be inseminated. The smallest female *P. latisulcatus* found inseminated was 27.0 mm CL. The frequency of inseminated females increased up to 42.0 mm CL (Fig. 3b) and approximately 95% of all female *P. latisulcatus* over 42.0 mm CL were inseminated. Throughout the year, a high proportion of *P. longistylus* and *P. latisulcatus* females greater than 34 and 42 mm CL, respectively, were inseminated (Figs 4a, 4b).

Seasonal Changes in Ovary Weight

P. latisulcatus specimens were generally larger than *P. longistylus*, and this was reflected in ovary weight. Maximum mean ovary weight for *P. longistylus* occurred in August (winter) for both years (Fig. 5a); there were also increases in ovary weight in January 1985 and November/December 1985 and 1986; minimum mean ovary weight for *P. longistylus* occurred in March 1985 and February 1986.

Mean ovary weight in *P. latisulcatus* in 1985 reached a peak in July, whereas there was an extended period of high mean ovary weight from June to August (winter) in 1986

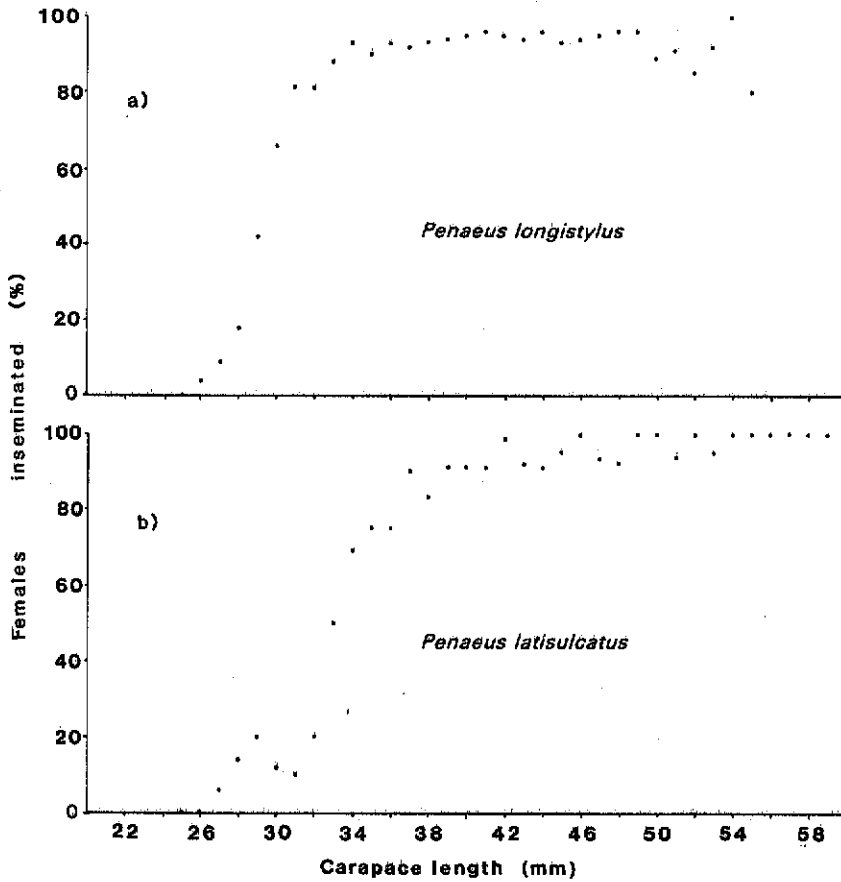


Fig. 3. The percentage of inseminated females in different size classes for (a) *Penaeus longistylus* and (b) *Penaeus latisulcatus*.

