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Developing indicators of recruitment and effective spawner stock levels in eastern king prawns (Penaeus plebejus)

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Objectives:

1. Develop procedures and protocols for measuring a fishery independent index of recruitment in eastern king prawns.
2. Develop a program designed to monitor long-term recruitment levels, and changes in recruitment levels, of eastern king prawns.
3. Identify indices of effective spawning stock abundance for eastern king prawns in anticipation of the need to manage for increasing spawner biomass.
4. Undertake preliminary investigations of larval and post-larval eastern king prawn distribution and abundance as functions of depth, distance from shore and estuaries.

Non-technical summary:

The eastern king prawn *Penaeus plebejus* is the basis of a major commercial trawl fishery in New South Wales and south-east Queensland. Logbook data indicate that a total of about 2700 tonnes are landed annually. The majority of the catch, about 1900 tonnes, is landed in Queensland waters. At a conservative wholesale price of $15 per kilogram, annual total landings are valued at $40.5 million. *P. plebejus* is the largest and most oceanic of Australia's endemic commercial penaeid prawns. It is trawled on the continental shelf to depths of about 300 m and is the most migratory of Australia's commercially important prawns. Tagging studies have shown that individuals can migrate over 1000 km, generally northward along the coast and usually from shallow to deep water.

In order to assess the stock annual recruitment must be accurately measured, monitored and assessed. In Queensland, a mandatory logbook system is used to record catch and fishing effort. However, in shallow areas such as Moreton Bay where recruitment occurs, the logbook data are of limited value because there are several species of prawns that are caught and fishers do not differentiate between them. Groups of species are retained and collectively recorded and marketed as 'bay prawns'. Clearly, a more precise method of monitoring recruitment is required and the project addressed this need by examining factors affecting recruit catch rates and by developing a fishery-independent index of recruitment.

In order to better understand the recruitment process, the seasonal, lunar and diel variations in the catch rates of young eastern king prawns were examined. Seasonal variation was examined at two areas (Deception Bay and South Peel Island) in Moreton Bay by sampling set transects for 24 consecutive lunar months. A third area, the Great Sandy Straits near Fraser Island, proved too difficult to trawl sample due to strong tidal currents. Catch rates were affected by area, month and depth, as well as some significant interaction terms, which were basically related to differences between the two areas. Both areas displayed the same general seasonal cycle in catch rates, but catch rates in Deception Bay were about twice that of the area south of Peel Island. Power analysis was used to examine how well a change in the catch rates could be detected from one year to the next if a similar sampling program was adopted as the recruitment index. The analysis suggested that the number of transects sampled would have to be greatly increased in order to detect a change.

The size range of prawns at these two areas was 10–25 mm CL which was probably sub-optimal for use as a recruitment index. Previous studies, and results from the current project, indicated that the seasonal trend in catch rates becomes less obvious as the size of the prawns being monitored gets smaller. The size of prawns that the recruitment index should focus on is in the order of 25–35 mm CL, which is closer to the sizes encountered in the fishery and, as such, would reflect trends in the fishery more closely. However, this size range occurs predominantly outside of Moreton Bay.

Therefore, in addition to increasing the number of transects, the recruitment sampling program should be located further offshore to include larger size classes. The monitoring program should also include a number of different areas because it is unlikely that an index based solely in, or around, Moreton Bay would adequately reflect recruitment for the whole fishery. These findings have significant cost implications with regard to the size of the vessel used for monitoring recruitment and the frequency with which sampling could occur. These results were considered carefully before an offshore recruitment survey was developed and carried out.

Surprisingly, no obvious influence of lunar phase on the catch rate of eastern king prawn recruits was found. The time of night that recruits are sampled is an important consideration. Catch rates are low early in the evening and shortly before dawn and, therefore, could be standardised to take account of this source of variation. A significant interaction term (transect by lunar phase) revealed that lunar phase did affect catch rates at a minority of transects and only during certain phases. For the majority of transects, lunar phase had no significant effect and for this reason it was not considered to be an important consideration for monitoring recruitment.

A 10-day trawl survey was undertaken over an extensive area in south-east Queensland to assess the relative number of eastern king prawns recruiting to the fishery in 1999. The survey was based on 115 one-nautical mile trawls undertaken with a chartered commercial trawler operating throughout five areas (Moreton Bay, Wide Bay Bar, and areas east of Moreton, North Stradbroke and South Stradbroke Islands) that are known to be important areas for recruitment. The mean catch rate was 68.2 prawns per one nautical mile transect. The survey’s coefficient of variation was 11.2%. This type of large-scale survey is the most appropriate method for monitoring recruitment in the fishery independently of the fleet.

Catch rates differed between areas and were affected by depth, although the depth influence differed across areas. A power analysis suggested that in its current design, the survey would not be capable of detecting a 20% decline in catch rates. The smallest decline that could be detected would be in the order of 30–40%. A 50% decline would be detectable with high confidence intervals. The precision of the survey could be improved by allocating additional transects in the Moreton Bay shallow stratum. Other changes to the survey design, including decreasing the duration of each trawl and increasing the number of transects, may also improve precision.

Although the logbook data have problems for monitoring recruitment in this particular sector, they are likely to provide the only practical approach for monitoring spawning stocks. The multi-species problem with the logbook data does not occur offshore where the fishery is largely mono-specific. As such, the logbook data catch per unit effort (CPUE) may be used as a measure of relative abundance to monitor spawning stock levels.

A monthly spawning stock index was derived for an average year at four locations that were considered to be important spawning areas. This index incorporated estimates of the size-related fecundity of females, the proportion of females whose ovaries were classed as mature or ripe, and an index of abundance. The areas were the Swain Reefs (22^{o}S), off Lady Elliot and Lady Musgrave Islands (24^{o}S), off Mooloolaba (26^{o}30’S) and off Moreton Island (27^{o}S). Research data from 1990–92 provided information on female size and ovary condition, while monthly logbook CPUEs, averaged across years, were used to construct a seasonal pattern of abundance. The index showed that while there were differences between areas, there was a general seasonal cycle common to all areas. Egg production was highest in the period May to June, with a second shorter period of high production in December or January. Egg production was lowest from September to November. The indices generally declined with latitude and decreasing depth. However, they cannot be used to provide information on the relative importance of different areas to overall egg production or recruitment because they incorporated CPUE, which was only a relative index of abundance. Spatially, the relative importance of each area is unknown. This could be addressed through further research.

When logbook CPUEs from May to June were used as proxy measures of spawning stock size, there was no evidence of a decline in spawning stocks in any of the four areas between 1988 and 2000. The suitability of the May to June CPUEs, as proxy measures of spawning stock size in each area, should be evaluated by examining how well they predict recruitment.

The location of the *effective* spawning areas remains largely unknown. While spawning in the eastern king prawn fishery takes place over a very large area, there is evidence to suggest that larvae produced offshore (distances of tens to hundreds of kilometres from the coast) are unable to be transported to coastal nursery areas due to weak cross-shelf currents, and therefore are lost to the recruitment process. The results from a larval sampling program conducted as part of the project suggest that more larvae and postlarvae are caught in the upper East Australian Current (EAC) water body than in the lower sub-EAC water. It also suggests that larvae that are spawned within about 30 kilometres of the coast could be advected to either nearby inshore nursery areas or to nurseries much further south, depending on the cross-shelf currents.

In summary, the project developed methods to improve monitoring of recruitment and spawning stocks in the eastern king prawn fishery. The Queensland Fisheries Service is responsible for adopting and maintaining the state’s fishery-independent monitoring programs. If such a program is implemented for eastern king prawns, it should be extended throughout the entire fishery as the relative contribution of recruits originating in New South Wales’ waters to landings in Queensland remains unknown. Conversely, the significance of spawning events in Queensland waters to stock renewal in New South Wales is also unknown. Future initiatives should promote collaborative research, monitoring and assessment of the stock between the two states. This could be overseen through an interstate committee that meets once or twice annually to discuss results and identify research needs.

Outcomes achieved:

The main outcome from the project was the initiation of a fishery-independent survey of recruits in the eastern king prawn fishery. This is one of the most valuable fished species on the east coast of Australia (conservatively at $40.5 million annually). There are problems with relying solely upon logbook data to monitor recruitment in the fishery and so the project designed and undertook a large fishery-independent survey, based on 115 one-nautical trawls, in south-east Queensland coastal waters. In order to improve our understanding of recruitment and the survey design, the project also examined factors affecting the catch rate of recruits, including influences due to lunar phase, time of night, season, depth, temperature, salinity and location. The project also examined long-term trends in spawning stock levels in the fishery and promoted the collaborative research and monitoring of the stock by both Queensland and New South Wales.

Keywords: *Penaeus plebejus,* eastern king prawn, fishery-independent recruitment, survey.

2. Background

The eastern king prawn (*Penaeus plebejus*) is endemic to the east coast of Australia where it constitutes a major commercial trawl fishery in New South Wales and south Queensland. Logbook data indicate a total of about 2700 tonnes of eastern king prawns are landed annually (Figure 2.1, Kailola *et al.* 1993), with a value of about $40.5 million. About two-thirds of the catch is taken in Queensland waters contributing 25–30% of the state's wild-harvest prawn landings. *Penaeus plebejus* is a migratory species that generally moves in a northerly direction along the coast. Young prawns that commence their migration in estuaries located in northern New South Wales are known to be caught off the Queensland coast. The species is generally more oceanic than other Australian penaeids with the adults occurring in greater depths and further offshore than those of other species. The biology of eastern king prawns has received considerable attention from researchers and quantitative assessments of the fishery have been undertaken by Glaister *et al.* 1990 and Gordon *et al.* 1995. Catch and effort statistics are obtained through mandatory logbook programs in both states. The New South Wales logbook program consists of monthly reporting of the catch and number of days of fishing effort by each operator with a spatial reference based on 10-one degree latitudinal zones along the coast. In Queensland, the logbook program is based on daily catch and effort records of individuals and the spatial resolution may range from a low 30'x 30' grid, to an intermediate precision of 6'x 6' grid to the precise latitude and longitude of each trawl.

In Queensland the eastern king prawn fishery is largely mono-specific (i.e. no other prawn species are targeted), particularly in offshore waters, and the logbook database adequately covers the catch and effort throughout the fishery. However, in shallow coastal areas that are important for recruitment, such as Moreton Bay, catches of eastern king prawn recruits are taken along with several other species of lower commercial value. These species are not differentiated by fishers, but rather, are recorded and marketed collectively as 'bay prawns'. As a result, it is difficult to interpret annual trends in recruitment to the fishery based on logbook data alone. In 1994, a national workshop on crustacean spawning stock-recruitment relationships (funded by FRDC 93/115) concluded that assessment of the fishery would benefit by initiating a fishery independent recruitment index which would overcome the multi-species problem associated with the logbook (Courtney and Cosgrove, 1995).

The benefits of such an index are that it can be used to monitor recruitment in the fishery independently of the commercial fishing fleet. Furthermore, if there is a high correlation between the index and commercial landings, it may be used to predict in-season catch and landings, and possibly forewarn fishers and managers of imminent poor landings or collapse. In some instances, a long-term time series of the index can also be used to 'tune' stock assessment models and examine the relationship between spawning stock size and recruitment. Monitoring spawning stock levels in the fishery is achieved using the logbook data, as catches of adults offshore are almost entirely mono-specific. Furthermore, the cost of undertaking a spawning stock survey over a large offshore area (several thousand square kilometres) is likely to be prohibitive.

The objective of this project was to develop a statistically robust fishery-independent recruitment index for the eastern king prawn fishery which considers the fishery in its entirety throughout New South Wales and south-east Queensland.

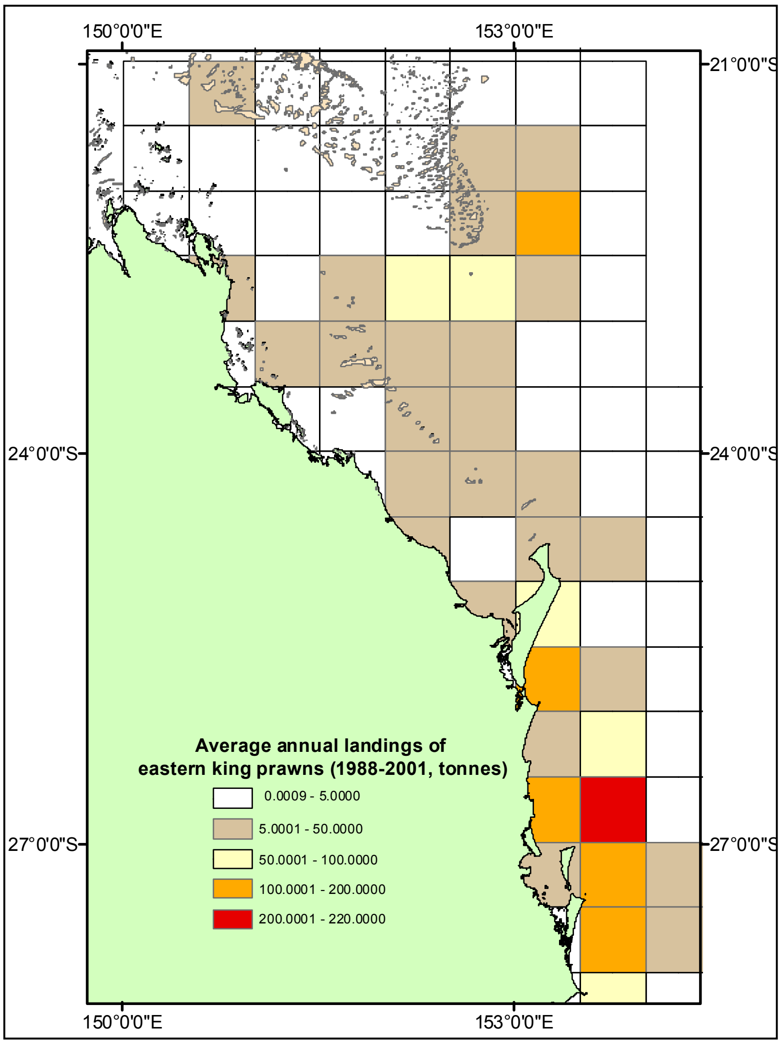

Figure 2.1 The spatial distribution of catch of eastern king prawns in Queensland coastal waters based on 30' logbook grids. Average annual landings from CFISH logbook data for the period 1988–2001.

Upon completion of the project it was anticipated that state government resources should be used to maintain the annual sampling and analyses required for the index.

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3. Need

The eastern king prawn fishery is a major fished resource in New South Wales and Queensland. Assessment of the fishery, and the ability to monitor recruitment and predict catches, would be greatly improved by instigating a fishery-independent index of recruitment. The multi-species nature of the inshore fishery creates problems with monitoring recruitment using logbook data and this could be overcome with a fishery-independent approach.

4. Objectives

I. Develop procedures and protocols for measuring a fishery-independent index of recruitment in eastern king prawns.
II. Develop a program designed to monitor long-term recruitment levels and changes in recruitment levels of eastern king prawns.
III. Identify indices of effective spawning stock abundance for eastern king prawns in anticipation of the need to manage for increasing spawner biomass.
IV. Undertake preliminary investigations of larval and post-larval eastern king prawn distribution and abundance as functions of depth, distance from shore and estuaries.

5. Objective 1. Develop procedures and protocols for measuring a fishery-independent index of recruitment in eastern king prawns.

5.1 Seasonal variation in the catch rate of eastern king prawn recruits in south-east Queensland.

5.1.1 Introduction

Any study directed towards monitoring recruitment in a fishery should firstly consider the definition of recruitment. In their review of *penaeid* prawn fishery dynamics and management, Garcia and Le Reste (1981) derived the following definition: 'The process by which an age group integrates itself for the first time into the exploitable stock.' This process is a function of both the size or age group present in a fishing zone and its selectivity to the fishing gear. Some understanding of these parameters already exists for the eastern king prawn fishery. For example, Moreton Bay is known to be an important nursery ground and source of recruits to the Bay and offshore fisheries (Young 1975, 1978, Young and Carpenter 1977). Other important recruitment areas are likely to include the estuaries of northern New South Wales and the Great Sandy Straits, near Fraser Island in south-east Queensland. These areas have received little attention from researchers and their relative importance to recruitment, on a local scale or to the fishery as a whole, has not been quantified.

Its also known that eastern king prawns recruit to the trawl grounds of Moreton Bay in October – November (Courtney *et al*. 1995) at the relatively small size of about 15 mm CL. However, at this size individuals are smaller than the size at which they are retained in commercial fishing nets. It is not until 2–3 months later in January – February, after the prawns have grown and migrated offshore, that they fully recruit to the fishery.

In this section of the report, we investigated the temporal (monthly), and to a lesser degree, the spatial, variation in catch rate of eastern king prawn recruits in south-east Queensland. The information is imperative for designing a recruitment-monitoring program. Hypotheses pertaining to the influence of area, month, water depth, temperature and salinity on catch rates of eastern king prawn recruits were tested. We also used power analysis to examine the level of change (50% or 70% reduction) in catch rate that might be detected from one year to the next, should a similar sampling program be used as a method for monitoring recruitment.

In the original project proposal, it was planned and budgeted to deploy the 13 m QDPI *RV Warrego* because it was the largest departmental vessel available for the study and could operate under a wide range of conditions. The *RV Warrego* can also travel at relatively high speeds and therefore sample a large number of sites on a given sampling night. However, for reasons beyond the project's control the *RV Warrego* was not available for this part of the project and a smaller 6 m vessel, *RV Nautilus* was used, which greatly restricted the areas and conditions under which the sampling could take place. Thus, while the original intention of the project was to identify a wide range of sampling sites in south-east Queensland that are likely to be important prawn recruitment areas, the sampling was largely restricted to shallow waters in partially enclosed embayments.

5.1.2 Methods

Temporal and spatial information on the catch rates of eastern king prawn recruits was obtained from a total of 24 one-nautical transects in the Great Sandy Straits (a narrow stretch of water between Fraser Island and the mainland) and Moreton Bay (Figure 5.1.1). While Moreton Bay was well known as an important area for eastern king prawn recruitment, there was considerable uncertainty over the relative importance of the Great Sandy Straits as a source of recruits. Each transect was sampled at night once each lunar month as close as possible to the new moon phase for two consecutive years (May 1998 – April 2000). Sampling gear consisted of a 5 m beam trawl with a 3.5 fathom Yankee Doodle type net with 1 ¼” mesh towed behind the 6 m *RV Nautilus*. A bycatch reduction grid was fitted to the net to reduce retention of large rays, sharks, turtles and jellyfish. Each transect was located and sampled using a differential global positioning system (DGPS) to maximise the precision of the trawl. Surface water temperature, depth and salinity measures were recorded each time a transect was sampled.

It was intended to extend the sampling program southwards into the estuaries and coastal waters of New South Wales because the fishery is shared by both states. This would have been undertaken through collaboration with NSW Fisheries and provided insight into how recruitment varies within time and space throughout the entire fishery (rather than just in Queensland waters). It may have also provided information on the relative contribution of different coastal regions to overall recruitment. However, despite initial support for the project and funding from FRDC, NSW Fisheries declined to participate in the project. The reasons for this are unclear but may be related to concerns over the impact of beam trawling in shallow coastal areas in New South Wales.

Statistical analyses

The influence of area, month, depth, temperature, and salinity on the catch rate of eastern king prawn recruits was examined using two statistical models developed with Genstat statistical software (5th edition/Release 4.2, VSN International). The first model was an accumulated analysis of variance with a normal distribution and identity link function. The response variable was the log-transformed catch rate data [ln n+0.1 prawns per transect)]. The second model was developed using a negative binomial distribution with logarithm link function, which is more suited to count data. The raw, non-transformed catch rate data were used in this model. Treatment factors and interaction terms were added in a forward step-wise procedure and then ‘dropped’ from the model if they were found to have no significant effect. The criterion used to assess the negative binomial model was the change in mean deviance. Both models were used to estimate adjusted mean catch rates from different months which were then used in a power analysis to examine the level of change that might be detectable from one year to the next, if the program was repeated.

5.1.3 Results

Sampling in the Great Sandy Straits was undertaken for several months but proved to be difficult and resulted in unreliable data. The main reason for this was the strong tidal currents, which frequently exceeded 4–5 knots. Often, in order to trawl the one-nautical transects at the set speed of 2 knots, the engine revolution speed had to be greatly increased to make-way against the current. This greatly increased the volume of water flowing through the net, which tended to lift the net, skids and beam up off the bottom, resulting in the trawl gear ‘flying’. Once the gear started flying in the water column it would then rotate and turn the beam trawl and net upside down, resulting in a failed sample. There were additional problems related to the topography.

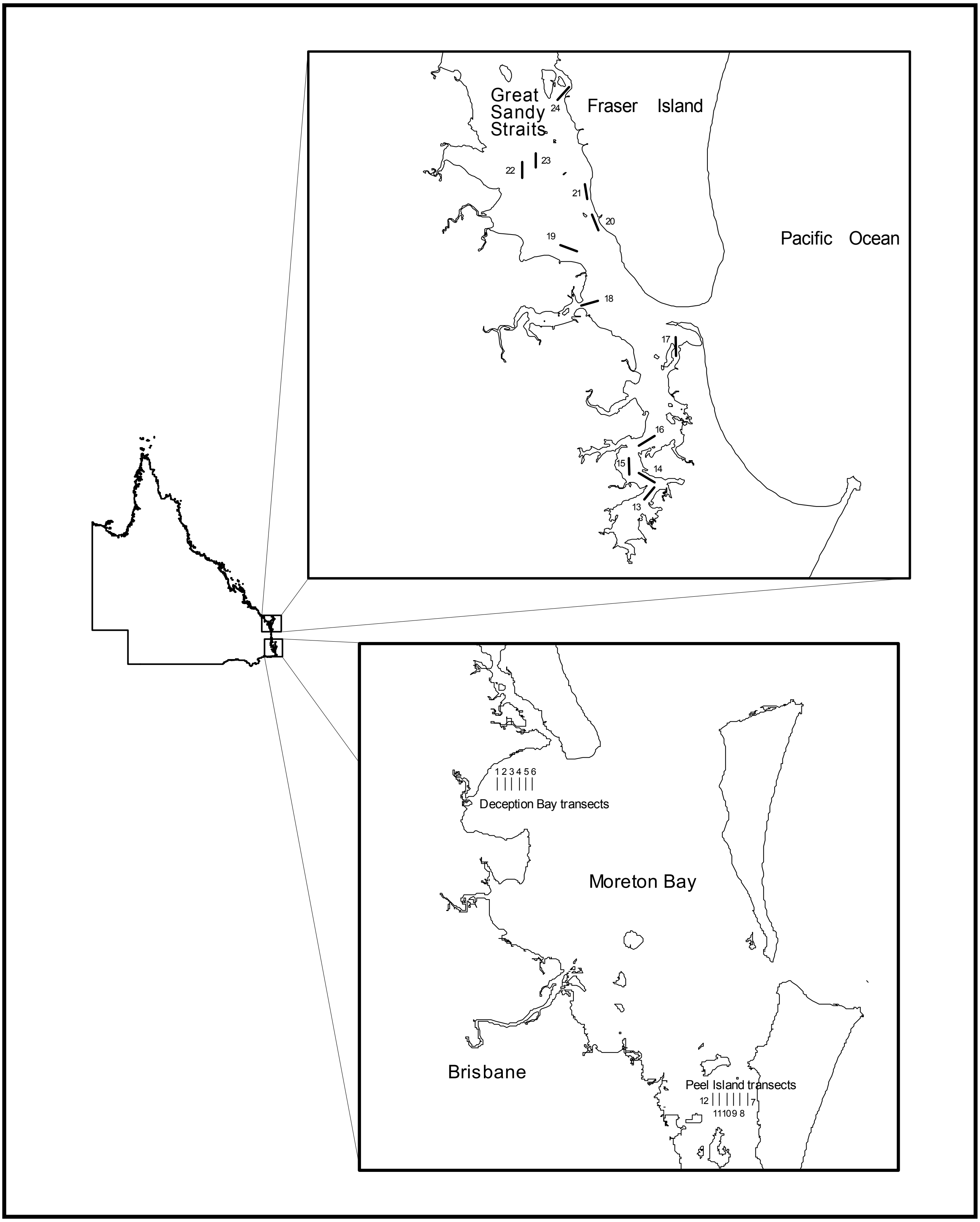

Figure 5.1.1 Location of 24 1-nautical mile transects in south-east Queensland where eastern king prawn recruits were sampled each month.

The Great Sandy Straits is a large narrow drainage canal between the mainland and Fraser Island, therefore the number of sites where the bottom is flat and outside of the main channel stream flow are limited. The few large open spaces present are also popular anchorages and on more than one occasion the trawl gear hooked up on an anchored yacht. The lack of an FM DGPS signal in the area also reduced our ability to locate and maintain our position on the transects. For these reasons, the data obtained from the area were unreliable and are not presented. Only results from the two other areas—Deception Bay and south of Peel Island (in Moreton Bay) are presented.

The 12 one-nautical transects established in Deception Bay and south of Peel Island were sampled for 24 consecutive lunar months from 25 May 1998 to 14 April 2000. A total of 10 644 eastern king prawns were obtained from the two areas. The number of males and females were similar (Figure 5.1.2). A total of 12 prawns larger than 30 mm CL were sampled, all of which were female. The general absence of small size classes (i.e. < 10 mm CL) was likely due to the selectivity of the meshes, while the absence of larger sizes (> 25 mm CL) was due to the effects of emigration (see Courtney *et. al.* 1995).

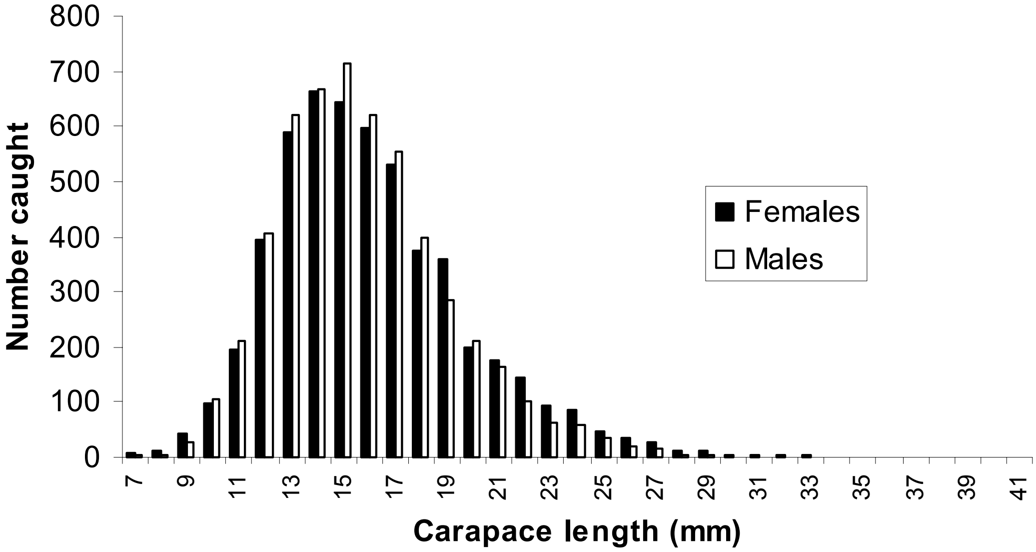

Figure 5.1.2 Size class frequency distribution of eastern king prawns sampled from two areas in Moreton Bay over 24 consecutive lunar monthly trips.

