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Sustainable *Penaeus monodon* (Black Tiger prawn) Populations for Broodstock Supply

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Information contained in this publication is provided as general advice only. For application to specific circumstances, professional advice should be sought. This document is intended for Black Tiger Prawn collectors and aquaculturalists interested in the sustainability of wild-caught broodstock.

The Department of Primary Industries, Queensland has taken all reasonable steps to ensure the information contained in this publication is accurate at the time of publication. Readers should ensure that they make appropriate enquiries to determine whether new information is available on the particular subject matter.

Frontispiece: Selection of photographs showing: typical juvenile habitat; the life-history stages collected during the study; and, the sorting tray of an inshore trawler in the Cairns region showing *P. monodon* catch

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NON-TECHNICAL SUMMARY

Outcomes Achieved (meeting performance indicators as per contract)

1. Two industry/management workshops were held. One initially to inform the stakeholders of the project objectives, ensure that all sectors were included in the process, and to enlist the assistance of broodstock collectors in the gathering of data. The second workshop was held prior to the completion of the project to explain the research results and obtain feedback from all sectors of the industry. Proceedings from the latter workshop were published and circulated to stakeholders separately.
2. All programmed fieldwork was completed and results have been reported progressively to the steering committee, through progress reports, and through the second industry/management workshop.
3. A fullscale study on alternate capture techniques was carried out in NT, Moreton Bay and finally in Trinity Inlet, Cairns. Some potentially usefull methods were identified, however comparative trials on *P. monodon* grounds in Cairns showed that trawl (Otter trawl or beam trawl) was orders of magnitude more effective than any other method.
4. Although a model for forecasting annual abundance proved difficult due to the inherent variability in the stock, we were able to suggest a management model to enhance the viability of *P. monodon* broodstock fishery and hence the aquaculture industry dependent on that supply. The core concept is the networking of broodstock collectors with commercial trawlers to collect *P. monodon* prior to it becoming frozen product. Potentially this would make the 10 tonne of frozen prawns currently harvested available to the aquaculture industry, increasing the broodstock supply 10-fold.

Executive summary

Reporting against each project objective:

1. *Collate fisheries information currently available on P. monodon across northern Australia from grey literature, fisheries databases, research projects, and from indigenous communities*. This objective was met as phase one of the project and published separately (see Appendix 1). The distribution of Black Tiger prawn (*P. monodon)* throughout Northern Australia was described and it highlighted that the Queensland east coast population was at the southern extreme of the species' geographic distribution. At extremes in the range large fluctuations in abundance are to be expected.

2. *Define the distribution of adult P. monodon stocks and habitats*. The commercial logbooks, broodstock collector logbooks and research trawl catch and effort information indicate that the concentration of black tiger populations in Queensland are in high-rainfall regions, adjacent to tropical mangrove coasts, between latitude 16° 30' S and 18° 30' S on the East Coast. This region is the "traditional" harvest area that has supplied the majority of broodstock; no new areas of unexploited populations were identified. The implication is that better management of the currently harvested populations is a more practical option than exploring for new "undiscovered" areas along the East Coast.

3. *Define the distribution of juvenile P. monodon stocks and habitats.* The juvenile habitat in Queensland was documented for the first time in this study. As with many other tropical species the coastal mangroves, wetlands and swamps are important nursery areas, and this finding reinforces the need for protection of these habitats. Loss of critical habitat through coastal development may be a bigger threat to the future supply of broodstock than overfishing.

4. *Determine seasonal patterns in P. monodon population dynamics (abundance, population structure).* A main summer spawning was documented but no reliable second spawning was identified in the Queensland populations. The most likely situation is that in "good" years the geographic range of the species increases up and down the coast, and in these years there is an increase in overall numbers spawning. In turn this would result in proportionately more individuals spawning later in the year; i.e. the tail of a normal distribution.

5. *Identify P. monodon biology (recruitment, movement, growth, reproduction) in Queensland.* The black tiger growth curve is typical of penaeids, with the female attaining an ultimate size larger than the male. Growth appears to continue for longer for this species than most prawns; up to 2.7 years for females and 1.4 years for males. Sub-adults recruit from the shallower inshore grounds (currently closed and/or protected) out to the recognised offshore grounds. The implication is that it is not imperative to open these protected areas to sustain the supply of broodstock to aquaculture.

6. *Examine alternative capture techniques and the associated stress testing of caught broodstock in particular for inshore and shallow water habitats which may contain useable quantities of currently unexploited broodstock.* Pots, lift-nets, trammel-nets and beam-trawling was tested on an established inshore prawn grounds against industry-standard Otter trawling. Trawling was significantly more effective than any other method and consequently the bycatch-to-prawn ratios were not significantly improved using alternate methods. In the case of trammel nets they were significantly worse. The management implication is that routine capture of black tiger prawn by non-trawl apparatus is currently not economically (nor environmentally) viable in Queensland.

7. *Conduct economic cost/benefit analyses of various fishing patterns, capture techniques and handling protocols.* The assessment of alternative methods of capture (see Objective 6, above) showed conclusively that trawling was currently the only practical method for supplying the quantities of broodstock required by aquaculture. While we have good cost and revenue data from the small fleet of trawl based collectors, these data were obtained from such small numbers of individuals that to respect confidentiality we

cannot release details. All that can be offered is that the broodstock collection fishery as a whole appears to be viable and profitable. No assessment was possible on the implications of sale of broodstock into overseas markets.

Keywords.

Black Tiger prawn, sustainability, broodstock collection, juvenile habitat, recruitment.

ACKNOWLEDGEMENTS

The authors wish to thank the *P. monodon* broodstock collectors and Black tiger aquaculture industry for their support, assistance, advice, and above all for their patience. Special thanks is due to Reef-farm Pty Ltd for financial support in the initial phase of the project. We would also like to thank the project steering committee, drawn from industry and management, for the support and constructive comments over the three-year project, particularly in the review of the final draft.

BACKGROUND

The Australian *Penaeus monodon* (black tiger prawn) farming industry is constrained by irregular fluctuations in supply to hatcheries of wild-caught broodstock. The industry requires further knowledge and understanding of stock dynamics for the efficient management of wild stocks to maximise market requirements and consumer demand. Currently, grow out farms must do the best they can when broodstock becomes available. There is a defined stocking window available to prawn farmers where post-larvae are required for stocking to maximise growth and profit as well as ideal growing conditions and to reduce the risk of disease. The problem is, broodstock availability does not line up with the stocking window.

This proposal is thus directed at improved understanding of the dynamics of the *P. monodon* wildstock, and developing the basis of effective sustainable management of the broodstock fisheries. Identification of alternative broodstock sources is also important to reduce the disease risk attendant on translocation.

Since the establishment of the *P. monodon* prawn farming industry 10-15 years ago, the industry in Queensland has grown to a total stocked area of 363 heactares (producing 1097.9 tonnes valued at $15.8 million, 1996/97). To produce this tonnage in Queensland alone, the industry sourced some 2900 – 4500 (1996/97) wild broodstock, valued at $290,000 - $450,000 (ranging from $50 - $150 per prawn depending on availability), from a few commercial collectors in the Cairns, Innisfail and Townsville regions of Queensland. With the expansion of the farmed prawn industry in Australia to double or treble over the next 1 to 2 years, (including the development of large foreign/Australian-owned farms and additional farms in Querensland and the Northern Terriotroy) along with increases in export sales, there will be a corresponding increase in the requirement of wild-sourced broodstock.. Queensland broodstock supplies *P. monodon* farms in NSW and NT, and there is interest in developing farms in WA. The area dedicated to prawn farming in the NT alone is anticipated tpo swell from 30 hectares in 1997 to exceed 300 hectares by 2003. In the very near future *P. monodon* will be a nationally cultured species.

Research efforts to close the life cycle and domesticate *P. monodon* (and allow hatcheries to breed their own broodstock) have been conducted in SE Asia over the past 15 years and are yet to succeed commercially: there are no known hatcheries that rely solely on farm-reared breeders. Current research in Australia is close to closing the life cycle but this technology is not generally available and will require a phasing in period when it does become available. It is also apparent that wild-caught male *P. monodon* will still be required. Furthermore, it is understood wild broodstock will be required for hatcheries to maintain genetic diversity and improve blood lines.

Wild *P. monodon* broodstock are sourced by approximately eight commercial collectors (Cairns 1, Innisfail 5, Cardwell 1, Townsville 1) from small populations located in shallow inshore coastal areas, creek mouths and foreshores. Little published information is available on wild broodstock biology and ecology, presumably because it is really an incidental catch of larger commercial prawn fisheries, such as the banana prawn (*Penaeus merguiensis*). Nevertheless, information on the species has been collected in logbook programs, and in many studies directed at other penaeids. Information on the species is thus thinly distributed over a large number of datasets, uncollated and unanalysed. Commercial collectors have provided much anecdotal information that indicates that wild *P. monodon* numbers are highly variable between seasons and that peak industry demand periods (June-August and November – February) for broodstock do not correlate with wild broodstock availability. Due to the disparity in available information on wild *P. monodon* stocks, the industry must rely on sporadic catches. Thus, the storage of adult broodstock in periods of demand could be exacerbated if existing supplies of *P. monodon* are overfished.

Commercial collection techniques of wild *P. monodon* involves otter trawling of specific inshore areas. This techniques is limited to specific areas and times and has been known to produce broodstock of variable quality. Work is carried out by Eric Boglio at BIARC identified modifications to trawling technioques to decrease levels of stress and increase broodstock quality, such as reduced trawl times and specific handling protocols. The distribution of *P. monodon* appears to be such that trawl collection techniques are limited and inappropriate in areas other than those sourced currently, including foreshores and creeks less than 5 m in depth. Alternative *P. monodon* broodstock capture techniques may not be viable in the context of large commercial fisheries but may be appropriate where the target is a small number of very valuable individuals that must be in excellent condition. These need to be sourced from shallow inshore areas and desirably with less by-catch than current collection techniques. Techniques that produce less byctach, are envionrmentally friendly and produce higher quality product, hence can potentially be used in sensitive inshore areas where current otter trawl methods are not appropriate. Alternative gear including pots, lift traps/nets, beam trawl and trammel nets was tested/evaluated in this project.

NEED

The overriding need for this project is to maintain a sustainable high quality *P. monodon* broodstock supply to the Australian Prawn Farming Industry.

1. Little published information is available on wild broodstock biology and ecology, presumably because *P. monodon* is really an incidental catch. Nevertheless, information on the species has been collected in logbook programs (eg. QDPI, Bill Izard tagging of adult *P. monodon* in the Cairns/Innisfail regions), and in many studies directed at other penaeids. Information on the species is thinly distributed over a large number of datasets, uncollated and unanalysed. The collation of this available information is therefore needed.

2. Although considerable effort and resources have been allocated to the full domestication of *P. monodon*, both nationally and internationally, the commercial production of closed broodstock is not yet viable. The *P. monodon* prawn farming industry is currently dependent on wild caught broodstock and will be for the foreseeable future. Pressures are building for the known wild stocks to supply an expanding local and international aquaculture market that is expected to double or triple, yet little is known of the size and sustainability of currently-sourced Queensland stocks of this species. There is a clear and present need to establish the size of the resource and to maintain the existing industry and further establish a regular and sustainable supply of broodstock to ensure national expansion and viability of *P. monodon* prawn farming.

3. Currently, otter trawling is the technique for collecting *P. monodon* broodstock in Queensland. Otter trawling is currently seen by the public as environmentally-damaging, and there are currently plans for large-scale reductions in trawl effort in the Queensland East Coast Trawl Fishery, including inshore regions that are regularly fished by commercial fishers for *P. monodon* broodstock. There is therefore a strong need to test alternative methods of capture and alternative handling techniques for *P. monodon* broodstock. This is required by commercial broodstock collectors and the Northern Territory fishery to capture the highest quality broodstock, source broodstock from different habitats, manage specific fisheries and to lessen environmental impacts of the fishery.

There is a need for an economic assessment of potential gains to the industry from optimising the quality, quantity and timing of the supply of *P. monodon* broodstock, as well as to assess the feasibility of alternative capture techniques and handling protocols.

OBJECTIVES

The objectives of the project were:

1. Collate fisheries information currently available on *P. monodon* across northern Australia from grey literature, fisheries databases, research projects, and from indigenous communities.

2. Define the distribution of adult *P. monodon* stocks and habitats.

3. Define the distribution of juvenile *P. monodon* stocks and habitats.

4. Determine seasonal patterns in *P. monodon* population dynamics (abundance, population structure).

5. Identify *P. monodon* biology (recruitment, movement, growth, reproduction) in Queensland.

6. Examine alternative capture techniques and the associated stress testing of caught broodstock, in particular for inshore and shallow water habitats which may contain useable quantities of currently unexploited broodstock.

7. Conduct economic cost/benefit analyses of various fishing patterns, capture techniques and handling protocols.

Each objective turned out to require a mini research project in itself; hence the objectives have been treated as separate chapters. While this leads to a certain amount of duplication, particularly in the methods, it also gives a contained "stand alone" report for each major question asked by industry and/or management. The executive summary and discussion chapter is similarly partitioned to reflect each objective.

GENERAL METHODOLOGY

Methods used to achieve Objective 1.

Information Collation and Review

Collation of Information Base

Information was collated from a variety of sources on the distribution, abundance, habitats, stock dynamics of *P. monodon*. The sources included the literature, anecdotal information from local recreational fishers, indigenous community, commercial fishers, local fishing charter operators. This formed the Collation of Information Report for Objective 1, but contributed to the knowledge of the species and assisted in designing sampling regimes. The information assisted in making informed decisions regarding the location, timing, and methodology to sample juvenile and adult stocks in North Queensland.

Literature Sources

Literature database "search engines" were used to interrogate internet-based libraries for information related to the biology, ecology, and fisheries of *P. monodon* throughout the world. Search engines used included Aquatic Sciences and Fisheries Abstracts (ASFA), WebSPIRS, ScienceDirect, Cambridge Scientific Abstracts, and Current Contents. The following terms were used for the searches: Penaeus monodon; black tiger prawn; leader prawn; sugpo; giant tiger prawn. The information of interest was then sourced via the QDPI or NT DPIF library services, and the reference sections of each paper acquired was then checked for further literature of interest.

Anecdotal Information

Anecdotal information was collected from a wide variety of sources. Recreational fishers were interviewed during boat ramp or boat-to-boat discussions in local waterways. Further information was sourced from local bait and tackle shops that deal with a large number of recreational fishers who regularly target juvenile prawns (as bait) in local waterways.

Approximately eight small commercial vessels (<18 m length) in the East Coast Trawl Fishery (ECTF) target adult populations of *P. monodon* when local and interstate prawn hatcheries require broodstock. These fishers were interviewed through informal and formal meetings between September 1999 and December 2000 and during observer field surveys on numerous commercial vessels during this time. Fishers that target other prawn species were also interviewed during informal discussions.

