FRDC 95/16

March 1997

THE IMPACT OF CHANGES IN FISHING PATTERNS ON RED-LEGGED BANANA PRAWNS (*PENAEUS INDICUS*) IN THE JOSEPH BONAPARTE GULF

Final Report to the FRDC
FRDC Project 95/16

Neil Loneragan, Rob Kenyon, David Die, Bob Pendrey and Brian Taylor

CSIRO Division of Marine Research
Cleveland Marine Laboratories

CSIRO
AUSTRALIA

MARINE RESEARCH

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

- Tagging did not effect either the growth or survival of *Penaeus indicus* under laboratory conditions. The results of this study show that a large scale field tag/release experiment in Joseph Bonaparte Gulf should be feasible.

- There was no difference in growth or mortality between the tagged and control prawns. Growth of all prawns was higher in the large 5000 l tanks than in the much smaller 50 l tanks. The mortality of both tagged and control prawns was higher in small tanks than large tanks. Female *P. indicus* grow faster than males.

- A prototype release cage was developed and tested under calm conditions in shallow water, the release mechanism activated successfully and the prawns left the cage. However, under extreme conditions in Joseph Bonaparte Gulf, the cage was less successful. The release cage reached depths greater than 60 m, however, upon retrieval, some prawns remained in the release cage to within 3 m of the surface.

- Tagging in Joseph Bonaparte Gulf would be very dependent on weather. It would be impossible to tag and release prawns under the conditions that the cage was tested. An improved release cage design is currently being developed.

- Log book data were used to examine effort patterns in the Joseph Bonaparte Gulf during different seasonal closures. In the early years of the fishery (1981-84), effort was concentrated at the end of the year (September to December), in 1985-86 effort was more in the middle of the year (June to September), whereas in recent years (1988-1995) effort peaks in May and June.

- Length frequency data and data on the maturity of red-legged banana prawns collected by Rik Buckworth of NT Fisheries were analysed to estimate parameters of growth and reproduction, and estimate the seasonal pattern of recruitment to the fishery. The estimates of growth rate were unreliable and as a consequence best estimates were obtained from the literature for *P. merguiensis*. The seasonal pattern of recruitment from the length frequency data suggests that most prawns recruit to the fishery between February and April. However, no length frequency data are available for the months between December and February.

- The yield, value of the catch and egg production were estimated for different seasonal patterns of effort using a per-recruit model (SIMSYS). The results from this model show that both yield and value can vary by as much as 15% depending on the pattern of effort. However, the results of the model were sensitive to the estimates of growth and mortality, which highlights the need to obtain better estimates of these parameters.

1. Background

The fishery for red-legged banana prawns in the Joseph Bonaparte Gulf (JBG) developed in the early 1980s. Since then, fishing effort has varied from 700 to 2600 boat-days per year and catches range from 200 to 1000 tonnes per year. Initially the JBG fishery developed as an alternative to fishing in the Gulf of Carpentaria: during years of poor catches in the Gulf of Carpentaria, more fishing effort was applied in the JBG. In the early years most effort was concentrated at the end of the year. In recent years, however, in addition to being more heavily fished in years of poor catches elsewhere, JBG stocks are fished earlier in the season by a consistent number of boats, regardless of catches elsewhere in the NPF.

Although the red-legged banana prawn has been fished in the JBG since the early 1980s, we know little of its biology or population dynamics. Apart from a 12-month study by Northern Territory (NT) Fisheries in 1990, there has been no research on this species in Australia. The NT findings suggested that growth and mortality rates — important parameters for estimating the effects of changes in fishing effort on stocks — could not be estimated precisely by length frequency analysis of data from commercial catches. There was a need to develop a preliminary model for the red-legged banana prawn fishery in the JBG. This model would help to evaluate the impacts of changes in the pattern of fishing effort on the yield and spawning biomass of red-legged banana prawns. However, the estimates of growth and mortality used by the model would, unfortunately, be imprecise.

Therefore, a well-designed tag/release study would significantly improve the reliability of our estimates of growth and mortality for red-legged banana prawns in the JBG. However, prior to conducting a large-scale field tagging trial, the effect of tagging on the growth and mortality of red-legged banana prawns needed to be studied. For tag/release experiments to be successful, tagging should not affect the growth and survival of the prawns. An effective release-cage also needed to be designed for the deep waters of the JBG.