Both areas displayed marked seasonal variation in the catch rate of eastern king prawns. Catch rates from both areas were at a minimum during the period February to June (Figure 5.1.3). Observed mean catch rates were 50.5±5.5se and 23.4±3.2se prawns per one nautical mile transect for Deception Bay and the area south of Peel Island, respectively.

Catch rates in Deception Bay peaked in August of both years, while south of Peel Island the peak occurred later from September to December. Within each area, catch rates were highly variable between transects, resulting in large standard deviations around the mean. Over the course of sampling, it became clear that high catch rates were associated with certain transects and not with others. The data for individual transects in Deception Bay (Figure 5.1.4) indicated that catch rates peaked in August of both years and were largely due to high catches in the deepest, most offshore transects (Transects 5 and 6).

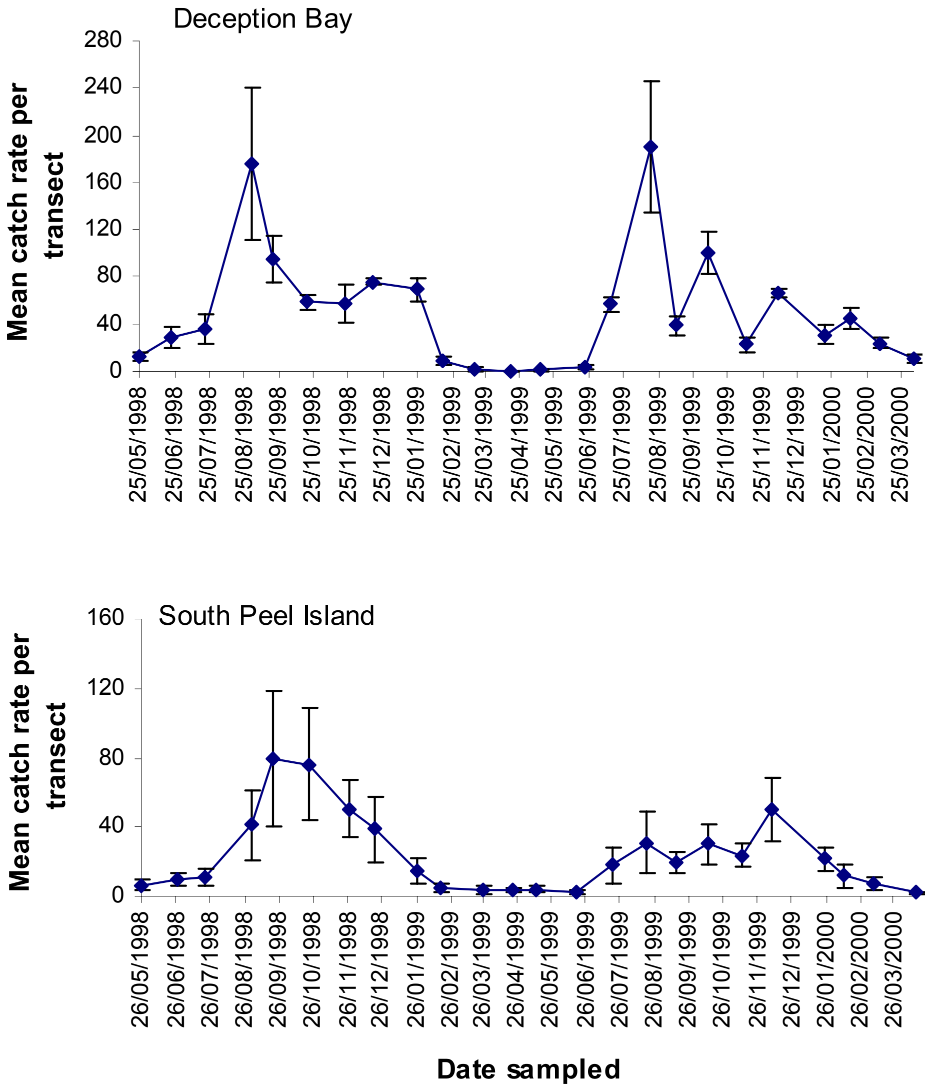

Figure 5.1.3 Observed mean catch rate of eastern king prawns from two areas in Moreton Bay over 24 consecutive lunar months. Vertical bars represent one standard error either side of the mean.

Figure 5.1.4 also indicates that recruitment may have commenced in the preceding months (June and July) when increased catches of prawns were detected in the shallower transects (Transects 1 and 2). By August the abundance had increased and the prawns had moved to the deeper transects further offshore. Large differences between transects, particularly in August, account for the large standard errors around the means in Figure 5.1.3. Results for the area south of Peel Island also show a high degree of variation between transects. However, they differ from those of Deception Bay in that peak catch rates did not occur in the deepest transects, but rather in the shallowest and most inshore transects (Transects 10, 11 and 12).

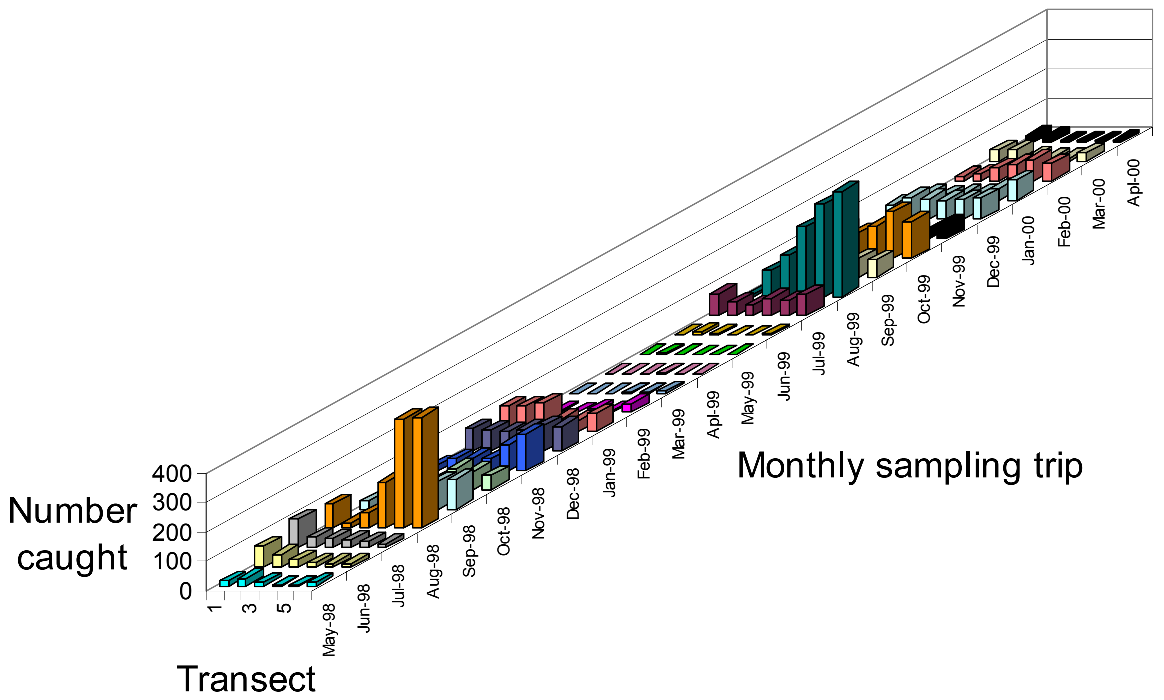

Figure 5.1.4 The temporal and spatial distribution of eastern king prawn catches from individual transects in Deception Bay during the sampling program. Transect 1 was the shallowest, most inshore transect; transect 6 the deepest and furthest offshore.

There was no significant difference in the size of the prawns between the two areas. Prawn size varied significantly between months ($P<0.001$). Depth had a marginal effect ($P=0.07$) —mean size (CL) increased with increasing transect depth. Neither temperature nor salinity affected the size of the prawns.

Mean bottom water temperature ranged from 27.3°C in February 1999 to 16.2°C in June 1999 and followed a typical seasonal cyclic pattern (Figure 5.1.5a). Salinity varied between 26 ppt and 36 ppt (Figure 5.1.5b) but did not display a discernible seasonal pattern. The mean depth of the transects (Figure 5.1.5c) varied between 3.7 m and 7.4 m. Deception Bay transects (numbered 1-7) were slightly shallower than those located south of Peel Island and while depths tended to increase with distance from the shore in Deception Bay, the transect depth profiles for the area south of Peel Island were more complex.

Modelling catch rates

Accumulated analysis of variance

This model explained 63.6% of the variation in catch rates. Month, depth and area were significant main effects, but there were also significant interaction terms (Table 5.1.1), of which the depth–area interaction was the most significant; catch rates increased with depth in Deception Bay and declined with depth south of Peel Island (Figure 5.1.6). There were no significant differences between years, nor were there any significant main effects, or interactions involving temperature or salinity. Adjusted back-transformed mean catch rates were 51.5 and 19.5 prawns per one nautical mile transect for Deception Bay and south of Peel Island, respectively, which are relatively close to the observed means.

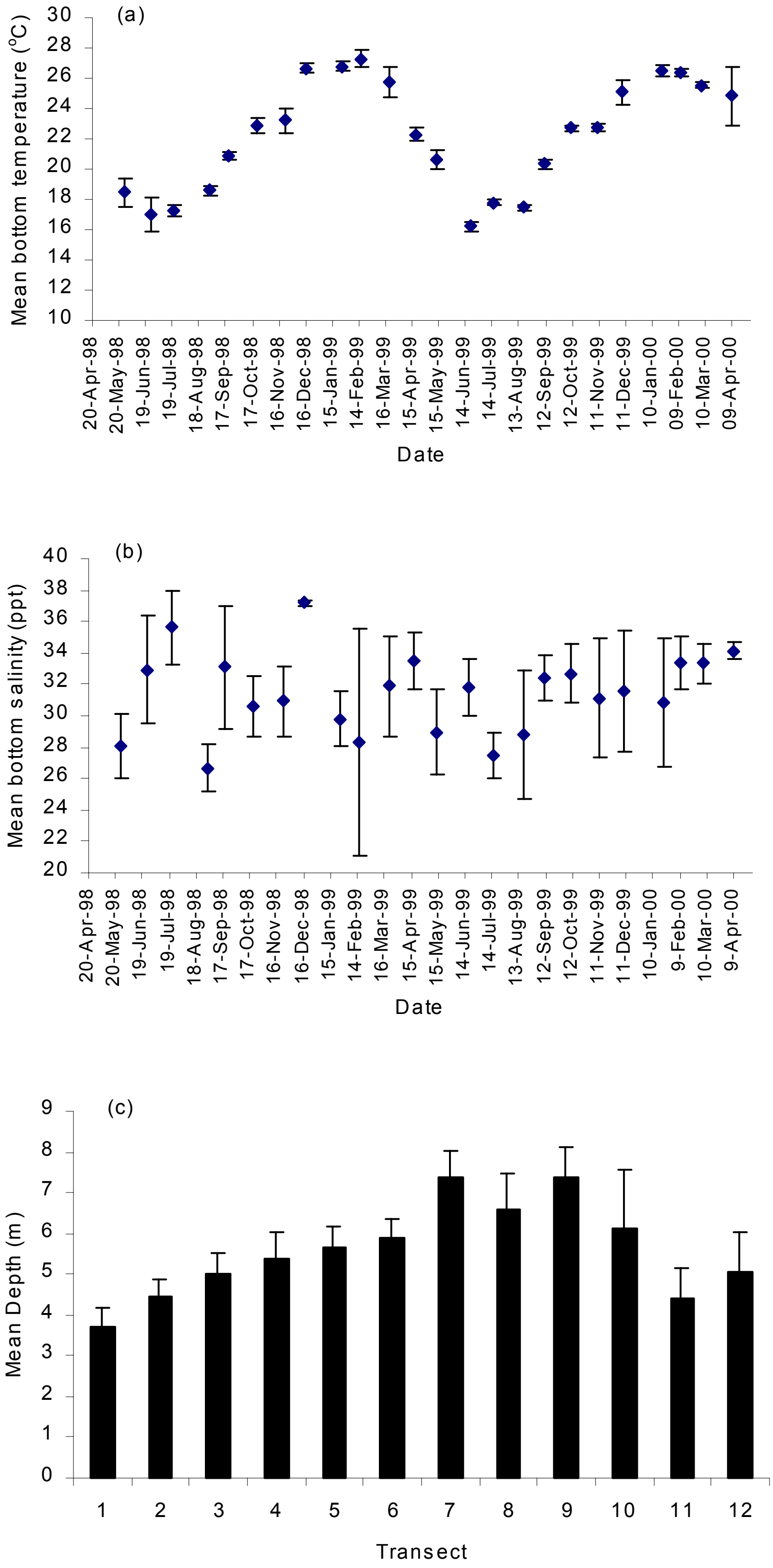

Figure 5.1.5 The mean water a) temperature and b) salinity at 12 transects during each of the 24 consecutive lunar months. The mean depth (c) of each transect is also provided. Transects 1–6 located in Deception Bay. Transects 7–12 located south Peel Island. Vertical bars represent one standard deviation either side of the mean.

Table 5.1.1 Accumulated analysis of variance of factors affecting the catch rate of eastern king prawns from two areas (Deception Bay and south of Peel Island) in Moreton Bay sampled over 24 consecutive lunar months.

Change	d.f.	Sum of squares	Mean square	Variance ratio	F probability
Month	11	460.124	41.829	23.87	<.001
Depth	1	189.799	189.799	108.31	<.001
Area	1	34.073	34.073	19.44	<.001
Depth.Area	1	74.296	74.296	42.4	<.001
Month.Year	12	128.917	10.743	6.13	<.001
Month.Area	11	56.335	5.121	2.92	0.001
Residual	250	438.081	1.752		
Total	287	1381.625	4.814		

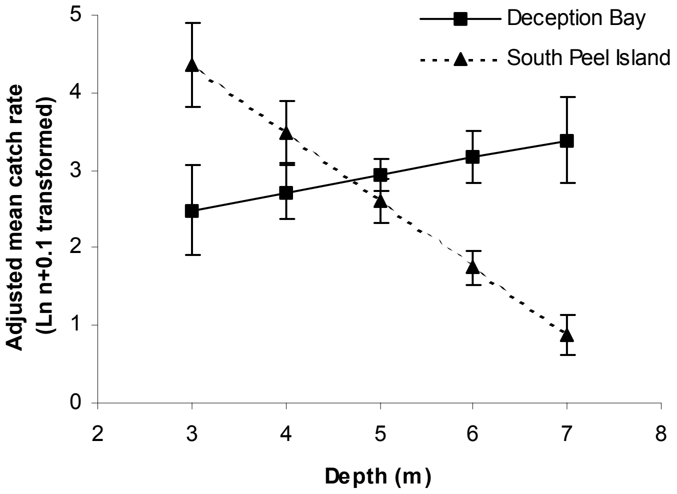

Figure 5.1.6 The relationship between adjusted mean catch rates of eastern king prawns and depth at the two locations. These means were derived from the model presented in Table 5.1.1. Vertical lines represent 95% confidence intervals.

Power analysis

By applying power analysis to the adjusted mean catch rates derived from the model we can obtain an understanding of the level of change in catch rates that might be detectable from one year to the next, if the sampling program was repeated for monitoring purposes. The power to detect a change in catch rates was investigated for a range of possible sampling months, from sampling only in August to sampling continuously throughout the year. Power analysis requires an estimate of the variance of each treatment. In this case different combinations of sampling months represented the different treatment effects. For the accumulated analysis of variance model the variance estimate is the residual error mean square.

From the power analysis results (Table 5.1.2) it can be seen that the adjusted mean catch rate increases as the number of months sampled declines. This is because sampling year-round includes those months when abundance is low, thus lowering the overall mean. Importantly, it can also be seen that the power to detect a change in catch rates declines with the number of trawls that are used in the model. It is also noteworthy that there is very little difference in adjusted means between estimates based on five months of sampling (August to December, mean of 3.88) through to estimates based on only two months (August to September, mean of

3.939). This suggests that catch rates are high during this time of year and that there is little variation between months from September to December.

Table 5.1.2 Power to detect a 20% and 50% decline in catch rate of eastern king prawns from two areas in Moreton Bay. The results are provided for a range of possible sampling times, ranging from continued sampling throughout the year (i.e. all months) to only one month when catch rates are high (i.e. August). Adjusted means and variance were obtained from the accumulated analysis of variance model. Adjusted means are number of prawns per one-nautical mile transect [log transformed (n+0.1].

Months Sampled	Adjusted mean catch rate from model	Number of one-nautical mile trawls used in model to estimate mean	Variance (Residual error mean square)	Power to detect 20% decline	Power to detect 50% decline
All 12 months	2.587	288	1.752	0.500	1.000
5 months; Aug-Dec	3.880	120	1.064	0.381	0.999
4 months; Aug-Nov	3.843	96	1.079	0.315	0.996
3 months; Aug-Oct	3.948	72	1.257	0.224	0.959
2 months; Aug-Sep	3.939	48	1.412	0.157	0.817
1 month only; Aug	4.526	24	1.435	0.109	0.532

* Power values larger than 0.8 are generally considered to be effective for detecting change.

Sampling year-round would give relatively high power to detect change, but low power to detect a 20% decline. Sampling over five months (August to December) would result in the lowest variance, but it would still only result in enough power to reliably detect a 50% decline. Collectively, the analysis indicates that if such a sampling program was repeated only relatively large declines (50% and greater) in catch rates would be detectable.

The negative binomial model

Results from this model were similar to those from the accumulated analysis of variance. Catch rates were significantly influenced by the month, depth and area, with several significant interaction terms, the most significant of which was the depth.area interaction (Table 5.1.3). Adjusted mean catch rates were 56.7 prawns per transect for Deception Bay and 27.2 prawns per transect south of Peel Island—slightly higher than the observed means.

When adjusted means from a negative binomial model are used in power analysis, the variance estimate of each treatment is:

$$Var(y) = u + \ u^2 / k$$

where μ is the adjusted mean catch rate from the model and k is the aggregation parameter associated with the dispersion from the model fit and is commonly equal to 1. From this equation it is apparent that the variance will generally increase with the adjusted mean catch rate. The power to detect a change in catch rates was investigated for a range of possible sampling months, ranging from continuous sampling throughout the year to sampling in only one month when catch rates are high.

Table 5.1.3 Accumulated analysis of deviance of factors affecting the catch rate of eastern king prawns from two areas (Deception Bay and south of Peel Island) in Moreton Bay sampled over 24 consecutive lunar months. A negative binomial distribution was specified for the model fit with a logarithm link function.

Change	d.f.	Deviance	Mean Deviance	Deviance Ratio	Approximate Chi-square Probability
Month	11	228.292	20.754	20.75	<0.001
Depth	1	38.292	38.292	38.29	<0.001
Area	1	23.246	23.246	23.25	<0.001
Depth.Area	1	10.326	10.326	10.33	0.001
Month.Year	12	68.874	5.740	5.74	<0.001
Month.Area	11	22.844	2.077	2.08	0.019
Residual	250	264.178	1.057		
Total	287	656.052	2.286		

The results in Table 5.1.4 are similar to those obtained for the previous power analysis. In general, the power to detect a change in catch rates declines as the number of transects sampled declines and as the variance increases. The best chance of detecting a change would be obtained if sampling was conducted all year round, but even if this were undertaken, it’s likely that only a 50% decline would be detectable. Sampling year-round would result in a low mean catch rate but, more importantly, a high number of samples and a relatively low variance. Although sampling in August would result in the highest mean catch rate it would also result in the fewest samples and highest variance, and thus in a very poor chance of detecting change.

Table 5.1.4 Power to detect a 20% and 50% decline in catch rate of eastern king prawns from two areas in Moreton Bay. The results are provided for a range of possible sampling times, ranging from continued sampling throughout the year (i.e. all months) to sampling in only one month when catch rates are high (i.e. August). Adjusted means were obtained from the negative binomial general linear model with logarithm link function.

Months Sampled	Adjusted mean catch rate (number per transect) from model	Number of one-nautical mile trawls used in model to estimate mean	Variance ($u+\mu^2/k$)	Power to detect 20% decline	Power to detect 50% decline
All 12 months	41.9	288	1,800.9	0.659	1.000
5 months; Aug–Dec	156.2	120	17,583	0.443	0.995
4 months; Aug–Nov	157.7	96	17,921	0.368	0.982
3 months; Aug–Oct	165.2	72	22,908	0.255	0.902
2 months; Aug–Sep	109.2	48	15,015	0.139	0.580
1 month only; Aug	192.6	24	31,105	0.115	0.457

Power values larger than 0.8 are generally considered to be effective for detecting change.

5.1.4 Discussion

Abiotic influences on eastern king prawn recruit catch rates

Adjusted mean catch rates from Deception Bay were more than twice those of the area south of Peel Island. The area–depth interactions indicated that prawn catch rates increased with depth in

Deception Bay but declined with depth south of Peel Island. This may be related to differences in the bathometry, which is relatively uncomplicated in Deception Bay and characterised by shallow inshore transect depths of about 3 m increasing to about 6 m offshore. The bathometry of the area south of Peel Island is more complex. The lowest catch rates south of Peel Island were generally obtained from the eastern-most and deepest transects (Transects 7 and 8), which were close to the main deepwater channel near Stradbroke Island. As a general observation, catch rates from transects that were influenced by strong tidal currents tended to be low.

Although temperature and salinity had no significant effect on catch rates, these results should be interpreted with caution. This is because seasonal, cyclic patterns in a) prawn catch rates b) temperature and c) salinity generate autocorrelations which make it difficult to interpret the influence of such abiotic factors. Salinity is known to have an influence on the distribution of postlarval eastern king prawns (Young and Carpenter 1977) and it is likely to influence the distribution of older stages. It is possible that salinity levels did affect the abundance and distribution in the present study, but that much of that influence was explained by the 'month' term. 'Month' and 'salinity' are not completely independent, but rather co-vary in a cyclic and lagged pattern. The problem of autocorrelation is partly addressed later through the analysis of a large trawl survey (Chapter 6).

The two models (normal and negative binomial) gave similar results, however, the adjusted mean catch rates from the negative binomial model tended to be higher than both the observed catch rates and the adjusted means from the analysis of variance model (i.e. the normal distribution model). The normal distribution model generally resulted in adjusted means that were closer to the observed catch rates, and for this reason it appears to be the better of the two.

Power analysis

In general, the adjusted mean catch rates from sampling in different months strongly suggested that this type of sampling program would not be effective at monitoring recruitment. This is because the number of transects sampled was too low and the variance associated with the adjusted means was too high to be able to detect a change. Collectively, the results suggested that a large number of transect samples would be required to detect a change of 20% with a power of at least 0.8. The exact number of transect samples varies depending upon the model used and the time span over which the data are collected. Ideally, a 5–10% decline in abundance of recruits is what the program should aim at being able to detect, however, all of the sampling scenarios considered herein would fail to detect even a 20% decline, and in many instances, they would also fail to detect a 50% decline.

Sampling a large number of transects (i.e. 200+) would mean that the program could not be repeated at different times of the year, as it would be too costly. Thus, if a large number of samples is to be obtained it would have to be undertaken once a year, and presumably during the peak recruitment period. It would also be prudent to locate this large number of trawls throughout the south Queensland coast, as restricting it to Moreton Bay is unlikely to result in the index accurately reflecting recruitment throughout the whole region.

Application as an index of recruitment

The early studies on postlarval *P. plebejus* in Moreton Bay by Young and Carpenter (1977) and Young (1978) found that these early life-history stages are present in the Bay all year round and that their catch rates were generally higher from May–November. More recent studies showed that older stages, in the size range 15–30 mm CL, displayed a clear annual peak from October –

November (Courtney *et al*. 1995). Recruitment to the Moreton Bay fishery occurs from November – December after the prawns have grown sufficiently to be retained in the commercial trawl nets. Recruitment to the offshore fishery occurs later, from January – February, after the prawns have grown further and migrated to oceanic waters. This is reflected in the logbook data as a clear annual peak in landings around this time (Figure 5.1.7). Following this period each year, the catch declines rapidly, probably as a result of both fishing and natural mortality.

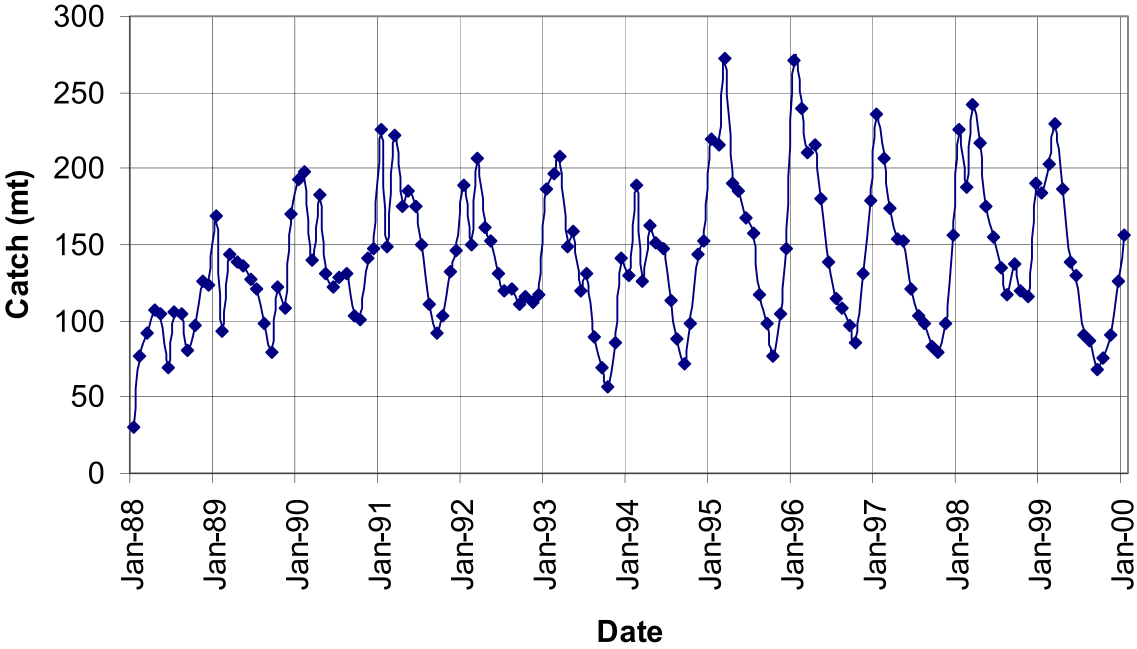

Figure 5.1.7 Monthly reported catch statistics for the eastern king prawn fishery from the Queensland CFISH logbook system. Catches for Moreton Bay have not been included because fishers do not differentiate between eastern king prawns and other prawn species trawled from the bay.