Members of the Yarrabah Community (Cairns region) were also interviewed during informal discussions at the boat ramp and on local foreshores.

Research Surveys (Historical)

Research effort has concentrated on the juvenile phase of commercially-important prawns in Northern Australia, particularly in the Gulf of Carpentaria. The research surveys sourced have concentrated upon the major commercial species found in each region. Penaeid prawns of low commercial importance or occurrence have thus been neglected in presentation of results and discussions and often are absent in datasets.

Research data was obtained from a CSIRO survey of the estuarine prawn populations in the Weipa area (Vance et al, 2002). The results were, at that stage, not published. Another source of data was from a preliminary survey completed in the initial stages of the current project that investigated the distribution and abundance of *P. monodon* in four habitat types in the Cairns region. The results of two research surveys of juvenile prawn communities were collated and reviewed for this report.

(Note: The literature review is contained in Appendix 1)

Methods used to achieve Objective 2.

Adult *P. monodon* Stocks and Habitats

Three types of information were used to describe the adult stocks and habitats of *P. monodon* in North Queensland. These included:

A. **Commercial Logbook Information (Fishery-Dependent)** - Commercial logbooks (official QFS) for the East Coast Trawl Fishery;

B. **Research Logbook Information (Fishery-Dependent)** - Research logbooks completed by a small number of broodstock collectors;

C. **QDPI Research Surveys (Fishery-Independent)** - Research surveys by QDPI project staff

The methods used to collect, collate, manipulate and analyse each type of information are described separately.

PART A. Commercial Logbook Information

Methods

Commercial catch and effort data for the East Coast Trawl Fishery (ECTF) was extracted from the Queensland Fisheries Service (QFS) CFISH database. All *trawl* records were extracted for all years on record (1988 to 2001). A copy of the commercial logbook sheet for the ECTF is provided in Appendix 3.1.

An MS Access© database was created with the extracted data. The data was then run through a series of standard queries that aim to check for errors, add in species names, group data, etc. For example, some of the catch information is recorded as “shot-by-shot” information. A query was run to combine records into one daily record per vessel. Summing the catch and effort data for each date for each vessel achieved this. In the process, a new column was created called “shots” which included a count of the number of shots or trawl records that were summarised to complete the daily record.

Only catch and effort information for Black Tiger (*P. monodon*) and Banana prawn categories were retained from the more comprehensive CFISH data and used for analysis.

Data Distributions

- *Catch frequency distribution (number of kilograms per day)*

Catch frequency distribution based on both 10kg and 1 kg interval catch categories was calculated in MS Access and displayed in MS Excel©.

Spatial Distribution of Catch

- *Large scale spatial distribution of catch in 30 grids (map)*

In Access, total annual catches for each 30-minute grid of the entire ECTF was calculated using all years' data (1988 – 2001). The averages of these totals were then calculated per grid. The average annual catch of *P. monodon* was then displayed on a map using MAPINFO©.

- *Medium scale spatial distribution of catch in 6 minute grids - Cairns (map)*

This was calculated using similar methods to the above, however only the years 1994 to 2001 were used due to the small proportion of records before 1994 that included the 6-minute grid reference information.

Temporal Distribution of Catch

- *Between-year patterns in catch- (total annual catches) 1988-2001*

The total annual catch of *P. monodon* was calculated by summing all daily catch records for each year on record (1988 – 2001). This was displayed on a plot in MS Excel.

- *Between-year monthly patterns in catch - (total monthly catches) 1988 – 2001*

The total catch for each month for the 14-year period was calculated by summing all daily catch records for each month for each year on record. This was displayed as a time series plot in MS Excel.

- *Seasonal patterns in catch- (average total monthly catches)*

Using the calculated 'total monthly catches' (above) for the 14-year period (ie. 168 months), an average total monthly catch was calculated. The average catch for each calendar month was based on an average for that month from 14-years of commercial catch data. This was displayed in Excel using standard error as error bars (where S.E. = Sqrt ((Stdev^2)/N)).

- *Spatio-temporal patterns in catch*

The average total monthly catch (as described above) was calculated for each 30-minute commercial grid. The changes in the average total monthly catch was then compared between the highest catch grids in North Queensland to identify any differences in the timing of catch between the grids/regions. The information was displayed on an area chart in MS Excel to identify these spatio-temporal patterns. The areas were stacked in latitudinal order in the displayed results.

- *Catch associations with the Banana prawn, Penaeus merguiensis*

The annual and seasonal patterns in the magnitude and timing of catch for both *P. merguiensis* and *P. monodon* were compared. The total annual catch and the average monthly catch of *P. merguiensis* were calculated similarly to the methods for calculating these two items for *P. monodon* as described above.

PART B. Research Logbook Information

Background

The official commercial logbooks for the East Coast Trawl Fishery do not have *P. monodon* itemised as a catch category. This limits the catch and effort information that can be extracted from the commercial database (CFISH). Catch records that exist in the database are voluntarily separated from the "Tiger" catch category and entered into the "Other" category. They are therefore unrepresentative and are highly likely to underestimate the catch of *P. monodon* product taken in the ECTF.

Fishery-dependent catch data that was more representative of the true patterns in effort and catch was sought. Research logbooks were identified as a method for collecting valuable information on the patterns of fishing effort and catch of the broodstock collector's fleet on a local scale. They do not, however represent the catch and effort of the entire East Coast Trawl fleet as they specialise their spatial and temporal searching patterns in shallow inshore fishing grounds and target *P. monodon* broodstock.

Research Logbook Survey Methodology

Initial discussions with broodstock collectors and observations on commercial vessels identified a small number of reliable fishers who were willing to collect detailed catch and effort information for the project (other than the Official QFS logbooks). These fishers were approached and designs were discussed and reviewed before a final logbook page design was agreed upon (Appendix 3.2).

The aim of the research logbook survey was to collect shot by shot information on effort and catch from the broodstock collectors that regularly target *P. monodon* for supply to the aquaculture industry. Research logbooks were provided to eight fishers. Only 3 fishers regularly collected the information. A project observer collected information from a further two vessels. Therefore, the information from a total of five fishers was collected. We estimate the number of broodstock collectors in North Queensland to be approximately 9. The involvement and effort in targeting *P. monodon* by these 9 fishers is highly variable, some only fishing when targeting the species for broodstock, others only providing animals to vessel "networkers" when the demand for broodstock is high. We estimate that the logbook survey sampled approximately 33% of the broodstock fishery in North Queensland during the survey period. We considered this sample size to be representative of the fishery, and that the participating fishers were representative of the broodstock collectors' fleet.

The survey period was between 1 April and 30 September 2000. A 6-month period was chosen by the fishers/collectors due to the imposition of the time and effort that was involved in filling out the research logbooks separate to the QFS official logbooks, and in addition to personal catch records.

Data Entry and Manipulation

The data was entered and stored in a MS Access database. In MS Access, exploratory data sorts and views of distributions were used to identify entry errors and outliers in the database. Errors were checked against original logbook sheets and adjustments made where necessary.

Catch

Fishers had entered 67% of catch records as numbers of *P. monodon* (as numbers of males and females) and 6% of records as biomass of *P. monodon* (kilograms). 27% of records included zero catch values. Anecdotal information suggests that the size and gender ratio of a population can change markedly between months, days, fishing grounds and even time of the day. Hence we knew that there was going to be a high level of error involved in calculating catch into a common denominator (ie. numbers or weights). We have therefore looked at the patterns of catch separately for numbers and weights. However, a conclusion on the patterns in catch therefore needs to be drawn from a combination of the results from numbers and weights.

Depth

Depth was recorded in both feet and meters. All depth records in feet were converted into meters.

Other Information

Extra information recorded in logbooks included water temperature, wind direction and site comments.

Data Analysis

Due to the QDPI policy on confidentiality of data (ie restricting release of data when sample size >5 fishers), the analyses were carefully constructed so that individual fishers were not identified and that favorite fishing grounds of individuals could not be identified. Only general patterns in the effort and catch were therefore analyzed.

Catch Per Unit Area

As the different vessels surveyed used different size of fishing gears, a Catch Per Unit Area (CPUA) calculation was applied to allow for the different areas swept by each different sized trawl. The Swept Area Method (Sparre et al 1989) was applied to first calculate the effective area of seabed that was swept or trawled by each vessels trawl gears.

The Swept Area Method

The Swept Area Method is a method for calculating the area fished or swept by the trawl. The swept area is the length of the path times the width of the trawl. It incorporates the trawl speed and sizes of the gears, so that catch can be compared amongst vessels. The swept area method was adopted from Sparre et al, 1989.

A = D * h * X2,   where D = V * t

Area (swept area)
D- Distance covered
H- length of headrope
V- velocity or speed of trawl
t- yime spent trawling
x2- fraction of the effective headrope length or “wing spread”

X2 was calculated using 0.65 (or 65% wing spread) that is common in trawls used in Australian waters’. The total length of head rope for each vessel included both try and main gears.

Catch Per Unit Area (CPUA)

Once the swept area was calculated, a catch per unit area (CPUA) was then calculated. This represented the number or weight of *P. monodon* per square nautical mile of seabed fished. This unit was then comparable between vessels. CPUA was calculated as:

CPUA = Catch (numbers or weights) / Swept Area

The CPUA was then analysed on a number of spatial and temporal scales:

Spatial

- *General patterns of catch (CPUA)*

The frequency distribution of catch per unit area for trawl records was calculated to demonstrate the low catch rates of *P. monodon* in the survey period. In Access, frequency distribution was calculated using 1000 individual and 5.0 kg intervals for those records of numbers and weight records respectively.

- *Regional patterns of catch (CPUA)*

Trawl records were allocated a region number and subsequent totals and averages were made per region. Average CPUA was calculated that included all catch records during the survey period. Standard error was calculated and used as error bars on the plot and was calculated as (SE = Sqrt ((Stdev^2)/N). Averages were calculated for catch records both in numbers and weights separately. Average CPUA (both numbers and weights) were mapped onto the study area in the MAPINFO© software package.

Temporal

- *Seasonal patterns in catch (CPUA)*

Average daily CPUA was calculated and plotted in Excel. Moon phase data was incorporated in the plot to identify similarities in the timing of the lunar phase and CPUA.

- *Diel patterns in catch (CPUA)*

The average CPUA was calculated for each hour of a 24-hour day. The middle time (calculated as Middle Time = Start Time + (Trawl Duration / 2)) was the time that grouped each trawl record into an "hour category". The average of the CPUA for each hour of the day was subsequently calculated. The total number of trawled hours that were conducted during each hour of the 24-hour clock was calculated and presented on the same plot as CPUA.

Habitat

- *Depth*

The relationship between depth and CPUA was investigated. The average CPUA per 1 metre depth interval was calculated and presented in Excel.

PART C. QDPI Research Surveys- Trinity Bay

Initial Survey of Trinity Bay Closure- May 2000

Adult populations were first surveyed on a medium size-scale in the Trinity Bay area closed to fishing between False Cape and Simpson Point (Figure 1). A randomised sampling design was chosen to best describe the distribution of *P. monodon* in the study area. The study area was visualised using the Geographical Information System (GIS) software, MapInfo®, and a 200m x 200m grid system applied. Each grid was numbered, the mid point of each grid retrieved. A trawl was started at the midpoint for a grid and random number tables used to randomly select seventy grids; ie, trawl sites. Grids that were too shallow or unable to be trawled (ie. in the shipping channel) were not used, and another random grid chosen.

Trinity Bay is permanently closed to commercial trawl fishing and includes a wide range of benthic habitats (mud, sand, seagrass communities, mangrove-lined, and sandy foreshores).

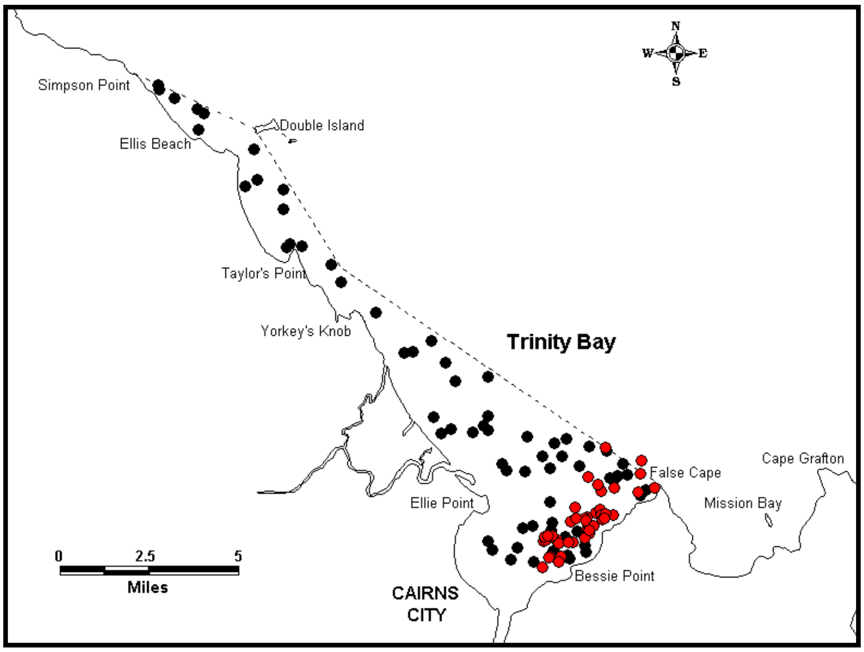


Figure 1. Distribution of fishing effort for P. monodon using 3-metre beam trawl during two surveys. The black circles represent the start location for 70-random trawls conducted during an initial survey in May 2000; and the red circles represent the start location of trawls conducted during a "follow-up" survey in July 2000.

The seventy randomly-selected grids were sampled in May 2000 using a beam trawl. The beam trawl used was 3 metres in beam length and 0.6 metres in height with a 25mm woven mesh. A 3-metre beam length was the longest beam length that could be used to maintain the vessel in survey requirements and be safe during operation. Trawls were conducted using the Queensland Department of Primary Industries' vessel, FRV Pearl Bay, at approximately 2.5 knots, with a warp length: water depth ratio of 6:1. Trawl sites were in waters between 1 metre and 8 metre deep. Trawls were 30 minutes duration and were generally towed roughly parallel to the shoreline and depth contours.

All prawns caught were identified to species and counted. Seabed habitats (sediment characteristics, depth and the presence of seagrass, mangrove detritus, etc.) were described by the presence/absence of material in a trawl. Three replicate grab samples (0.0625m^2 van Veen grab) were collected at the start of each trawl to sample sediments.

Underwater video trials and qualitative analysis of catch indicated that the beam trawl was fishing effectively, (ie, consistently on the seabed), and did so in most local weather and sea state conditions.