2. Tagging experiments

Adult *Penaeus indicus* were caught in the Joseph Bonaparte Gulf, north-western Australia and transported to Darwin by sea, then by air to CSIRO Marine Laboratories at Brisbane. The first two batches of prawns were caught in November/December 1995 through the goodwill of fishers (see acknowledgements) who voluntareed to supply live prawns for experiments. The third batch of prawns was caught in July 1996 by commercial charter. We intended to target small prawns of about 20-25 mm carapace length (CL) during the commercial charter. Unfortunately no prawns in this size range were caught .

Prawns were held in 5000 l (1.8 m in diameter, 1 m deep) tanks prior to being tagged. During holding periods and during all of the experiments, prawns were fed once each day on a diet of chopped prawn and squid flesh and prawn food pellets to excess. Blue streamer tags, 90 mm long and 3 mm wide, were inserted using a needle daubed in Aureomycin antibiotic ointment.

The Experiments

Three experiments, each of about 3 months duration, were undertaken over an 11 month period. The experiments ran from: 24 November to 26 February (Experiment 1; 94 days); 12 January to 12 April (Experiment 2; 91 days); and the last experiment from 2 August to 22 October (Experiment 3; 83 days). The first two batches of prawns were tagged and held in two different types of tanks (50 l and 5000 l tanks) to determine the optimum tank size for these experiments. The 50 l tank measured 60 cm x 38 cm and was 22 cm deep. The third batch of prawns was held in the 5000 l tanks. Tanks were supplied with aerated seawater, at a water temperature of 28°C.

In the small tanks, the moulted carapaces (exuviae) from each moult were collected and measured. In the large tanks, individual growth rates could be calculated only for the tagged prawns and the frequency of moulting could only be recorded for each tank i.e. exuviae could not be assigned to individual prawns. However, in the large tanks, exuviae were counted every dail to estimate the frequency of moulting.

The Prawns

At the start of Experiment One, the tagged prawns (n=15) had a mean carapace length (± 1 SE) of 29.5 ± 0.64 mm, compared with 28.4 ± 0.62 mm for the controls (n=10). Ten tagged and 10 control prawns were held, two to a 50 l tank, in pairs of tagged/control prawns. The remaining five tagged prawns were held, one to a tank, in one half of a 50 l tank. Eight tagged prawns were male and seven were female, while seven control prawns were male and three were female.

The prawns in Experiment Two were larger than those in the first experiment, with mean CLs for tagged prawns of 35.4 ± 0.52 mm, and 35.7 ± 0.58 mm for the controls. Two 5000 l tanks, each with sixteen prawns (eight tagged and eight control) were used , as well as ten 50 l tanks with one prawn per tank (five tagged and five controls. The tagged and control prawns in each of the large tanks, and the group of small tanks, were matched by sex and size. Prawns in the 5000 l tanks were measured four times: on 12 January; 13 February; 12 March; and at the end of the experiment on 12 April, 1996.

The prawns in Experiment Three were similar in size to those from Experiment One (mean ± 1 SE for tagged prawns = 28.6 ± 0.18 mm CL ; and for controls = 28.3 ± 0.19 mm CL). Four 5000 l tanks, each with 20 prawns matched by size (ten tagged and ten control) were used. One tank contained all female prawns, while the other three tanks contained all male prawns. Carapace lengths were measured five times: at the time of tagging (02/08/98); after 17 days (19/08/96); after 1 month (30/08/96); after 2 months (27/9/96); and at the end of the experiment (22/10/96).

Results of tagging experiments

Mortality and tag shedding

None of the 76 prawns tagged for the three experiments shed their tags. The mortality rates did not differ between the tagged and control prawns in any tank type. However, the mortality of both tagged and control prawns was much higher in the 50 l tanks than in the 5000 l tanks. All the tagged and control prawns survived to moult once. In the 50 l tanks of Experiment 1, 50% of the tagged prawns moulted six times (an average of 62.2 days), while 50% of the control prawns moulted five times (an average of 44.2 days). After three months, most prawns (80%-90%) in the 50 l tanks had died. In contrast, in the 5000 l tanks, only one prawn died in Experiment 2 (<4% mortality) and only one died in Experiment 3 (< 2% mortality).