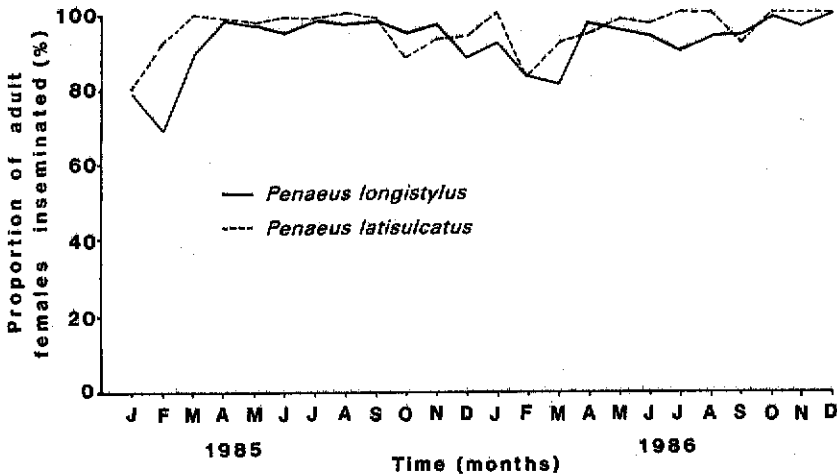


Fig. 4. The proportion of inseminated adult females each month for *Penaeus longistylus* and *Penaeus latisulcatus*.

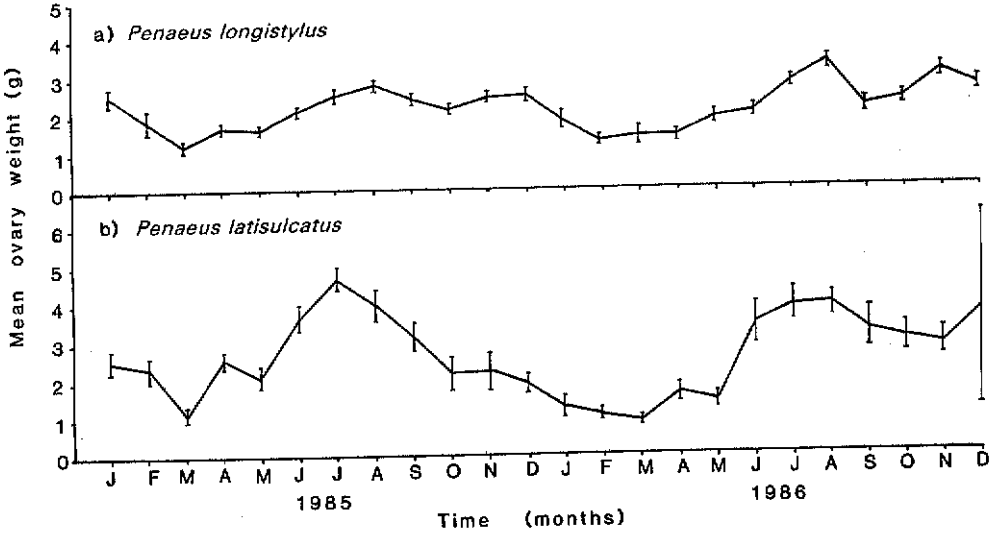


Fig. 5. Mean monthly ovary weights of adult females of (a) *Penaeus longistylus* and (b) *Penaeus latisulcatus*. Vertical bars represent one standard error either side of the mean.