The size range of the individuals sampled in the present study (Figure 5.1.2) was mainly 10–25 mm CL with a mode of 14–15 mm CL, which is intermediate between the postlarval stages examined by Young and Carpenter (1977) and the size ranges sampled by Courtney *et al.* (1995). Similarly, the seasonal variation in catch rates in the present study also appears to be intermediate between that of the postlarvae and the older stages. The reason the prawns sampled in the present study were smaller than those sampled by Courtney *et al*. (1995) was due to sampling shallower sites and smaller mesh size.

Collectively these studies suggest that while postlarvae may be abundant for extended periods throughout the year, there is likely to be marked seasonal variation in the mortality rates which results in only certain cohorts surviving to recruit to the fishery in a single clearly defined annual pulse. Theses studies suggest that, as far as developing a fishery-independent recruitment index is concerned, the index would more closely reflect the true level of recruitment to the fishery if it focused on larger/older (> 25 mm CL) size/age classes rather than the younger/smaller (< 20 mm CL) individuals. The size classes obtained herein from sampling in

Deception Bay and south of Peel Island (10–20 mm CL, mode of 14–15 mm CL) are probably too small/young to be considered as the most suitable for the index.

The recruitment index will forecast, and co-vary with, commercial catches more accurately when the size/age classes sampled are as close as possible to those caught in the fishery. The further removed the size/age classes are (i.e. the younger the age classes sampled) the less likely they are to reflect commercial landings. This is particularly important for fast-growing invertebrates, like prawns, that have high and variable mortality rates, especially when they are young (postlarvae or juveniles). The recruitment index should be based on cohorts that are 1–2 months younger than those caught by the fleet. In this way, the index would be obtained early enough to forewarn fishers of recruitment failure, as well as closely representing the age classes and abundance encountered by the fleet at the time of recruitment. For the eastern king prawn fishery the optimum size/age class range is likely to be 25–35 mm CL, which is above the range encountered in Moreton Bay. The incidence of *P. plebejus* that are larger than 25 mm CL in Moreton Bay is uncommon, and size classes larger than 30 mm CL are even scarcer. Therefore, a monitoring program that specifically targets 25–35 mm CL sizes would require working further offshore, in open waters outside of the sandbars of Fraser, Moreton and Stradbroke Islands.

For these reasons, the sampling methods and approaches used herein are unlikely to be the most appropriate for a recruitment index of the eastern king prawn fishery. Specifically, the vessel was too small to sample a large number of appropriate sites and areas. As a result, the locations and depths the vessel was restricted to resulted in only relatively shallow transects being sampled and this in turn restricted the size range of prawns that could be sampled. Sampling should target larger size classes further offshore. This has a significant impact on the size of the vessel suitable for the sampling, the frequency with which the sampling would occur and the cost of the sampling program.

5.1.5 Conclusions

- This study examined the seasonal variation in eastern king prawn catch rates from two areas in Moreton Bay that were sampled for 24 consecutive lunar months. Two types of models were used to examine factors affecting the catch rates. There were significant interactions between the effects of area, month and depth, suggesting that each of those factors did not have a consistent effect on catch rate. Both areas displayed the same general seasonal cycle in catch rates, but catch rates in Deception Bay were about twice that of the area south of Peel Island. The accumulated analysis of variance model (normal distribution) provided catch rate estimates that were closer to the observed catch rates than those derived from the negative binomial model.
- Power analysis was used to examine whether a change in catch rates could be detected if the program was repeated. The analysis suggested that the number of transects sampled would have to be greatly increased in order to detect a change.
- The size range of prawns encountered was probably too small to be considered as the most suitable for the recruitment index. Therefore, in addition to increasing the number of transects sampled, the sampling program should be located further offshore to include larger size classes which are closer to those encountered in the fishery. It should also include a number of different areas because it is unlikely that an index based in Moreton Bay alone would adequately reflect recruitment for the whole fishery.

5.1.6 References

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5.2 The influence of lunar phase and time of night on the catch rates and catchability of eastern king prawn recruits.

5.2.1 Introduction

In the previous section (Section 5.1), the seasonal variation and, to a lesser extent, the spatial variation in the catch rate of young eastern king prawns was examined. This section examines the influence of lunar phase and time of night on the catch rates. If these factors are found to have a significant effect then it would be necessary to consider their influence in the development of the recruitment index.

There is evidence to suggest that the catch rates of adult eastern king prawn recruits are affected by both lunar phase and the time of night. For example, Wassenberg and Hill (1994) examined the emergence patterns of eight species of prawns under laboratory conditions and found that *Penaeus plebejus* spent the least time emerged above the substrate at night. Individuals began to bury themselves relatively soon after emerging at around 2000 hours, suggesting that the time of night that sampling takes place may affect catch rates.

The catch rates and reproductive cycles of adults (35–45 mm CL for males and 45–60 mm CL for females) in relatively deep (> 150 m) offshore waters display marked lunar phase periodicity (Courtney *et al.* 1996). Fishers are well aware of these influences and regulate their offshore fishing trips accordingly. Catch rates of adults increase in the period leading up to the full moon and decline to a minimum a few days before and after the new moon. The ratio between male and female adults in the catch also varies with lunar phase, suggesting that it affects the sexes differently. Catch rates of adult males and females also differ and vary throughout the night. Ovarian histological condition also varies with lunar phase and undergoes two cycles of development each lunar month (Courtney *et al.* 1996).

Lunar phase and diel influences on the catch rate of the smaller and younger stages associated with recruitment are not as well understood. Giffiths (1999) examined the catch rate of sub-adult (14–39 mm CL) *P. plebejus*, using a recreational scoop net in an intermittently open shallow coastal lagoon, and found that it varied significantly between the new moon and full moon. Catch rates were significantly higher during the new-moon phase, contrasting markedly with the patterns observed for adults offshore.

In summary, adult eastern king prawn catch rates are affected by lunar phase and time of night, but these influences appear to differ in earlier life history stages and affect males and females differently. In this section, we examined how catch rates of recruits varied between lunar phases, throughout the night and over small spatial ranges. Clearly, the proposed recruitment-monitoring program would need to consider such variation, if it exists. If lunar phase significantly affects the catch rate of recruits then the timing of the collection of data should be standardised. The results are based on an intensive field-sampling program that was designed to test several hypotheses pertaining to lunar and diel effects on the catch rates of eastern king prawns in Moreton Bay.

5.2.2 Methods

5.2.2.1 Field sampling

A field sampling study was designed to determine whether catch rates of sub-adult eastern king and other prawn species are affected by lunar phase and the time of night. The influence of additional abiotic factors, including the location of transects, temperature, depth and salinity were also examined. Ten one-nautical mile transects were established in Deception Bay (27°09'S, 153°04'E), in the north-west of Moreton Bay, on the south Queensland coast (Figure 5.2.1). Transects were located inside a trawl closure to avoid possible effects of commercial fishing operations on the results. Sampling was conducted every third night (weather permitting) for approximately 2.3 consecutive lunar months from 14 September to 23 November 1998 (Table 5.2.1). Only five of the ten transects were randomly selected and sampled on each trip in order to reduce the possibility of depletion effects occurring as the sampling program progressed.

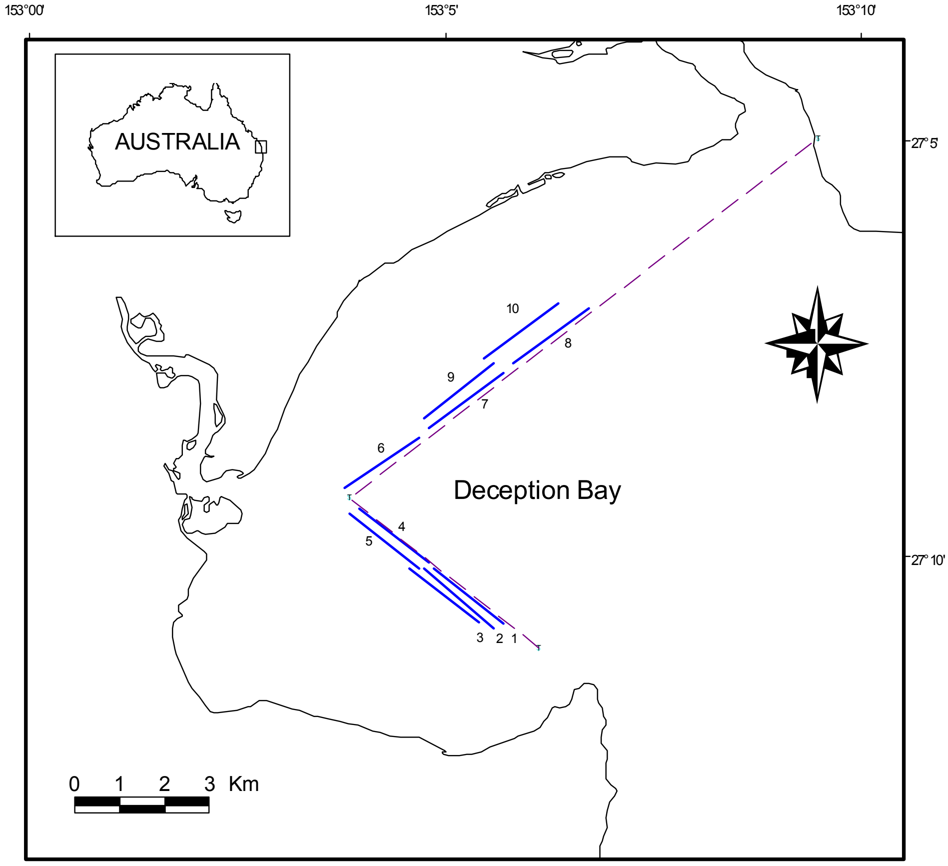


Figure 5.2.1 Location of 10-one-nautical mile transects in Deception Bay, south-east Queensland that were sampled to examine fine-scale temporal and spatial effects on prawn catch rates.

Transects were trawled at a speed of 2.5 knots and at set times of the night: shortly after sunset (18:00–18:40), 20:30, 23:00, 01:30 and 04:00 using the *RV Warrego*. Sampling of the first transect occurred progressively later on each trip to ensure it commenced 15–20 minutes after sunset. All other sampling times were fixed. A Differential Global Positioning System was used to locate and maintain position along each transect.

Table 5.2.1 Details of the sampling dates, lunar phases and lunar cycles over the sampling period. Five transects were randomly selected and sampled during each trip. Each night of sampling was assigned to a lunar phase within a lunar monthly cycle. Sampling was conducted over four lunar monthly cycles, two of which (cycles 2 and 3) were sampled over their entirety while the first and last (cycles 1 and 4) were only sampled at their end and beginning, respectively. Within each lunar cycle four lunar phases were identified; phase 1 = new moon (± 3 days), phase 2 = half moon waxing to full moon (± 3 days), phase 3 = full moon (± 3 days) and phase 4 = half moon waning to new moon (± 3 days). Trips 17, 23 and 24 were delayed 24 hours due to poor weather conditions.

Sampling Trip	Date	Luminesce measure (0=New moon; 1=Full moon)	Allocated Lunar Phase (1–4)	Lunar cycle
1	Sep 14–15	0.30	4	1
2	Sep 17–18	0.07	1	2
3	Sep 20–21	0.00	1	2
4	Sep 23–24	0.09	1	2
5	Sep 26–27	0.32	2	2
6	Sep 29–30	0.61	2	2
7	Oct 02–03	0.88	3	2
8	Oct 05–06	1.00	3	2
9	Oct 08–09	0.86	3	2
10	Oct 11–12	0.55	4	2
11	Oct 14–15	0.25	4	2
12	Oct 17–18	0.05	1	3
13	Oct 20–21	0.00	1	3
14	Oct 23–24	0.11	1	3
15	Oct 26–27	0.35	2	3
16	Oct 29–30	0.66	2	3
17	Nov 02–03	0.98	3	3
18	Nov 04–05	0.99	3	3
19	Nov 07–08	0.81	4	3
20	Nov 10–11	0.51	4	3
21	Nov 13–14	0.23	4	3
22	Nov 16–17	0.04	1	4
23	Nov 20–21	0.03	1	4
24	Nov 23–24	0.29	2	4

The trawl gear consisted of a 9-ply polyethylene 3.5 fathom Yankee Doodle net with 1" mesh attached to a 5 m beam trawl (Figure 5.2.2). A bycatch reduction grid was inserted in the throat of the net to reduce catches of large jellyfish (*Catostylus* sp.) and other large bycatch species, such as rays and turtles. Depth (± 0.1 m) surface water salinity (± 0.1 PSU) and bottom temperature (± 0.1^{o}C) were measured during each trawl. Four-hourly measurements of barometric pressure (hPa) were obtained from the Bureau of Meteorology for the duration of the sampling program. Immediately after each trawl, all of the penaeid prawns were sorted from the bycatch and stored in labelled plastic bags. At the end of each night the samples were transported to the laboratory and frozen. Over the following months the species, size (mm CL) and gender of each individual prawn in the samples were recorded.

5.2.2.2 Statistical design

An accumulated analysis of variance (Genstat statistical software 5th edition/Release 4.2, VSN International) was used to examine the influence of several factors on catch rates. The model used a step-forward approach for testing factors. Treatment factors were lunar cycle (1–4), lunar phase (1–4), time of night (5 levels; 18:00–18:40, 20:30, 23:00, 01:30, 04:00) and transect (1–10); and the co-variates depth, barometric pressure, bottom temperature and surface salinity. Where possible, the effect of interaction terms was also tested. The response variate (number of prawns caught per trawl) was log transformed [ln(x+1)] prior to undertaking the modelling.

Figure 5.2.2 The QDPI *RV Warrego* and 5 m beam trawl used to examine fine-scale temporal and spatial effects on prawn catch rates.

5.2.3 Results

One hundred and twenty samples (five one-nautical mile transects sampled on each of the 24 sampling trips) were collected over the duration of the sampling program. A total of 23 278 penaeid prawns comprised of nine species were collected, with the four most abundant species being *Penaeus plebejus* (15 088 individuals), *Metapenaeus bennettae* (7482), *Penaeus esculentus* (411) and *Trachypenaeus fulvus* (259) (Figure 5.2.3). Those four species included over 99% of all prawns collected. While *M. bennettae* is generally more abundant than *P. plebejus* in Moreton Bay, the temporal and spatial conditions for the sampling program coincided with the annual peak in abundance of *P. plebejus*.

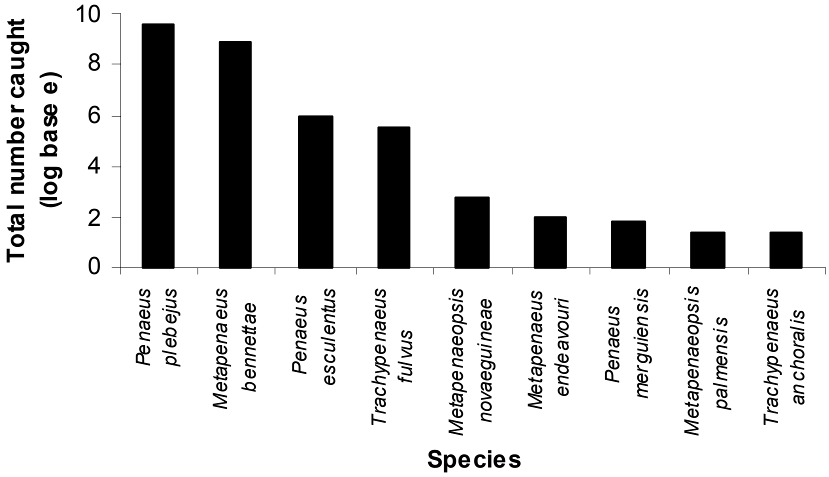


Figure 5.2.3 Total number of each prawn species caught during the sampling program.

The carapace lengths of *P. plebejus* ranged from 7–32 mm with a mode at 16 mm for both sexes (Figure 5.2.4). Carapace lengths of *M. bennettae* ranged from 7–26 mm with modes occurring at 13 mm CL for both sexes, with males dominating the smaller classes and females the larger. *P. esculentus* carapace lengths ranged from 14–44 mm, although no males were larger than 35 mm CL. Carapace lengths of *T. fulvus* ranged from 8–22 mm with modes at 11–12 mm CL. Females were more numerous and dominated the larger size classes, while males dominated the smaller sizes (Figure 5.2.4).

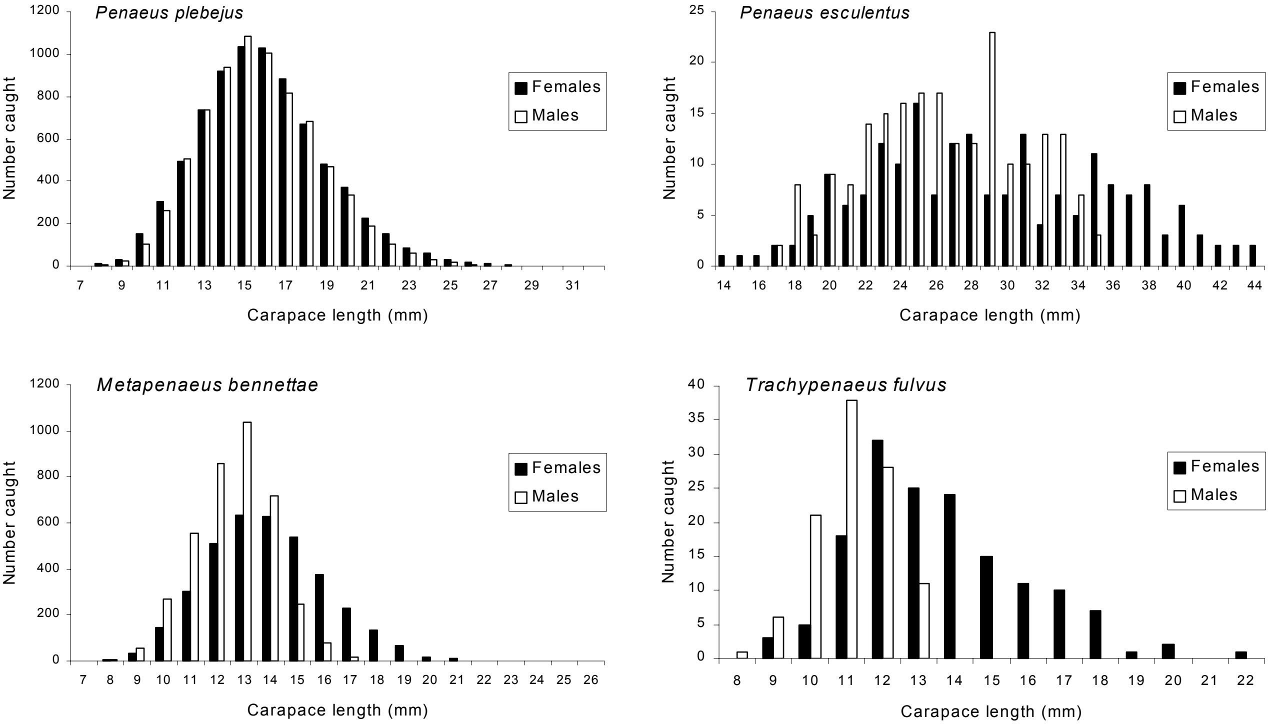
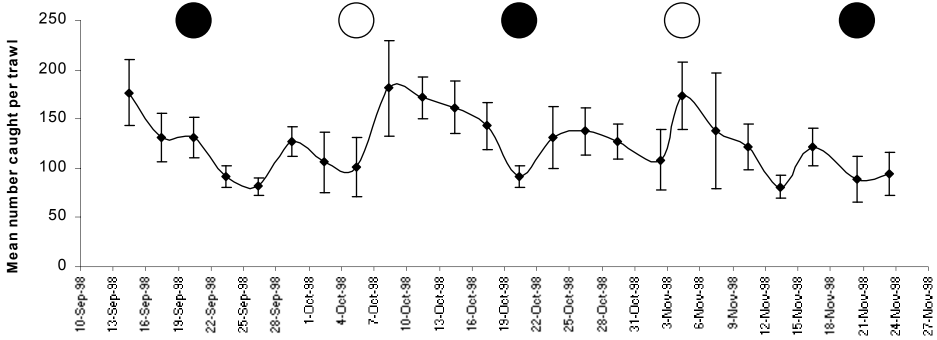


Figure 5.2.4 Size class frequency distributions of the four most abundant prawn species caught during the sampling program.

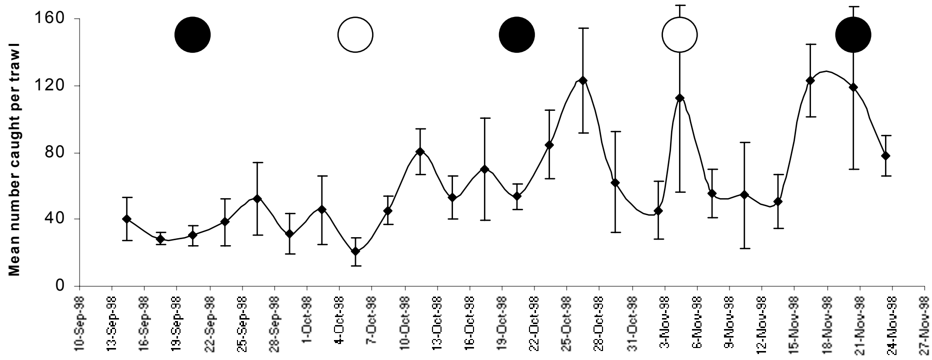
There was no obvious lunar phase influence on the catch rate of any species (Figure 5.2.5a-d). *P. plebejus* had the highest mean catch rate of 125.7±5.7se individuals per one nautical mile trawl. While there were no obvious patterns, the highest standard errors for *P. plebejus* occurred shortly after the full moon (Figure 5.2.5a). *M. bennettae* had a mean of 62.4±5.1se individuals per one nautical mile trawl and displayed a slight increase over the sampling period (Figure 5.2.5b). *P. esculentus* had a mean catch rate of 3.4±0.3se individuals per one nautical mile trawl (Figure 5.2.5c). The mean catch rate of *T. fulvus* was 2.2 ±0.4 individuals per one nautical mile trawl and declined markedly over the sampling period (Figure 5.2.5d).

Average nightly bottom temperatures varied between 20.7±0.1se ^{o}C and 24.6±0.2se ^{o}C (Figure 5.2.6a). The general increase in water temperature over the sampling period reflects the seasonal change from spring to early summer as the sampling progressed. Mean surface salinity ranged between 34.9±0.5 ppt and 37.3±0.2 ppt and was generally higher and less variable over the latter half of the sampling period (Figure 5.2.6b). Transect depths ranged between 2.9±0.4 m (Transect 6) and 4.9±0.5 m (Transect 8) (Figure 5.2.6c).

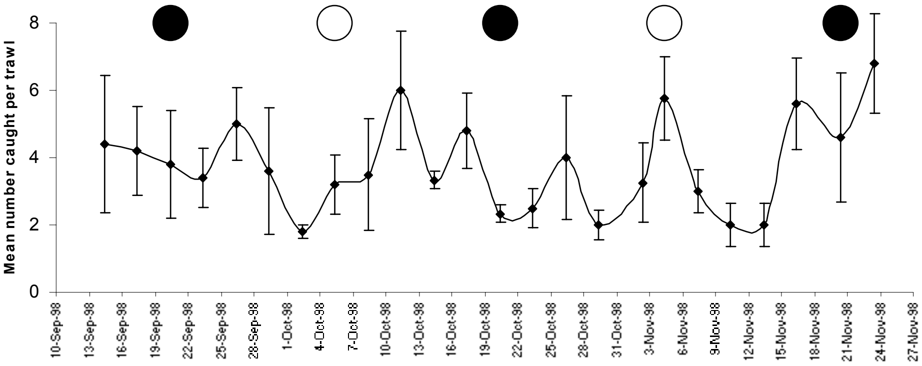
a) Penaeus plebejus



b) Metapenaeus bennettae



c) Penaeus esculentus



d) Trachypenaeus fulvus

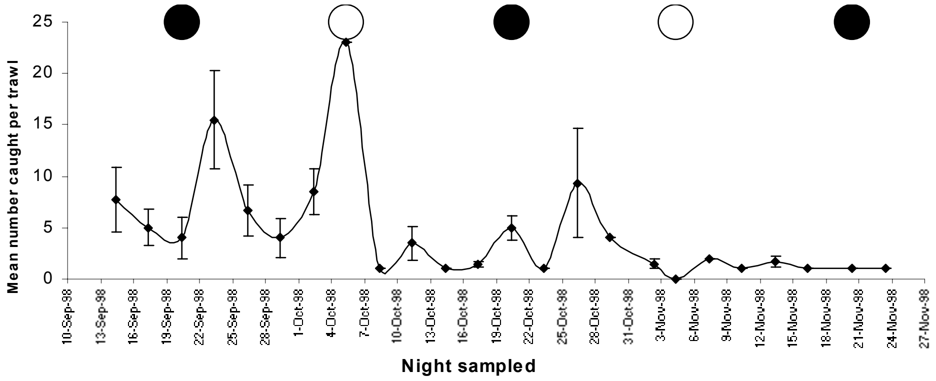


Figure 5.2.5 The variation in catch rates of four prawn species sampled every third night for just over two lunar cycles. On each night five one-nautical transects were sampled. Vertical bars represent one standard error above and below the mean.

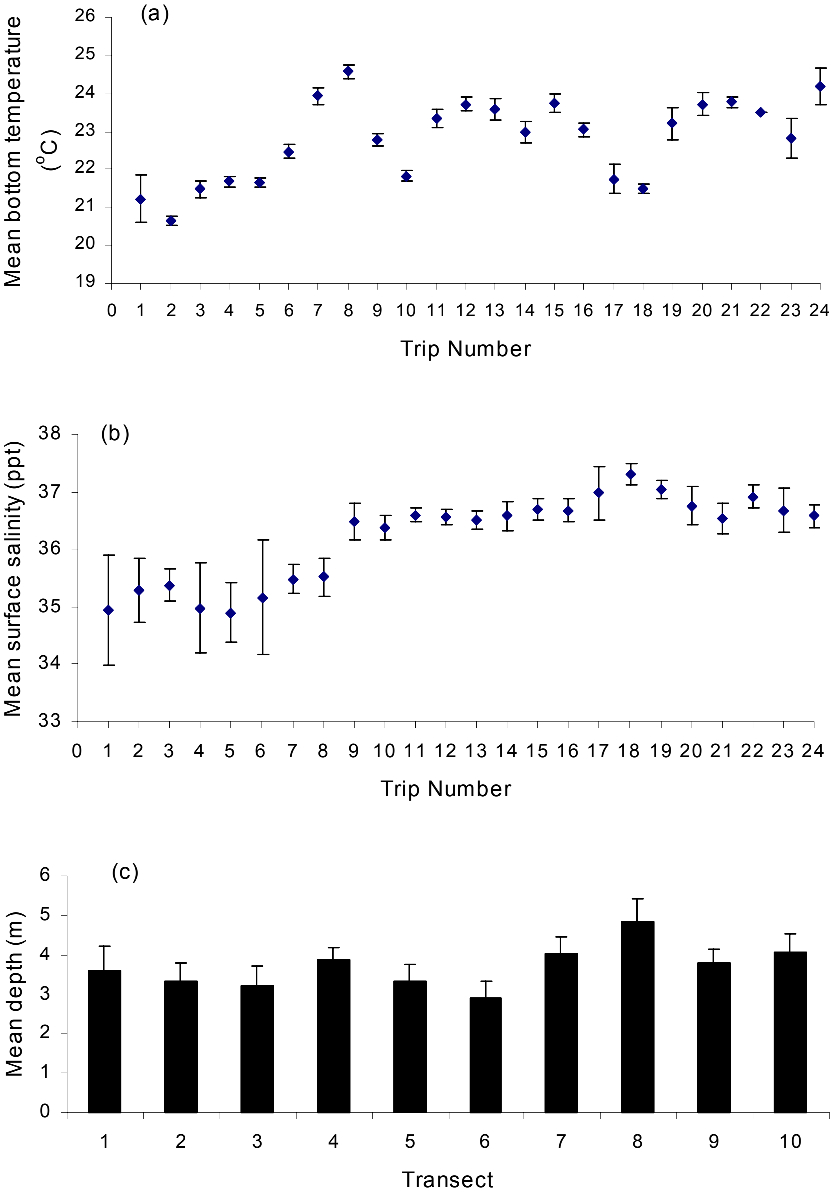


Figure 5.2.6 Mean water temperature and salinity for each trip and the mean depth of the transects.