Growth and moult interval

Over all the experiments, both tagged and control prawns, held in the same tank type, grew at the same rate. However, growth was faster in the large tanks than the small tanks. During Experiment One, the tagged prawns grew 0.12 mm wk^{-1} after 5 moults, while control prawns grew 0.14 mm wk^{-1} after 4 moults. The average moult interval was significantly longer for tagged prawns (10.3 days) than for control prawns (8.8 days, $p=0.04$).

Prawns held in the small tanks in Experiment Two also grew at a similar rate to those in Experiment 1: tagged - 0.16 mm wk^{-1}, control - 0.20 mm wk^{-1}. In Experiment Two, the tagged and control prawns grew at the same rate in both the small and large tanks (Table 1). However, the growth of prawns was faster in the large than ithe small tanks. Growth rates differed between the two large tanks, ranging from 0.2 - 0.35 mm CL wk^{-1} (Table 1). The female prawns in tank 1 grew faster than the mixed males and females in tank 2 (Table 1).

During Experiment Two, the average moult interval in the small tanks did not differ between tagged (9.7 days) and control prawns (9.2 days). The moult interval for both tagged and control prawns in the 5000 l tanks was 16.2 days in tank 1 and 17.5 days in tank 2.

In Experiment Three, growth rates did not differ significantly between tagged and control prawns in each of the 5000 l tanks ($p=0.17$). Averaged over the four tanks, after 83 days, the tagged prawns grew 3.15 mm (0.27 mm wk^{-1}) and the control prawns grew 3.29 mm (0.28 mm wk^{-1}). However, growth rates differed between tanks (Table 1, Figure 1).Although tagged and control prawns grew at the same rate, females grew faster than males (Table 1). The average moult interval for tagged and control prawns was 16.9 days in tank 1, 18.9 days in tank 2, 18.9 days in tank 3 and 21.0 days in tank 4.

The moult interval of both tagged and control prawns in the 5000 l tanks in Experiments Two and Three was longer than those in the 50 l tanks. This may be due to exuviae being eaten or lost in the large tanks, or it may be due to less stress on the prawns in the large tanks. Importantly, the moult intervals in the large tanks were relatively consistent between tanks and experiments.

The results suggest that tagging did not affect the growth or increase the mortality of *P. indicus* under laboratory conditions and show that a field tag/release experiment in Joseph Bonaparte Gulf should be feasible.

3. Testing a release cage for tagged prawns

A prototype release cage was developed and tested using live prawns in Moreton Bay. Observations were made by a diver and recorded on video. Under relatively calm, shallow conditions in the bay, the release mechanism activated successfully and the prawns left the cage when it opened on the bottom.

However, conditions in the Joseph Bonaparte Gulf were much rougher than those in Moreton Bay — when the cage was tested the wind strength was >30 knots and waves were 3-4 m high. Under these extreme conditions, the cage was less successful. The release cage reached depths greater than 60 m. The attachment line was at an angle of 40-60° to vertical, with a bow in the line. During the retrieval of the cage, some prawns remained in the release cage to within 3 m of the surface. The cage release mechanism activates by a messenger sent down its attachment line. As no underwater observations were made, we do not know whether the release mechanism activated near the bottom or near the surface as the attachment line straightened out when it was retrieved.

Tagging in Joseph Bonaparte Gulf would be very dependent on weather. It would be impossible to tag and release prawns under the conditions that the cage was tested in. Another release cage has been built and tested in Moreton Bay. It will be trialled in the Joseph Bonaparte Gulf in March, 1997.

4. Assessment of the effect of fishing effort patterns on yield, value and egg production of red-legged banana prawns in the Joseph Bonaparte Gulf

We used SIMSYS to model the effects of different seasonal fishing effort patterns on the yield and value of red-legged banana prawns. This modelling package was developed to evaluate seasonal closures in tropical penaeid fisheries (Watson et al. 1996a). Modelling is based on a per-recruit model that requires the input of parameters for growth, recruitment, mortality and fishing effort. SIMSYS models complex recruitment and seasonal fishing effort patterns, and systematically evaluates different seasonal closures, or different seasonal patterns of fishing effort.