Follow Up Survey- July 2000

In July 2000, a follow-up survey was conducted in the area of highest abundance of *P. monodon*. This area included the southern end of the Trinity Bay trawl closure, between Bessie Point and False Cape, out to the shipping channel (see Figure 1 on the previous page). This survey aimed to better describe the abundance of *P. monodon* in this section of the closure, and based on the results, construct transects/sites that could be monitored over time. The survey was conducted over two daylight and two night periods from July 3 to July 6, 2000. This aimed to determine if there was a difference in the catch rates between day and night. During this time, 48 individual trawls were conducted parallel to the shoreline.

Monthly Sampling of Adult Stocks

The survey conducted in July 2000 recorded highest catches closest to Trinity Inlet. Although more *P. monodon* was captured at night, this was not significant, however night sampling was chosen due to the high level of daytime boat traffic and reduced bycatch biomass recorded during the night. From the distribution of catch and effort data (July 2000 survey), and a knowledge of the depth contours throughout the area, six transects were constructed to be monitored on a monthly basis (Figure 2). These included three parallel transects close to Trinity Inlet at approximately 1, 2, and 3 metres depth (on a mid-tide), and three parallel transects closer to False Cape at 3, 4 and 5 metres depth (on a mid-tide). Transects followed along the depth contours, rather than run parallel to the shoreline.

Each transect was trawled with the 3 metre beam trawl described above, towed by the RV Pearl Bay. Each transect was sampled approximately 4 times (with a total of 24 trawls each monthly survey), maintaining the same trawl speed at 2.5 kts and using 30-minute trawl durations. The sampling was completed over two or three nights each month during the new moon period. Sampling commenced each night after dusk, which occurs between 18:30pm and 19:15pm each night in the Cairns region with some seasonal variation.

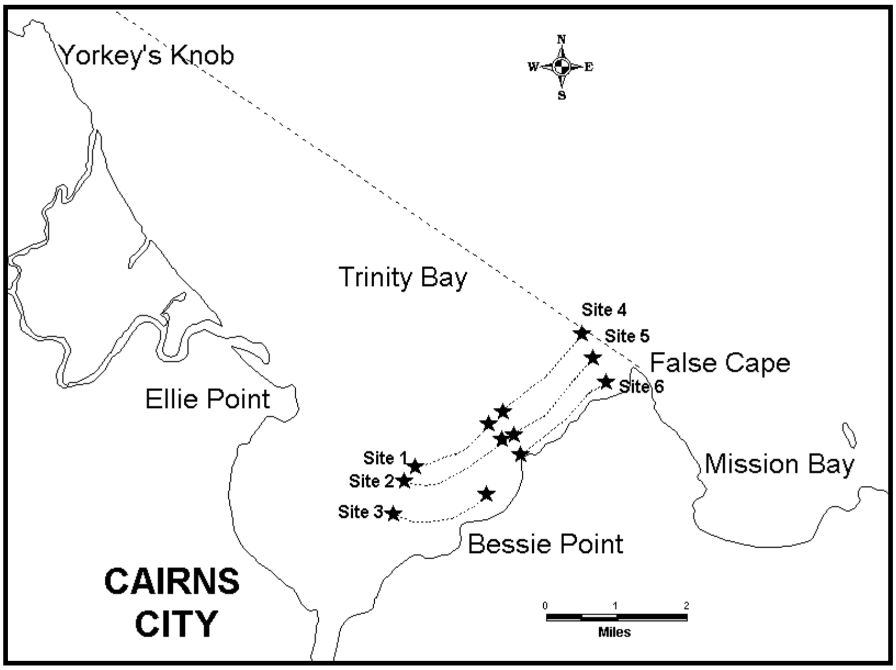


Figure 2. Location of 6 site-transects in Trinity Bay between Bessie Point and False Cape that were monitored on a regular monthly basis during the new moon phase.

Water Quality

Water quality parameters including salinity, temperature, conductivity, dissolved oxygen, turbidity and pH were measured *in situ* and recorded at two stations set up in the study area (Figure 2). Parameters were measured using a portable Horiba® water quality meter (model U-10 water quality checker). Water quality at each station was taken at the end of sampling each night and taken at approximately 0.5 metres above the seabed surface. The latitude and longitude were also recorded each time, together with weather conditions, sea conditions and wind speed and direction.

Processing of Catch

The abundance, size (total and carapace length), sex, maturation and condition of prawns were monitored from 31 July 2000 until 12 December 2001 to describe the seasonal patterns in catch and size of individuals, as well as determine whether these inshore closures produce broodstock-sized individuals during times when other sources are devoid of broodstock.

Logbook and Observer Program

To make better use of the limited project resources, a logbook program was established with broodstock collectors to obtain commercial catch data over the larger fishery areas. Fishers who target banana prawns, but also collect *P. monodon* as by-catch, are part of this group that supply broodstock.

The logbooks included information on catch (numbers of male and of female *P. monodon*), depth, date/time, weather conditions, capture location and provides space for recapture information of tagged prawns (Appendix 3.1, QFS logbook sheet). The logbooks were designed after consultation with fishers and other scientists and feedback was sought from the fishers to improve the operational effectiveness and appropriateness.

An observer program on commercial vessels was conducted throughout the project period. This aimed to:

- improve the reliability of information being recorded in the research logbooks;
- obtain regular length-frequency data on the adult *P. monodon* population;
- contribute to an ongoing tagging program; to add to anecdotal information; and enhance relations with the prawn fishing industry.

Data Analysis

The patterns in catch was described and analysed using a number of variables on spatial, temporal and spatio-temporal scales.

P. monodon Stocks

a. Spatial Patterns in Catch

Distribution of catch in the Trinity Bay Fishing Closure

The catch rates were calculated as number captured per hour of trawling (CPUE). This was done to allow for comparison between surveys (May and July 2000) where trawl durations differed. In MAPINFO, a bubble plot of the catch rates (number per 30-minute trawl) was constructed. The latitude and longitude used for positioning in the softwares was the start lat/long of each trawl.

The size of both males and females (separately) was extracted from the Access database, and a size-class distribution constructed using 5mm intervals for Total Length categories.

Distribution of catch at Bessie Point and False Cape, Trinity Bay

In MAPINFO, a bubble plot of the catch rates (number per 30-minute trawl) was constructed as described above. A length-frequency distribution was also constructed as described above.

Frequency Distribution of catch rates at Regular Monthly Monitoring Sites

In Access, a frequency distribution of the catch rates of *P. monodon* during the entire 18 month survey of 6 sites was conducted. The catch rates were converted to a Catch Per Unit Area (CPUA) unit. The CPUA was calculated as previously described in the methodology for the research logbook survey information. A length-frequency distribution was completed using categories (bins) of 500 individuals per sq nautical mile

Temporal Patterns in Catch

Seasonal Patterns

The average Catch Per Unit Area was calculated by averaging the CPUA for all trawls during each monthly survey. This combined all nights in each survey period (ie. Between 1 and 3 nights of fishing). The standard error was also calculated to provide information on the in month variability in CPUA. This was calculated as: STDERR = (Square Root of ((Standard Deviation^2)/Number of samples). The average size of *P. monodon* was calculated for each month of the survey period. This was displayed on the same plot as average monthly CPUA.

Diel Variation

The diel variation in catch was analysed in two ways. Firstly, an average was calculated for each photoperiod using 27 trawls for the “day” and 20 trawls for the “night” periods. Standard errors were calculated for each photoperiod using the formula described above. These averages were plotted in Excel with the standard error bars demonstrating the high variation between periods. Secondly, the middle time (Middle Time = ((Trawl Duration)/2) + Start Time)) was used to plot the time against the CPUA in Excel. The time and CPUA for all trawls was used (and not only a summary value).

Spatio-Temporal Patterns in Catch

Site and Seasonal Patterns in Catch

The average CPUA was calculated for each of the six sites during each of the 18 months of the monthly monitoring survey period (July 2000 to December 2001). The averages were plotted on a time scale plot to demonstrate the seasonal changes in the CPUA for all six sites.

P. monodon Habitats

Depth

The depth of all trawls and their Catch Per Unit Area values were plotted in Excel to identify any depth-related patterns in catch.

Depth and Seagrass

A similar plot to the above was replicated, however the trawls that captured seagrass in the samples were separated from those that had no traces of seagrass in their samples or evidence on the trawl gear.

Sediment

The sediment samples that were collected were not processed due to the high cost of processing versus the little conclusions that were expected from the sediment particle analysis results. This was enhanced by the low catch rates of *P. monodon*, which meant fewer data points, and a reduced power of analysis.

Other Species

A table of the species captured in association with *P. monodon* was constructed from anecdotal information from broodstock collectors and QDPI research surveys. A list of finfish and penaeid prawns that are captured from similar habitats to *P. monodon* and a list of those species that are captured from dissimilar habitats to *P. monodon* were constructed.

The catch of *P. monodon* was related to the catch of the banana prawn (*P. merguiensis*) and the catch of a number of species of endeavour prawns (*Metapenaeus* spp.). A regression analysis (MS Excel) was conducted between the catch of each species of penaeids. The software also calculated a best-fit plot and residuals. The F-value of significance for each analysis is provided with each plot.

Water Quality

The values for each of the water quality parameters of salinity, pH, turbidity, and bottom water temperature were plotted against the average monthly CPUA for each month of the 18 month survey (July 2000 to December 2001). For each month an average value was calculated for each water quality parameter by averaging the values between sites and between nights of fishing (ie. between dates).

Methods used to achieve Objective 3.

Juvenile *P. monodon* Stocks and Habitats

An inventory of juvenile *P. monodon* stocks and habitat assessment of their capture locations in North Queensland was conducted between November 1999 and December 2001 in freshwater, estuarine and foreshore areas. These include:

a. Field surveys using cast netting techniques;
b. Opportunistic surveys using alternate gears;
c. Information and data collected by recreational fishers;
d. Abiotic information (water quality, rainfall data, water flow).

The methods used to collect, collate, manipulate and analyse each type of information are described separately.

Cast netting

Cast nets were used as a sampling method for juvenile *P. monodon* due to their effectiveness to fish between and in structured habitat. These nets can be accurately thrown between snags or in small drains, and can sample from peg root and weed habitats, dragging and fishing over the top of them. Prawn communities in tidal systems are known to live in and amongst structured habitat. A cast net is one method for effectively fishing for them at low tide when the prawns are forced out of the riparian and bank habitat and are effectively concentrated in the remaining water. This allows for higher catch rates and thus larger sample sizes to monitor the population over a longer time frame. Cast nets were also a valuable tool in crocodile habitats as they can be deployed and retrieved from in a vessel, allowing Workplace Health and Safety requirements to be met.

A Seahorse brand cast net was used, made from ¾ inch (19mm) mesh, multi-mono filament nylon with pockets, and was 7 foot (2.4m) in radius. Cast nets were deployed from a variety of departmental outboard vessels, but generally from a small 3.2m, v-hulled aluminium, 20hp vessel, which allowed slow, smooth manoeuvring in and from the bank.

Cast Netting Survey Design

P. monodon juvenile stocks were sampled by cast net in five survey designs:

a. An initial large spatial scale and intensive pilot study (pre-wet season, November and December 1999) to describe the distribution and abundance of *P. monodon* in North Queensland;
b. An intensive small temporal scale survey (mid-wet season, January 2000) to determine the effect of day/night and tidal phases on the catch of *P. monodon;*

c. Monthly monitoring of *P. monodon* stocks at sites of high *P. monodon* abundance (7 sites) to describe the seasonality of *P. monodon* abundance in North Queensland (this survey was conducted for Objective 4, but will also assist to describe the stocks and habitats of juvenile *P. monodon; and*
d. A medium spatial scale survey (pre-wet season, November 2001) to describe the stocks of *P. monodon* in the Innisfail region of North Queensland and compare them to monthly monitored sites.

A post-wet intensive survey was planned for February/March 2000, however was not conducted due to prolonged flood conditions that prevented any sampling in local creeks and estuaries. Close consultation with recreational fishers confirmed that juvenile prawns were absent in these habitats during this post-wet season, even through to May 2000.

Pilot Study -Initial pre-wet season survey

The pilot study consisted of an initial pre-wet cast netting survey in November and December 1999. The study was designed to determine distribution and abundance of *P. monodon* in the Cairns region and as a means of selecting highly abundant sites for monthly monitoring to study seasonality patterns the species. Local knowledge was obtained from Northern Fisheries Centre researchers, recreational fishers (including local fishing icons and long standing community members), tackle shop and charter fishing operators prior to sampling in order to maximise searching efficiencies in the field. Ten estuarine systems throughout the Cairns region were then visited with a total of 58 sites sampled (see map in Appendix 3.1 and list of sites in Appendix 3.4). Sites were constructed in potential areas of high density of prawns, and in areas where cast nets could be used without snagging. Sites were between 50 and 200 metres in length upon which approximately 20 casts were thrown at a minimum opening of 80%. Casts were thrown in areas clear of thick vegetation to maximise prawn capture potential, as snags and thick large mangrove peg roots reduce ability to drag and capture prawns in net effectively by snagging and tearing of the net. Smaller peg roots, drains, and shady over hangings were targeted due to prawns refuging here (Vance, D. J. *et. al*. (2002)). Cast nets were retrieved low in the water so that prawn retainment was maximised. All sampling was conducted on day-time low tides in depths ranging from 0-3.5 metres for a 4-week period. These 58 sites were located in different stream types, including: upper, middle and lower sections of tidal rivers; tributaries of tidal rivers; creeks and channels in complex mangrove systems; mangrove-lined creeks directly open to the sea; canalised systems; ephemeral systems; and foreshore and estuary mouths. Sites of highest prawn density were selected for monthly monitoring, as described below in section 6.4

The majority of sites surveyed in the Trinity Inlet system were dominated by the structurally-complex mangrove *Rhizophora*, whereas the more open *Avicennia marina* dominated mangrove forest communities were found in creeks open to the sea, drainways and the lower reaches of the Barron River and Mowbray River that were surveyed.

Tidal and Diurnal Effects on Catchability

The prawn stocks in the Barron River were sampled during two day and two night-time phases, and over five high and four low tidal phases. This aimed to describe the difference in the catchability of *P. monodon* over the day/night and tidal phases. Results also were to contribute to the determination of day and/or night time sampling for seasonality and abundance monitoring. The survey was conducted over a 48-hour period from 11 to 13 January 2000. Anecdotal reports from recreational fishers together with site and distribution information from pilot surveys in the Barron River (November 1999) assisted in site selection for the survey. Two teams of staff sampled three sites, displayed in map in Appendix 3.2, during the 48 hours using the cast netting technique as used for the pilot study described above. Each site was sampled during each of the low, rising, high, and lowering tidal phases during the survey period. Sites 1, 2 and 3 were sampled 16, 13 and 15 times respectively.