Transect was the single most influential factor affecting catch rates of *P. plebejus* (Table 5.2.2). The time-of-night effect was also highly significant ($P<0.001$); catch rates were low early in the evening and shortly before sunrise and displayed two modal peaks throughout the night (Figure 5.2.7). There was also a significant transect–lunar phase interaction term, which suggested that any influence of lunar phase on catch rates varied across transects. The adjusted values for this interaction term revealed that it was due largely to a decline in catch rates at two transects (Transects 6 and 7) during some lunar phases, but no clear lunar phase effect was apparent. A second interaction term (transect by time of night) was marginally significant ($P=0.055$). The model explained 49.5% of the variation in the catch rate of *P. plebejus*.

Table 5.2.2 Accumulated analysis of variance of factors found to have a significant influence on the catch rate of *P. plebejus*.

Change	**d.f.**	**Sum of squares**	**Mean square**	**Variance ratio**	**F probability**
Transect	9	8.2959	0.9218	5.49	<.001
Time of night	4	4.6993	1.1748	7.00	<.001
Transect–Lunar phase	30	10.3681	0.3456	2.06	0.013
Transect–Time of night	30	8.473	0.2824	1.68	0.055
Residual	46	7.7199	0.1678		
Total	119	39.5562	0.3324		

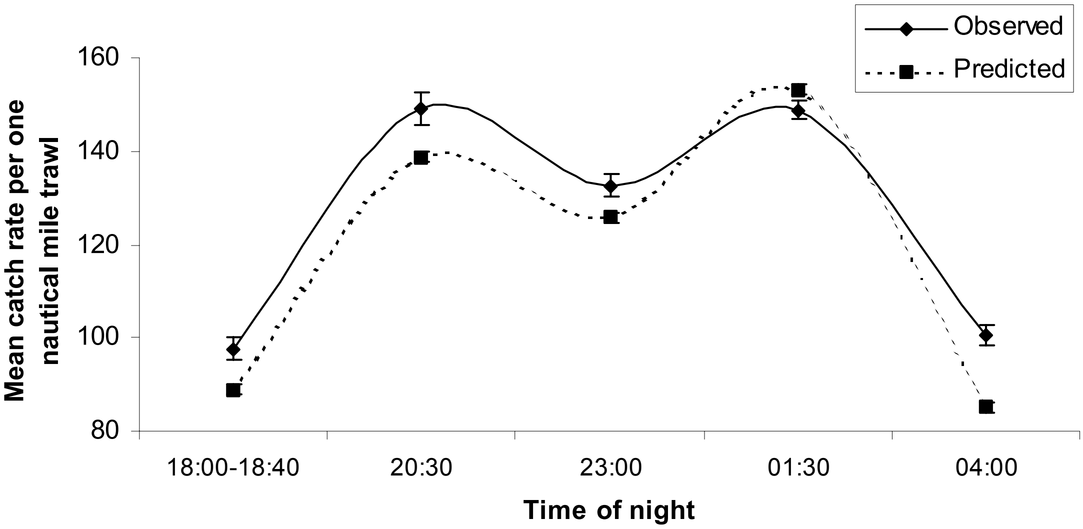


Figure 5.2.7 The mean catch rates of *P. plebejus* sampled at different times of the night. The adjusted means are based on the accumulated analysis of variance model in Table 5.2.2. Vertical lines represent one standard error either side of the mean.

Catch rates of *M. bennettae* varied significantly with transect, salinity, lunar phase and barometric pressure (Table 5.2.3). There was also a significant interaction between time of night and lunar cycle. The influence of salinity should be interpreted with caution because both catch rates and salinity increased over the sampling period and therefore it is difficult to determine whether catch rates were affected by salinity or whether the two parameters simply co-varied. The model explained 42.1% of variation.

Catch rates of *M. bennettae* were high early in the evening (18:00–18:40, Figure 5.2.8), which is in contrast to *P. plebejus* (Figure 5.2.7). Catch rates of *M. bennettae* were lowest during the full moon (Phase 3, Figure 5.2.9).

Table 5.2.3 Accumulated analysis of variance of factors found to have a significant influence on the catch rate of *M. bennettae*.

Change	d.f.	Sum of squares	Mean square	Variance ratio	F probability
Transect	9	18.0573	2.0064	4.39	<.001
Salinity	1	9.2179	9.2179	20.15	<.001
Lunar phase	3	5.5519	1.8506	4.05	0.01
Time-of-night	4	6.6076	1.6519	3.61	0.009
Barometric pressure	1	2.2256	2.2256	4.87	0.03
Time-of-night.Cycle	15	12.9875	0.8658	1.89	0.035
Residual	86	39.3415	0.4575		
Total	119	93.9892	0.7898		

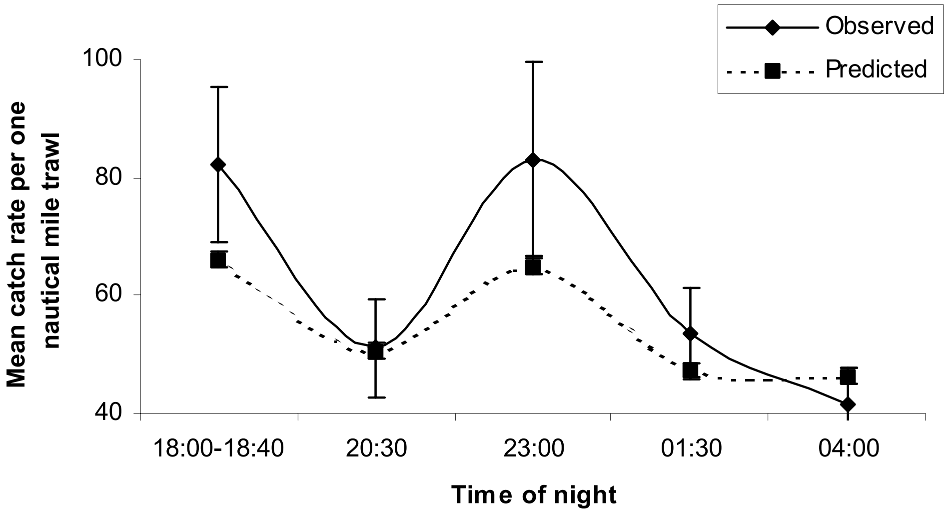


Figure 5.2.8 The mean catch rates of *M. bennettae* sampled at different times of the night. The adjusted means are based on the accumulated analysis of variance model in Table 5.2.3. Vertical lines represent one standard error either side of the mean.

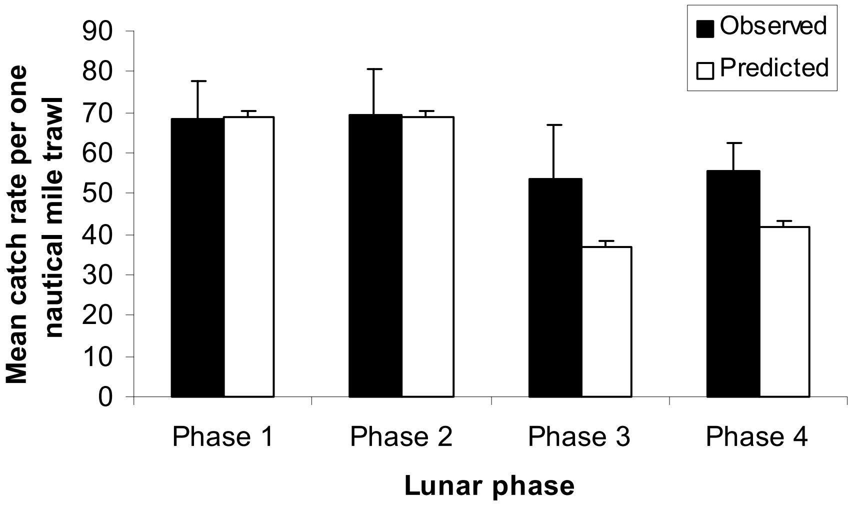


Figure 5.2.9 The mean catch rates of *M. bennettae* sampled at different lunar phases. The adjusted means are derived from the accumulated analysis of variance model in Table 5.2.3. Vertical lines represent one standard error either side of the mean.

The catch rate of *P. esculentus* was affected by lunar cycle on some transects (Table 5.2.4). Catch rates for *P. esculentus* were also affected by transect, depth, salinity and two interaction terms. The model explained 52.3% of the variation in catch rates.

Table 5.2.4 Accumulated analysis of variance of factors found to have a significant influence on the catch rate of *P. esculentus*.

Change	**d.f.**	**Sum of squares**	**Mean square**	**Variance ratio**	**F probability**
Lunar Cycle	3	16.1816	5.3939	7.04	<.001
Transect	9	21.2528	2.3614	3.08	0.005
Depth	1	5.2742	5.2742	6.89	0.011
Salinity	1	4.5877	4.5877	5.99	0.018
Transect.Lunar Phase	30	64.1304	2.1377	2.79	<.001
Lunar Cycle.Transect	20	37.34	1.867	2.44	0.005
Residual	55	42.1238	0.7659		
Total	119	190.8906	1.6041		

The analysis for *T. fulvus* was complicated by the high incidence of zero catches; 61 of the 120 observations had zero catch. Transect, salinity and the interaction term were the only significant factors. The model explained 43.7% of the variation.

Table 5.2.5 Accumulated analysis of variance of factors found to have a significant influence on the catch rate of *T. fulvus*.

Change	d.f.	Sum of squares	Mean square	Variance ratio	F probability
Transect	9	143.043	15.894	9	<.001
Salinity	1	18.965	18.965	10.74	0.001
Transect.Salinity	9	34.659	3.851	2.18	0.029
Residual	100	176.596	1.766		
Total	119	373.263	3.137		

5.2.4 Discussion

The results suggest that lunar phase is unlikely to be a significant main treatment effect on the catch rate of young (7–32 mm CL) *P. plebejus*. There was a significant transect–lunar phase interaction term in the model as catch rates varied significantly at only two of the 10 transects during certain lunar phases. Lunar phase was not a significant influence under the vast majority of transect–lunar phase combinations and for this reason, it does not appear to be an important factor for consideration in developing a fishery-independent recruitment index for eastern king prawns.

These results contrast with those of Griffiths (1999) who found a significant lunar phase effect on the catch rate of *P. plebejus* in a temperate intermittently open coastal lagoon in New South

Wales. Griffiths sampled prawns along transects (100 m long x 4 m wide) on a fortnightly basis around the time of the new and full moons for three consecutive lunar cycles. The sampling method appeared to be based upon visually spotting prawns with an underwater lamp and then catching them with a hand-held scoop net. The depth of water was 1–1.5 m, which was considerably shallower than the depths encountered during the present study. Griffiths found that catch rates were consistently higher during the new-moon phase, which is difficult to explain given the findings from the present study. Differences between the two studies may be due to differences in a) depth and the subsequent effect on the attenuation of light through the water column, b) bottom habitat type and/or, c) the methods used for catching prawns (spotting prawns and catching with scoop net versus beam trawl). The ability to visually spot prawns with a lamp and catch them may be higher during the new-moon phase. As such, there may be a method-dependent increase in *catchability* in the coastal lake that is enhanced during the new-moon phase. Differences in the size of the prawns between the two studies are unlikely to account for the conflicting results because the size range of the prawns sampled in both studies was similar, although the modal size obtained by Griffiths was larger.

Fishery logbook data and research trawls indicate that lunar phase has a significant influence on the catch rate of adult *P. plebejus* in relatively deep (100–300 m), offshore waters (Courtney *et al.* 1996). They found that catch rates peaked 2–3 days before the full moon and declined for about 7 days following the full moon. The variation was significant and in the order of a 2–3 fold increase. Courtney *et al*. (1996) also found that catch rates of adult males and females were affected differently, resulting in a cyclic lunar phase pattern in the sex ratio of the catch. The sex ratio (males:females) was normally dominated by females, but approached 1:1 during the peak period (2–3 days before the full moon). Combining data from the present study with those of Courtney *et al*. (1996), it appears that the influence of lunar phase upon catch rates may differ markedly between adults in deep, offshore waters and sub-adults in shallow coastal areas. While lunar phase may be an important consideration for monitoring spawning stocks offshore, it is unlikely to be a significant factor for monitoring recruitment.

Offshore, fishers regulate their fishing trips to take account of the lunar phase variation. In shallower waters, such as Moreton Bay, the influence of lunar phase on when fishers prefer to fish is more complex because of the multi-species composition of the catches and also because trawling in Moreton Bay is restricted to Sunday to Thursday nights. Results from the present study suggest that total prawn catches in Moreton Bay are likely to be higher around the time of Phase 1 (new moon ± 3 days) and Phase 2 (half moon waxing to full moon ± 3 days) as catch rates of the dominant species *M. bennettae* are higher during these phases (Figure 5.2.9).

Catch rates of all four species varied significantly between transects (Tables 5.2.2–5.2.5). Clearly, the location of individual transects is an important source of variation. The only abiotic data measured for each transect were depth, temperature and salinity. In general, these did not vary greatly because the sampling was conducted over a relatively small area and short period (about 10 weeks). Depth and temperature had no significant influence for any species and the apparent salinity effect detected for *M. bennettae* and *T. fulvus* may have simply reflected seasonal variation in abundance. While the specific abiotic factors responsible for differences between transects remain largely unknown, they are likely to be at least partially due to differences in sediment type, vegetative cover and availability of food and shelter.

The time-of-night effect was significant for both *P. plebejus* and *M. bennettae*, although the response was very different for the two species. Catch rates of *P. plebejus* were low early in the evening (18:00–18:40), displayed two minor peaks throughout the night with a lull around 23:30, and declined by 04:00 (Figure 5.2.7). In contrast, catch rates of *M. bennettae* (Figure 5.2.8) were high early in the evening (18:00–18:40), peaked at 23:00 and declined to a minimum at 04:00. Catch rate trends for the two species throughout the night were almost the inverse of one another. For *P. plebejus* most of the variation occurred early in the evening and shortly before sunrise. There was less variation between 20:30 and 01:30. The recruitment-monitoring program should take account of this source of variability in catch rates.

5.2.5 Conclusions

- There was no obvious or simple influence of lunar phase upon the catch rate of eastern king prawn recruits. A significant interaction term (transect by lunar phase) revealed that lunar phase did affect catch rates, but only at a minority of transects and only during certain phases. For the majority of transects, lunar phase had no significant effect and for this reason it is not considered to be an important consideration for monitoring recruitment.

- The time of night that eastern king prawn recruits were sampled is an important consideration and should be taken into account whenever sampling. Catch rates of eastern king prawn recruits were low early in the evening and shortly before dawn. Catch rates should be standardised to take account of this source of variation.

5.2.6 References

Courtney, A. J., Die, D. J. and McGilvray, J. G. (1996). Lunar periodicity in catch rate and reproductive condition of adult eastern king prawns, *Penaeus plebejus* in coastal waters of south-east Queensland, Australia. *Marine and Freshwater Research* **47,** 67–76.

Griffiths, S. P. (1999). Effects of lunar periodicity on catches of *Penaeus plebejus* (Hess) in an Australian coastal lagoon. *Fisheries Research* **42**, 195–199.

Wassenberg, T. J., and Hill, B. J. (1994). Laboratory study of the effects of light on the emergence behaviour of eight species of commercially important adult penaeid prawns. *Australian Journal of Marine and Freshwater Research* **45**, 43–50.

6. Objective 2. Develop a program designed to monitor long-term recruitment levels and changes in recruitment levels of eastern king prawns.

Survey of eastern king prawn recruits in coastal waters of south-east Queensland.

6.1 Introduction

The previous section (Section 5) considered seasonal, spatial and short-term (i.e. lunar and diel) variation in the catch rate of eastern king prawn recruits in Moreton Bay. In this section the large-scale spatial variation in the relative abundance of recruits along the south Queensland coast was examined using data obtained from a trawl survey of areas that are likely to be important sources of recruits. The likelihood of detecting a change in recruitment from one year to the next was also examined and specifically whether a 20% or 50% change could be detectable with acceptable confidence intervals.

6.2 Methods

A 10-day trawl survey of eastern king prawn recruits was conducted in the period 22 October 1999 to 8 November 1999 over the known spatial distribution of recruits in south-east Queensland. Five areas were sampled: the Wide Bay Bar region off southern Fraser Island; Moreton Bay; and areas directly east of and adjacent to Moreton Island; North Stradbroke Island; and South Stradbroke Island (Figure 6.1). The commercial trawler *Elizabeth G* was chartered specifically for the survey. It was fitted with two 3.5-fathom Yankee Doodle trawl nets made from 9-ply polyethylene and towed with small wooden otter boards. The influences of two different mesh sizes on the catch rate of recruits were compared. The port side net had a mesh size of 1 ¼" while the starboard net mesh size was 1 ½". Since a previous study in Moreton Bay had shown that catch rates were negatively correlated with depth, each of the five areas was stratified into 2 or 3 depth strata, resulting in a total of 11 strata (Figure 6.1). Stratifying is generally encouraged as it tends to reduce the standard error, increase the precision of the population mean and lower the coefficient of variation (CV) (Sparre and Venema 1992, Hilborn and Walters 1992). One-nautical mile sampling stations were randomly allocated to each strata, and the precise location of each station was determined using differential global positioning system. Bottom water temperature, surface salinity and average depth were recorded from each sampling station. After each station was sampled all of the prawns collected were sorted from the bycatch, placed into labelled plastic bags and frozen on board. The species, sex and carapace length (CL) of each prawn was determined in the laboratory and entered into a database.

The survey analysis was based on a stratified random sampling design that considered the variation and standard error within strata. A detailed description and example of this method is provided by Haddon (1997) in the FRDC Quantitative Fisheries Training Unit's *Introduction to Fisheries Methods*. In addition, an accumulated analysis of variance was undertaken using Genstat statistical software to examine factors affecting catch rates and to provide information on how the survey might be improved by further stratification. The response variate was the number of prawns (y) caught per one nautical mile trawl [log transformed ($\ln(y+0.1)$)]. Explanatory variables were area, net mesh size, temperature, depth and salinity.

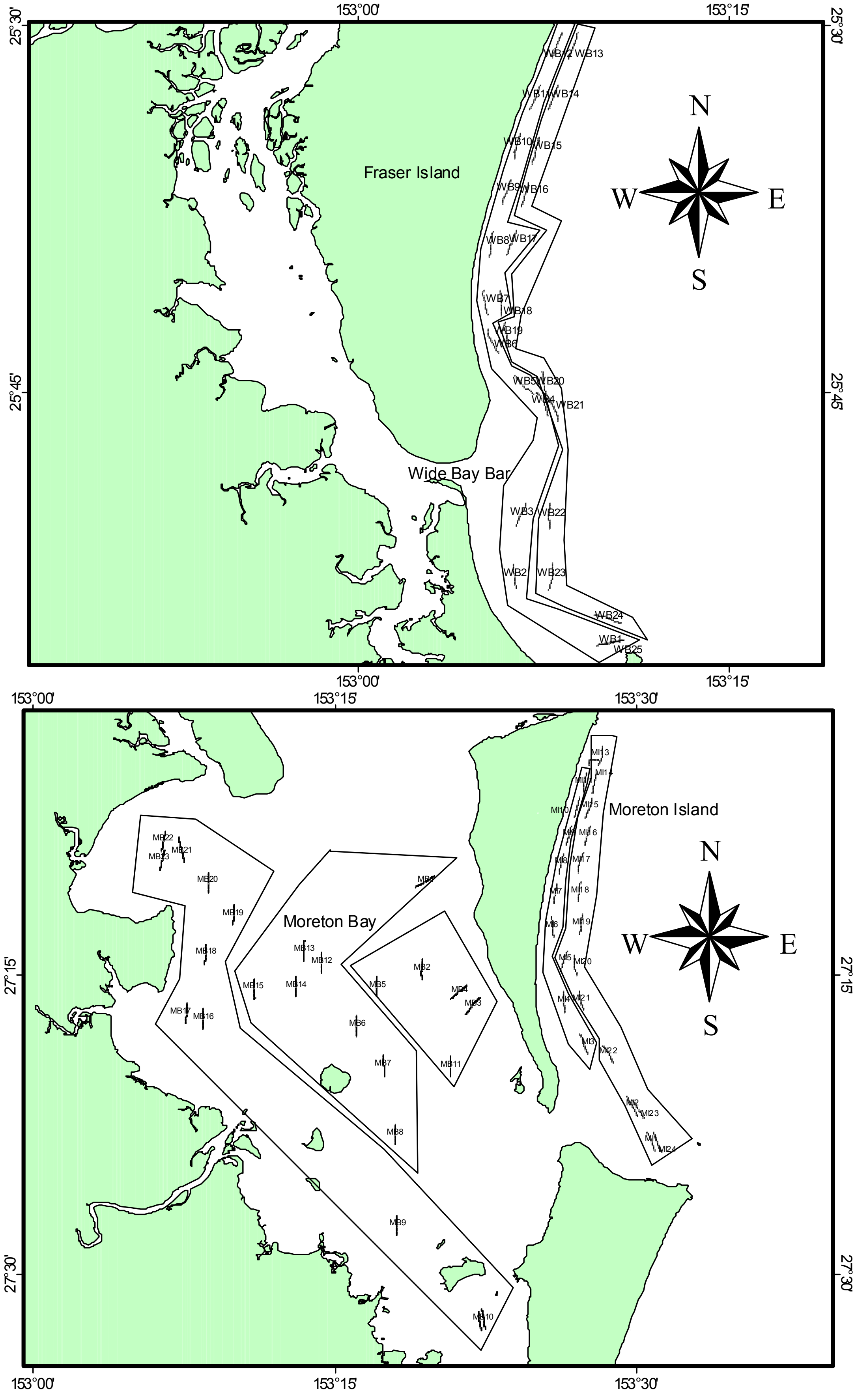


Figure 6.1. Location of 115 one-nautical mile transects along the south Queensland coast. The five areas sampled were the Wide Bay Bar, Moreton Bay and areas east of Moreton Island, North Stradbroke Island and South Stradbroke Island. Each area was stratified into depth zones, resulting in a total of 11 strata. (Cont. next page)

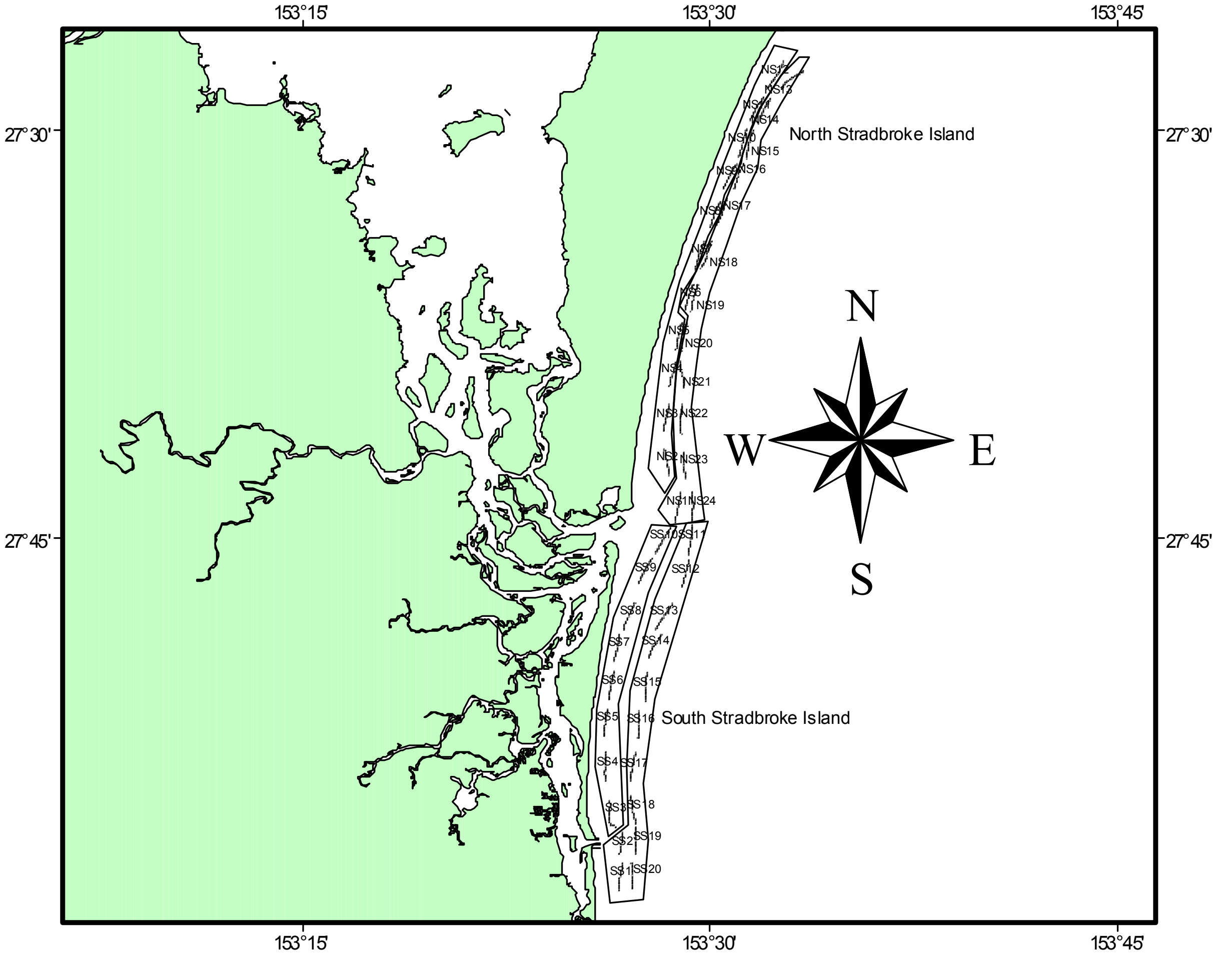


Figure 6.1 (Continued)

Power analysis was used to examine whether a change in the catch rate could be detected if a similar survey was undertaken in the future. The ability to detect two levels of decline (20% and 50%) was examined.