The time step selected for the model was one month and 3 generations of 12 months each were used to estimate the equilibrium per-recruit values.

Population parameters

a) Growth

We attempted to estimate the growth parameters of red-leg banana prawns by modal progression analysis (with FISAT, Gayanilo et al. 1996) of the length frequency data collected by Rick Buckworth, Northern Territory Fisheries (NT Fisheries). These data were collected during a FIRTA funded project, in two research surveys (March and June) and from observers on commercial vessels during four other months of 1990 (May, July, October, November). No data were collected from December to February, or in April and August. Unfortunately, this analysis did not produce reliable estimates of Von Bertalanffy growth parameters. Two of the most likely reasons for this are: the paucity of data for small sized prawns; and that recruitment may extend over a long period, which would mask the modes in the length frequency histograms. We therefore surveyed the literature to find growth parameters for *P. indicus*. However, none of the literature parameters seemed to match the observed length frequencies for *P. indicus* in the Joseph Bonaparte Gulf. The maximum lengths found in the samples of *P. indicus* collected by NT Fisheries lead us to use values of L_∞ of 38 mm carapace length for males, and 50 mm carapace length for females. In the absence of reliable information on the Von Bertalanffy value of k, we used a value of 0.2 per month, which is similar to the value of k for *P. merguiensis* in the Gulf of Carpentaria (Lucas et al. 1979).

The length-weight relationship for male and female red leg banana prawns were estimated from data collected by NT Fisheries:

Females Weight (g) = $0.000889\ CL\ (mm)^{2.914}$

Males Weight (g) = $0.000372\ CL\ (mm)^{3.197}$

b) Recruitment

To estimate the seasonal pattern of recruitment we again used the length frequency data from NT Fisheries. These data were standardised to represent relative abundance by using the catch (in numbers) per unit of fishing effort from the commercial fishery. Because of the lack of reliable growth parameters, we estimated the total number of recruits for each month, sex and age from the "maximum of minima" method (Watson et al. 1996b). The main assumption of this method is that there is at least one month of the year where no recruits enter the fishery. The estimation suggests that a peak in recruitment occurs in March, and that 95% of the recruits arrive during the period between December and April. Unfortunately, these results were obtained by making some strong assumptions regarding the nature of length frequencies during periods that were not sampled, particularly the months of December, January and February. We assumed that the length frequencies during these months could be obtained by linear interpolation of the length frequencies in November and March. The same assumption was made for the other two months (April and August) without length frequency data. Such an assumption equates to a broad, single peak recruitment pattern for red-leg banana prawns. Our lack of length frequency data at the beginning of the year means that we cannot dismiss the possibility that recruitment is only found during three months (February to April).

The total number of annual recruits was scaled to be 1,000 million, which is equivalent to a total catch of about 700 tonnes a year for the red-leg fishery, close to the observed historical average.

c) Mortality

No estimates of natural mortality exist for red-leg banana prawns. We used the value estimated for *P. merguiensis* in the Gulf of Carpentaria (M = 0.2 per month).

The seasonal pattern of fishing effort was estimated for three different periods: 1981-84, 1985-86 and 1988-1995. The year 1987 was considered to be a transitional year between different closure regimes and was not evaluated. The average monthly percentage of effort was calculated for each of the three different periods and used to distribute the 1000 boat-days that, on average, the red-leg fishery receives every year.

The catchability (q) of red-leg banana prawns in the Joseph Bonaparte Gulf has not been estimated. We have used the values for white banana prawns (*P. merguiensis*) and tiger prawns (*P. esculentus*, *P. semisulcatus*) in the NPF to provide a basis for assuming values for red-legged banana prawns (*P. indicus*) in the Joseph Bonaparte Gulf (Table 2). In this region, red-leg banana prawns are fished more like tiger prawns than like the more common banana prawn *Penaeus merguiensis*. However, red-legged banana prawns aggregate more than tiger prawns. Given the estimate of q = 0.000088 (Wang and Die 1996) used for NPF tiger prawns and the current levels of fishing effort (8000-10000 boat days) targeted at each tiger prawn species, the annual fishing mortality for NPF tiger prawn stocks should be about 0.7-0.9 (Table 2). This is less than half the annual natural mortality of 2.3 and gives an annual exploitation ratio (F/(M+F)) of 0.25.