Sampling in the Innisfail region

The Innisfail and Russell/Mulgrave regions south of Cairns were sampled between 9 and 13 November 2001. This pre-wet season survey aimed to describe the pre-wet distribution and abundance of *P. monodon* in systems other than monthly monitored sites, and to further document their habitat preferences. This region is the wettest in North Queensland, and has the largest recorded rivers flows accordingly. Although not previously surveyed in 1999, these systems were of considerable interest due to high commercial catches of *P. monodon* in the foreshore and inshore regions, the observed presence of small juvenile *P. monodon* during the FRDC Mangrove Jack project field surveys and antec dotal information from local recreational fishers.

A total of 14 sites were sampled by cast and hand scoop nets in the upper, middle and lower tidal sections of the Russell/Mulgrave and Johnstone Rivers (see map in Appendix 3.3). Knowledge from previous surveys of the habitat preferences *P. monodon* in estuaries was used to choose sites in each system, inconjunction with use of site location given of *P. monodon* observations by other reasearchers. The sampling methods used were as described for the pre-wet season pilot survey conducted in 1999 (as above), and a hand scoop net was used in addition to capture post larvae/juvenile *P. monodon* from steep bank walls and highly abundant sites.

Opportunistic surveys using alternate gear types

Seven alternate fishing methods, other than cast nets, were used to sample and collect *P. monodon* from tidal systems in habitats in North Queensland. Alternate gears were applied in attempt to increase catch rate at sample sites where it was deemed cast nets not to be effective due to habitat compositions or size of animal. A description of gears, methodology and study sites follows, and details are presented Appendix 3.4. Cast netting for prawns was found to be the most effective fishing method for juvenile prawns in estuaries, and therefore other gear were not pursued as a regular sampling methods.

Small Beam Trawl

Juvenile prawns were sampled on 20 November 2000 in the Barron River using a small mesh beam trawl (2 mm mesh and 1.5 m beam). This sampling was conducted on the day time high tide, to first establish suitability of site selection and effectiveness of capture methodology. The beam trawl was towed at a constant speed over mud and sand-mud substrate, between 30 and 80 m transect lengths, over three sites (see Appendix 3.2) in upper and middle tidal sections of the river. Sites were chosen for their bottom composition, relatively constant flat contour and likely hood of prawn catch. Prawns on capture were kept for identification and processing in the laboratory. Due to appropriate tidal heights being limited to times when adult and monthly cat net monitoring occurred, as well as limited staff resources, this beam trawling was limited to a one off exercise to establish *P. monodon* presence at this time.

Fyke Net

A Japanese eel fyke net consisting of two wings (12m long and 2m height) with 2 mm mesh leading to 0.8m diameter with a funnel and 500um cod end was used to sample post larvae *P. monodon* in the Barron River. Sampling occurred on the 26 September 2001, coinciding with high density juveniles found during monthly surveys. The net was set at the one site (site 3, see Appendix 3.2) deemed to have appropriate stream bottom characteristics for effective employment, after pilot runs at other sites. The net was set flush against mangrove habitat at low tide on exposed soft-mud bank and utilised the incoming tide to sweep post larvae animals inside the net. The net was checked approximately every 30 minutes, for two hours with samples being kept for verification of species and length and abundance recording. Due to limited time and personnel resources the application of fyke net surveys was not replicated, and data was used to record abundance and size presence during this period.

Hand Scoop Net

A small aquarium 10” hand scoop net was used to opportunistically capture visually sighted post larvae to juvenile *P.monodon.* The hand scoop net was utilised during surveys in the Russell/Mulgrave and Johnstone Rivers (November 2001) were post larvae prawns were in high densities in a variety of habitats. The hand scoop net proved to be an extremely effective capture method for sampling prawns upon rock walls, in hollows on steep, hard, mud walls and shallow rocky bottom substrates. The hand scoop net was simply passed over the area that prawns were sighted as well habitat similar to that were others had been caught by hand scoop. Post larvae prawns were kept for detailed measurement and recordings in the laboratory and juveniles processed and released. A recording of number scoop and estimated area sampled per scoop was also recorded.

Drag Net

A drag net was trailed in attempt to capture adolescent and sub-adult P. monodon in estuarine mouth and foreshore environments, a method used by local indigenous communities. The drag net was 20 m in length, 2.4 m in height with 15 mm stretch mesh. The net was trailed at four sites (see Appendix 3.2) on 1 and 2 June 2000 over high and low tides.

Electrofishing

(1) Backpack

Three upper tidal systems in five relatively shallow sites (see Appendix 3.2) were fished between the 3 and 13 April 2000 using a Smoth-Root® Model 12 backpack electrofisher both by wadding and from a 2.4 m dingy. Sites were chosen from anecdotal information of *P. monodon* presence as well suitable conductivity levels required for effective electrofishing. Site lengths fished were between 25 to 250 metres and varied due to suitable site structure, depth and salinities.

(2) Vessel

Opportunistic sampling and observations were made by Northern Fisheries Centre researchers whilst conducting mangrove jack surveys for the FRDC project "Biology, Ecology and Genetic Distribution of *Lutjanus argentimaculatus* in Australia". Surveys were conducted using a generator powered Smith-Root® model 7.5 GPP electrofisher mounted to a 4.3 m vessel. A total of 16 tidal systems (see Appendix 3.3) were surveyed with *P. monodon* being observed in eight systems between November 1999 and March 2001. The upper, middle and lower reaches of these systems were sampled, with set sites monitored regularly. In general presence of *P. monodon* was observed and estimated abundance and size range recorded at a site, with individual samples being captured and kept for laboratory processing when this did not interfere with capture of the target survey species.

Data from Indigenous and recreational fishers

Recreational fishers assisted in the collection of information on juvenile *P. Monodon* catch and effort during their recreational fishing trips. Tackle shops in the Cairns region were notified of the project and assisted by display and distribution of information sheets. The information sheets requested the assistance in the return of tagged prawn information. Antic dotal information was collected from fishers who contacted the project officers with tagged prawn information and during informal discussions at boat ramps and in the field. Information collected on prawns that included accurate measurements, catch counts, date collected, site collected was entered in to juvenile databases to assist in prawn distribution, abundance and seasonality study anaylises.

Collection of Abiotic information

Water quality and habitat information were collected during each survey of juvenile stocks and habitats throughout the project.

Water Quality

Water quality parameters including salinity, temperature, conductivity, dissolved oxygen, turbidity and pH were measured *in situ* and recorded at sites surveyed for juvenile *P. monodon*. Parameters were measured using a portable Horiba® water quality meter (model U-10 water quality checker). Water quality recordings were taken at the beginning or end of each individual survey, although some data is absent due to malfunctioning equipment.

Habitat Information

Site habitat parameters including stream structure, disturbance rating, riparian vegetation structure and instream bank structure and vegetation were assessed at all sites visited for various survey types. During data manipulation and analysis it was determined that broader classifications were required to analysis site parameters, than that recorded from habitat assessment sheets. One project researcher utilised habitat assessment sheets and from indepth knowledge of the sites assessed the following site parameters.

Disturbance

Disturbance ratings were given to sites sampled using the following catergories:

a.
b. Extreme – canalised, weeds or grass choking water course, stagnant water with significant decaying organics, no riparian cover or canopy cover;
c. High – man made bank alterations or disturbance, limited (<25%) riparian or canopy cover, evidence of natural vegetation and structural composition;
d. Moderate – adequate (>50%) riparian vegetation and canopy cover, man made disturbance present in site, vegetation and bank structure natural or providing similar characteristics;
e. Low – riparian vegetation undisturbed, man made disturbance in immediate surrounds eg. bunded wall, boat traffic effects evident eg. prop marks in mud; and
f. Undisturbed – riparian vegetation undisturbed for 50 m on bank, no evidence of boat traffic effects.

Mangrove Dominance

Mangrove dominance was categorised in to high (70 – 100 %), medium (30 - 70 %) or low (1 – 30 %) presence and absence (0 %) in in a site.

Stream Salinity

Salinity (ppt) was taken at each site and then used inconjunction with a systems tidal knowledge to give spatial placement to each site in to the category of upper, middle or lower estuarine or foreshore (see Appendix 3.4).

Stream Type

Sites were classified by the type and part of a system they were contained in according to these categories (see Appendix 3.4):

a. River – main arm of a large river whose waters enter the sea;
b. Creek – small creek whose water s directly enter the sea;
c. Tributary – small creek or branch of the main arm of a river;
d. Emphemeral – seasonal watercourse;
e. Inlet – complex mangrove system with no distinct main water channel;
f. Foreshore – coastline
g. Drain – channellised system

Rainfall

Rainfall data was obtained from a model and database from the QDPI Climate Centre in Cairns. The rainfall data was obtained for the two systems monitored for juvenile *P. monodon*, the Barron River (-16^{o}52.26, 145^{o}44.0) and Hills Creek (-16.921,145.792). The data obtained was pin-point data for the period that juvenile *P. monodon* was monitored which was between 1 November 1999 and 31 December 2001.

Water flow

Water flow data was obtained from a database from the Queensland Government department of Natural Resources and Mines. Water flow data was obtained from gauging stations located upstream of surveyed sites for the Barron River at Myola (station 110001d) and for Hills Creek at the Hamilton Road Bridge (station 111010a). This water flow data has been analysed and discussed in the seasonality chapter of this report,

Methods used to achieve Objective 4.

Seasonal Patterns in *P. monodon* Population Dynamics

Background

Previous studies have shown that *P. monodon* utilise the mangrove-lined estuaries as nursery habitats during their early life-history phases (Vance et al, 2002). Anecdotal evidence from recreational fishers suggested that *P. monodon* also utilise these mangrove-lined creeks, rivers, drain ways and swamps in North Queensland. It is thought that they spawn inshore and offshore, their larvae travel inshore and into estuaries with the currents and tides and by swimming, where they settle as post-larvae in the estuarine habitats. They are known to then grow as they move down the estuaries, and emigrate out from the estuaries as adolescents and sub-adults. Their first copulation occurs around the mouth of estuaries and they then move out and undergo their first spawning.

Previous studies have shown that the presence of juvenile *P. monodon* in nursery habitats (such as mangrove-lined estuaries) occurs seasonally (Rao, 1967; Subrahmanyam, 1967; Mohan, 1995; Su and Liao, 1987), with their presence recorded during only a couple months of the year.

Previous research studies and anecdotal evidence from commercial fishers suggests that adult abundance is also highly seasonal in North Queensland, with a short pulse of adult abundance for only a couple of months of the year. Anecdotal evidence suggests that adults in North Queensland almost disappear during the summer wet-season from late November to February. During these times, *P. monodon* cannot be captured on the inshore fishing grounds where they are captured in abundance during the mid- and post- wet season (April-May).

Adult *P. monodon* spawn in inshore and offshore waters where eggs sink to the seabed and hatch in 12 hours (Motoh, 1981; Solis, 1988). The larval stages that follow hatching include 6 nauplius, 3 protozoea, 3 mysis, and 3 or 4 megalopa substages. The following phases include juvenile, adolescent, sub-adult and adult phases respectively.

Table 1. The life history phases of Penaeus monodon *(Langstreth et al, 2000, after Motoh, 1981).*

Phase	Duration of phase *[1]	Carapace Length (mm)	Total Length (mm)	Body Weight (g)	Habitat	Mode of Life
Embryo	12 hours	0.29*[2]	#	#	Outer littoral area	Planktonic
Larval	< 20 Days	0.5 – 2.2	#	#	Outer/Inner littoral area	Planktonic
Juvenile	15 days	2.2 – 11	29 – 56	0.02 – 1.3	Estuarine area	Benthic
Adolescent	4 months	11 – 37	56 – 134	1.3 – 33	Estuarine area	Benthic
Sub-Adult	4 months	30 – 47	134 – 164	33 – 60	Inner/Outer littoral area	Benthic
Adult	10 months	37 – 81	164 - 266	60 – 261	Outer littoral area	Benthic

*[1] Duration of the adolescent phase is longer from an Autumn spawning

*[2] Egg diameter

Data not directly available

The seasonal patterns in population dynamics of P. monodon were described using time-plots and simple regression analysis.

Methodology

PART A- Seasonality of abiotic environment

The abiotic environment of *P. monodon* habitats was described using the following parameters:

1. Rainfall,
2. Waterflow,
3. Water Quality:
    a. Water Temperature;
    b. Salinity;
    c. Turbidity (Note: wind direction was used as a surrogate for sea turbidity);
    d. PH;
    e. Dissolved Oxygen; and
    f. Conductivity.

The method of data collection and manipulation are described for each type of data.

1. Rainfall

Rainfall data was obtained from a model and database from the DPI Climate Centre in Cairns. The rainfall data was obtained for two sites in both the estuary sites where seasonal abundance and size data was obtained for "juvenile" P.

monodon. These included the Barron River (-16°52.26, 145°44.00) and Hills Creek (145.792, -16.921). The data obtained was pin-point data for the period that *P. monodon* was monitored which was between 1 November 1999 and 31 December 2001.

A rainfall map of Queensland was also obtained from the Bureau of Meteorology electronic website (http://www.bom.gov.au) to display the trend in the distribution of rainfall throughout the state. The map constructed included the last 3 years of total rainfall, where isobars connected areas of equal rainfall.

2. Waterflow

Waterflow data was obtained from a waterflow database from the Department of Natural Resources, Cairns Branch. The water flow data was obstined for several large rivers in North Queenland including the Barron, Daintree, Russell, Mulgrave, North Johnstone, and South Johnstone Rivers, and Hills Creek. Where possible, waterflow data was obtained from the most downstream site in the main channel of each of these systems. This was done to ensure that a waterflow reading that most closely affects animals in the upper and entire estuarine systems were used.

3. Water Quality

Water quality information was collected during the monthly monitoring surveys of both juvenile and adult systems that include the Barron River, Hills Creek and the Trinity Bay closure between Bessie Point and False Cape. The collection of this water quality information has been described previously in the methods sections for Objective 2 and 3.

We used this same water quality information to describe the seasonal changes in the abiotic environment. Water temperature, salinity, and turbidity were used to describe the seasonal changes in the abiotic environment between November 1999 and December 2001. Other water quality parameters, including pH, dissolved oxygen, and conductivity demonstrated no strong seasonal trends (Results Objective 3) and were therefore not included in the seasonal analysis for this objective.

Time series plots were used to display the average water quality values per system. An average value was calculated for each system for each month of the survey period. This was done for water temperature, salinity and turbidity.

PART B – Seasonality in *P. monodon* relative abundance and size

The seasonality of *P. monodon* was described on two spatial scales. Firstly, on a large spatial scale, *P. monodon* reported commercial catch for North Queensland was described on a seasonal basis for years between 1988 and 2001. Secondly, on a small spatial scale, *P. monodon* captured during the monthly monitoring surveys of estuarine (Barron River and Hills Creek) and foreshore (Trinity Bay) sites were used to describe the seasonal changes in the abundance and size of *P. monodon* between November 1999 and December 2001.