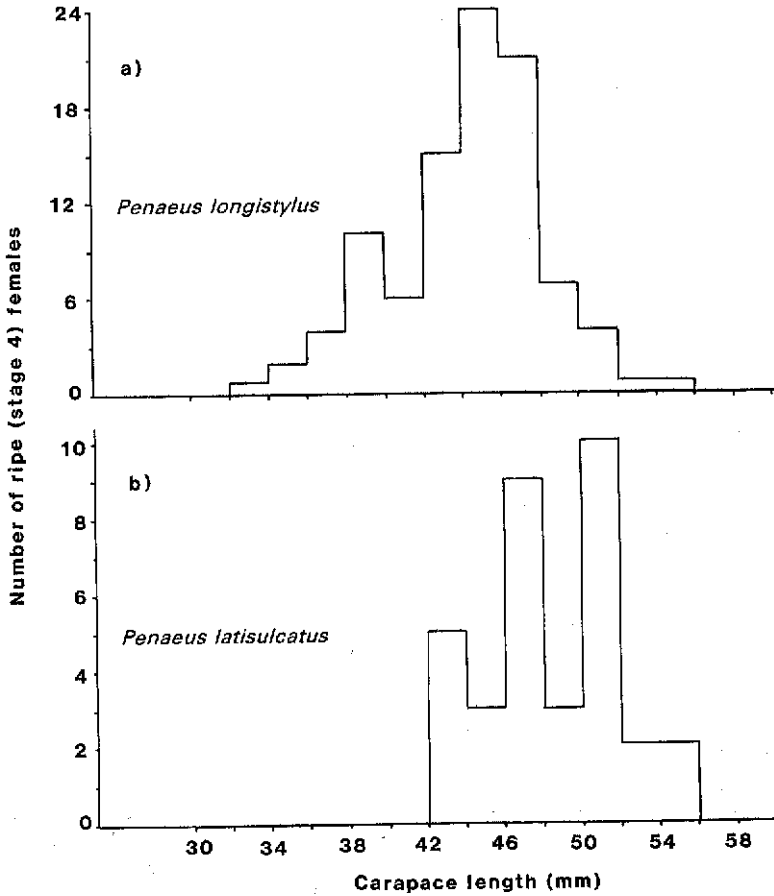


Fig. 6. Size-frequency distribution for ripe (stage 4) females of (a) *Penaeus longistylus* and (b) *Penaeus latisulcatus*.

(Fig. 5b); there was a steady decline from July 1985 to March 1986. The minimum occurred in March (late summer) of both years.

Histological Development of Ovaries

Fewer than 3.0% of the adult *P. longistylus* females were histologically classed as ripe (stage 4, Tuma 1967). Ripe females ranged in size from 33.3 mm to 54.5 mm CL, and most were between 44.0 mm and 46.0 mm CL (Fig. 6a). In *P. latisulcatus*, 3.4% of the adult females were classed as ripe (stage 4); they ranged from 43.1 mm to 55.6 mm CL (Fig. 6b).

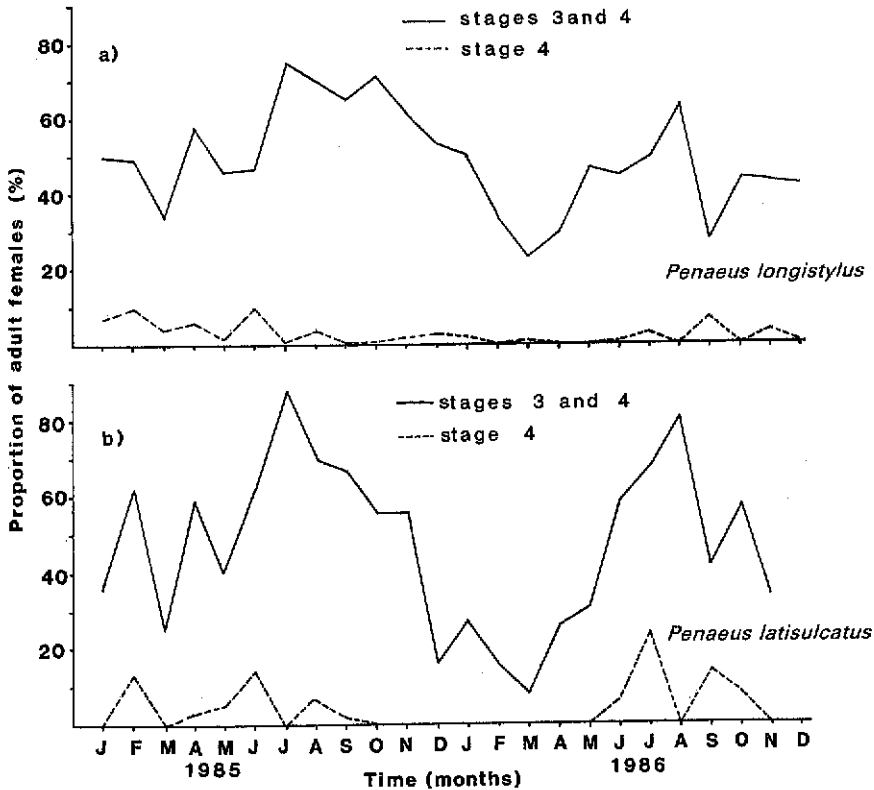


Fig. 7. The proportion of females of (a) *Penaeus longistylus* and (b) *Penaeus latisulcatus* in stages 3 and 4, and stage 4 only, for each month over the 2-year sampling period.