In contrast to tiger prawns, *P. merguiensis* has a q = 0.00024 (Somers and Wang in press), three times larger than that for tiger prawns and an average annual effort of 5000-7000 boat days (Table 2). This equates to an annual fishing mortality of 1.2 - 1.7 and a total annual natural mortality of 2.6, which gives an exploitation ratio of 0.36.

We believe that the red leg banana prawns has an exploitation ratio that is somewhere between that of tiger and white banana prawns and have assumed an exploitation ratio of 0.3 (Table 2). Given an assumed annual mortality of 2.4 for *P. indicus*, this leads to an estimated annual fishing mortality 1.0. If annual fishing effort averages 1, 000 boat days, this leads to a value of q of 0.0001, much smaller than banana prawns, but slightly greater than tiger prawns (Table 2).

d) Reproduction

NT Fisheries collected information on the stage of maturity for female red leg banana prawns based on the number of females with visible ovaries i.e. Stage 3 and 4 ovaries. We used the numbers of mature females (i.e. those with visible ovaries) and total number of female sampled per 1 mm size group to estimate the proportion mature at length following the model of Restrepo and Watson (1991). We estimated this relationship for each month where data were collected. However, the fits formed two distinct groups: April - September when the proportion of mature females is low; and October - March when it is high. The data were grouped according to these two periods and we obtained the following relationships:

Apr. - Sep.	Proportion mature = $0.37 / (1 + e^{10.8 - 0.3\ CL})$
Oct. - Mar.	Proportion mature = $0.66 / (1 + e^{10.8 - 0.3\ CL})$

The model fitted assumed only that the asymptote of the proportion mature changes during the season. This is similar to the approach taken by Restrepo and Watson (1991) for *P. esculentus* in the Torres Strait.

There is no information on the number of eggs produced by female red-legged banana prawns. We therefore used the fecundity relationship for *P. esculentus* (Restrepo and Watson 1991) as an approximation.

e) Price

In order to calculate the value of the catch, SIMSYS uses prices per commercial size category. In our analyses we used a price of $10 for all red-leg banana prawns with a carapace length of 25 mm or larger, and $0 for smaller prawns. This size is equivalent to prawns weighting 11 g, thus belonging to the 40 count per pound size category.

Parameter uncertainty and sensitivity analysis

Due to the high uncertainty associated with most population parameters, we investigated the sensitivity of the results to the values of the most important parameters. So far we have investigated the sensitivity to the values of growth (i.e. the k parameter), natural mortality, total annual fishing effort, and the pattern of recruitment through an analysis of extreme values. All the analyses have been done assuming that uncertainty in a parameter is independent of the other parameters, except for natural mortality and growth, which we have assumed are positively correlated.

Comparison of historical seasonal fishing patterns

All comparisons were made by using the same level of annual fishing effort but only changing the seasonal pattern of this effort (Table 3). Using the best set of parameters (base model), the highest yield (tonnes) and value (1000$'s) were obtained with the fishing pattern during 1985-86, where most of the effort was concentrated in the middle of the year (June to September) (Table 3). The present pattern of effort (1988-95), where effort is high during May-June and October-November, produces marginally smaller yields (-1.5%) and values (-2.7%). The fishing pattern present at the beginning of the fishery (1981-1984), when effort was mainly concentrated between September and December, produced significantly lower yields (-15.8%) and values(-16.6%) than the 1985-86 pattern of effort.

In contrast to yield and value, egg production changed by less than 5% between the 3 patterns of effort. This is the result of our assumption that all mature females produce eggs that contribute recruits to the fishery. It is important to note that in *P. merguiensis*, only those eggs produced during August to October, contribute recruits to the fishery.

The above results are sensitive to the values of mortality and growth, but not to the annual level of fishing effort. For example, at low values of natural mortality and growth (M=0.15 per month, k = 0.15 per month), the highest value is obtained for the 1981-84 pattern of effort (i.e. effort is late in the year) (Table 3). On the other hand for high values of M and k (0.25 per month for both), the highest value and yield are obtained for the 1988-1995 pattern of effort (most effort in May and June).