6.3 Results

6.3.1 Survey results

A total of 35 013 penaeid prawns of 14 species were collected (Table 6.1) from the 115 one-nautical-mile transects (Figure 6.1). *Penaeus plebejus* were the most numerous, comprising 43% of the prawns collected, followed by *Trachypenaeus fulvus*, *Metapenaeus macleayi* and *Metapenaeus bennettae*. Collectively these four species accounted for 98% of all prawns caught.

The size class frequency distribution for *P. plebejus* (Figure 6.2) displayed a mode at 17–20 mm CL. There were very few individuals in the samples that were less than 10 mm CL or greater than 37 mm CL. While the overall number of males and females were similar (7762 and 7336 respectively), males tended to dominate the smaller size classes and females the larger. This feature of the length frequency distributions for *P. plebejus* was also observed by Courtney and Masel (1995). No males larger than 36 mm CL were collected, while the largest female was 50 mm CL.

Table 6.1 Numerical breakdown of the prawn species caught in the trawl survey conducted in eastern king prawn recruitment areas of south Queensland during October – November 1999.

Species	Number caught	% of Total	Cumulative %
Penaeus plebejus	15 098	43.12	43.12
Trachypenaeus fulvus	12 089	34.53	77.65
Metapenaeus macleayi	5 256	15.01	92.66
Metapenaeus bennettae	1 863	5.32	97.98
Parapenaeopsis cornuta	165	0.47	98.45
Metapenaeopsis palmensis	141	0.40	98.85
Penaeus latisulcatus	81	0.23	99.09
Metapenaeopsis novaeguineae	80	0.23	99.31
Metapenaeus ensis	66	0.19	99.50
Penaeus esculentus	66	0.19	99.69
Trachypenaeus anchoralis	49	0.14	99.83
Metapenaeus endeavouri	37	0.11	99.94
Atypopenaeus formosus	11	0.03	99.97
Penaeus merguiensis	11	0.03	100.00
Total	**35 013**	**100.00**	

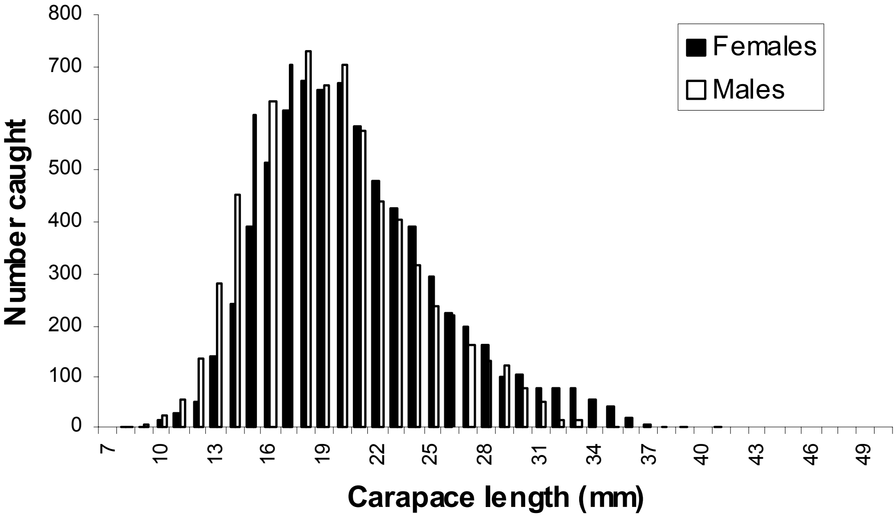


Figure 6.2 Size class frequency distribution of eastern king prawns obtained from the survey.

In general, there was relatively little variation in the average size of the prawns across strata (Figure 6.3a). The smallest mean (16.7 mm CL, n=575 prawns) was found at the South Stradbroke shallow strata and the largest mean (22.4 mm CL, n=2,280) occurred at the Moreton Island deep strata. The mean depth of the strata ranged from 6.3 m for the Moreton Bay shallow stratum to 24.7 m for the deep stratum off Moreton Island (Figure 6.3b). There was relatively little variation in bottom temperature. The minimum and maximum temperatures recorded for individual trawls were 20.4°C to 24.3°C, respectively. Depth and salinity were positively correlated. Mean salinities ranged from a minimum of 31.9 ppt at the Moreton Bay shallow stratum to a maximum of 34.9 ppt at the South Stradbroke shallow stratum.

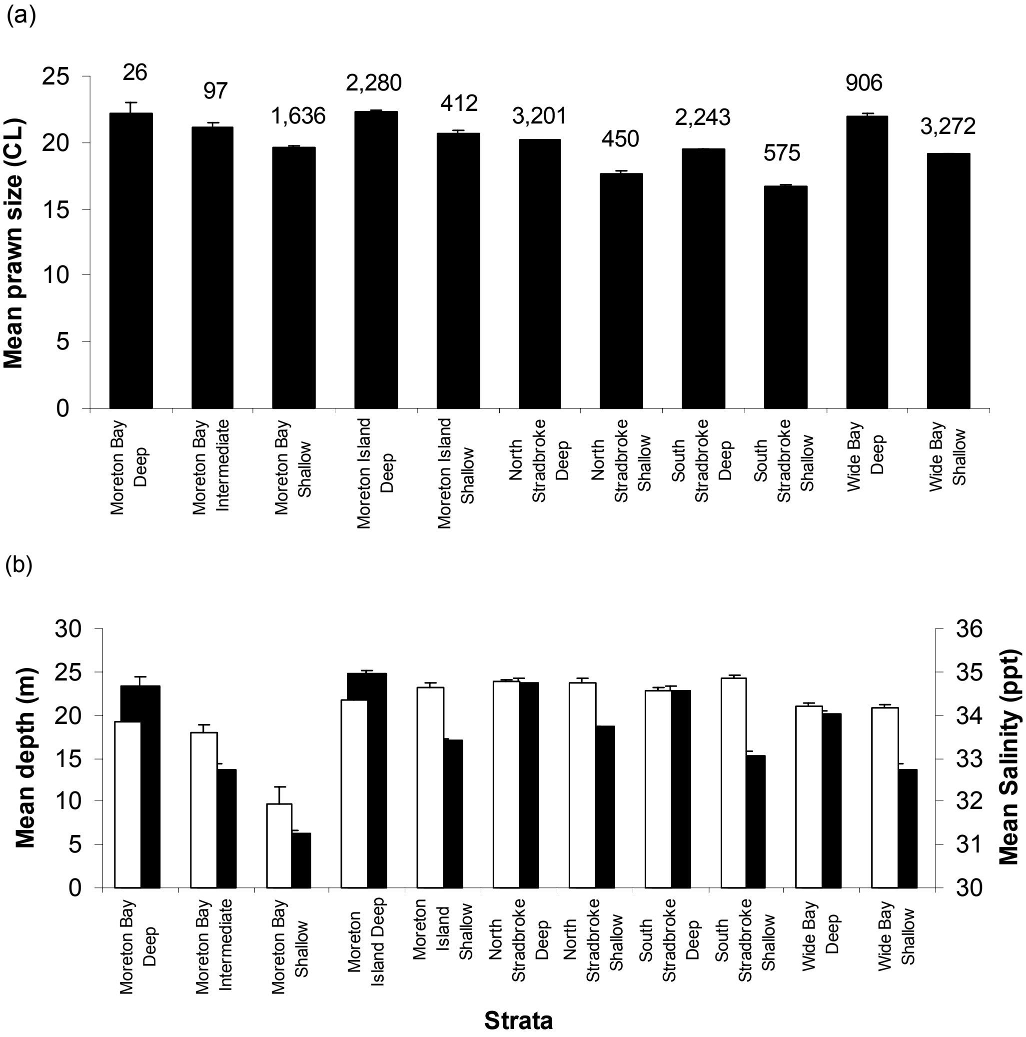


Figure 6.3 (a) The mean size (CL mm) and total number (above bars) of eastern king prawns caught in each strata during the survey. (b) Mean depth (solid bars) and surface salinity (open bars) for each strata. Vertical lines represent one standard error.

The mean catch rate of eastern king prawns varied between a minimum of 5.2 prawns per nautical mile trawl in the Moreton Bay deep stratum to a maximum of 228.6 prawns per nautical mile trawl in the North Stradbroke deep stratum (Table 6.2). Most of the variance (85%) was attributed to a single stratum—the Moreton Bay shallow stratum. This was because the high standard deviation and large area (383 square kilometres) associated with this stratum resulted in a high spatial weighting. This source of variation and the resulting coefficient of variation of 11.2% could be reduced in a future survey by a) increasing the number of trawls in the Moreton Bay shallow stratum, b) reducing the area, or c) further stratification. The variation may also be reduced by omitting this stratum from the survey altogether, but since the catch rates were relatively high (163.6 prawns per nautical mile trawl) it appears to be an important area for recruits and should therefore be retained.

From the survey it was estimated that the relative number of recruits in the 11 strata was 8 697 477. This estimate is relative (rather than absolute) as the survey does not take account of a) the proportion of prawns that were in the path of the net that actually entered the net, or b) the selectivity (retention) of the trawl mesh once prawns were inside.

6.3.2 Factors affecting survey catch rates

Preliminary analysis revealed that there was no significant difference between the two nets and so subsequent analyses were undertaken using pooled catches. There was a significant interaction between Area and Depth (Table 6.3). Both the observed and adjusted catch rates from the model revealed that for most areas (east of Moreton Island, South Stradbroke and North Stradbroke) catch rates increased with depth. However, for Moreton Bay and, to a lesser extent, the Wide Bay Bar area, catch rates declined with depth. Bottom temperature had no significant influence on catch rates.

Table 6.2. Accumulated analysis of variance of main factor and interaction term effects on the catch rate of eastern king prawns derived from survey results.

Change	d.f.	Sum of squares	Mean square	Variance ratio	F probability
Area	4	94.798	23.699	13.53	<0.001
Salinity	1	117.883	117.883	67.28	<0.001
Depth	1	26.866	26.866	15.33	<0.001
Depth.Area	4	92.698	23.174	13.23	<0.001
Residual	104	182.23	1.752		
Total	114	514.475	4.513		

There was also a significant salinity effect (Table 6.3)—catch rates tended to decline with increasing salinity (Figure 6.4).

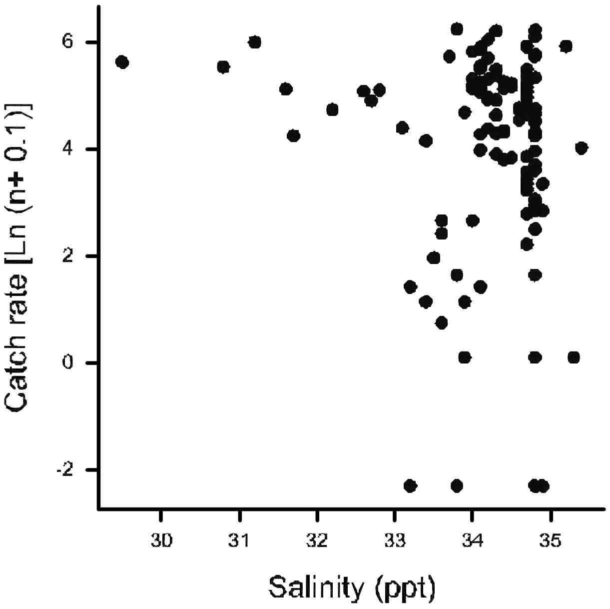


Figure 6.4 The relationship between salinity and observed catch rate of eastern king prawn recruits from 115 trawls located off south Queensland.

Table 6.3 Stratified random sampling survey analysis, which considers variation within strata, of eastern king prawn recruit catch rates from 115 sampling stations in south-east Queensland. Survey conducted October–November 1999.

Stratum	Moreton Bay			Moreton Island		North Stradbroke		South Stradbroke		Wide Bay Bar		Totals
	Deep 1	Intermediate 2	Shallow 3	Deep 4	Shallow 5	Deep 6	Shallow 7	Deep 8	Shallow 9	Deep 10	Shallow 11	
Mean catch rate of prawns	5.2	12.1	163.6	152.0	51.5	228.6	45.0	186.9	71.9	90.6	218.1	
No. stations sampled	5	8	10	15	8	14	10	12	8	10	15	115
Strata area (sq km)	109.02	280.94	383.33	105.94	38.25	43.53	32.64	47.08	34.25	72.98	101.38	1249.34
SD of mean	5.26	27.52	115.82	70.12	44.47	135.03	41.69	168.47	155.49	41.08	122.93	
Strata weight	0.09	0.22	0.31	0.08	0.03	0.03	0.03	0.04	0.03	0.06	0.08	1
Weighted mean	0.45	2.73	50.20	12.89	1.58	7.97	1.18	7.04	1.97	5.29	17.70	108.99
Weighted standard error	0.04	4.79	126.28	2.36	0.23	1.58	0.12	3.36	2.27	0.58	6.63	148.24

Stratified standard error	**12.18**
Total number of recruits	**8,697,477**
Coefficient of variation	**11.2**

The model explained 61.2% of the variation in catch rates. A plot of the residuals against the fitted (adjusted) values from the model (Figure 6.5) indicated that the higher fitted values (adjusted catch rate values between 4 and 6) fitted the model better than the lower fitted values (values between –1 and 2). An alternative generalised linear model with a Poisson distribution was trialed to improve upon the distribution of the residuals but no significant improvement in homoscedasticity was obtained.

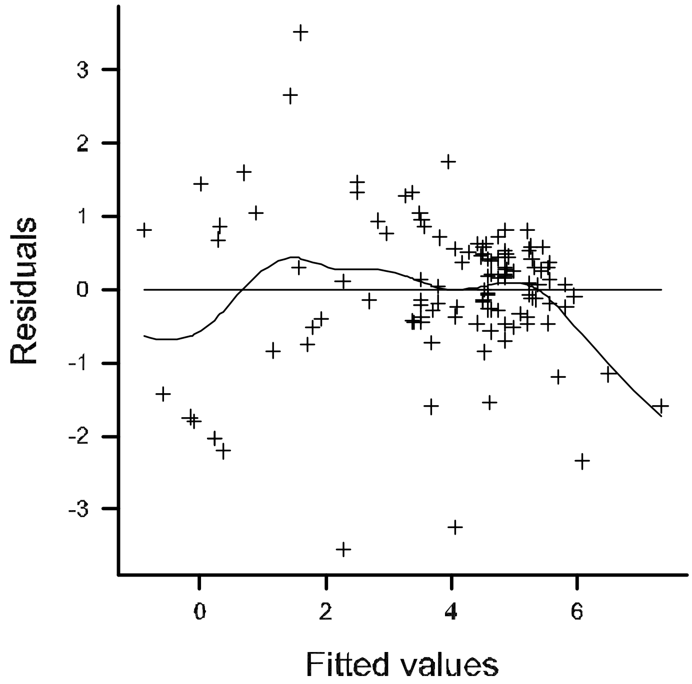


Figure 6.5 Plot of the residuals against adjusted catch rates.

6.3.3 Power analysis and the likelihood of detecting change in catch rates from future surveys

An estimate of the adjusted mean catch rate of recruits was obtained from the general linear model described in Table 6.3. The adjusted mean catch rate was 68.2 prawns per one nautical mile transect.

The power analysis (Table 6.4) indicated that a 20% decline in catch rates (i.e. from 68.2 to 54.6 prawns per one nautical mile trawl) would be unlikely to be detectable if the survey was repeated. The smallest decline that could be detected with confidence is in the order of 30–40%. A 50% decline (i.e. from 68.2 to 34.1 prawns per one nautical mile) would be detectable with high confidence.

Table 6.4 The adjusted mean catch rate of eastern king prawn recruits and the power to detect a 20% or 50% decline in catch rates.

Adjusted mean catch rate from model (prawns per nautical mile)	Number of one-nautical mile trawls used in model to estimate mean	Variance (Residual error mean square)	Power to detect 20% decline	Power to detect 50% decline
68.2	115	1.752	0.242	0.976

* Power values larger than 0.8 are generally considered to be effective for detecting change

6.4 Discussion

The survey results showed that recruit catch rates were affected by area and salinity, and that the effect of depth differed between areas. Moreton Bay catch rates declined with depth while in most other areas catch rates increased with depth.

Catch rates were negatively correlated with salinity. However, this should be interpreted with caution as salinity varied between geographic locations, with all salinity measurements lower than 34 ppm coming from Moreton Bay. If the Moreton Bay samples were omitted then a salinity influence may not have been detected. Salinity was also partially correlated with depth (correlation factor = 0.615) but this was largely due, and restricted to, the shallower stations (i.e. < 10 m) within Moreton Bay. Outside the Bay there was no correlation between salinity and depth.

In terms of identifying influential abiotic factors (such as temperature, depth or salinity) that should be considered in the survey design, it is disappointing that no simple relationship between an abiotic factor and recruit catch rate was identified. This makes it difficult to stratify the survey on any single abiotic factor. For example, it would have been relatively simple to design the survey based on depth strata. However, the relationship between depth and recruit catch rate varied between areas.

The survey design could be improved by obtaining additional trawls in the shallow Moreton Bay stratum. This stratum had the largest area and highest spatial weighting of all strata, and accounted for 85% of the survey variance. Obtaining additional samples from this stratum would reduce its variance, lower the overall survey variance and reduce the coefficient of variation, thus making it more likely that a difference in catch rates could be detected from one year to the next.

It may also be possible to improve the survey design by reducing the duration or length of the trawls (reducing the swept area). In the present study all samples were based on one-nautical mile transects, which took approximately 25 minutes to trawl. It is possible that the duration of the trawls could be reduced, to say 0.5 nautical miles without decreasing the precision of the mean catch rate (as measured by the coefficient of variation). Folmer and Pennington (2000) evaluated changes in the design of a large annual pandalid shrimp (*Pandalus borealis*) bottom trawl survey conducted off the west coast of Greenland. They found that the coefficients of variation derived from 60-minute trawl tows were no more precise than 30-minute tows. They also found that reducing the duration of tows had several positive effects, including a) increasing the number of trawls, which lowered the coefficient of variation, b) reducing sample processing time, c) lowering the incidence of having to sub-sample the catch, d) improving length–frequency distributions as a result of increasing the number of stations sampled (Folmer & Pennington, 2000).

However, reducing the length of trawls may increase error as a result of uncertainty associated with the precise time and location at which the trawl contacts the bottom and commences sampling, and again when it lifts up off the bottom and stops sampling. The influence of this uncertainty varies with the length of transect sampled. With short transects (in the order of hundreds of metres), the influence of this imprecision upon the catch rate would be proportionally greater than for longer transects. Thus, although there may be some merit in reducing the length or duration of trawls, they should not be shortened to the point where the imprecision is unacceptably high. Trawls of less than 15 minutes or 0.6 nautical mile (1111 m) would probably have relatively high within-trawl imprecision and therefore should be discouraged.

Although the transects were randomised, their precise location was often constrained by the narrow and elongated shape of most of the strata which reflected the bathometry (Figure 6.1) and by minimising travelling time from one transect location to another and maximising bottom trawl sampling time (i.e. to maximise the cost-benefit of the charter the transects were often quite close to one another). The direction of the transects was predominantly along a north–south axis, which was also largely due to the necessity to follow depth contours.

The power analysis suggested that if the survey was repeated in its present form it would be unlikely that a 20% decline in recruit catch rates would be detectable (Table 6.4). A 50% decline could be detected with 95% confidence. The smallest decline that could be detected at this level of confidence is in the order of 30–40%. If the survey design was improved, as discussed above, it is likely that this level of detectable change would be reduced.

The total number of recruits in the 11 strata (8 697 477) was not an absolute estimate of population size in the swept area as this number does not take account of the efficiency of the gear to effectively sweep the area in front of the net or the selectivity of the mesh. If half of the prawns that were in the path of the net were retained (i.e. efficiency and selectivity = 0.5, Sparre and Venema, 1992), then the total number of recruits in the swept area would have been 17 394 954.

6.5 Conclusions

- A bottom trawl survey was undertaken to develop an index of recruitment of eastern king prawns to the south Queensland EKP fishery in 1999. The survey was based on 115 one-nautical mile trawls undertaken with a chartered commercial trawler operating throughout five areas (Moreton Bay, Wide Bay Bar, and areas east of Moreton, North Stradbroke and South Stradbroke Islands) that are known to be important areas for recruitment of eastern king prawns.

- The survey provided a mean catch rate of 68.2 prawns per one nautical mile transect. The coefficient of variation was 11.2%.

- A general linear model applied to the data revealed that the catch rates differed between areas and that the effect of depth differed between areas.

- A power analysis of the survey results suggested that in its current design, the survey would not be capable of detecting a 20% decline in catch rates. The smallest decline that could be detected would be in the order of 30–40%. A 50% decline would be detectable with high confidence intervals.

- The survey design could be improved by allocating additional transects in the Moreton Bay shallow stratum, locating transects randomly and possibly decreasing the duration of each trawl and increasing the number of trawls. These changes may reduce the survey coefficient of variation.

6.6 References

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7. Objective 3. Identify indices of effective spawning stock abundance for eastern king prawns in anticipation of the need to manage for increasing spawner biomass.

7.1 Introduction

The main reason for developing a fishery-independent index, rather than relying upon logbook data to monitor recruitmentm, is due to the multi-species recording problem of logbook data in those shallow inshore areas where recruitment occurs. In Moreton Bay, for example, fishers do not record their catch on a taxonomic basis, but rather record several species under the marketed name of 'bay prawns'. As such, the logbook data are of limited value for monitoring catch rates for eastern king prawn recruits.

Eastern king prawns remain in shallow waters for a relatively short period before migrating offshore to continue growing, and eventually, mature and reproduce. In the offshore waters they are the only commercially important and targeted prawn species trawled and so catch records are almost entirely mono-specific. As such, the logbook catch per unit effort (CPUE) data are likely to provide a relatively robust and cost-effective method for monitoring spawning stock levels. Alternative methods, such as fishery-independent surveys, would probably be too costly given the large spatial distribution of adults offshore.

The precise temporal and spatial conditions that result in *effective* spawning in the eastern king prawn fishery – that is, those spawning events that contribute to recruitment and stock renewal – are not well understood. This is despite the findings of several authors (Dakin 1938, Racek 1959, Ruello 1975, Rothlisberg *et al.* 1995 and Courtney 1995a, 1997).

A statistically robust and representative index of spawning stock should consider the proportion of females in the population that are spawning, the total abundance of females, and their size frequency distribution as these population characteristics all affect the number of eggs that are produced. To this end, this chapter has two objectives. The first is to develop a spawning stock index for the eastern king prawn fishery so that the temporal and spatial distribution of egg production can be examined. Once the seasonality of *effective* spawning events has been identified, the second objective will be to use logbook data (catch per unit of effort, CPUE) from these temporal and spatial 'windows' to examine and monitor trends in spawning stocks levels over several years. The logbook data will be used as proxy measures of spawning stock size.

7.2 Methods

7.2.1 Development of the spawning stock index

There were two phases to the methodology. The first phase was the development of a monthly spawning stock index for a 'typical or average' year for a number of areas off the Queensland coast that were considered to be major spawning areas. The index was based on the product of a) the size-related fecundity of females in the population, b) the proportion of females whose ovaries were classed as histologically mature or ripe and c) the abundance of females, and can be expressed thus:

$$Spawning\ stock\ index = p_{am} \times fs_{am} \times a_{am}$$

where:

p_{am} is the proportion of females spawning in area a and month m,

fs_{am} is the fecundity of the average size of females in area a and month m, and

a_{am} is an index of the relative abundance of females in area a and month m. Logbook data (catch per unit of effort, CPUE) were used to provide these indices of relative abundance.

The relationship between prawn size (carapace length—CL) and fecundity of ripe female *P. plebejus* (Courtney *et al.* 1995a) is expressed as:

$$Log_{10}\ number\ ripe\ oocytes\ = 0.0199 \times Carapace\ length\ (mm) + 4.7528$$

Monthly data on female size and the incidence of mature and ripe females were obtained from a two-year research project conducted in 1990–92 (Courtney 1997). Samples of eastern king prawns were purchased each month from fishers operating in four main fishing areas; the Swain Reefs (22°S), Lady Elliot and Lady Musgrave Islands (24°S), Fraser Island (26°S) and Mooloolaba (26°30'S). In addition, the same monthly measures were obtained over a 12-month (1990–91) dedicated research sampling program located off Moreton Island (27°S) that trawled three fixed-depth strata each month (see Figure 7.1). The sampling procedures and methods are described in more detail in Courtney (1997). These data were pooled from the two years to provide the typical or average monthly values.

Mean monthly CPUE from each area was used as an index of relative abundance. This was achieved by pooling data across years and generating an average monthly pattern.

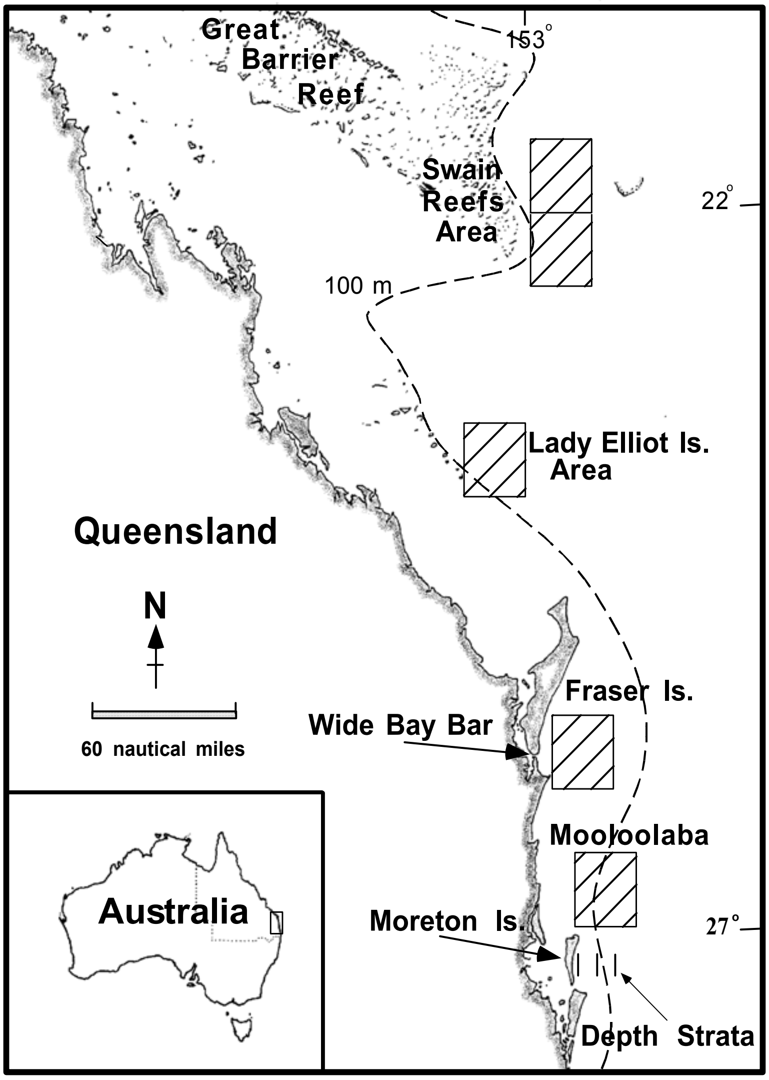

Figure 7.1 Sites in south-east Queensland where reproductive samples of eastern king prawns were obtained from 1990–92. Commercial vessels provided regular monthly samples from the logbook grids and research vessel samples were obtained from the depth strata transects.