The proportion of *P. longistylus* adult females with ripe ovaries never exceeded 10% in any month sampled. A high proportion of early mature (stage 3) and ripe (stage 4) adult females of both species occurred from July to November in 1985 (Figs 7a, 7b). The proportion of females at these advanced stages reached a maximum in July 1985 for both species and then declined steadily until March 1986; after this, there was a steady increase to a peak in August. In general, peaks appeared more clearly defined for *P. latisulcatus* than for *P. longistylus*, which had relatively high proportions of stage 3s and 4s for prolonged periods.

Spawning Stock Abundance

Adult *Penaeus longistylus* females were generally 3-4 times more abundant than *P. latisulcatus*, except for a period between February and April 1986 when large catches of

the latter were recorded (Fig. 8a). Abundance of adult females for both species displayed two peaks in 1985 (one in February and one in July to August), declined from August to December 1985, then increased steadily to an extended period of high abundance from March to May 1986, with a peak in April for *P. longistylus* and in March for *P. latisulcatus*. This was followed by a second, minor, peak in July in *P. longistylus* and subsequent decline to October 1986, but by a rapid decline to June in *P. latisulcatus*.

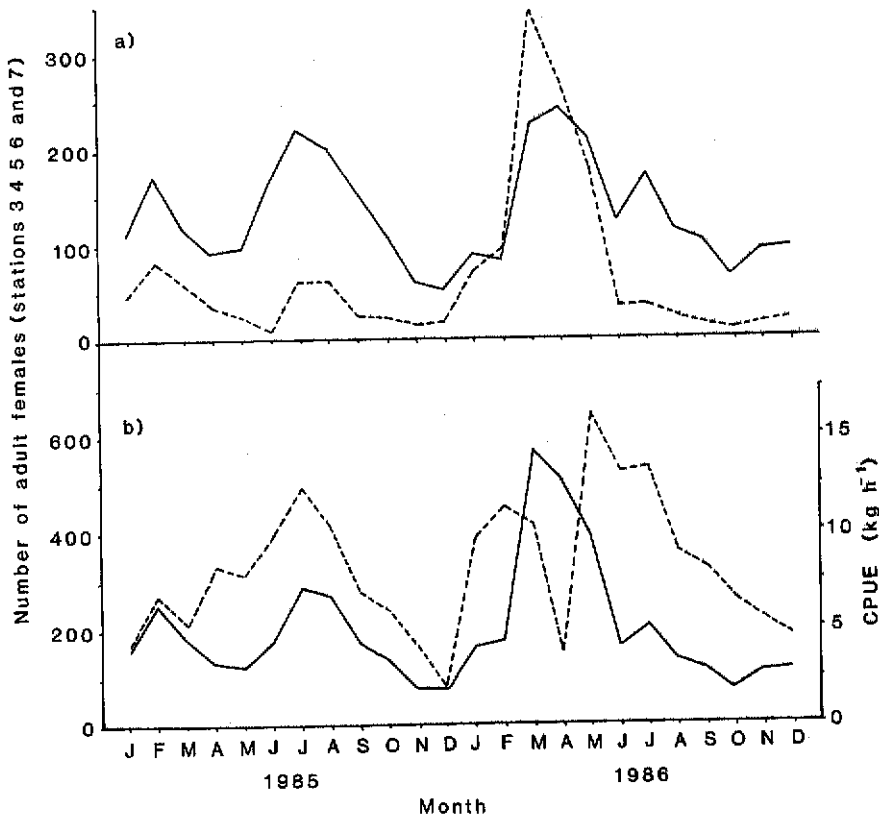


Fig. 8. (a) Abundance of adult *Penaeus longistylus* (—) and *Penaeus latisulcatus* (---) females for each month; (b) combined number of adult female king prawns of both species determined from the research programme (—) and commercial catch rates (CPUE, ---) for each month of the 2 years.

The catch rates determined from commercial fishermen's log-books generally displayed a similar pattern to that of the data from the sampling programme in 1985 (Fig. 8b). An increase in CPUE in February and July 1985, and the decline in CPUE from July to December 1985, were also apparent in the sampling programme. From March to April 1985, however, log-book data indicated increasing catch rates whereas the sampling programme displayed decreasing numbers of adults.