Large Spatial Scale
The reported commercial catch data presented for Objective 2 was used again in this chapter. Total monthly catch for all months between January 1988 and December 2001 were used for analysis.

Small Spatial Scale
Information on the catch abundance and size of *P. monodon* was used to describe the seasonal changes in *P. monodon* between November 1999 and December 2001.

Information on the seasonal changes in the catch abundances and size information was collected during monthly monitoring surveys of estuarine sites that included Hills creek and the Barron River, and Foreshore sites of Trinity Bay (Bessie Point to False Cape).

Identifying relationships between catch and the abiotic environment

The changes in the magnitude of catch over time were compared to the timing of the changes in the abiotic environment. This was done by comparing time series plots of catch of *P. monodon* with similar plots abiotic parameters.

A strong belief from fisher/collectors was that turbidity was the explanatory variable for *P. monodon* catch, and that turbid water was caused by winds blowing from the SE. They believe this changes dramatically when seasonal Northerlies begin. Wind direction and magnitude data was taken from ADAM, the Australian Commonwealth Bureau of Meteorology's climate archive.
The data was extracted using a system called EVE. The extract of data for Cairns (Cairns Airport, 16°52'25"S , 145°44'45"E) contained:

- Daily values of Wind Speed at around 09:00 (9 am) (km/h)
- Daily values of Wind Direction at around 09:00 (9 am) (compass points)
- Daily values of Wind Speed at around 15:00 (3 pm) (km/h)
- Daily values of Wind Direction at around 15:00 (3 pm) (compass points)

The extract was prepared by the Climate and Consultancy Section in the Brisbane Regional Office of the Bureau of Meteorology on 9 July 2002

On the smaller scale research logbooks recorded the wind direction on a daily or shot by shot basis. Wind direction was taken as a surrogate for water turbidity.

Methods used for Objective 5.

Biology of *P. monodon*

Movement, Growth and Recruitment

A tag-release and recapture program was used to describe the biology of *P. monodon* more particularly, the movement and growth of individuals, as well as the recruitment of individuals from estuarine nursery habitats to the inshore fishery. This study also assisted in the description of the adult *P. monodon* stocks, in identifying any offshore movements to other grounds not identified in the commercial catch data.

Individuals used in the tag-release and recapture study were collected from a variety of sources and methods including:

a. Commercial operations (either during observer field work, tagged by the commercial operators or received via donation or purchase for nominal amount);
b. Adult beam trawling surveys;
c. Juvenile cast netting surveys;
d. Opportunistic surveys of juvenile habitats; and
e. Recreational fishers often donated specimens captured.

Tag and release program

The Streamer Tag (Hallprint™) needle was inserted into the middle of the second abdominal segment on either the left or right ventral side, and then pushed through to the same position on the other side of the prawn. The tag was pulled through the body smoothly and cleanly, before the needle was broken off. Tags regularly broke away from the needle during the procedure. Often, a new tag and needle had to be used, but care was then taken to ensure that a new hole through the exoskeleton was not made.

Following the tagging procedure, prawns were held for a minimum of ten minutes (and up to 24 hours if aquarium tanks were available) before release to allow the animal to rest after the handling and tagging procedure. Adult *P. monodon* were released at the surface, however water depth was always shallow (between 1 and 8 metres depth). Juvenile *P. monodon* were released into structured habitat (see Appendix 3.5). All tagged *P. monodon* were released away from potential predators; ie, scavenging birds, dolphins.

Prawn recaptures were reported as total length measurements for ease of understanding by commercial and recreational fishers. Details on recapture site and date were also reported.

All live individuals captured throughout our juvenile (> 50 mm total length) and adult surveys were tagged, and their length (carapace and total lengths), gender and condition recorded before release. In addition, recreational and commercial fishers often donated live *P. monodon* for opportunistic tagging. Tagging kits were also provided to a small number of trained commercial collectors, who played a key role in tagging prawns and assisting with the coordination of tag-return information.

The promotional program to enhance the chance of recaptures being reported includes posters and information sheets at local bait and tackle shops, television, newspaper and fishing magazine reports (including an article in Queensland Fisherman) (Appendix 3.6). Discussions with anglers at boat ramps and boat-to-boat also assist the tagging program.

Promotion for the tag-release-recapture program included:

a. Article in the Ecofish Newsletter (June 2000);
b. Article in the Queensland Fisherman (February 2001);
c. Advertisement in the Queensland Fisherman (early 2000);
d. Article in the APFA newsletter (October 1999);
e. Posters in tackle shops and chandlery, and discussions with shop owners/managers;
f. Discussions with recreational fishers at boat ramps and boat-to-boat discussions in the field; and
g. Media release (February 21 2000) specifically on the tagging program released in Cairns and Townsville and the project in general (July 27 1999; 3 May 2000).

The above media releases were followed up with the newspaper and television media reports

Recapture information was obtained through close association with commercial fishers/collectors involved as volunteers in tag-release operations. No incentive program (rewards or lottery) was instituted for tag returns as the research was of direct benefit to the collaborating fisher/collectors and their time and effort was considered as an in-kind contribution to the project.

Reproductive Biology of *P. monodon*

All *P. monodon* captured during the study were sexed. The presence of a petasma (pair of endopods of the first pleopods) was used in the positive identification of male *P. monodon*. It was noted whether the two endopods were joined or unjoined, signifying a stage of development towards sexual maturity. In small juveniles, it was difficult to determine the sex of live individuals in the field, and an undermined category was sued to describe these animals.

The female was identified by the presence of the thelycum located between the fifth pair of pleopods.

Following the onset of sexual maturity, the stage of development can be determined for females without histological study. The maturity of the ovary has been categorised into five stages: I to IV. The external appearance of the ovaries seen through the dorsal exoskeleton allows for easy classification or identification of stage number using light behind the animal. However, the handling of live prawns in a field situation is much more difficult, and can inflict much stress on a prawn, especially given the strength of light required. The classification of individuals in the field situation was therefore more difficult and potentially has a higher error involved. Furthermore, the animals were used for the tag-release-recapture program and therefore required individuals to be handled carefully to avoid added stress and damage.

We used two categories to describe the ovarian stage of maturity for the female *P. monodon*. These included:

a. Includes the early and late developing, and ripe stages of development. (Stages II, III and IV as described by Primavera 1983, *In* Motoh, 1988). In this stage, the ovaries develop, are visible through the dorsal exoskeleton and are light to dark olive green in colour.

b. Includes the undeveloped and spent stages of development (Stages V and I, as described by Primavera 1983, *In* Motoh, 1988). In this phase, the ovaries are thin, transparent and not visible through the dorsal exoskeleton.

If ovarian development could be identified from the live animal, then it was categorised into further stages using the stages defined by Motoh, 1981, and used by the AIMS and CSIRO in Australia currently. Rarely was an animal captured dead, therefore histological staging was not conducted in order to maximise the number of *P. monodon* tagged and released.

Data Analysis

Distances moved were taken as the straight-line distance between tagging and recapture sites. Growth curves were calculated according to the Von Bertalanfy equation:

$L(t) = L_\infty (1-e^{-K(t-t0)})$ (see Per Sparre et al 1989)

Parameter estimates for the Von Bertalanfy equation were made using the "Solver" routine in Excell™

Methods for Objective 6.

Introduction/background.

Information and literature on gear other than trawls that are used to take penaeid prawns has been reviewed by research staff based in Darwin, Cairns (Northern Fisheries Centre) and Deception Bay (Southern Fisheries Centre).

Approximately 1 million tons of penaeid prawns are taken annually by conventional fisheries throughout the world. The bulk of these are taken by various configurations of trawl gear that are actively towed from boats ranging from small dinghies to industrial trawlers of 30m and greater length.

There are, however, a number of prawn fisheries based on gear other than trawls. Most of these are artisinal or recreational. Information on the nature of gear used and the nature and extent of these fisheries is largely unconsolidated although Vendeville (1990) describes the basics of a number of fishing techniques. The array of equipment used in artisinal fisheries is, however, spectacular. They can be roughly divided into passive and active systems.

Simple barriers made of bamboo or netting, placed along tidal gutters or at the mouths of lagoons at high tide, are used to trap prawns in countries including Thailand and China (von Brandt 1984). Funnel-shaped "Stow" nets with fixed mouth openings that are set up to take advantage of fish or prawns travelling with the prevailing water flow. There are numerous variants on the stow net principal, varying from simple traps set in streams to what are effectively fixed trawls. Set pocket nets or ‘stripe’ nets are used in many countries, including Australia (Andrews *et al.* 1994). Set pocket nets are forms of stow nets. They consist of small trawl nets set out at fixed sites, using anchors, floats and/or posts to open the mouth of the net. Tide flows maintain the shape of the net and prawns are captured as they move from area to area with tidal flow. They can be a highly effective device for catching estuarine prawns, but considerable skill is required in terms of timing and locating sets for such equipment.

Barus (1989) discussed the use of baited traps for taking penaeid shrimp in Indonesia without giving any real insight into the cost-effectiveness of the technique. Traps have been used in deep water fisheries adjacent to islands in Oceania (King 1986), and as a means of taking prawns from aquaculture ponds, either for sampling or for the live prawn trade. Buckworth (1995) trialed traps for catching penaeid prawns in northern Australian waters with very little success.

Trammel nets are used in some south-east Asian prawn fisheries. Gangs of small nets, each typically 20-30m in length are hung with a central 40-50mm mesh panel and 150-300mm outside panels hung on common float and lead lines. Trammel nets are non-selective, and tend to be used as a form of multi-species net that takes fish as well as prawns.

Push nets or scissor nets are used by both artisinal and recreation fishers as a means of taking prawns in shallow water. On an historical note, Welsby (via Thomson 1967) refers to the use of such nets in the Brisbane River by fishers of Chinese origin. These nets have limited application, as they are worked by wading fishers and can therefore only be used on firm substrates. Further, their relatively small mouth opening limits catches.

Cast nets are used in artisinal fisheries throughout the tropics and subtropics. These nets vary in size and complexity, between simple 2-3m 'cones' to complex, 10-15m diameter shaped nets that require considerable skill to use. There are variants on the drop net / cast net concept that involve the use of a number of boats, but these are normally used to take finfish rather than prawns.

Ranges of designs for more complex lift nets exist. These nets are used from the shore, from pontoons or fixed structures in the sea, or from boats. They rely on the target species swimming over the lift net and being captured when the net is lifted. Catches from such equipment are obviously limited by the size of nets and abundance of prawns. Berleying such traps with pulverised fish waste has been demonstrated to improve catches in some circumstances (Adkins 1993).

There are a number of variants on cast nets and trammel nets that are used as drifting equipment in central and southern American prawn fisheries. They include a device known locally as a 'gerival' that is used in certain areas of Brazil. The gerival is a hybrid drift net with much the same configuration as a cast net, but with one side of the foot line being hung with floats rather than leads. Prawns moving on or near the bottom encounter the leaded aspect of the net only after the float side of the foot line has passed over them. Their escape response is to climb up the mesh and into a pocket in the net. Drift nets similar to trammel nets are widely used in Mexico and Colombia, again as artisinal equipment.

We did not have the time, expertise or capacity to trial all of these gear types. We therefore selected representative types that might give some insight into the reality of taking *Penaeus monodon* broodstock economically and sustainably. We chose to start work with three pot types, three types of trammel and two forms of lift net. Where possible, we used conventional beam trawling equipment as a means of establishing baseline number of prawns in trial areas.

Gear used

During trials on alternative means of capturing prawns, three types of trap, three forms of trammel net and two types of lift net were tested for their capacity to capture prawns. Their performance was evaluated against conventional beam trawl gear.

TRAPS

1. A 1m diameter by 40cm high collapsible (**Munyana**) trap covered with 5mm multifilament prawn mesh, and with horizontal openings cut, under tension, into 90% of the trap's vertical perimeter (Figure 3). The trap's mesh was constructed to allow the trap to be opened from the bottom by quick release knots, and a bait bag was clipped into the top mesh.
2. A commercially made collapsible '**opera house**' trap. This had an oval shaped base and two cantilever spans on either side of the central diameter of the oval. When the spans were lifted and locked together, the pot became a 0.75m by 0.5m hemisphere, covered with 12mm multifilament netting. The pot had two circular 8cm openings and was fitted with a clip-on bait bag (Figure 3).
3. A small **top opening** trap with a rigid frame (50cm diameter, 50cm high, covered with 25mm monofilament mesh).

Figure 3. Munyana and opera house pots used in field trials

LIFT NETS

1. The lift nets included a 1.5m diameter **collapsible lift net**. Such lift nets lack a rigid vertical frame and will collapse when on the sea floor, becoming a flat disc (Figure 4). The net is baited and free access is allowed in and out whilst the net is collapsed. The net is then hauled and the sides of the net are lifted, trapping the prawns inside.
2. **Open rigid nets** were also used. These nets were 1.5m in diameter at the base and 1.2m in diameter at the top, with rigid side frames 0.5m in hight, and were covered on the sides and base with 17mm multifilament mesh. The top of this lift net was open, allowing free entry and exit of animals into the nets to access the bait. The nets therefore needed to be lifted regularly to catch animals present.

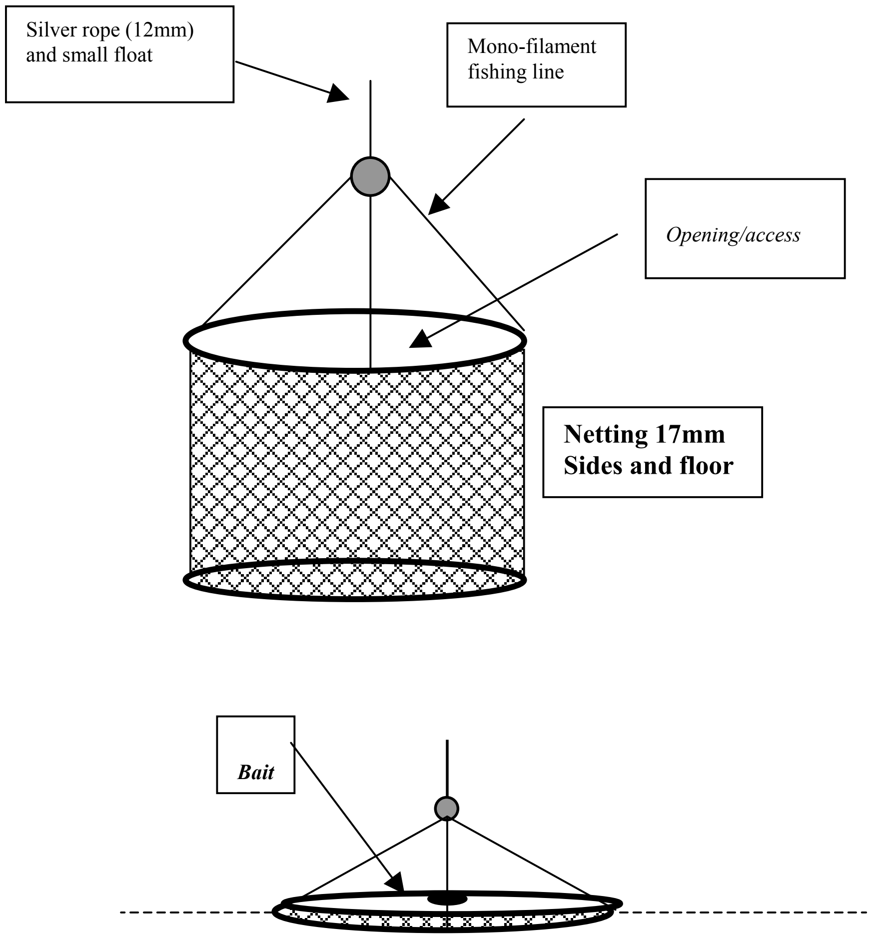


Figure 4. Lift net design: a) during hauling; b) when on the sea floor, collapsed to become a flat disc.