Once the months of high egg production were identified for each area, the second phase used logbook CPUE from these months as a proxy measure of spawning stock. Trends in both the observed and adjusted CPUEs were examined. The adjusted CPUEs were derived from an accumulated analysis of variance that corrected the observed data for the effects of vessel, year and lunar phase.

7.3 Results

Swain Reefs area

The size of females sampled tended to increase with depth and decrease with latitude. Females from the Swain Reefs area, which was the deepest and most northerly area sampled, had the largest mean carapace length (52.7 mm, Figure 7.2). The depths at which these samples were obtained varied between 136 and 240 m.

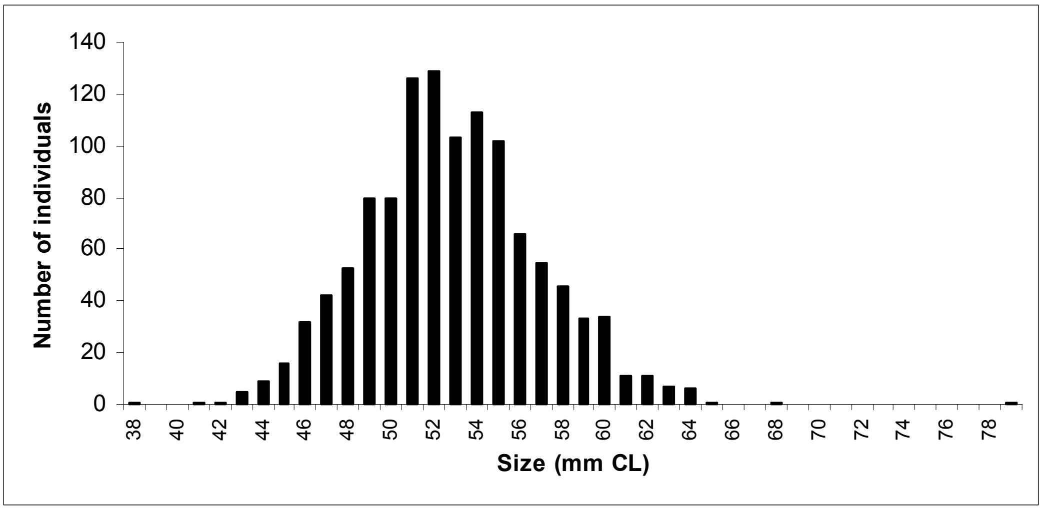

Figure 7.2 The size class frequency distribution of female eastern king prawns obtained from the Swain Reefs region.

The proportion of females from the Swain Reefs that were classed as mature or ripe peaked in January (0.93) and from May (0.95) to June (0.96) and was at a minimum in February (0.54) and August (0.52) (Figure 7.3a).

The mean size of females peaked in November and was at a minimum in May (Figure 7.3b).

The monthly mean catch rates from the Swain Reefs area (logbook grids W26, W27 and W28) peaked at 150–160 kilogram per boat night from March to June (Figure 7.3c), suggesting that abundance was highest at that time of the year. Catch per unit effort declined markedly from June to a minimum of about 95 kilogram per boat night in November.

The product of these parameters indicated that the main period of egg production in the Swain Reefs area was from May to June. There was also high egg production in January. The lowest periods of egg production were February, and September–December (Figure 7.3d).

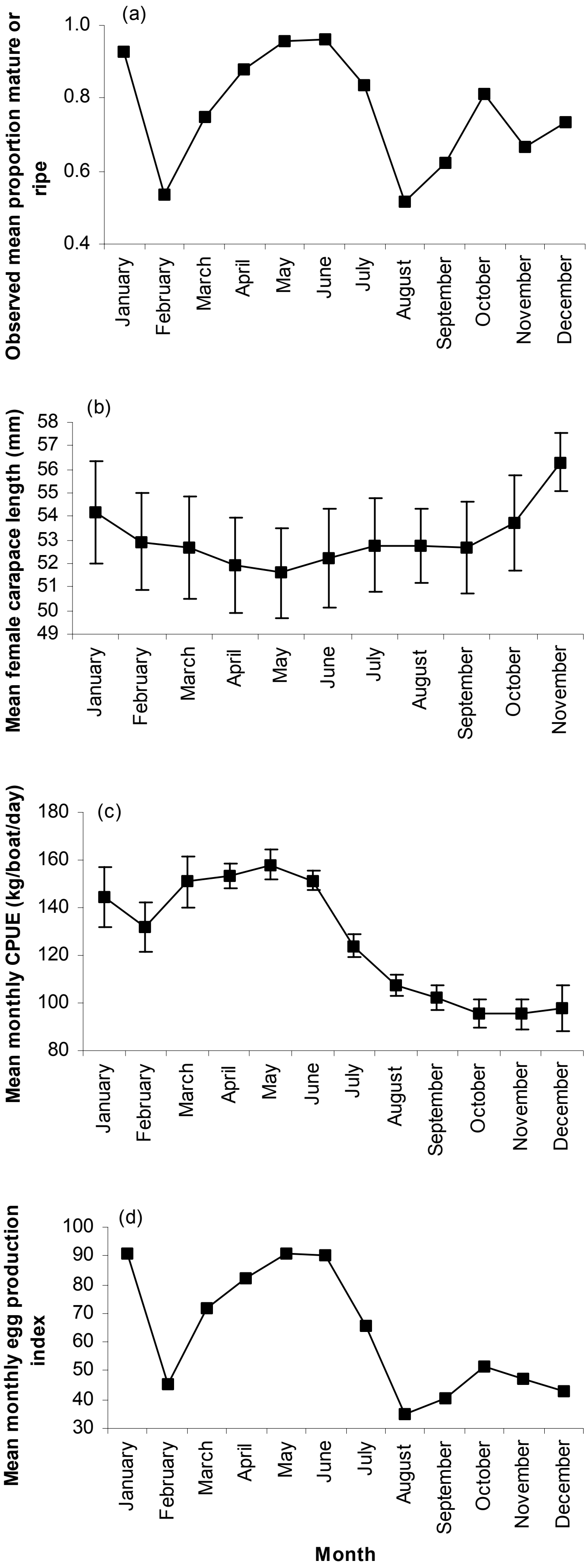

Figure 7.3 Monthly variation in the reproductive dynamics of eastern king prawns in the Swain Reefs area. a) Proportion of females with mature or ripe ovaries, b) Mean size of females, c) Mean monthly catch rate (based on logbook data from Grids W26, W27 and W28 from 1988-2000), and d) mean monthly egg production (based on the spawning stock index). Vertical lines represent 1 standard error either side of the means.

Lady Elliot and Lady Musgrave Islands area

Females from the Lady Elliot and Lady Musgrave Islands area were generally smaller than those from the Swain Reefs and had a mean size of 46.9 mm CL (Figure 7.4).

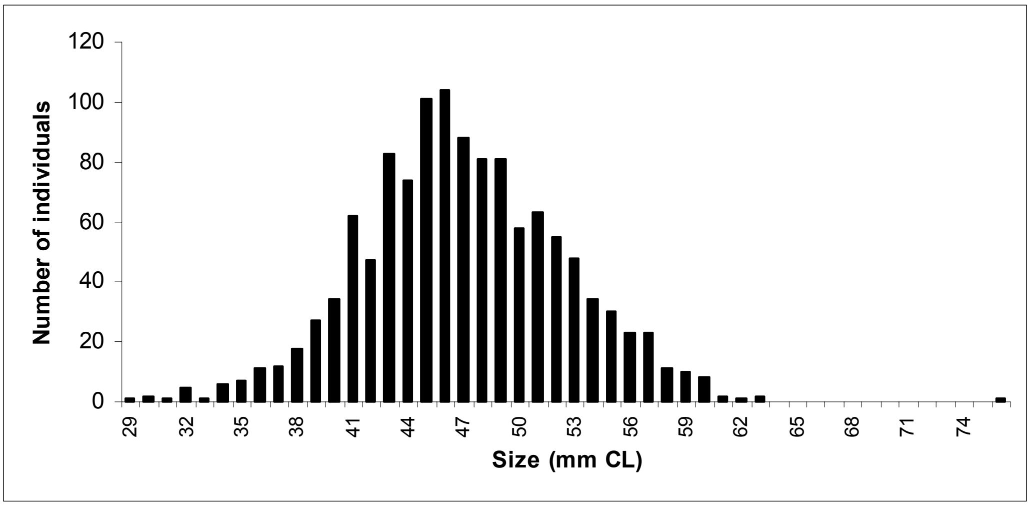

Figure 7.4 The size class frequency distribution of female eastern king prawns obtained from the Lady Elliot and Lady Musgrave Islands area.

The proportion of females classed as mature or ripe varied considerably throughout the year (Figure 7.5a). Peak periods occurred in April (0.88) to May (0.94) and February (0.93). The proportion was lowest in November (0.53) and December (0.53).

The mean size of females remained between 45–50 mm CL for most of the year but declined markedly from October to a minimum of about 41 mm CL in November, possibly indicating an influx of recruits into the population (Figure 7.5b). Catch rates in the region (logbook grid V30) peaked at a mean of about 120 kg per boat night in May and declined to a minimum of about 65 kg per boat night in October (Figure 7.5c).

When the spawning stock index indicated that, while egg production was likely to occur year-round in the Lady Elliot and Lady Musgrave Islands area, it peaked in May and declined thereafter to a minimum in November.

Fraser Island area

Within a few months of obtaining samples from the Fraser Island and Wide Bay region it became apparent that this was a recruitment area, characterised by large catches of sub-adults. The mean size of females was 28.9 mm CL, which is well below the size at which ovary maturation commences in *P. plebejus*. The area is relatively shallow and remains so for several kilometres offshore. Samples were provided from depths ranging from 10–20 fathoms (20–40 m). The small size of the prawns, the lack of mature females and shallow depth range collectively indicated that the level of egg production in the area was likely to be negligible and for this reason it was not considered to be a significant or important spawning area for the stock.

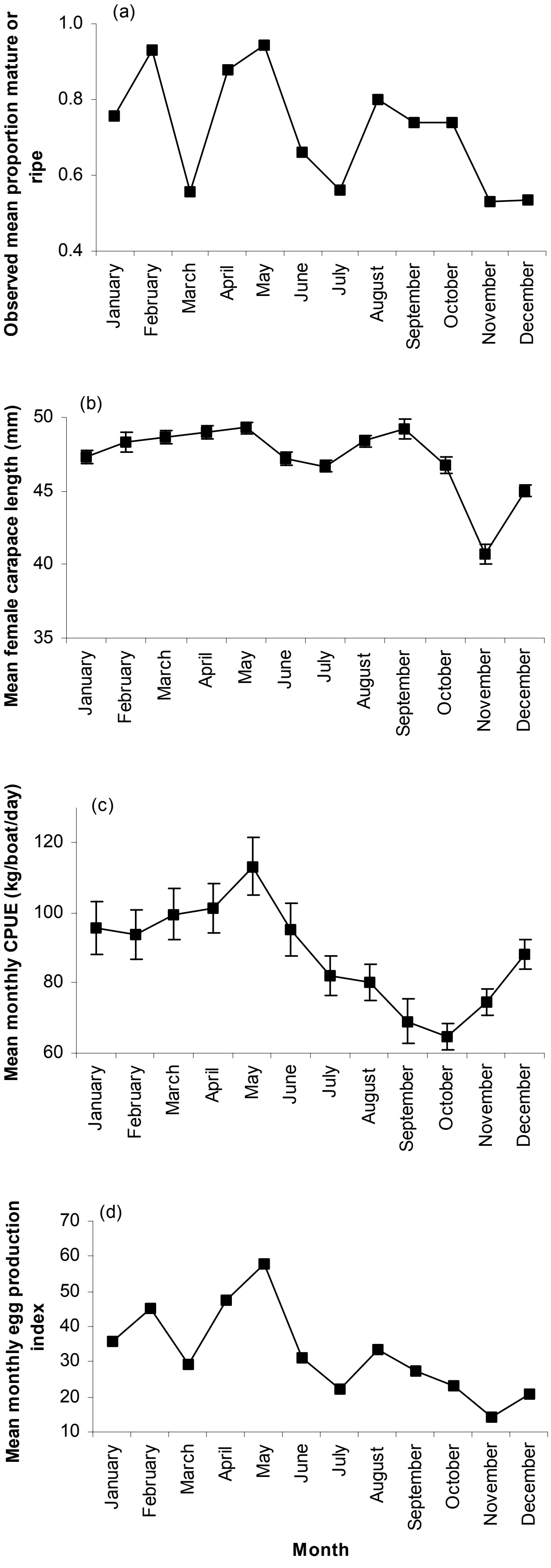

Figure 7.5 Monthly variation in the reproductive dynamics of eastern king prawns in the Lady Elliot – Lady Musgrave Islands area. a) Proportion of females with mature or ripe ovaries, b) Mean size of females, c) Mean monthly catch rate (based on logbook data from Grid V30 from 1988–2000), and d) mean monthly egg production (based on the spawning stock index). Vertical lines represent 1 standard error either side of the means.

Mooloolaba area

The mean size of females in samples from the Mooloolaba area was 46.0 mm CL (Figure 7.6). Sampled depths ranged from 40–80 fathoms (90–160 m).

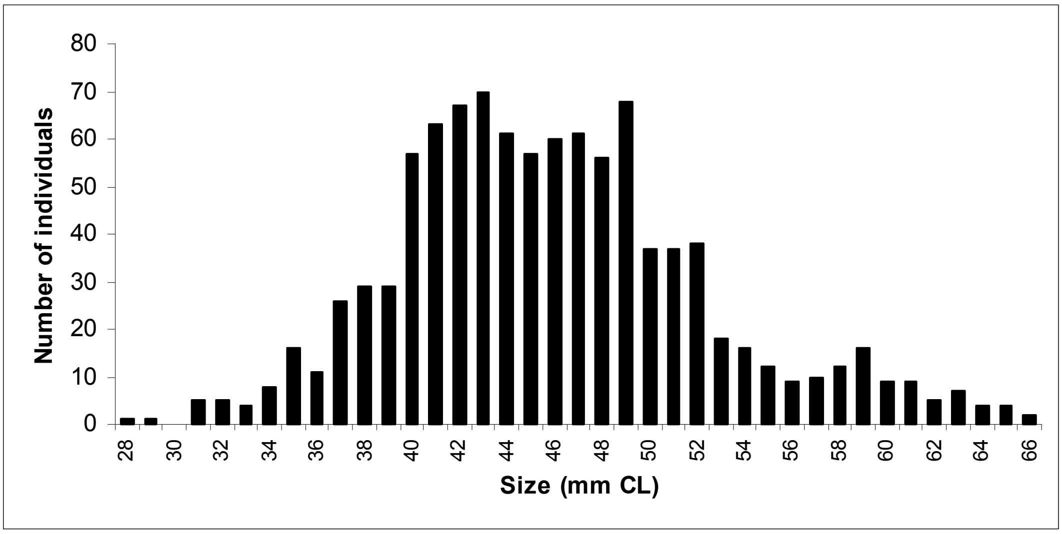

Figure 7.6 The size class frequency distribution of female eastern king prawns obtained from the Mooloolaba area.

Unfortunately, samples were not provided from all months of the year as the fisher involved targeted other species at those times. No samples were obtained in April, October or December. Data for the remaining months showed that the incidence of mature or ripe females was highest from May to July, and lowest in February (Figure 7.7a).

The mean size of females (mm CL) was highest from May to August and at a minimum in February (Figure 7.7b).

Logbook data indicated that catch rates peaked in January to April at about 100 kg per boat-night and declined thereafter to a minimum of about 62 kilogram per boat night in October (Figure 7.7c). Much of the peak was likely to be due to small/young recruits entering the fishery from Moreton Bay.

Egg production (Figure 7.7d) was highest in May and June and declined thereafter to a minimum in February.

Moreton Island area

Compared with the other areas, the size class frequency distribution of females from the Moreton Island area was very broad and ranged from 20 to 70 mm CL (Figure 7.8). The mean size of females was 40.7 mm CL. The wide size class distribution most likely resulted from using a 12-month research vessel sampling program that trawled in three transects that were located in a wide range of depths—14, 42 and 87 fm (28, 85 and 175 m), respectively.

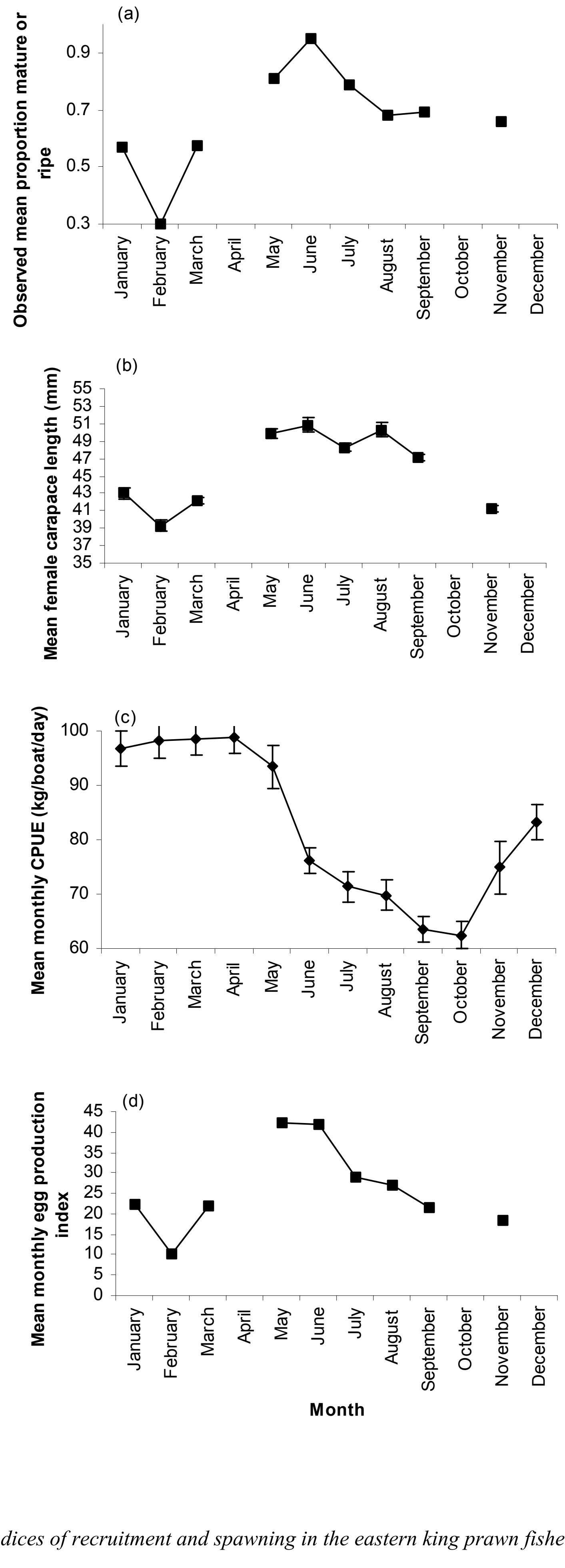

Figure 7.7 Monthly variation in the reproductive dynamics of eastern king prawns in the Mooloolaba area. a) Proportion of females with mature or ripe ovaries, b) Mean size of females, c) Mean monthly catch rate (based on logbook data from Grids X36 and W36 from 1988–2000), and d) mean monthly egg production (based on the spawning stock index). Vertical lines represent 1 standard error either side of the means.

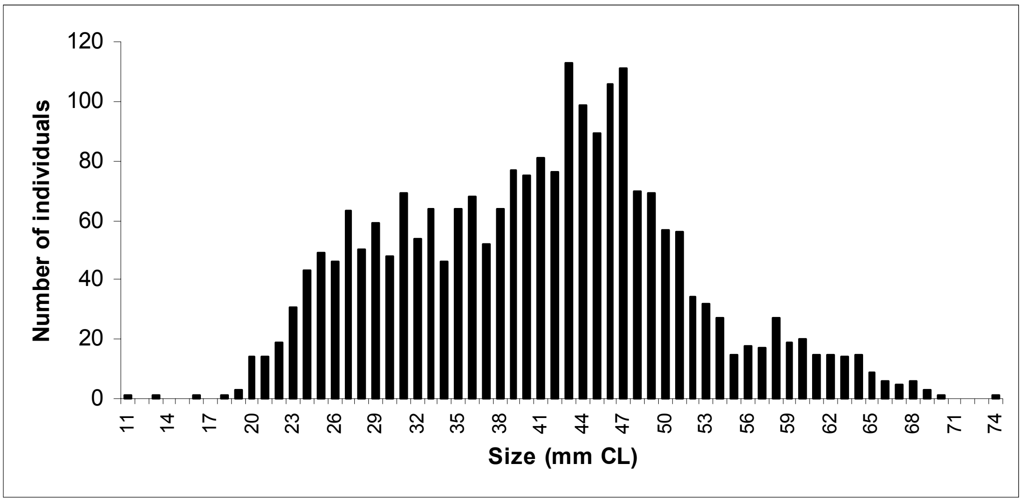

Figure 7.8 The size class frequency distribution of female eastern king prawns obtained from the Moreton Island area.

The proportion of females that was classed as mature or ripe peaked at 59% in December (Figure 7.9a), but there was also an extended high period from May to July.

The size of females peaked at 44.5 mm CL in June and was at a minimum of 36.2 mm CL in March (Figure 7.9b).

The logbook data indicated that catch rates in the area (logbook grid X37) peaked at 104 kg per boat night in March and declined thereafter to a minimum of about 61 kg per boat night in October (Figure 7.9c).

The subsequent spawning index for the Moreton Island area indicated that egg production peaked in December, and was also high for an extended period from May to July. Egg production was lowest in January, and from September to November (Figure 7.9d).

Temporal and spatial patterns in egg production

Although there were considerable differences between the four areas (Swain Reefs, Lady Elliot and Lady Musgrave Islands, Mooloolaba and Moreton Island), the spawning stock indices indicated that there was a general seasonal pattern in the production of eggs common to all areas. Most egg production occurred from May to June with a second, shorter period of high production in January or December. Egg production was generally at a minimum from September to November (Figures 7.3d, 7.5d, 7.7d and 7.9d).

The size of females, the incidence of females with mature or ripe ovaries and the commercial catch rates all declined with increasing latitude (see Figures 7.2 to 7.9). As a result, the spawning indices also declined with increasing latitude. For example, the index ranged from 30–90 at the Swain Reefs (Figure 7.3d) and from 5–18 in the Moreton Island area (Figure 7.9d). This does not necessarily imply that the absolute number of eggs produced in the Moreton Island area is lower than that of the Swain Reefs because the index is strongly affected by the catch rate (CPUE) which is a relative index of abundance (i.e. catch rates at the Swain Reefs may be higher because there are fewer vessels working in the area, not necessarily because absolute abundance is higher).

A peak spawning period in May to June is generally consistent with the temporal patterns in recruitment of eastern king prawns in Moreton Bay (Courtney *et al.* 1995b and Chapter 5 of this report). Catch rates of young eastern king prawns in the bay have shown a succinct peak in October to November—about five months after the peak spawning period.

The only practical and available means of monitoring egg production over the long term (i.e., several years) is through logbook data. For these reasons therefore, commercial catch rate data from each of the four areas has been used to examine long-term inter-annual trends in egg production.

Figure 7.10 shows the reported mean catch rate of eastern king prawns from Swain Reefs area (W26, W27 and W28) during the spawning period (May–June) each from 1988–2000.

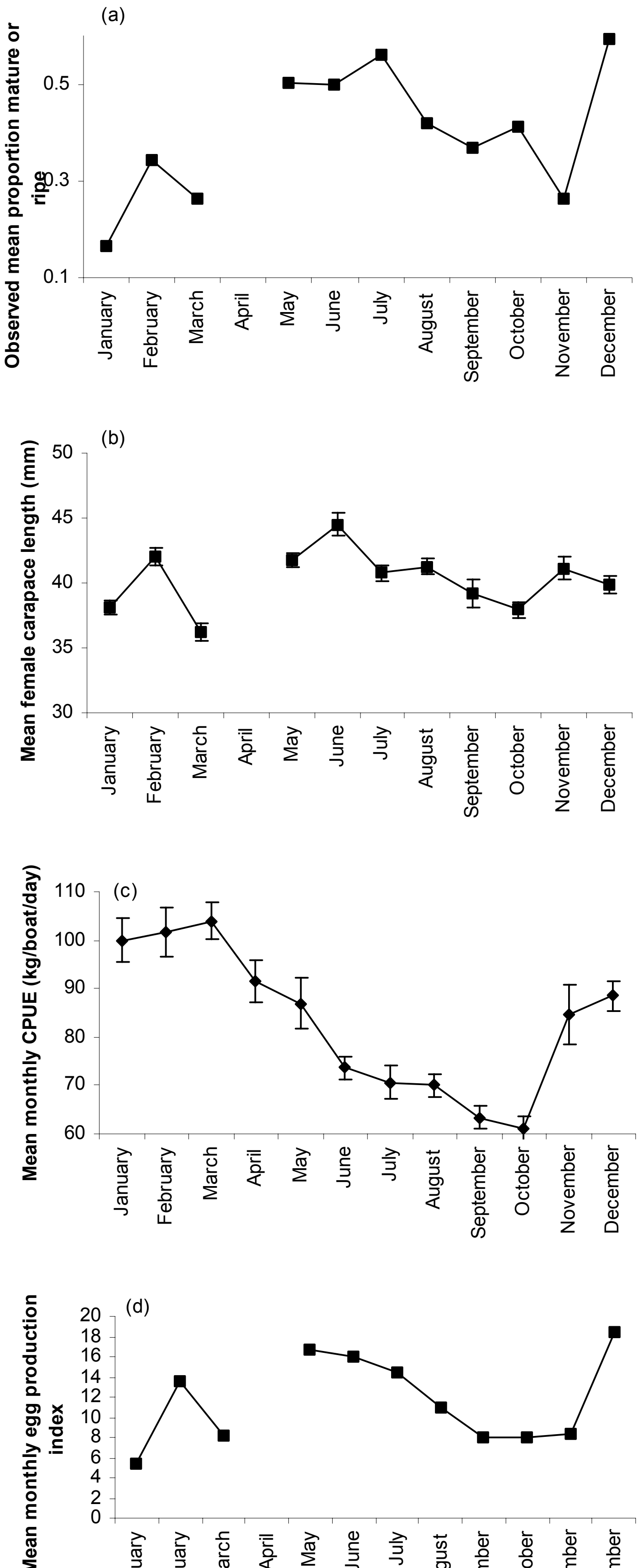

Figure 7.9 Monthly variation in the reproductive dynamics of eastern king prawns in the Moreton Island area.
a) Proportion of females with mature or ripe ovaries, b) Mean size of females,
c) Mean monthly catch rate (based on logbook data from Grid X37 from 1988–2000), and d) mean monthly egg production (based on the spawning stock index). Vertical lines represent 1 standard error either side of the means.