Log-books and the sampling programme both indicated increasing abundance early in 1986. During March and April, log-book catch rates fell rapidly. Although there was a clear peak in abundance in the sampling programme in March 1986, a peak in commercial catch rates did not occur until May. Both techniques indicated a steady decline in abundance from May to December.

Temperature

Except for the trip in October 1985, when instrument failure prevented measurement, temperatures were recorded at each site from September 1985 to August 1986. Bottom mean sea-water temperatures from those five stations used to determine prawn abundance reached a minimum of 23.6°C in September 1985 and a maximum of 28.5°C during March 1986 (Fig. 9).

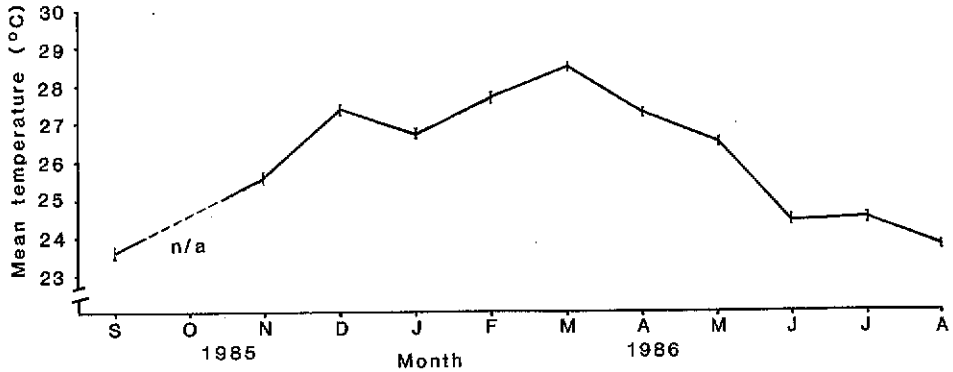


Fig. 9. Monthly mean bottom sea-water temperatures from September 1985 to August 1986. Vertical bars represent one standard error either side of the mean.

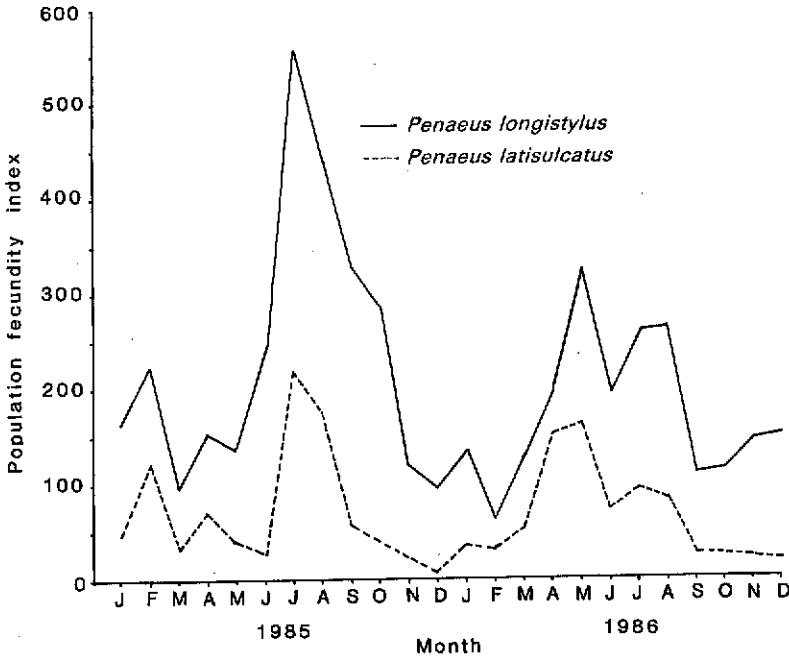


Fig. 10. Monthly population fecundity indices for *Penaeus longistylus* and *Penaeus latisulcatus* from Queensland's central east coast over a 2-year period.

Population Fecundity

Penaeus longistylus displayed a minor peak in population fecundity in February 1985, with a major peak in July (Fig. 10). In 1986, there was a small increase in January and no

major peak, but an extended period of high population fecundity from April to August, with a maximum in May. Population fecundity fell to a minimum in February 1986.