TRAMMEL NETS

Trammel nets passively fish the water column by capturing animals in pockets created by a loose hung and fine inner mesh opening into a coarser mesh outer panel (Figure 5).

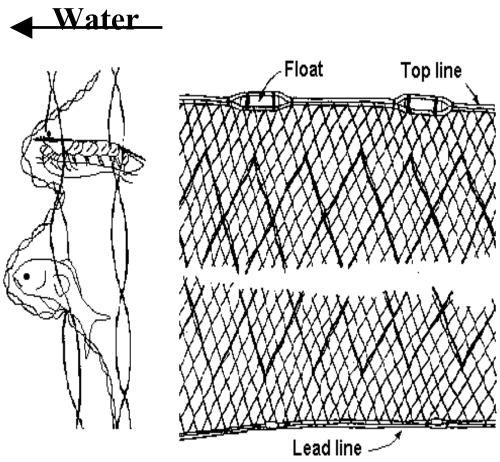


Figure 5. Trammel net design illustrating the capture of animals in pockets.

Three trammel net designs were tested. They included a 20m long Indonesian trammel net made from multi-filament mesh. The inner panel consisted of a fine 40mm cotton mesh that had panels of 250mm polyethylene mesh hung on either side. The net had an effective drop of ca. 1.5m, and was weighted and floated to fish from the bottom. The second, referred to as a 3-panel net, was a multi-panel net made from three panels hung on common foot and head lines. The mesh sizes were 140mm (multi-monofilament) 50mm (monofilament) and 25mm (monofilament). This net was 20m in length, had an effective drop of 2m, and was again designed and weighted to fish from the bottom. The third net (2-panel net) was made from two panels (50mm multifilament, 25mm monofilament), 20m long, ca. 2m drop and designed to fish from the bottom.

BEAM TRAWL

We used two beam trawls, one in Moreton Bay (deployed from the R.V. “Warrego”) and a smaller one in Trinity Inlet (Cairns) deployed from the R.V. “Pearl Bay”. The beam used in Moreton Bay was 4m long, and spread a single 6.5m headrope trawl made of 41mm (1 5/8’’) knotted Kurrilon mesh. It was towed at ca. 2.5 knots.

The beam used from the “Pearl Bay” was 3m wide with a height of 0.6m. The net had a 4.5m headrope and was made of 38mm mesh multi-strand, knotless polyethelene. The beam trawl was towed at approximately 2.5 knots towing speed, with a warp (trawl line) to depth ratio of 6:1.

Operational procedures

PRELIMINARY TRIALS - LIFT NETS

Initial trials on the effectiveness of lift nets were carried out in Bayview Haven Marina, Darwin Harbour, which is a new marina in which no boating activity had occurred prior to and during our trials. Catches from baited collapsible lift nets and open rigid nets were compared with those from opera house pots and a small wooden trap. All gear was soaked for 72 hours before trials to stabilise and neutralise their surface. All pots and lift nets were baited with 300gm of fish carcase (*Pristimoides spp*.) over the course of 3 nights' sampling. During each night's sampling, 3 collapsible lift nets, 6 open rigid nets, three opera house pots and three wooden traps were set from sampling points located on vacant finger pontoons in the marina. Each device was allocated to a sample site using an independent randomisation process each night. Nets and pots were set at sunset and lifted between 2100 and 2130 each night – i.e. a soak time of ca. 3 hours. Prawn numbers, species composition and size, and bycatch were recorded from each treatment.

PRELIMINARY TRIALS - TRAPS

Initial work was undertaken to see if traps would capture prawns under optimal conditions. Work undertaken by Buckworth (1995) indicated that prawns did not enter traps readily. We trialed three trap types (modified Munyana trap, opera house trap, top opening trap, see above) over 4 nights in aquaculture ponds stocked with banana prawns *(P. merguiensis*) (mean size - 27 mm carapace length, C.L.) at a density of 3 per m^2 at the Bribie Island Aquaculture Research Centre. A single bait type (aquaculture feed pellets) was used. During the course of the trials, a total of 20 trap lifts were completed for each pot type. Soak times were typically 16 hours. All prawns taken in the pots were counted, but not measured, and returned to the ponds alive.

PRELIMINARY TRIALS – MORETON BAY

Preliminary fieldwork on alternative gears commenced in Moreton Bay in February 2001. We compared catch rates of prawns taken by beam trawl (control) against catch rates taken in traps (two designs – Munyana and opera house traps, two bait types) and the three forms of trammel net. Gear and bait types were selected on the basis of existing literature and outcomes of preliminary trials in aquaculture ponds (A, above, Wassenburg and Hill 1990). The purpose of these trials was to examine the logistics and procedures for trialing alternative capture gears, and look at sampling needs for power to detect change in catch rates between gear types and baits.

We compared catch rates of prawns and bycatch from traps, trammel net and a beam trawl types during 4 nights' trials. Abundance of prawns were unusually high for the time of year when we tested our gear, with commercial (Moreton Bay) trawlers taking upwards of 200kgs of prawns (predominantly brown tigers, *P. esculentus*) per night at the time of trials. This gave good scope for comparing catch rates of different gears. Trials were conducted in waters of Deception Bay, ca $27^0$10'S $153^0$04'E, which are normally closed to trawling, but in the immediate vicinity of trawl grounds, in depths of 2-4m.

We commenced the trials by setting out an array of 40 pots (20 of each type, half baited with beach worms (*Australonophis sp.)* and half with pilchards (*Sardinops sagax*)), with about 50gms of bait per pot, using mesh bait bags held in the pots by shark clips. The pots were deployed on 5 lines of 8 pots, the lines being about 40 - 50m apart and the pots being spaced by about 40m along the lines. Spacing trials have previously shown that pots spaced 50m apart fish competitively for mud crabs (*Scylla serrata)*, whilst there is no difference in crab catch rates between those placed 100m and 200m apart (Williams and Hill, 1982). This suggested that pots would effectively saturate the grid area of study for mudcrabs at 40m pot spacing. With no other information available, this knowledge was used to form the basis of calculating the effective fishing area of the pots for prawns. At 40m spacing, the effective fishing area included all area inside the grid, as well as a 50m wide area around the grid's border. Each pot and bait type was allocated to the sampling array randomly. Pots were set out about half an hour before darkness in the evening. We then set out 4 trammel nets (two 'Indonesian ' nets, one 3-panel net and one 2-panel net, see above for details) for a period of 4 hours in the immediate vicinity of the pots, putting the nets into the water just before dark. We very quickly established that 4-hour soak times were excessive for this type of net, and cut back soak times to ca. 30 minutes for the remaining three nights. By this time, both the Indonesian-type nets had been damaged to a point they could not be used in this set of trials. We used the remaining two trammel nets for the last three nights' work.

After deploying the trammel nets (and retrieving them shortly after, on the 2^{nd}, 3^{rd} and 4^{th} nights) we conducted 4 by 20-minute shots with the trawl gear, covering a distance of ca. 1400m. Starting and finishing positions were located using differential G.P.S., allowing us to estimate distance trawled with an accuracy of ca. 10m.

Traps were retrieved at daylight on the next morning, giving a soak time of ca. 12 hours.

All prawns and bycatch taken in all sample gear were retained. Prawns were identified and measured (carapace length, C.L., to the nearest mm) and bycatch was identified, weighed and measured.

Trials directed at Black Tiger Prawns– Trinity Bay

A comparative survey was conducted to compare catch rates broodstock-sized of adult black tiger prawns on shallow flats (Bessie Point, off Trinity Bay) ($16^0$45'S, $145^0$40'E) from different capture gears. Eight gear forms were trialed over the four-night period April 5th - 9th 2001. Gears types (and numbers of each piece of equipment) included:

1. Beam trawl (1)
2. Trammel net- Indonesian design (1)
3. Trammel net- Three-panel design (1)
4. Trammel net- Two Panel design (1)
5. Munyana traps (16) (Two bait types)
6. Opera-house traps (16) (Two bait types)
7. Lift nets (3)
8. Open-rigid lift nets (3)

Each gear form was trialed during night hours for each of the four days of the survey in a shallow inshore area known to support black tiger populations. Three vessels were used in the gear trials in order that the eight gears could be tested simultaneously. The study area was adjacent to the sites monitored monthly for adult black tiger numbers. A beam trawler has been used to survey the prawn populations at six shallow-water sites in Trinity Bay, Cairns, on a monthly basis since May 2000. During these surveys, black tiger adults of broodstock size (up to 287mm TL) have been captured in the study area. This knowledge was the basis for site selection for the present study.

The sampling process basically replicated that undertaken in Moreton Bay, but included the addition of lift nets.

Fishing began each night after sunset when light levels were low. The location of the study area was approximately 500m from Bessie Point, between 1 – 3m depth (mid-water tide). All gears were used in close proximity, but far enough apart to maintain safety during night operations.

Nets were set after sunset when light levels were very low. Trammel nets were set across the tide flow, adjacent to, but down-tide, from the array of traps. They were held by Danforth anchors so that they fished the bottom 1.5 – 2m of the water column. Trammel nets were soaked for approximately one half-hour before lifting. The nets were set twice on the first night of operations and once there-on after. Nets were brought back to the wharf and cleaned and checked at Northern Fisheries Centre. All animals captured were recorded for each net.

Traps were set in a grid design approximately 40m apart. We used 16 of each trap type, with two bait types (prawn, pilchard, ca. 50 –100gms / pot, bait in bait nets, clipped to top-inside of each trap. Traps were numbered and set in a grid that included four rows of eight traps. Trap types were randomly assigned in the grid, and bait type randomly assigned to each trap using a random number generator. The grid used for sampling covered an area of ca 400m by 300m. Traps were baited, weighted, and set at sunset each day. They were left to fish overnight, and were checked and removed from the water at sunrise the next day. Catch for each trap was recorded, along with comments on the presence of remaining bait.

Both types of lift net had to be checked regularly, as they don't fish until hauled from the seabed surface. Lift nets and open pots were set after sunset and checked regularly at between 30 minute and 60 minute intervals for a 4-5 hour sampling period. Lift nets were baited with a mixed bait of prawns and pilchards.

Four, 20 minute trawls were conducted each night in the immediate vicinity of the other sampling procedures. They included two shallow water trawls (<1m depth, mid-tide) and two deeper trawls (approx. 3m depth, mid-tide). All animals captured, with the exception of sea snakes, rays and black tigers were brought back to the laboratory for identification. All black tigers captured were tagged and released in the field, and their condition recorded**.**

Each catch from all gear types was sorted and identified to species (where possible, otherwise to the lowest level of taxonomy that was possible) and counted. Prawns and bycatch were kept and sorted in the laboratory, where they were identified, measured and weighed.

We opportunistically obtained data on catches and catch rates of black tigers recorded by commercial fishers who otter trawled for the species in the immediate vicinity of our sample area.

Data analysis – comparisons between gear types

PRELIMINARY TRIALS WITH LIFT NETS

Data summaries from preliminary trials in Darwin Harbour were supplied in tabular form. Given the nature and extent of these trials, no attempt was made to undertake any form of formal analysis.

FIELD TRIALS – MORETON BAY, TRINITY BAY

Data were entered into Microsoft® databases (MS Excel, MS Access) and checked in the laboratory. The following calculations were carried on data collected from the main field trials:

1. Catch Per Unit Effort Catch Per Unit Effort (CPUE) was calculated as the number of individuals (prawns, bycatch) captured per hour of fishing. This was calculated as:

CPUE = Number of individuals captured / total hours fished

There are intrinsic problems in comparing catch rates between gear types. Catch rates are used as an implied measurement of population abundance or density. While spread and area coverage by trawl gear can be measured quite *accurately, the effective fishing range of gear such as traps, trammels and baited lift pots is unknown and to therefore imply knowledge of density is misleading. We have therefore developed a common parameter of catch per person-hour's labour for comparing catch rates between gear types. This parameter has little biological meaning, but can be used in economic analyses, in term of the economic viability for different gear types (see objective 7)*

2. Bycatch to Prawn ratios

Total catch counts of all prawns, *Penaeus spp.* and bycatch were made as raw counts and counts per hour fished. The total catch count was totalled for each gear across all four nights. Bycatch ratios were calculated as:

Ratio = Total prawn / *Penaeus spp.* counts: total bycatch counts (individual organisms) per gear type

3. Length-Frequency of black tigers and banana prawns

Lengths of *P. monodon, P. merguiensis and P. esculentus* were grouped according to size (carapace lengths, C.L.).

4. Density Calculations

The relative numbers and catch rates of prawns captured per unit area of seabed were estimated for trawl samples, in order to obtain baseline estimates of prawn density at the time field sampling occurred. The density estimates are based on:

Area swept = Vessel speed * mouth opening width of trawl, and estimated prawn density = (Area swept/ total prawn catch)* Correction Factor of 3, to account for gear effectiveness.

We used a correction factor of 3 on the basis of data given in Joll and Penn (1990)

Methods used to achieve Objective 7.

Economic Review of the Broodstock Collection Fishery

The Queensland prawn aquaculture industry currently produces about 2,500 tonnes of prawns a year (Lobegeiger 2002). Production statistics do not give a break down by species, but informal discussion with fisheries extension officers and prawn farmers indicates that black tiger prawns, *Peneaus monodon* accounts for approximately 70% of this production. Given prawn aquaculture (excluding kuruma prawn*, Penaeus japonicus*) production is worth approximately $37m annually, production and value of black tiger aquaculture is in the order of 1700 tonnes and $25m. This production is based upon a complex chain of production that originates with the supply of broodstock to hatcheries. All black tiger prawn culture in Queensland is currently based upon animals that originated from an open water, natural environment.