The seasonal pattern of recruitment used in the analysis is highly uncertain because of the lack of length frequency samples during the December to February period. Varying the recruitment pattern within the December to April period from one of increasing recruitment between December and March to one with no recruitment until February had little effect on yield and value. However, this is only one possible example of a seasonal recruitment and the results do not mean that the seasonal recruitment pattern is not important for establishing which seasonal fishing pattern will maximise yield and value. It is important to obtain more information about recruitment.

Evaluation of optimal seasonal fishing pattern

An initial evaluation of single seasonal closures was carried out with SIMSYS. The yield, value, and egg production were compared for closures of up to 8 months duration and starting at any month of the year. Maximum yield and value were obtained with a four month closure starting in January. The present scenario is of a 5 month closure from December to April. Note that although the NPF is only closed from December to March, during April, fishing concentrates on *P. merguiensis* in the Gulf of Carpentaria, with very little effort in the Joseph Bonaparte Gulf. In the NPF there is also a mid-year closure during part of June and July. Such a complex seasonal closure can not be evaluated by SIMSYS. However, the net effect would be somewhere between that of a December - April closure and a December to July closure, which can both be evaluated by SIMSYS. According to SIMSYS the present fishing pattern results in about 10% less yield and 15% less value, than the optimum January to April closure.

It is very important to note that in the same way that the comparison of seasonal fishing patterns revealed how sensitive these comparisons were to the values of some of the parameters, defining optimum closures may be equally sensitive. For instance, for the scenario we investigated of high natural mortality and growth, the optimum closure is one from January to March, and does not include April as before. Therefore, the above results which suggest that both yield and value of the red-leg banana prawn fishery can be improved through changes in the present pattern of effort must be considered with caution. Moreover, presently the JBG fishery is not managed separately from the NPF, and thus an optimum fishing pattern for the JBG may never be achievable. However, if Industry wants to consider future seasonal or spatial closure options for the JBG, it is essential that further work on red-leg population dynamics is conducted to reduce the large amount of uncertainty for most population parameters.

5. Acknowledgements

We thank Vivian Colless and the crew of the "Ocean Pearl" (RAPTIS), Mike Farrell and the crew of the "Territory Leader" (AUSTFISH), and Richard Powell and the crew of the "KFV Heron" (NEWFISHING) for catching and maintaining live red-legged banana prawns for us. We also thank Mike Farrell and the crew of the "Sandpiper" (AUSTFISH) for their contributions during our charter fishing for red-legged banana prawns. Rik Buckworth of Northern Territory Fisheries provided us with data collected during 1990 and helpful discussions about red-legged banana prawns in the Joseph Bonaparte Gulf.

6. References

Gayanilo FC Jr, Sparre P, Pauly P (1996). *FAO-ICLARM stock assessment tools — users manual.* International Centre for Living Aquatic Resources Management. Food and Agriculture Organisation of the United Nations, Rome.

Lucas C, Kirkwood G, Somers I (1979). An assessment of the stocks of the banana prawn Penaeus merguiensis in the Gulf of Carpentaria. *Australian Journal of Marine and Freshwater Research* **30:** 639-652.

Restrepo VR, Watson RA (1991). An approach to modelling crustacean egg-bearing fractions as a function of size and season. *Canadian Journal of Fisheries and Aquatic Sciences* **48**: 1431–1436.

Wang YG, Die DJ (1996). Stock-recruitment relationships of the tiger prawns (*Penaeus esculentus* and *Penaeus semisulcatus*) in the Australian Northern Prawn Fishery. *Marine and Freshwater Research* **47**: 87–95.

Wang YG, Somers IF (in press). Evaluating seasonal closures in the Australian Northern Prawn Fishery. North American Journal of Fisheries Management.

Watson R, Die D, Turnbull C (1996a). *SIMSYS version 3.6. Trawl fishery simulation.* Unpublished manuscript, available from senior author. WA Fisheries Department, PO Box 20, North Beach WA 6020.

Watson RA, Turnbull CT, Derbyshire K (1996b). Identifying tropical penaeid recruitment patterns. *Marine and Freshwater Research* **47**: 77–85.