The pattern in *P. latisulcatus* was similar, with peaks in July and May in 1985 and 1986, respectively (Fig. 10). A minor peak in February was observed in 1985, but not apparent in 1986. Minimum population fecundity occurred in December in each year. As with *P. longistylus*, there was no single clearly defined peak in population fecundity for *P. latisulcatus* in 1986 but rather a period from April to August of high population fecundity. Population fecundity declined from August to December in 1986.

Discussion

Insemination and Size at Maturity

Female *P. longistylus* and *P. latisulcatus* both start mating at approximately the same size (26–27 mm CL). The results for *P. latisulcatus* are similar to those of Penn (1980a), who found that females less than 28 mm CL were rarely mated in Western Australian waters (22°S.–32°S.)

The plateau of high insemination frequency (Figs 3a, 3b) was attained at a much smaller size for *P. longistylus* than *P. latisulcatus* (34.0 mm and 42.0 mm CL, respectively). This suggests that *P. longistylus* mate more frequently and mature at a smaller size than *P. latisulcatus*. Results from the histological analysis of the ovaries support this finding. The smallest females in the ripe stage (stage 4) had carapace lengths of 33.3 mm and 43.1 mm for *P. longistylus* and *P. latisulcatus*, respectively.

Penn (1980a) reported that female *P. latisulcatus* from the Western Australian coast are physically mature at 25 mm CL and the smallest ripe female used in ovary weight–carapace length regressions by Penn (1980a) was 29 mm CL. This is much smaller than the sizes determined for vitellogenesis and spawning in the present study. Somers *et al.* (1987) studied the penaeid fauna of Torres Strait from four survey trips and defined the size of maturation as that size when at least 1% of female prawns had visibly developed ovaries. Somers *et al.* (1987) concluded that the smallest size at maturity for *P. longistylus* was 24 mm CL, which is also much smaller than the minimum size for vitellogenesis determined in the present study. Yolk production and spawning, therefore, appear to occur at much smaller sizes for populations *P. latisulcatus* in Western Australia and *P. longistylus* in Torres Strait, than for populations from Queensland's central east coast.

Ovary Maturation, Histology and Spawning

The proportion of ripe *P. longistylus* in the monthly samples never exceeded 10%. This proportion is low compared with *P. merguensis* in the south-eastern Gulf of Carpentaria (Crocos and Kerr 1983), where the proportion of ripe females exceeds 30% at certain times of the year. During the present study, spent (stage 5) ovaries were difficult to distinguish histologically from rematuring and resorbed ovaries in both species. Ovaries that were redeveloping after a spawning or after being resorbed were also difficult to distinguish from ovaries in younger females that were maturing for the first time. Penn (1980a) also had difficulty in identifying spent ovaries of *P. latisulcatus* from the Western Australian coast. The ovaries of soft-shelled prawns were all at a low level of sexual development and this was reflected in ovary weight as well as histology.

The high mean ovary weights for *P. longistylus* in August of both years occurred at approximately the same time as peaks in the proportion of early-mature and ripe females, which occurred in July 1985 and August 1986. The results were similar for *P. latisulcatus*, with the peaks in mean ovary weight in July 1985 and August 1986 coinciding with peaks of advanced histological stages for 1985 and 1986. These two independent methods for determining seasonality in yolk production, therefore, support each other.

From their four surveys (March, June, September and December) of the penaeid fauna of Torres Strait during 1985, Somers *et al.* (1987) found that the highest proportion (61%)

of *P. longistylus* with visible ovaries occurred in September. This proportion, however, was also relatively high during the March and June surveys (55% and 54% respectively) and therefore no clearly defined seasonal peak in ovarian maturation was determined. Commercial catch rates of *P. longistylus* from Torres Strait and the surveyed abundance of mature females were highest in March but relatively low in September. If a September spawning had occurred in Torres Strait, then the number of eggs released would have been comparatively low because of the low abundance of adult females at that time.

Rothlisberg *et al.* (1987) related zoeal abundance of *P. longistylus* and *P. latisulcatus* to spawning periodicity in the Gulf of Carpentaria, Australia. From six larval surveys which were approximately 2 months apart, Rothlisberg *et al.* (1987) noted that zoeal larval density was low: a total of 10 and 35 zoeae of *P. longistylus* and *P. latisulcatus*, respectively. They concluded that patterns of reproduction for *P. latisulcatus* varied by location within the Gulf and larval abundance showed two peaks: one on the September cruise and another over the January and March cruises; larval abundance of *P. latisulcatus* was highest during the January surveys, which suggested that although this may not be the main spawning period (due to the limited number of sampling trips), there was a spawning at that time of the year. Population fecundity indices from the present study suggest that larval abundance for *P. latisulcatus* on the east coast would have been greatest in July to August 1985, and April to August 1986 (Fig. 10).