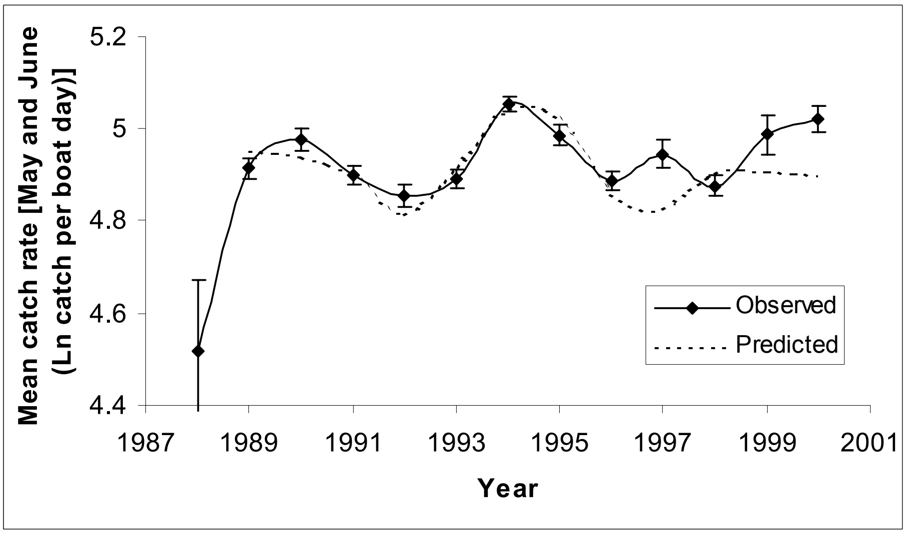

Figure 7.10. The observed and adjusted mean catch rate of eastern king prawns during the May–June peak spawning period from 1988–2000 in the Swain Reefs area (logbook grids W26, W27 and W28). The data are transformed ($\log_e$+1).

The data for 1988 should be considered with caution because it was the first year of the mandatory logbook database and as such, the data are generally less reliable. The log-transformed catch rates varied between about 4.82 and 5.04, which equates to 122–153 kilogram per boat night. Also provided are the adjusted, or adjusted catch rates from a general linear model that considered the variation between vessels, years and lunar phase.

The adjusted catch rates closely followed the observed catch rates until 1997 and, thereafter, were lower than the observed catch rates. Using these data as an index of the spawning stock size, there was no evidence of a decline in spawning stock at the Swain Reefs area over the 11-year period (1989–2000).

The reported mean catch rate of eastern king prawns during May and June for the Lady Elliot and Lady Musgrave Islands area is provided in Figure 7.11 and varied considerably between years.

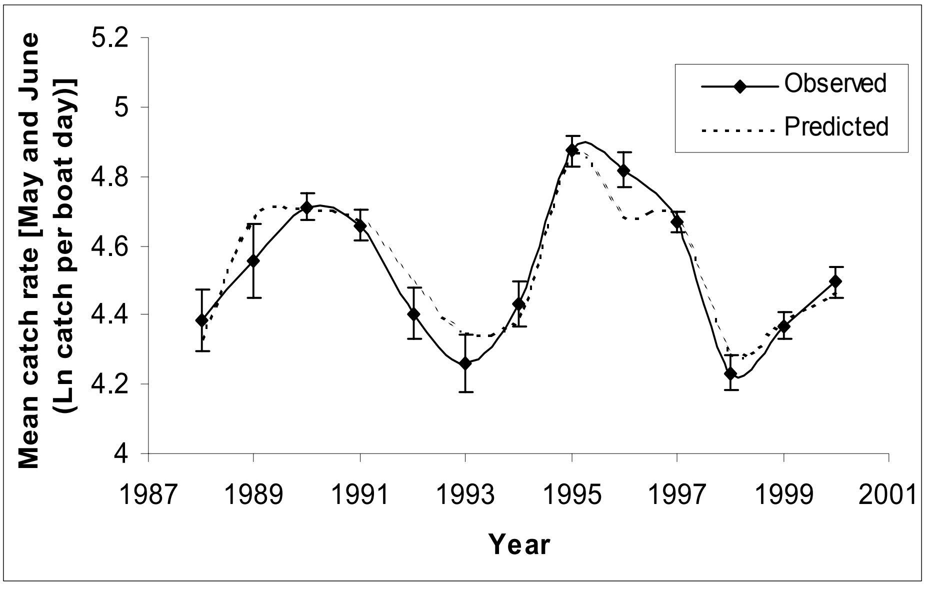

Figure 7.11 The observed and adjusted mean catch rate of eastern king prawns during the May–June peak spawning period from 1988–2000 in the Lady Elliot and Lady Musgrave Islands area (logbook grid V30). The data are transformed ($\log_e$+1).

The minimum of 4.35 in 1993 equates to approximately 77 kilogram per boat night while the maximum mean of 4.86 in 1995 equates to approximately 128 kilogram per boat night.

The adjusted means closely followed the observed means. The marked decline from 1995 to 1998 was a concern, but has been followed by increased catch rates in 1999 and 2000.

Long-term trends in the catch rates during the May–June spawning period in the Mooloolaba area (logbook grids X36 and W36) are provided in Figure 7.12.

The catch rate varied annually from a minimum of 4.11 in 1993, which equates to approximately 60 kilogram per boat per night, to a maximum of 4.45 in 1991, which equates to approximately 85 kilogram per boat per night.

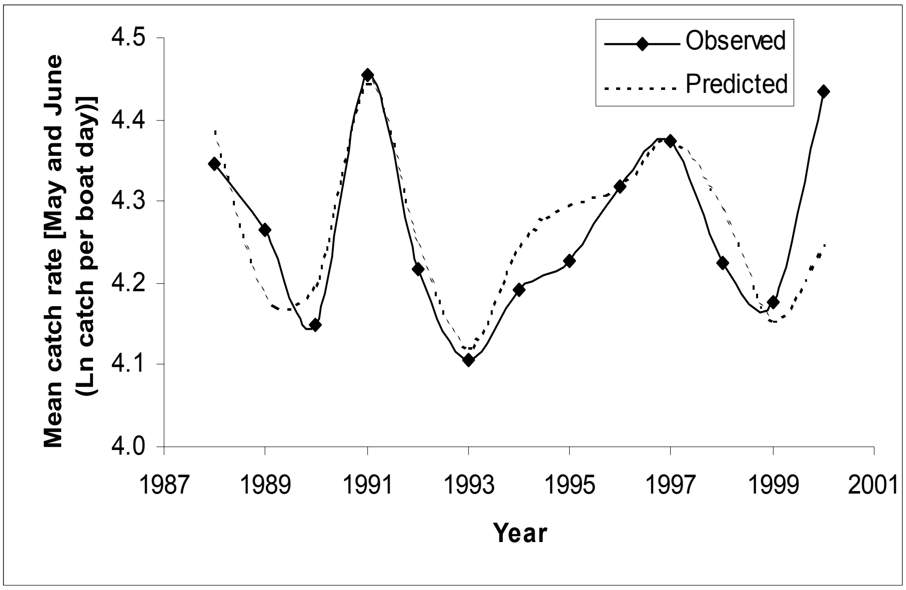

Figure 7.12 The observed and adjusted mean catch rate of eastern king prawns during the May–June peak spawning period from 1988–2000 in the Mooloolaba area (logbook grids X36 and W36). The data are transformed ($\log_e$+1).

The adjusted means generally closely followed the observed means. The data do not show any discernible long-term trend in spawning stock catch rates for this area.

Long-term trends in the catch rates during the May–June spawning period in the Moreton Island area (logbook grid X37) are provided in Figure 7.13. The catch rate varied annually from a minimum of 4.11 in 1992, which equates to approximately 60 kg per boat per night, to a maximum of 4.47 in 1991 or 86 kg per boat per night. The adjusted means closely followed the observed means. Although the data do not show any discernible long-term trend in spawning stock catch rates for the area, the trend is similar to that of the Mooloolaba area (Figure 7.12), possibly because the two areas are in close proximity. Both areas show a peak in the spawning stock index in 1991, which is followed by a marked decline in 1992 or 1993, and a general increase from 1993 to 1997.

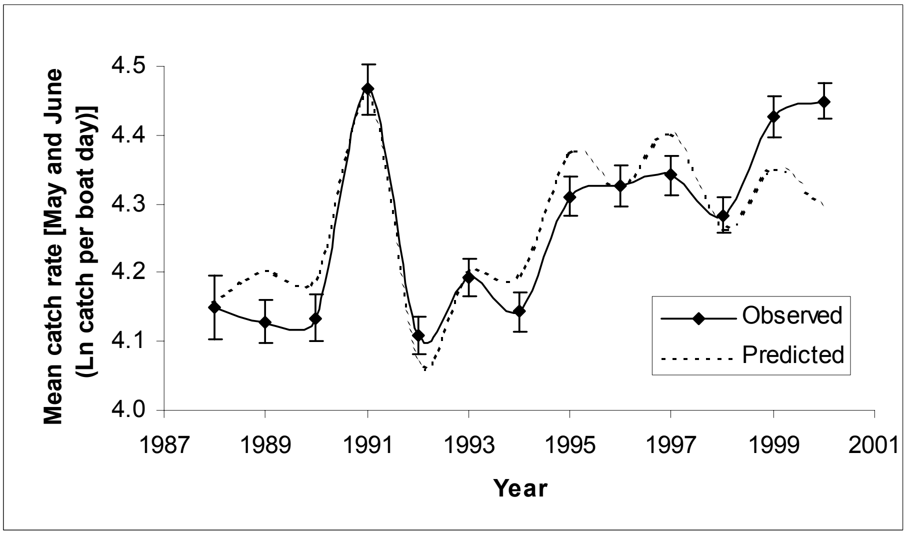

Figure 7.13 The observed and adjusted mean catch rate of eastern king prawns during the May-June peak spawning period from 1988-2000 in the Moreton Island area (logbook grid X37). The data are transformed ($\log_e$+1).

7.4 Discussion

Earlier studies and observations

Our understanding of the temporal and spatial spawning stock dynamics of the eastern king prawn fishery, and precisely what comprises *effective* spawning events, is limited because the species is relatively oceanic and highly migratory, adults occur in relatively deep, offshore waters and spawning may occur hundreds of kilometres from shallow coastal nursery areas. That the resource is shared between two principle states has also complicated examination of the spawning stock dynamics. The early conclusions by Dakin (1938) and Racek (1959) were based on field observations on the distribution of inseminated adult females, eggs, and larval stages. Racek (1959) observed the population between 27^{o}S and 36^{o}S and suggested the ‘period of maturity’ was from March to June and that breeding grounds were in depths of 50–70 fathoms, but warned his results were inconclusive due to difficulties in identifying larvae to species level.

The results from tagging studies in the 1970s–80s also influenced concepts of the spawning stock dynamics. Migrations by individual tagged prawns were considerable, with maximum-recorded distances of 930 km (Ruello 1975) and 1333 km (Montgomery 1981). Ruello (1975) referred to this as a spawning migration and suggested the coastal area between Fraser Island and Southport was the most important spawning area for the species. However, this was prior to the establishment of additional trawling grounds north of about 26^{o}S and further offshore. Laboratory experiments on the spawning and hatching success for *P. plebejus* by Preston (1985) supported the contention that the species prefers to spawn in oceanic salinities (30–34 ppt).

The significance of a large spawning migration may not be as important as once thought, according to Rothlisberg *et al.* (1995). Instead, relatively localised inshore spawning events may be responsible for stock renewal. Rothlisberg *et al.* (1995) studied the vertical migratory behaviour and immigration of post-larval *P. plebejus* on the south Queensland coast and inferred effective spawning locations based on larval biology and physical oceanographic data. According to their proposed larval advection mechanism, larvae spawned in deep water (200 m) on the outer continental shelf (40 km or more from the coast) will rarely, if ever, contribute to local recruitment. The majority of larvae are carried offshore by the East Australian Current, or one of its eddies and those that reach coastal nursery areas do so hundreds of kilometres south of the spawning area. The main reason few such larvae reach the coast is because the cross-shelf current (flowing east to west) is weak and unlikely to transport the larvae within a period consistent with the age at which they enter the estuaries. Rothlisberg *et al.* (1995) argued that the significance of *P. plebejus'* northerly migration has been overemphasised and stressed the importance of small, localised near-shore (Rothlisberg *et al.* used ≤10 km from the coast to indicate near-shore) spawning populations, particularly for localised recruitment.

The spawning stock index

In this chapter, information on the incidence of mature and ripe females was combined with size and abundance data to generate a spawning stock index. Indices were derived for four areas that are likely to be major areas of egg production—Swain Reefs (22^{o}S), Lady Elliot and Lady Musgrave Islands (24^{o}S), Mooloolaba (26^{o}30’S) and east of Moreton Island (27^{o}S). A fifth area, Fraser Island (26^{o}S) was also initially considered, but found to have no significant level of egg production.

Spatially, the index was higher at the Swain Reefs area, where it varied between 30–90. The index generally declined with increasing latitude and decreasing depth to a minimum of 5–18 in the Moreton Island area. The reason for this was because the size of the females, the incidence of mature and ripe females, and relative abundance (logbook CPUE) all generally declined with increasing latitude and decreasing depth.

The lower values of the spawning index for the Moreton Island area do not necessarily imply that there are fewer eggs produced in the area. It should be noted that the CPUE data, which is incorporated into the spawning stock index, is only a *relative* measure of abundance, and is not absolute. The lower CPUEs from the Moreton Island area do not necessarily imply that the population is smaller than the other areas, such as the Swain Reefs. The lower CPUEs from the Moreton Island area may be the result of higher fishing effort compared with the Swain Reefs.

Thus, the CPUE, and the subsequent lower spawning indices, may be the result of higher fishing effort. If effort in each of the four areas (Swain Reefs, Lady Elliot and Lady Musgrave Islands, Mooloolaba and Moreton Island) was considered to be equal, then the difference in CPUEs would in fact, imply that egg production was highest at the Swain Reefs and lowest in the Moreton Island area.

Further work would be required to generate more accurate indices of abundance from the CPUE data and this is likely to require considering the total amount of fishing effort in each area.

However, this is not a simple task as one night of effort in the Swain Reefs is unlikely to be equivalent to one night of effort off Moreton Island. Vessels working the Swain Reefs generally tow larger nets than those working off Moreton Island. Thus, the effort would need to be standardised between areas, in order to estimate absolute abundance. At present, the spawning stock indices provide an understanding of the ‘within area’ seasonal variation in egg production only and they should not be used to compare areas. Thus, spatially, we still do not know where the main production of eggs occurs, i.e., whether the Swain Reefs are more important than any of the other areas (Lady Elliot and Lady Musgrave, Mooloolaba or Moreton Island). The seasonal pattern in egg production for each area is understood, but the relative importance of each area to egg production, or to recruitment and stock renewal, remain unknown.

Temporally, there was a general consistency in the seasonal production of eggs between areas. The period when most eggs were produced was May to June, with a second shorter period of production in December or January. Egg production was generally at a minimum from September to November (Figures 7.3d, 7.5d, 7.7d and 7.9d).

Logbook CPUE data from these specific months (May and June) were then used as a proxy measure of spawning stock abundance to examine long-term trends at each of the four areas (Figures 7.10–13). There was no evidence of a decline in spawning stock catch rates from the Swain Reefs area (logbook grids W26, W27 and W28). From 1989 to 2000, annual May–June CPUEs varied between 122–153 kg per boat night, which suggests that the spawning stock is relatively stable. In fact, spawning stock CPUEs from the Swain Reefs were the most stable of the four areas examined. This should be considered carefully as vessels that work the Swain Reefs are generally larger and have greater capital and operational costs. The ‘hyperstability’ of the spawning stock catch rates from this area may simply result from fishers not trawling in this remote area when catch rates fall below a certain level because it is not economically viable or profitable to do so. Fishers may not trawl this area when catch rates are low and this could account for the apparently stable CPUEs.

Annual trends in the spawning stock catch rates from the Lady Elliot and Lady Musgrave Island areas (logbook grid V30) were much more variable (Figure 7.11). The minimum was approximately 77 kg per boat night while the maximum was 128 kg per boat night. There was a marked decline from 1995 to 1998, but this has been followed by increased catch rates in 1999 and 2000.

The spawning stock CPUEs from the Mooloolaba (logbook grid X36 and W36) and Moreton Island areas (logbook grid X37, Figures 7.12 and 7.13) displayed similar trends. Spawning stock catch rates peaked in 1991, fell to a minimum in 1992–93 and have increased since. While the variation between years is considerable, there does not appear to be evidence of a long-term decline in spawning stock size from these two areas.

Recently, the fishery managers introduced a large seasonal closure in the southern part of the state. The closure prevents trawling in depths less than 50 fathoms at latitudes south of 22^{o} S for about six weeks from 20 September to 1 November. As such, it affects thousands of boat days of fishing effort in the scallop and eastern king prawn sectors. It is currently unknown whether this effort has been dissipated or is re-directed to other months, areas or sectors. Given that egg production is generally low during these months, it seems unlikely that the closure would have had a significant impact upon egg production in the eastern king prawn fishery.

7.5 Conclusions

- A monthly spawning stock index was derived for a typical or average year at four locations that were considered to be important spawning areas. These were the Swain Reefs (22°S), Lady Elliot and Lady Musgrave Islands (24°S), Mooloolaba (26°30'S) and Moreton Island (27°S). The index incorporated estimates of the size-related fecundity of females, the proportion of females whose ovaries were classed as mature or ripe, and an index of abundance. Research data from 1990–92 provided information on female size and ovary condition, while logbook CPUE, averaged across years, were used as a measure of abundance.

- The index showed that while there were differences between areas, there was a general seasonal cycle common to all areas. Egg production was highest in the period May to June, with a second shorter period of high production in December or January. Egg production was generally lowest from September to November.

- The period of high egg production in May to June was consistent with the timing and abundance of recruits that occur in shallow waters 3–5 months later.

- The indices generally declined with latitude and decreasing depth. However, they could not be used to provide information on the relative importance of different areas to overall egg production or recruitment, because they incorporated CPUE which was only a relative index of abundance. Spatially, the relative importance of each area is unknown. This could be addressed in further work but it would require standardised estimates of fishing effort in each area.

- When logbook CPUE data from May to June were used as a proxy measure of spawning stock size, there was no evidence of a decline in spawning stocks in any of the four areas between 1988 and 2000.

- The suitability of the May to June CPUEs, as proxy measures of spawning stock size in each area, could be evaluated in the future by examining how well they predict recruitment. More research is required to examine the relationship between spawning stock size and recruitment.

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8. OBJECTIVE 4. Undertake preliminary investigations of larval and postlarval eastern king prawn distribution and abundance as functions of depth, distance from shore and estuaries.

8.1 Introduction

Knowledge of the relationship between the size of the spawning population and the number of young adults that recruit to a fishery in the next generation is important for the effective management of most fisheries. Most stock-recruitment relationships (SRRs) assume that the total adult population, or the total adult population at a particular time, is the effective spawning stock, i.e. all spawners contribute to the next generation's stock. This is not necessarily correct. For example, CSIRO modelling work in the south-eastern Gulf of Carpentaria has shown that most of the larvae produced during the autumn fishing season (when adult banana prawns are most abundant) are lost to the population (Rothlisberg *et al.* 1983). This is because spawning occurs too far offshore, and the currents are unfavourable for transporting the larvae and postlarvae to estuarine nursery areas.

If larvae and postlarvae from only one small area of the adult fishing grounds will become next year's recruits to the fishery, it would be meaningless to use total adult stocks to detect effects of fishing pressure on the spawning stock. We need to understand the patterns of movement of larvae and postlarvae into the nursery areas, so that we can clearly identify the critical spawning areas in fisheries. This will allow us to improve strategies for protecting these spawning stocks and to determine whether annual variations in recruitment are due to variations in the size of the spawning stock.

For *Penaeus plebejus*, it has been suggested that long-distance migration of spawners in a northerly direction has been followed by a corresponding migration of larvae and postlarvae to coastal nursery grounds in the south, largely mediated by the East Australian Current (EAC) (Ruello 1975, Montgomery 1990). More recently, Rothlisberg *et al.* (1995) have proposed that small, localised near-shore spawning populations may be more important in determining recruitment of postlarvae to nursery areas. Their model predicts that only those larvae spawned close to the estuary entrances will be likely to recruit to the nursery areas. This would suggest that a large proportion of adult eastern king prawns caught in the offshore fishery do not contribute to the spawning stock. Therefore, fishing sub-adult king prawns in estuaries and adult king prawns in the entrances of these estuaries would have the most impact on spawning stocks, rather than fishing for adult eastern king prawns in offshore waters. Before these results can be used to recommend management measures aimed at protecting eastern king prawn stocks, it is necessary to test some of the assumptions of the model by Rothlisberg *et al.* (1995), particularly those related to the spatial distribution of larvae and postlarvae.

At present, there is very little data available on the distribution of larvae or postlarvae of *P. plebejus* to support either of these hypotheses. The aim of this section of the project was to gather preliminary observations on the vertical distribution of *P. plebejus* larvae and postlarvae in the water column with respect to the East Australian Current (EAC) and also with distance offshore.

8.2 Methods

The original project proposal provided for the collection of samples along several transects from the Queensland/New South Wales border to Sandy Cape (25°S) in conjunction with a pilchard egg survey. However, it became clear that the timing of the pilchard survey and the small size of the samples taken were not useful for collecting penaeid prawn larvae and a modified sampling schedule was developed. This sampling schedule was much reduced in area and frequency from the original proposal.

Sampling was carried out at night from the 13.7 m Research Vessel *Warrego* along two transects offshore from Moreton Island (Figure 8.1). We trawled at night because previous sampling for penaeid larvae has shown that they are more likely to be caught in the water column at night than during the day (Rothlisberg *et al.* 1995). Plankton trawls were carried out at four locations along each transect: at 30, 100, 200 and 300 m water depths.

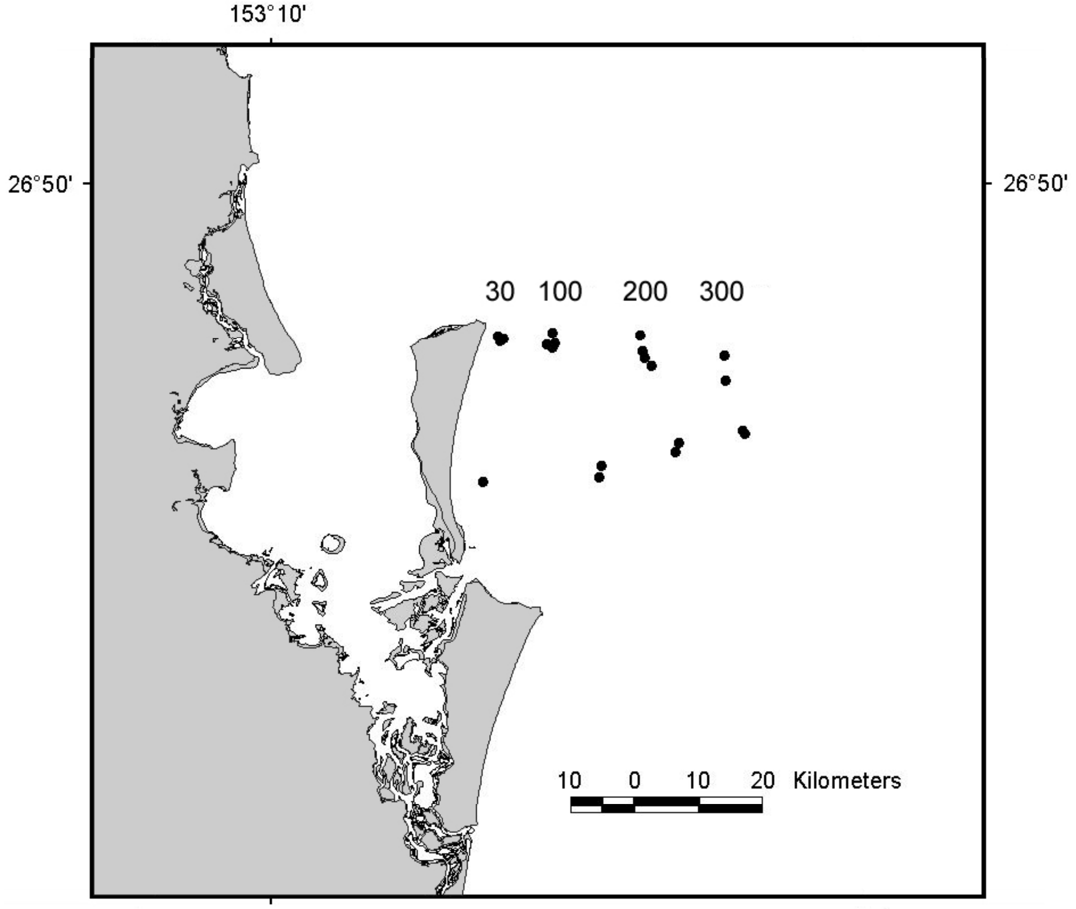

Figure 8.1 Locations of trawl stations at 30, 100, 200 and 300 m water depth offshore from Moreton Island in 1998. Each dot represents the approximate midpoint of one plankton tow.

On arrival at each location, a submersible data logger (SDL) was lowered to the seabed and then retrieved, to measure the temperature profile of the water column. The SDL was immediately interrogated using a laptop computer and the shape of the temperature/depth profile was used to determine the approximate position of the boundary of the EAC. On most occasions there was a strong temperature gradient and the location of EAC water could be clearly determined (Figure 8.2).