Table 1. Growth of tagged and control *Penaeus indicus* in 50 l tanks (Experiments One and Two) and 5000 l tanks (Experiments Two and Three). The prawns in the 50 l tanks and tank 2 were males and females matched by size. During Experiment Two, the prawns in tank 1 were all females. During Experiment Three, the prawns in tank 1 were all females, while those in the other tanks were males. "Start" is the carapace length (mm) at the beginning of the experiment and "End" is the carapace length (mm) at the conclusion. Growth is in mm wk^{-1}.

Exp. and Tank	Mean carapace length (mm)					
	Tagged prawns			Control prawns		
	Start	End	Growth	Start	End	Growth
Experiment One						
50 l tank	29.5	30.6	0.12	28.4	29.3	0.14
Experiment Two						
50 l tank	35.6	36.0	0.16	33.3	33.8	0.20
5000 l tank						
Tank 1	37.0	41.5	0.34	37.3	41.8	0.35
Tank 2	33.9	36.8	0.22	34.2	36.7	0.19
Experiment Three						
Tank 1	28.7	32.7	0.34	28.5	33.6	0.42
Tank 2	28.9	31.6	0.22	29.5	31.6	0.18
Tank 3	28.6	31.2	0.21	28.8	31.4	0.22
Tank 4	27.0	30.4	0.29	27.7	31.1	0.29

Table 2. Values of catchability (q), effort, annual fishing mortality (F) and annual natural mortality (M), and exploitation ratio (F/(M+F)) for white banana prawns, tiger prawns and those used as parameters for red-legged banana prawns in modelling with SIMSYS.

Parameter	Species		
	White banana prawn (*P. merguiensis*)[1]	Tiger prawns (*P. esculentus*, *P. semisulcatus*)[2]	Red-legged banana prawns (*P. indicus*)
Catchability (q)	0.00024	0.000088	0.0001
Annual effort (boat days)	5, 000 – 7, 000	8,000 – 10, 000 (each species)	1, 000
Annual F	1.2 – 1.7	0.7 – 0.9	1.0
Annual M	2.6	2.3	2.4
Exploitation ratio	0.36	0.25	0.3

[1] from Somers and Wang in press; [2] from Wang and Die 1996

Table 3. Yield, value and egg production for red-legged banana prawns during 3 historical periods of the fishery in the Joseph Bonaparte Gulf: 1981-84; 1985-86; 1988-1995, estimated from SIMSYS. Estimates are obtained for different combinations of population parameters (Base model, High mortality and growth, Low mortality and growth, High and Low fishing effort, different recruitment pattern).

Model and parameter	Parameter value	Pattern of fishing	Estimates of Yield (Kg)	Value (1000$)	Eggs (millions)
Base model					
Recruits (millions)	1, 000	81-84	703, 060	6, 937	155, 437
Effort (boat-days)	1, 000	85-86	833, 922	8, 317	152, 797
M (per month)	0.20	88-95	822, 034	8, 090	152, 859
K (per month)	0.20				
Low natural mortality, low K					
Recruits (millions)	1, 000	81-84	764, 278	7, 575	155, 280
Effort (boat-days)	1, 000	85-86	766, 254	7, 445	153, 339
M (per month)	0.15	88-95	758, 240	7, 098	154, 205
K (per month)	0.15				
High natural mortality, high K					
Recruits (millions)	1, 000	81-84	582, 925	5, 697	143, 895
Effort (boat-days)	1, 000	85-86	791, 610	7, 892	141, 604
M (per month)	0.25	88-95	814, 176	8, 080	141, 116
K (per month)	0.25				
Base model, high effort					
Recruits (millions)	1, 000	81-84	1, 343, 711	13, 250	147, 035
Effort (boat-days)	2, 000	85-86	1, 592, 081	15, 876	142, 021
M (per month)	0.20	88-95	1, 565, 846	15, 400	142, 085
K (per month)	0.20				
Base model, low effort					
Recruits (millions)	1, 000	81-84	359, 714	3, 550	159, 910
Effort (boat-days)	500	85-86	426, 903	4, 258	158, 555
M (per month)	0.20	88-95	421, 317	4, 148	158, 594
K (per month)	0.20				
Base model, recruitment in Feb. to April					
Recruits (millions)	1, 000	81-84	750, 968	7, 494	155, 943
Effort (boat-days)	1, 000	85-86	883, 012	8, 819	152, 698
M (per month)	0.20	88-95	851, 920	8, 329	153,184
K (per month)	0.20				