Although a minor peak in egg production was observed in February 1985, this was not present in 1986 and therefore it cannot be concluded that a double-peaked spawning pattern, suggested by Garcia (1985) as the most common seasonal pattern for penaeids, occurs for *P. latisulcatus* on the east coast.

Penn (1980a) calculated population fecundity indices for *P. latisulcatus* from three different latitudes on the western coast of Australia and concluded that in the northern latitudes (22°S.-26°S.) the species spawns throughout the year. In more temperate latitudes near Cockburn Sound (32°S.), he concluded that spawning was reduced to only the warmer summer months, December to March, when water temperatures were above 17°C. Water temperatures on the east coast of Australia between 18°S. and 20°S. were well above 17°C all year round (Fig. 9) and so this lower temperature threshold was probably not a limiting factor for spawning of *P. latisulcatus* in this region. However, maximum mean bottom temperature (28.5°C, Fig. 9) may have been a limiting factor. Minimum mean ovary weight of *P. latisulcatus* (Fig. 5b) occurred in March of both years when temperatures were highest. These high temperatures were also associated with low incidence of advanced ovary development, as determined by histology (Fig. 7b). The results were similar for *P. longistylus*, with low mean ovary weight (Fig. 5a) and low proportions of advanced histology stages (Fig. 7a) associated with the maximum temperatures which occurred in March. The influence of these higher temperatures may partially explain why spawning was not as extended as that found by Penn (1980a) for *P. latisulcatus* in Shark Bay (26°S.) in Western Australia.

The few *P. longistylus* larvae collected by Rothlisberg *et al.* (1987) were caught only during the June and September cruises and therefore indicate spawning at this time of the year. Population fecundity indices from the present study suggest that zoeae for *P. longistylus* would have been most abundant during July to August 1985 and May to August 1986. Although 10 larvae are a small sample size from which to infer spawning, there appears to be little geographic variation in spawning periodicity between populations of *P. longistylus* from the Gulf of Carpentaria and the central Queensland east coast.

The discrepancies between log-book data and research data on abundance (Fig. 8b) may be partially explained by changes in the effort targeted at different species. During the warmer summer months (October to March), the more valuable inshore tiger prawns are targeted in this region; the offshore king prawns are targeted during the winter (April to September). The differences in catch rates for the two methods occurred in both years between February and May and therefore may reflect that period when fishermen change target species and move offshore.

The large increase in catch rates of *P. latisulcatus* during March and April 1986 suggest that abundance of this species was more variable than abundance of *P. longistylus*. For both species, the greatest influence on inter-annual variation of the population fecundity indices were the abundance of adult females. Mean ovary weight and the proportion of early-mature and ripe females showed similar patterns for both years, with peaks consistently occurring in July and August. In 1986, peaks in abundance of both species, but particularly *P. latisulcatus*, occurred earlier (March to May in Figs 8a and 8b) than in the previous years. This increase in the number of adult females increased the populations' fecundity indices at that time. By July and August, even though there were high proportions of early-mature and ripe females (Figs 7a, 7b), abundance had declined in both species, resulting in extended periods of high population fecundity rather than the more clearly defined peaks of fecundity in 1985.

Acknowledgments

The author would like to thank Pam Te Amo, Millin Curtis, Malcolm Pearce and Graham Low for their assistance. Mr P. Crocos (CSIRO) provided advice on the histological staging of ovaries. The project was funded by the Australian Fishing Industry Research Trust Account (FIRTA).