Production figures (Lobegeiger 2002) and industry estimates suggest that Queensland hatcheries use between 5,000 and 10,000 adult black tiger broodstock, the bulk of which are female.

All black tiger broodstock are taken by trawl, almost exclusively along the Queensland coast between Port Douglas and Cardwell. The broodstock collection industry is currently managed as an element of the Queensland East Coast trawl fishery, with specific elements of the East Coast Trawl Plan being directed towards the broodstock fishery. Black tiger prawns are taken as a byproduct in the fishery's general operation, in addition to being targeted by broodstock collectors. Q-Fish records (the compulsory Queensland fisheries catch and effort data collection system) indicate that catches of black tigers have averaged approximately 7.5 tonnes per year. If prawns are taken at an average weight of 100 grams, this represents an annual catch of ca. 75,000 individuals by the trawl fishery. We are aware, however, that the C-Fish system under-reports catches of black tiger prawns. There is no specific data column for entering catches of the species, and they are almost invariably taken as a byproduct in the fishery for banana prawns, *Penaeus merguiensis*. Catches are typically quite small – normally in the order of a few individuals to a few kilos per day, and much of the catch is boxed with and recorded as banana prawns, if noted at all. We cannot estimate the extent of under-reporting the total catch of black tiger prawns.

The broodstock collection fishery now operates under two clearly identifiable procedures. The first involves direct targeting of broodstock. Fishers operate small trawlers and work in areas where the bulk of their catch, in value terms, is made up of live black tiger prawns. They operate as single person enterprises and fish to fill orders of broodstock, rather than undertaking fishing operations to maximise total catch. The alternative procedure involves a 'subcontracting' process, wherein a contractor purchases live black tiger broodstock from trawl operators who are conducting conventional fishing operations for banana prawns. These operations may be slightly distorted, in spatial terms, in order that the operators take more black tiger prawns than they would if they were fishing solely for banana prawns. The contractor arranges a local schedule under which he collects the broodstock prawns from these trawlers via a speedboat, and on-sells them to hatcheries.

There is recent evidence that some operators are now starting to sell broodstock to markets in south east Asia as well as to Queensland hatcheries.

Economic analysis – methodology and outcomes

Data for economic appraisal of the black tiger prawn broodstock fishery has been derived from four sources. Information on total catches, catch rates and spatial distribution of catch for black tiger prawns has been obtained from the Queensland Fisheries Service catch and effort database C-Fish. An annual survey of the aquaculture industry (Lobegeiger 2002) and background interviews and discussions have been used to obtain information on the magnitude of the broodstock collection industry. Summary data from an as yet unpublished report to FRDC (Project 98/137, Economic Performance of the Queensland Trawl Fishery, Taylor-Moore, m/s) has been reviewed to obtain insight into the general economic performance of broodstock collectors and other east coast trawl fishers. Finally, a directed interview process directed towards a small number of broodstock industry participants was undertaken as an element of the current project. This involved a professional economist obtaining detailed data on revenue, costs, and depreciation and repairs of a typical broodstock collection business. These data were then analysed and presented, along with economic performance indicators including internal rates of return and benefit : cost ratios.

Data Handling.

Data Entry

Data collected between May 2000 and December 2001 was entered directly into a spreadsheet in Microsoft Excel® software. The information collected from initial surveys and regular monthly monitoring surveys were recorded in the same worksheet. A separate sheet was used to collate the catch information (catch) and trawl log information (effort).

Information collected during the other surveys (such as the alternative gear trials) was also entered and stored in separate databases.

The size and gender information collected during the adult surveys was stored in a database together with the information from the tag-release-recapture program. The details of the capture location/site and date were the identifying features to later draw out the size and gender information relating to the sampling of adult populations.

Once entered, each trawl was allocated a site number (1-6) based on their start latitude and longitude.

Data Validation

The data was validated through a number of data checking and summarising processes. These included:

1. ***Data checking***

The entry operator visually checked data during the data entry process. Where the entry operator did not include a project officer, the data was visually re-checked against the raw datasheets. All datasheets were stamped, signed and dated upon entry to ensure that all data was entered and only entered once.

2. ***Sources of error***

Any errors identified in the latitude or longitudes were highlighted and the entire trawl entry was re-checked against the original datasheets. Errors were removed and correct lat/longs replaced where necessary.

The data was checked for replicates by conducting a sort by trawl/sample number and then by date. Replicate trawl/sample numbers for each date were highlighted then checked against the original datasheets. This assisted in identifying errors in the date or trawl/sample number that was originally entered.

A plot of the latitude and longitude was made in Excel©. Each site was coded in a different colour. Errors were identified as outliers on the plot from the start and end latitude and longitudes or as a site that was “out of place”. This allowed identification of errors in the classification of sites (ie. the incorrect site number) and obvious incorrect recording of original data. Data was also sorted by each recorded parameter to identify outliers and corrections made by checking original datasheets.

Objective 1. To collect and collate existing information.

Objective 1 was addressed at the beginning of the project during 1999 and 2000. The collation of all currently available data on *P. monodon* from across northern Australia, ie grey literature, fisheries databases, research projects, and from indigenous communities, was presented in the first year Milestone Report (44pp.). This was distributed to the FRDC and the steering committee in early 2000. The milestone report was accepted and supported by the steering committee and a copy of this report is provided in Appendix 1.

Objective 2. Adult Stocks and Habitats

The adults stocks and habitats of *P. monodon* in Queensland are described in four sections. These include:

1. Distributions, assumptions and limitations of the data;
2. The *spatial* distribution of adult *P. monodon* stocks;
3. The *temporal* and *spatio-temporal* distribution of adult *P. monodon* stocks; and
4. The *spatial and temporal* distribution of adult *P. monodon* habitats.

Three different types of information were used to describe both the *spatial* and *temporal* stocks and habitats of adult *P. monodon* in North Queensland. These included:

a) **East Coast Trawl Fishery** – Commercial Logbooks: Fishery-Dependent data from the commercial logbooks (official QFS) for the East Coast Trawl Fishery;

b) **East Coast Trawl Fishery** – Research Logbooks: Fishery-Dependent data from research logbooks collected by a small number of reliable broodstock collectors in North Queensland; and

c) **Fishery-Independent Surveys**: Fishery-independent research surveys conducted by QDPI project staff in Trinity Bay, Cairns Region.

The results from these three data types are presented in the four sections outlined.

Distributions, assumptions and limitations of the data

a) Commercial Logbooks

A total of 226 vessels were recorded as having captured *P. monodon* in the East Coast Trawl Fishery between 1988 and 2001. A total of 5881 daily catch records exist in the 14-year data set. A total of 102 130 kgs of *P. monodon* were captured during this time, with a majority of the catch (80.1%) being taken by a minority of the fleet (20.0% of vessels).

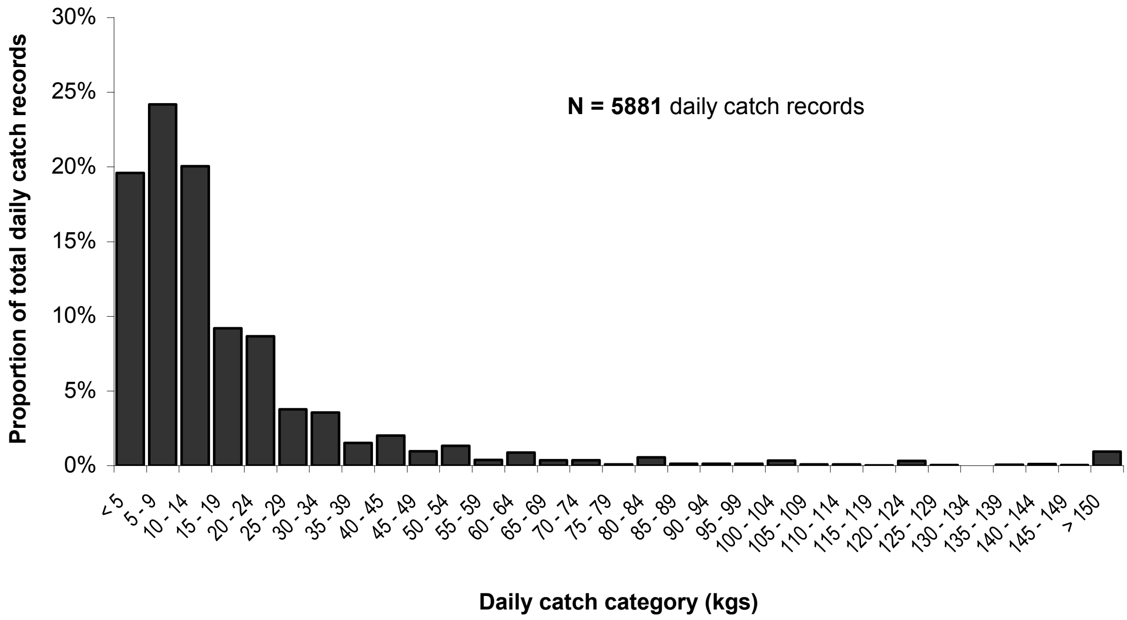


Figure 6. Daily Catch Frequency Distribution of P. monodon in the East Coast Trawl Fishery, 1988 to 2001. Values are daily catch of P. monodon (kgs) per vessel. Only positive catches are recognised.

The distribution of vessel's daily catches of *P. monodon* in the fishery is highly skewed towards lower catches (Figure 6). The majority of daily catch records (73%) were below 20 kgs per day. The distribution has a long tail with catches reaching up to 520 kgs per day per vessel, suggesting that although catches are generally low, high sporadic catches of *P. monodon* occur irregularly.

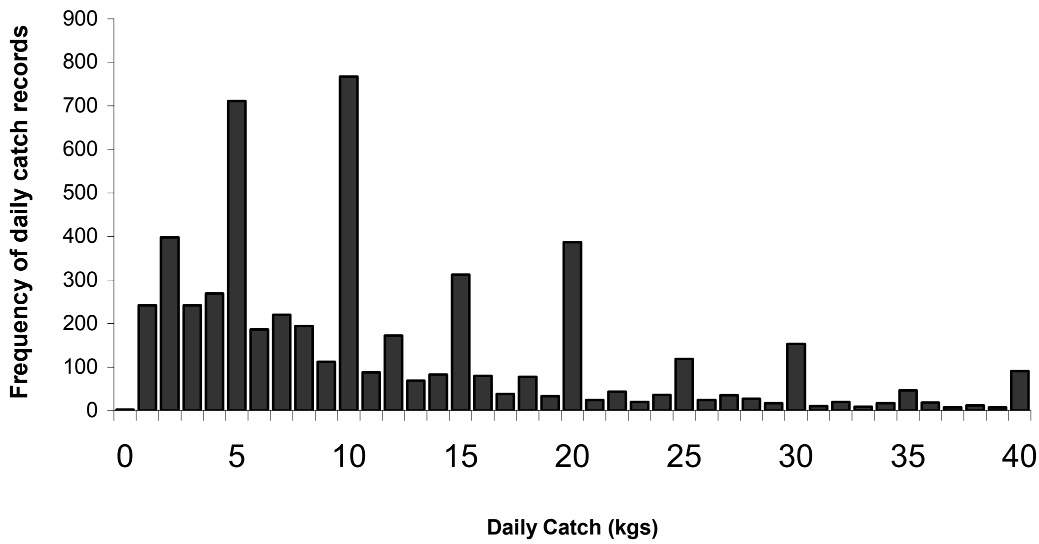


Figure 7. Daily Catch Frequency distribution for daily catch records in the East Coast Trawl Fishery from 1988 to 1994, with 1 kilogram categories.

The catch frequency distribution of daily catch records on a 1kg interval demonstrates that a large proportion of daily catch records are less than 10 kgs (43.8% of all daily records) (Figure 7). This suggests that vessels are reporting their absolute daily catches of *P. monodon*, rather than reporting only a “filled carton” (approx. 10-14 kgs).

There are peaks in the catch frequency distribution of reported commercial catch recorded at 5, 10, 15, 20, 25, 30, 35 and 40 kg catch categories (7). Five kilogram peaks in catch suggest that at least some of the fishers were reporting as full or half full cartons. This suggests some inaccuracy in the weight of catch or position reported.

The commercial logbook data has not been through a formal “on-board fisheries observer” validation process and therefore relied on the reported information only and includes erroneous/inaccurate data points.

Firstly, spatial information included some data points both in 100% land-based grids and some off-shore reports of catch. Although we can dismiss the reports for the land-based grids, we can not dismiss the offshore catches without validation. We can only highlight that they are unlikely to be true locations of catch.

Secondly, *P. monodon* is not listed as an individual catch category on the ECTF logbook sheet (see Appendix 3.2). The reporting of *P. monodon* is a voluntary separation of the catch from “Tiger” catch into the “Other” category. Therefore, the catch of *P. monodon* reported in logbooks is highly likely to be underestimated. This level of underestimation is unknown.

There are three assumptions of interpreting the logbook data presented in this report.

1. That the logbook data is representative of trends in the spatial, temporal and data distributions of the capture fishery for P. monodon in Queensland;
2. That the catch of P. monodon may be underestimated due to non-reporting of P. monodon catch, and the mis-reporting of *P. monodon* catch as “Tiger” prawns.
3. That reported commercial catch (as fishery-dependent data) only be used to suggest trends in the distribution and abundance of *P. monodon* stocks.

[Editors note: We attempted unsuccessfully to confirm/validate the logbook data through buyer's records at local fish processors. Such information is "commercial-in-confidence" requiring cooperation of both buyer and seller, unfortunately at that time there was considerable angst and suspicion in the Trawl fleet created by the negotiations/introduction of the Queensland East Coast Prawn Trawl Management Plan.]

b) Research Logbooks (broodstock collection fishery)

P. monodon catch reported in research logbooks recorded low numbers and low weights of *P. monodon* for the majority of trawl records. Catch rates recorded between 0 and 4,802 individuals per square nautical mile (Figure 8), and between 0 and 142 kgs per sq. nautical mile (Figure 9). Most trawls captured between 0 and 1000 individuals per sq nautical mile or between 0 and 15 kilograms per sq nmile. The long tail of the distributions in Figure 8 and 9 suggests that catch rates are regularly low, however a few sporadic catches occur when very large numbers of *P. monodon* are captured.