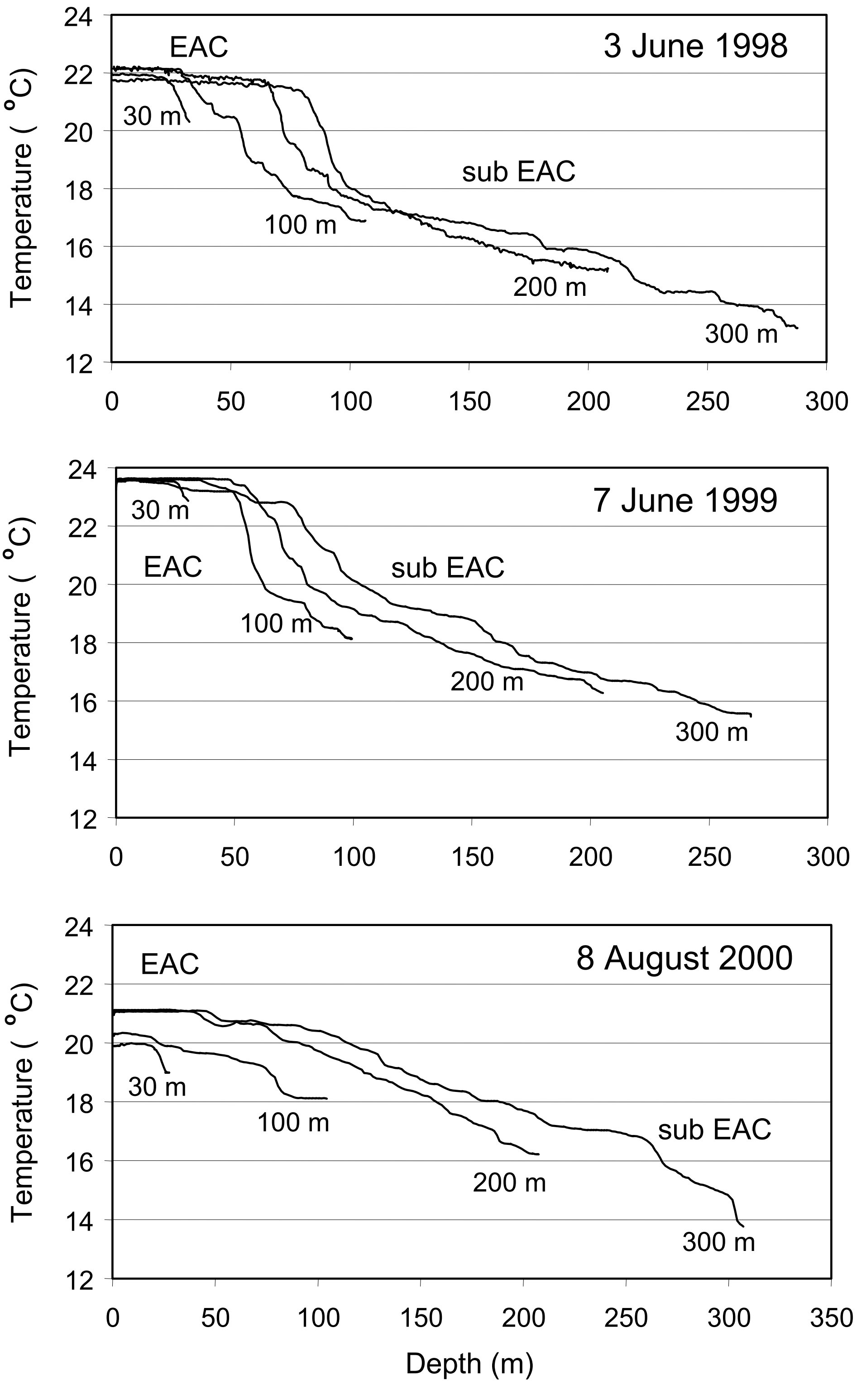

Figure 8.2 Temperature profiles from surface to seabed at 30, 100, 200 and 300 m water depth on three sampling occasions: 3 June 1998, 7 June 1999 and 8 August 2000.

At all locations except the 30 m water depths, a plankton tow was then made for about 20 minutes in the EAC (upper) part of the water column and a second tow was made with the net fishing in the sub-EAC (lower) part of the water column. The plankton net had mouth dimensions of 0.5 by 0.5 m and mesh size of 250 micron and was attached to a large net depressor with several vanes that forced the net downwards in the water column. The length of tow wire let out during trawling determined the actual depth fished and each sample consisted of a stepped oblique tow within the depth range selected. A flowmeter attached to the mouth of the net was used to calculate the volume of water filtered through the net for each tow.

The SDL was attached to the depressor for each tow to provide a record of the depth of the net throughout the tows. The mouth of the plankton net was continually open so that even when sampling the sub-EAC water column, some of the EAC water column was sampled at the beginning and end of each tow. However, the SDL records allowed the time spent in each layer of the water column to be measured. For the sub-EAC tow at each location the density of larvae and postlarvae calculated for the EAC tow was used along with the time spent passing through the EAC layer to correct for the density of larvae and postlarvae calculated in the sub-EAC layer.

At the completion of each tow the net was washed with a deck hose to concentrate the catch in the codend (Pendrey 1999). The codend was then removed from the net and the contents were transferred into a jar with 10% formalin. At the laboratory, the samples were filtered and transferred to 2% 2-phenoxyethanol for long-term storage. The samples were sorted under a binocular microscope and all penaeid larvae and postlarvae were removed. Postlarvae were identified to species but larvae and mysis stages were only identified to genus.

Sampling was carried out on seven occasions from June 1998 to August 2000. Other attempts to sample were aborted due to dangerous weather conditions or technical problems with the sampling gear.

8.3 Results

On all sampling occasions, the EAC was close inshore to Moreton Island (Figure 8.2), although the depth of the current layer varied between sampling periods. In June 1998 and 1999, the pattern of temperature variation was quite clear and surface water temperatures were constant at all sampling locations. However, in August 2000, surface water temperatures were more variable between sampling locations, suggesting that the EAC may have been more broken up. There was usually a large variation between surface and bottom temperatures at the deepest sampling location. In June 1998, temperatures ranged from about 22°C at the surface to about 13°C at the seabed at the 300 m station.

Penaeus spp. larvae and *Penaeus plebejus* postlarvae were widely distributed across the sampling area and were caught in plankton tows at all locations (Figure 8.3). On average, larvae were caught in equal densities at all locations. Postlarvae and mysis catches were more variable; the highest overall catches of postlarvae were at the 30 m station and the highest mysis catches were at the 100 m station. However, catches were highly variable between sampling periods as reflected in the large standard deviations (Figure 8.3). *Penaeus* spp. mysis were caught at all locations except the 30 m stations.

Overall, more larvae, mysis and postlarvae were caught in the EAC plankton tows (mean 1.03 *Penaeus* spp. 100 m^{-3}) than the sub-EAC tows (mean 0.20 *Penaeus* spp. 100 m^{-3}) although the patterns were quite variable between locations and sampling periods (Figures 8.4, 8.5, 8.6). Because of the high variability between samples, the difference in distribution was not strongly significant when tested with ANOVA (p=0.08). Catches in the EAC plankton tows were higher in 10 of the comparisons made while catches were higher in the sub-EAC tows for 7 comparisons.

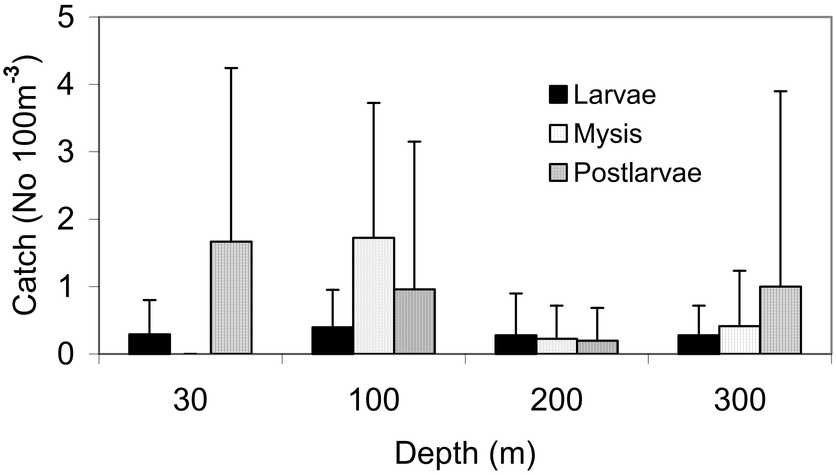

Figure 8.3 Mean catches (+ 1 standard deviation) of Penaeus spp. larvae and mysis and *P. plebejus* postlarvae caught at stations at 30, 100, 200 and 300 m water depths for all samples in 1998, 1999 and 2000.

8.4 Discussion

Very little information is available on the distribution of larvae and postlarvae of *Penaeus plebejus* in offshore waters of southern Queensland. Rothlisberg *et al.* (1995) sampled with a plankton pump at three levels in the water column for several days in 1984 at stations in 20 m and 50 m water depths. They did not report on larval densities, although small numbers of larvae were caught, but the densities of postlarvae caught in their samples were of the same order of magnitude as were recorded from our samples.

Our sampling covered a wider range of depths than Rothlisberg *et al.* (1995) (from 30 m to 300 m water depth), with two main results. A large proportion of the larvae and postlarvae were caught in the EAC waters and the larvae and postlarvae were widely distributed along the offshore transects. They were equally abundant in the deeper water offshore stations as well as in the relatively shallow inshore stations.

Our results need to be treated with some caution for two reasons. Firstly, the level of sampling was not high and the variability in catches between samples suggests that the absolute densities reported here could have been quite different if it had been possible to sample more intensively. Secondly, our method of calculating densities in the sub-EAC water levels was not ideal. A more accurate method of measuring the densities of postlarvae in the sub-EAC waters would have been to use a plankton net with the capability of opening and closing at preset depths, ensuring no contamination of sub-EAC catches with animals from the EAC level. This equipment was not available and densities had to be estimated in the sub-EAC level by making a correction for the time that the net was passing through the EAC level on its way to and from the sub-EAC level. This correction was based on catches in the EAC level made just before the sub-EAC tow. Given the variability in catches between different tows, it is likely that there was some error in the estimation of densities in the sub-EAC level calculated this way.

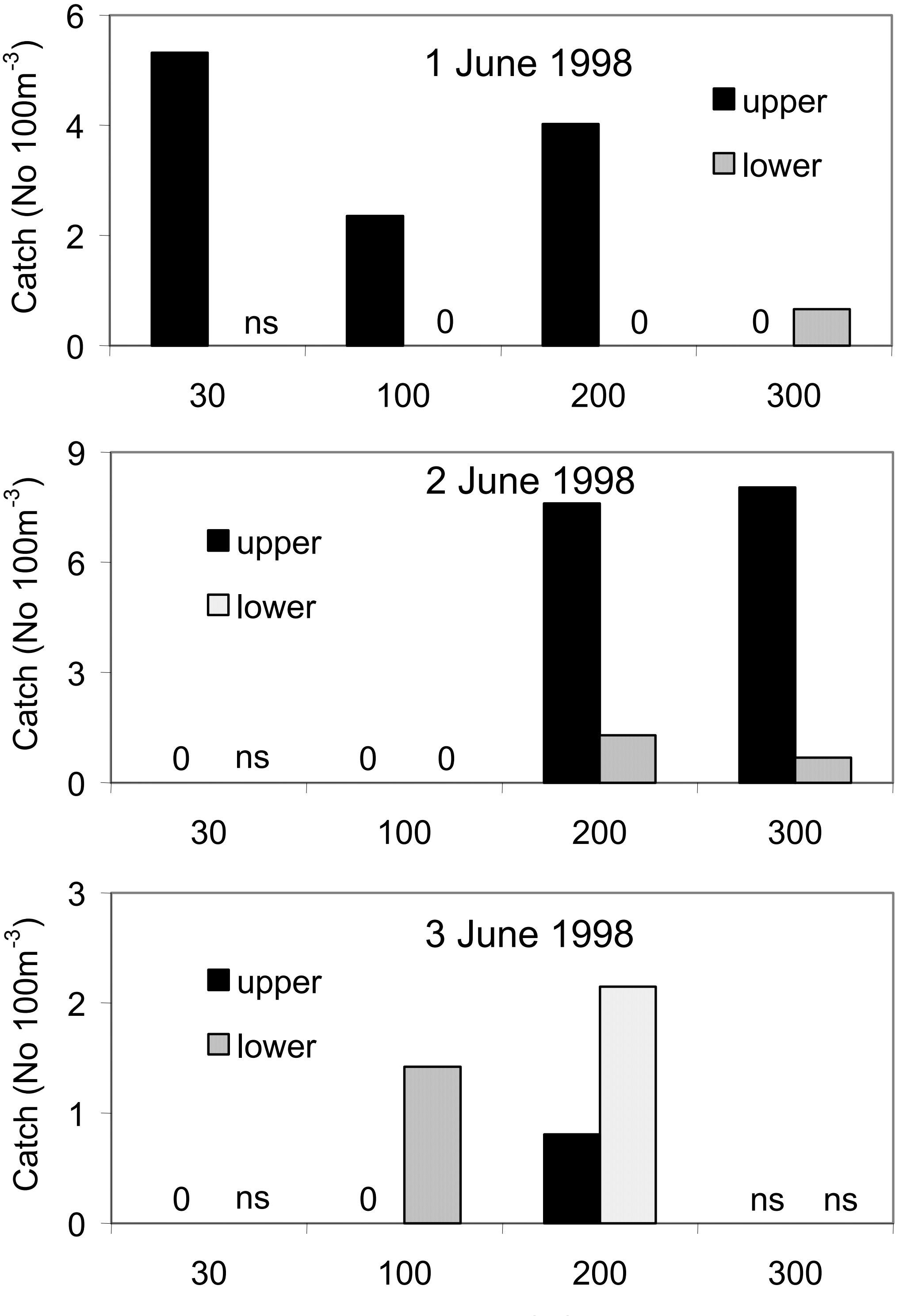

Figure 8.4 Combined catches of *Penaeus* spp. larvae and mysis and *P. plebejus* postlarvae caught at stations at 30, 100, 200 and 300 m water depths in the EAC and sub-EAC water levels on three occasions in 1998.

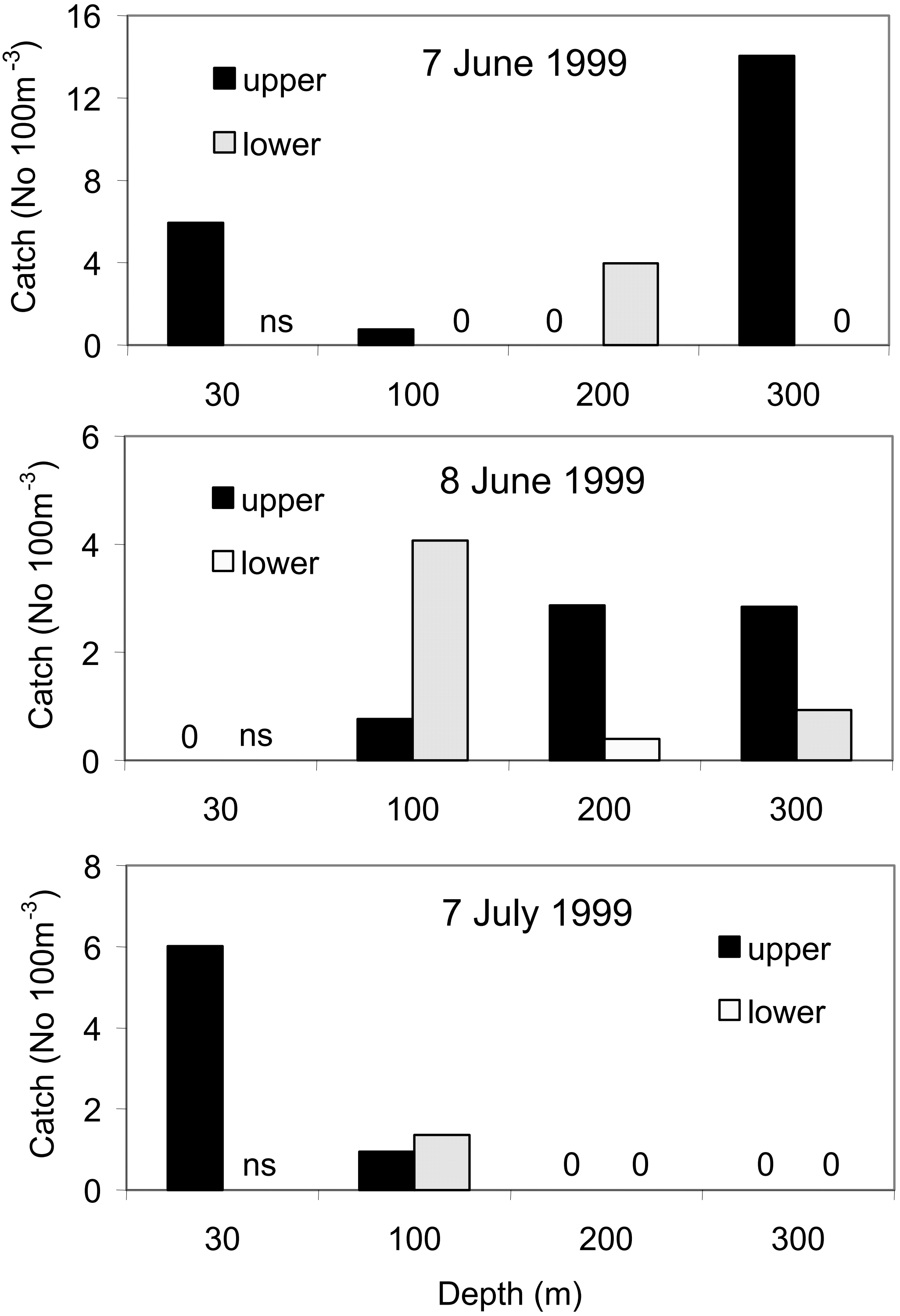

Figure 8.5 Combined catches of *Penaeus* spp. larvae and mysis and *P. plebejus* postlarvae caught at stations at 30, 100, 200 and 300 m water depths in the EAC and sub-EAC water levels on three occasions in 1999.

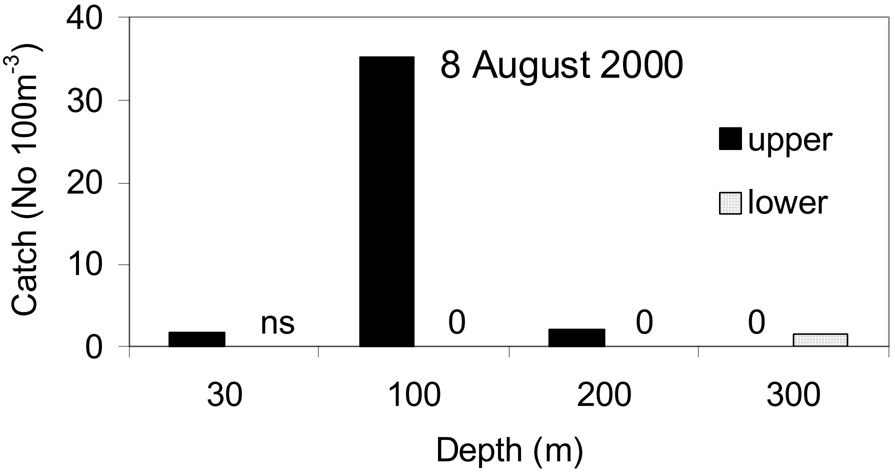

Figure 8.6 Combined catches of *Penaeus* spp. larvae and mysis and *P. plebejus* postlarvae caught at stations at 30, 100, 200 and 300 m water depths in the EAC and sub-EAC water levels on one occasion in 2000.

Nevertheless, the overall conclusions from the sampling should remain valid. The results lend support to both hypotheses of larval and postlarval recruitment to nursery areas but it cannot categorically be determined which hypothesis is more likely, based on these results. The fact that larvae and postlarvae were caught in the EAC in deep water over 40 km offshore suggests that these larvae had the potential to recruit to nursery areas far to the south as described by Ruello (1975), Montgomery (1990) and Rothlisberg *et al.* (1995). It is unlikely that they would have recruited to nursery areas adjacent to our sampling area. However larvae and postlarvae were also caught at the most inshore station, less than 5 km from Moreton Island, and many of these animals would probably have recruited to nursery areas near by as postulated by Rothlisberg *et al.* (1995).

Clearly, a much larger sampling program needs to be carried out to more accurately identify the spatial and temporal distribution of *Penaeus plebejus* larvae and postlarvae in southern Queensland. A much more detailed study also must be made of the water circulation in this area. As described by Rothlisberg *et al.* (1995), there is no clear understanding of the cross-shelf currents that must eventually move larvae and postlarvae from the offshore spawning areas into the inshore nursery areas. It is important in the long term to develop a hydrodynamic model of larval and postlarval advection in this region as has been developed for the Gulf of Carpentaria (Condie *et al.* 1999).

8.5 Conclusions

- *Penaeus* spp. larvae and *Penaeus plebejus* postlarvae were caught at sampling stations located <5 km from shore (30 m water depth) out to about 30 km from shore (300 m water depth).

- More larvae and postlarvae were caught in the upper East Australian Current water body than in the lower sub-EAC water.

- Larvae and postlarvae were caught at the inshore as well as the offshore stations, suggesting that larvae spawned in this general region could be advected to either nearby inshore nursery grounds or to nursery grounds much further south, depending on the local cross-shelf water currents.

- To understand the migrations and dispersal patterns of East Coast King Prawn larvae and, therefore, the effective spawning areas better, it is critical that a hydrodynamic model of the coastal waters of this region of eastern Australia be developed.

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9. Benefits

The project a) provided a clearer understanding of the recruitment dynamics, b) identified seasonal, spatial, temporal and abiotic factors affecting the catch rates of recruits, and c) designed, carried out and put forward a large fishery-independent recruitment survey as the preferred method for monitoring recruitment in the eastern king prawn fishery.

If the Queensland Fisheries Service adopts the survey then it should result in more accurate assessment of the stocks, improved stock and catch forecasting ability, and more accurate data with which to examine the relationship between spawning stock and recruitment. These are long-term benefits.

The project identified months when egg production is high and then used CPUE data during those months to examine the long-term trends in spawning stock size. The results suggest that, although there is considerable variation between years, spawning stock levels have not declined from 1988–2000. This information should be of interest to the fishery managers and fishers. The information on the seasonal timing of spawning should help managers to design and implement measures to increase egg production (i.e. closures), should there be a need to do so.

10. Further development

1. There is a need to improve upon the recruitment trawl survey design (Chapter 6) to increase the power of detecting change in catch rates between years. This could be achieved by increasing the number of trawls (by shortening the duration of each trawl), particularly in strata that had high standard deviations and strata that had high spatial weighting (i.e. strata with large areas).

2. Egg production was found to be highest in the period from May to June. There is a need to examine the relationship between catch rates at this time each year and the subsequent level of recruitment. Currently, the logbook provides about 12 years of data with which to examine this relationship. There is a need to determine how well the spawning stock levels can be used to predict recruitment.

3. The spawning stock index incorporates influential parameters on size-related fecundity, the proportion of females classed as mature or ripe, and the relative abundance of females, and, as such, provides some understanding of the seasonal variation in egg production within each area. However, it does not provide an understanding of the relative contribution of each area to overall egg production. We still do not have a good understanding of the relative importance of each area or where the effective spawning events are located. This could be addressed by using absolute measures of female abundance (rather than CPUE which is a relative index). It could also be addressed by developing physical oceanographic larval advection models to examine how larvae are likely to be transported.

4. The eastern king prawn fishery is one of the most highly valued commercially fished resources in Queensland and New South Wales. It is based on a single migratory stock that occurs over a very large area. There is a need for the two states to collaborate more closely with regard to research, monitoring and assessment of the stock.

11. Conclusion

The project focused on identifying factors affecting the catch rate and distribution of eastern king prawn recruits with the specific intention of developing and implementing an annual fishery-independent index of recruitment. The fishery is one of the most valuable on the east coast of Australia and it was considered that its stock assessment, monitoring and attempts to predict or forecast catch trends could be significantly improved by adopting such an index.

The project was successful at examining and determining some important abiotic factors affecting recruit catch rates. Such influences that were examined included lunar phase effects, time of night, temperature, depth, salinity, season and location. After examining these factors a large-scale survey was designed and undertaken based on 115 one-nautical mile trawls in five areas in south-east Queensland (Wide Bay Bar region off southern Fraser Island, Moreton Bay, and areas east of Moreton, North Stradbroke and South Stradbroke Islands) and deployed a commercial trawler. While the survey design appears to be the most appropriate approach for monitoring recruitment independently of the fleet dynamics, some further suggestions to improve it (i.e. lower the coefficient of variation) were put forward.

The monitoring and assessment of spawning stock levels in the fishery is likely to remain reliant upon logbook data. The offshore spawning stock catches in the logbook database do not experience the same multi-species recording problems associated with recruits in shallow water and offshore the fishery is largely mono-specific. Furthermore, the cost of establishing an offshore fishery-independent index of spawning stock could be prohibitive, given the large spatial distribution of spawning. The *effective* spawning period for the stock, and the period when most egg production occurs, was derived to be from May to June. The logbook catch rates during these months from four areas that may be important spawning locations (Swain Reefs, Lady Elliot and Lady Musgrave Islands, Mooloolaba and Moreton Island) show no evidence of decline for the period 1988–2000.

There is considerable uncertainty with respect to the spatial location of *effective* spawning areas in the fishery. It's possible that most of the eggs and larvae spawned offshore are not transported to coastal nursery grounds and are lost to the recruitment process. The project found that catch rates of larvae and postlarvae are higher in the upper East Australian Current and so it is possible that they are transported long distances to southerly nursery grounds. There is therefore a need for further study to identify the *effective* spatial spawning distribution and this will be partly dependent on the advection currents that the larvae experience.

Further, more detailed findings and conclusions are provided at the end of each section and chapter of the report.

The project attempted to instigate the collaborative fishery-independent monitoring of recruits by both Queensland and New South Wales, with limited success. However, because the eastern king prawn stock is so valuable ($40.5+million annually), and because it is considered to be a single stock that is shared by the two states, there should be continued efforts to promote collaborative research, monitoring, assessment and management.

12. Acknowledgments

We thank Craig Richards, Mark Tonks, Mark McLennan, Brad May and Wayne Sumpton for assisting with the seasonal (Chapter 5.1), lunar-phase (Chapter 5.2) and recruitment survey (Chapter 6) field sampling programs. We appreciated the dedication and professionalism of the owner, Mr. Peter Gaddes and crew of the *Elizabeth G* during the recruitment survey (Chapter 6). Myra Beamish kindly sorted and identified all the larval and postlarval prawns (Chapter 8). Brett Davidson skippered the RV *Warrego* and provided much assistance with the benthic trawl sampling and planktonic larval sampling programs. Dave Vance acknowledges the help provided by Michael Cosgrove, Mike Dichmont, and Kate Yeomans during the collection of the plankton samples. Finally, we are very grateful to John Kirkwood and Wayne Sumpton for reviewing earlier drafts of the report.

Appendix 1. Intellectual Property

There are no intellectual property issues pertaining to the project.

Appendix 2. Staff

Staff	**Position/Role**	**Percentage of time committed to the project**
Dr. Tony Courtney (QDPI)	Senior Fisheries Biologist, Principal Investigator	60
Mr. Michael Cosgrove (QDPI)	Fisheries technician	100
Dr. David Mayer (QDPI)	Biometrician	5
Mr. Mike Dredge	Industry manager	5
Mr. Brett Davidson	Skipper RV *Warrego*	5
Mr. David Vance (CSIRO)	Fisheries ecologist	5
Mr. Bob Pendrey (CSIRO)	Fisheries technician	5

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