References

- Anderson, S. L., Clark, Jr, W. H., and Chang, E. S. (1985). Multiple spawning and moult synchrony in a free spawning shrimp (*Sicyonia ingentis*: Penaeoidea). *Biol. Bull. (Woods Hole)* **168**, 377-94.
- Badawi, K. W. (1975). On maturation and spawning in some penaeid prawns of the Arabian Gulf. *Mar. Biol. (Berl.)* **32**, 1-6.
- Crocos, P. J. (1987a). Reproductive dynamics of the grooved tiger prawn, *Penaeus semisulcatus*, in the north-western Gulf of Carpentaria, Australia. *Aust. J. Mar. Freshwater Res.* **38**, 79-90.
- Crocos, P. J. (1987b). Reproductive dynamics of the tiger prawn, *Penaeus esculentus*, and a comparison with *P. semisulcatus*, in the north-western Gulf of Carpentaria, Australia. *Aust. J. Mar. Freshwater Res.* **38**, 91-102.
- Crocos, P. J., and Kerr, J. D. (1983). Maturation and spawning in the banana prawn *Penaeus merguensis* de Man (Crustacea: Penaeidae) in the Gulf of Carpentaria, Australia. *J. Exp. Mar. Biol. Ecol.* **69**, 37-59.
- Cummings, W. C. (1961). Maturation and spawning of the pink shrimp, *Penaeus duorarum* Burkenroad. *Trans. Am. Fish. Soc.* **90**, 462-8.
- Garcia, S. (1985). Reproduction, stock assessment models and population parameters in exploited penaeid shrimp populations. In 'Second Australian National Prawn Seminar'. (Eds P. C. Rothlisberg, B. J. Hill and D. J. Staples.) pp. 139-58. (NPS2: Cleveland, Australia.)
- Kulkarni, G. K., and Nagabhushanam, R. (1982). Reproductive biology of female penaeid prawn: *Parapenaeopsis hardwickii* (Miers) (Crustacea, Decapoda, Penaeidae). *J. Anim. Morphol. Physiol.* **29**, 55-63.
- O'Connor, C. (1979). Reproductive periodicity of a *Penaeus esculentus* population near Low Islets, Queensland, Australia. *Aquaculture* **16**, 153-62.
- Penn, J. W. (1975). Tagging experiments with the western king prawn, *Penaeus latisulcatus* Kishinouye. I. Survival, growth and reproduction of tagged prawns. *Aust. J. Mar. Freshwater Res.* **26**, 197-211.
- Penn, J. W. (1976). Tagging experiments with the western king prawn, *Penaeus latisulcatus* Kishinouye. II. Estimation of the population parameters. *Aust. J. Mar. Freshwater Res.* **27**, 239-50.
- Penn, J. W. (1980a). Spawning and fecundity of the western king prawn, *Penaeus latisulcatus* Kishinouye, in Western Australian waters. *Aust. J. Mar. Freshwater Res.* **31**, 21-35.
- Penn, J. W. (1980b). Observations on the length-weight relationships and distribution of the red spot king prawn, *Penaeus longistylus* Kubo, in Western Australian waters. *Aust. J. Mar. Freshwater Res.* **31**, 547-52.
- Robertson, J., and Dredge, M. (1986). Redspot king prawn research off central Queensland. *Aust. Fish.* **45**(6), 18-20.
- Rothlisberg, P. C., Jackson, C. J., and Pendrey, R. C. (1987). Larval ecology of penaeids of the Gulf of Carpentaria, Australia. I. Assessing the reproductive activity of five species of *Penaeus* from the distribution and abundance of the zoeal stages. *Aust. J. Mar. Freshwater Res.* **38**, 1-17.

- Somers, I. F., Poiner, I. R., and Harris, A. N. (1987). A study of the species composition and distribution of commercial penaeid prawns of Torres Strait. *Aust. J. Mar. Freshwater Res.* **38**, 47-63.
- Tseng, W., and Cheng, W. (1981). The artificial propagation of bear shrimp, *Penaeus semisulcatus* de Haan, in Hong Kong. *J. World Mariculture Soc.* **12**, 260-81.
- Tuma, D. J. (1967). A description of the development of primary and secondary sexual characteristics in the banana prawn, *Penaeus merguensis* de Man (Crustacea : Decapoda : Penaeinae). *Aust. J. Mar. Freshwater Res.* **18**, 73-88.
- Yano, I. (1984). Rematuration of spent kuruma prawn, *Penaeus japonicus*. *Aquaculture* **42**, 179-83.

Manuscript received 30 November 1987, revised 13 September 1988, accepted 20 September 1988