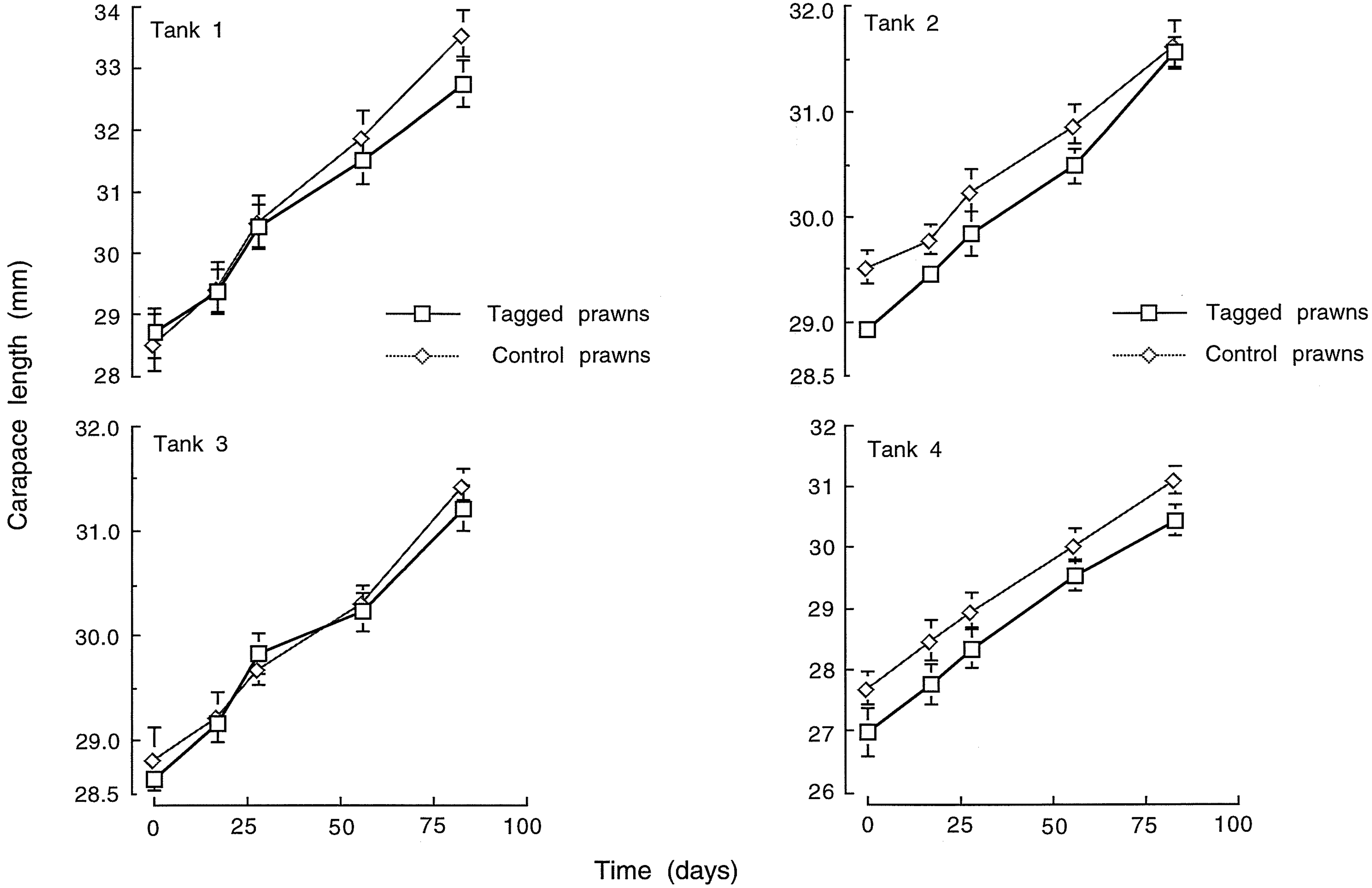

Figure 1. Growth of tagged and control *Penaeus indicus* in four tanks under controlled laboratory conditions