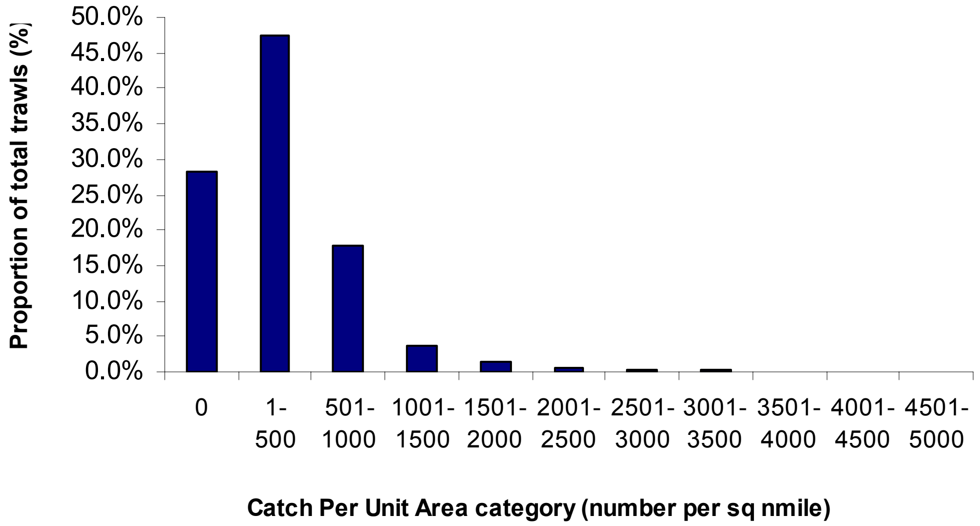


Figure 8. Catch Per Unit Area Frequency class distribution for P. monodon recorded in research logbook survey April 2000 to September 2000. Catch records included were recorded as numbers of P. monodon for each trawl.

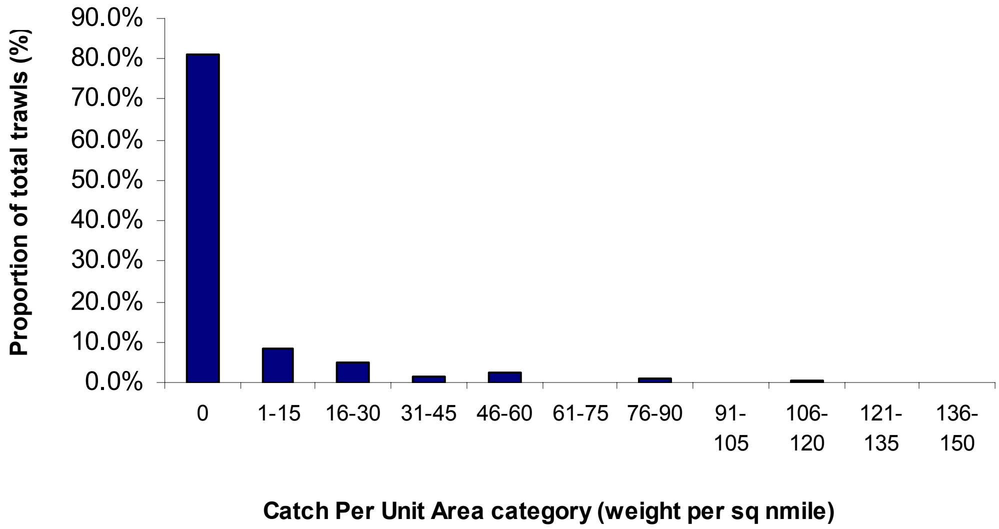


Figure 9. Catch Per Unit Area frequency class distribution for P. monodon recorded in research logbook survey, April 2000 to September 2000. Catch records included were recorded as weights of P. monodon for each trawl.

Assumptions underlying the research logbook data include:

1. That the spatial and temporal trends in catch and effort recorded in research logbooks are representative of the larger sector of the broodstock collection fishery.
2. The spatial catch information presented includes only those records between Simpson Point and Hinchinbrook Island. The catch records outside of this area were too few, and therefore not representative sample of the fishery outside of this region, for valid spatial comparisons. The assumption therefore is that the catch and effort information is comparable between areas in this Simpson Point to Hinchinbrook Island region.

c) QDPI Research Surveys: Trinity Bay

The stocks in Trinity Bay were sampled at six sites in the south-east section between False Cape and Bessie Point. Regular sampling occurred during the new moon phase period each month from July 2000 to December 2001. Catch rates were low and strongly seasonal.

Out of a total of 360 trawls conducted during the 18-month period, 295 trawls captured no *P. monodon* (Figure 10). *P. monodon* capture densities reached up to 20 individuals per hour or 5145 per sq nmile.

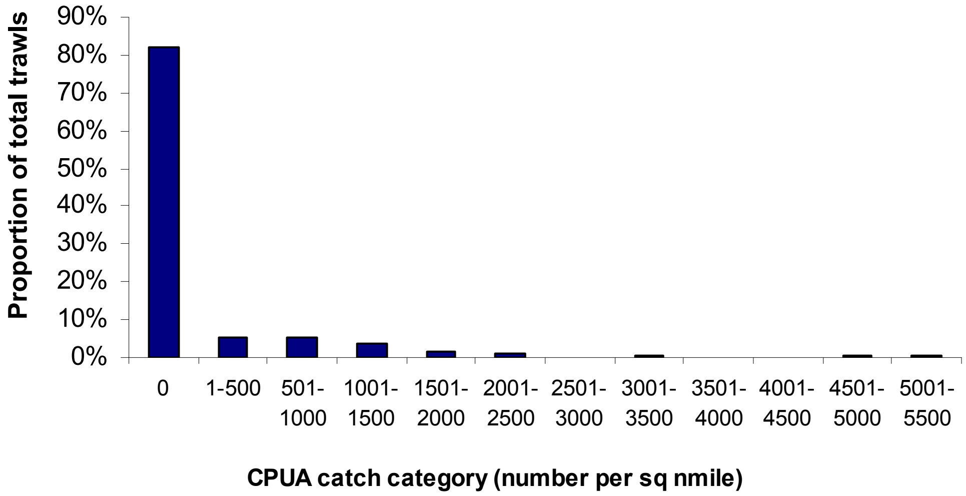


Figure 10. Catch Per Unit Area-Class Frequency Distribution of beam trawls conducted in Trinity Bay, July 2000 to December 2001.

The assumption for the QDPI research surveys catch information are:

1. That as independent fisheries data, that the catch of *P. monodon* in Trinity Bay accurately describes the spatial and temporal trends of the *P. monodon* stocks in that region.

Spatial Distribution of adult *P. monodon* stocks.

Large Spatial Scale: Patterns in catch in Queensland

a) Reported Commercial Logbooks (note constraints on this data).

Reported commercial catches of *P. monodon* in the ECTF were recorded between the 30-minute grids C4 and R27 (Figure 11), which encompasses from the inter-reef sections from Cape York (10.5 deg latitude) to the Hervey Islands (22.5 deg latitude) near Shoalwater Bay.

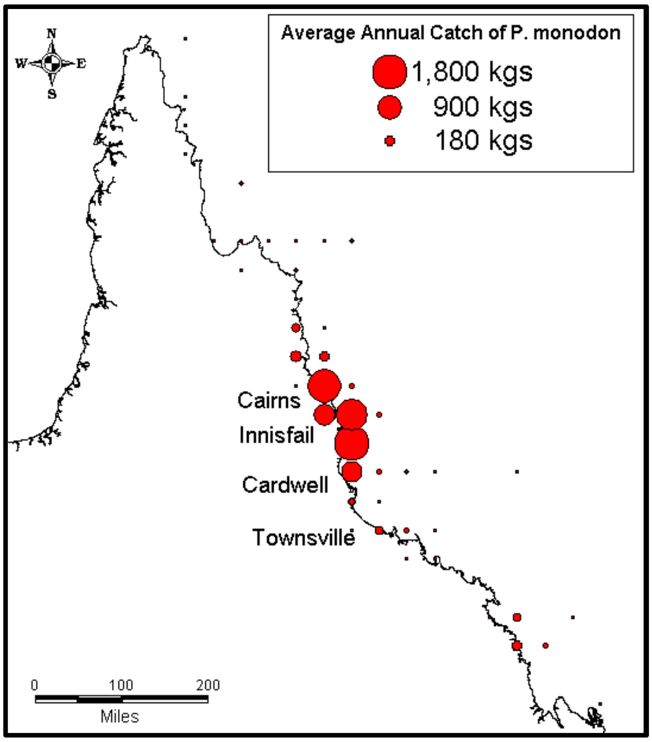


Figure 11. Map of Queensland's East Coast Trawl Fishery and the distribution of average annual reported commercial catch of P. monodon for 30-minute reporting grids (dataset between 1988 and 2001).

The majority of the catch (77.6%) was recorded between 30-minute grids H16 and I19, which encompasses from south of Port Douglas (including Cairns) to Cardwell and Hinchinbrook Island (Figure 12). Commercial logbooks reported average annual catches up to 1, 776 kgs per 30-minute grid in this region. Outside of this North Queensland region, small catches are reported with average annual catches within 30-minute grids less than 230 kgs per year.

Medium Spatial Scale: Patterns of catch in the Cairns to Cardwell Region

a) Commercial Logbooks

Utilising the optional (for the fisher) smaller spatial scale information recorded in commercial logbooks, six-minute grid reference catch information was analysed. This information includes only catch data between 1994 and 2001, due to the relevance of these records to the study. For example, from 1988 to 1994, less than 40% of daily catch records reported on 6-minute grid references. The reported catch information from 1994 to 2001 included an average of 48.3 % of all records (up to 90%) for each year during this latter period.

Throughout the Cairns to Cardwell region, reported catches were patchy, with high average annual catches occurring in "hot-spots" along the Cairns to Cardwell coastline (Figure 12). Highest biomasses of *P. monodon* were captured in the Innisfail region. In this region, average annual catches recorded up to 467 kgs per 6-minute grid at this medium spatial scale.

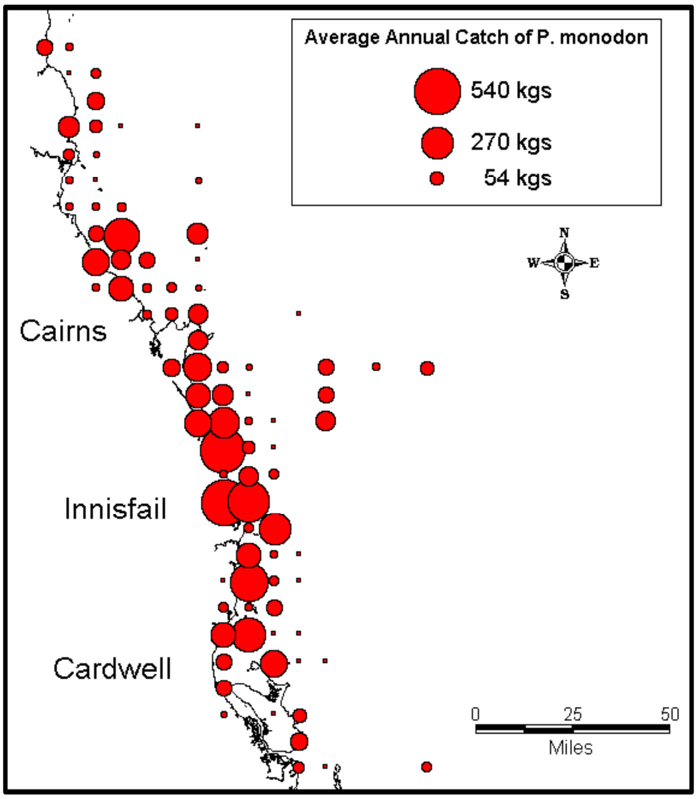


Figure 12. Distribution of average annual reported commercial catch of P. monodon in North Queensland (Cairns to Cardwell region) for the Queensland's East Coast Trawl Fishery (dataset from 1994 to 2001).

b) Research Logbooks

Low catch rates of *P. monodon* were also recorded in research logbooks from North Queensland. Catch per unit area, (number of prawns captured per area of seabed fished), ranged from 0 to 4,802 individuals per sq nautical mile and between 0 and 144 kgs per sq nautical mile.

The average number of *P. monodon* per unit area was highest in the *False Cape* and *South Yarrabah* region (including Oombunghi Beach) with an average of 738 individuals per sq nmile (Figure 13). The *South of Hinchinbrook* region recorded some good catch rates of *P. monodon*, however this region had a higher variability of catch rates. The *Russell River*, *Double Point* to *Bramston Beach*, and *Mission Beach* regions produced consistent and similar catch densities.

The weight or biomass of *P. monodon* captured per unit area was highest in the *Mission Beach* and *Rockingham Bay and Murray River* regions (Figure 14). The *South of Hinchinbrook* and *Yorkey's & Palm Cove Closure* regions were also consistently high producers of *P. monodon*, with average catch per unit area of 21 and 16 kg per sq nmile, respectively.

The spatial distribution of CPUA (weights and numbers captured) recorded in research logbooks between Cairns to Cardwell is displayed in Figure 15.

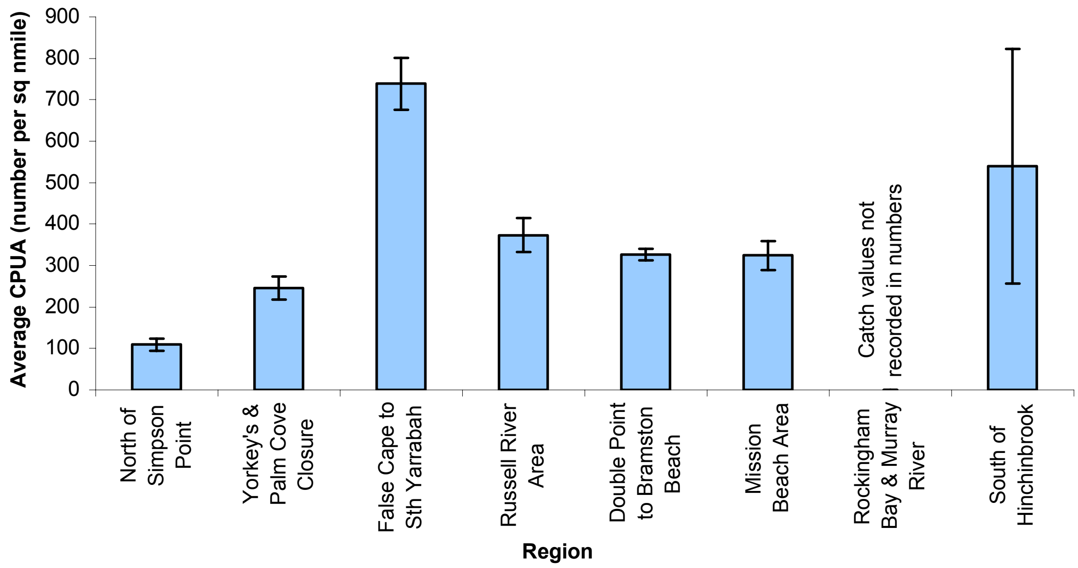


Figure 13. Average catch per unit area of P. monodon for fishing regions during research logbook survey, April to September 2000. Values are the average number of P. monodon captured per square nautical mile (+-standard error).

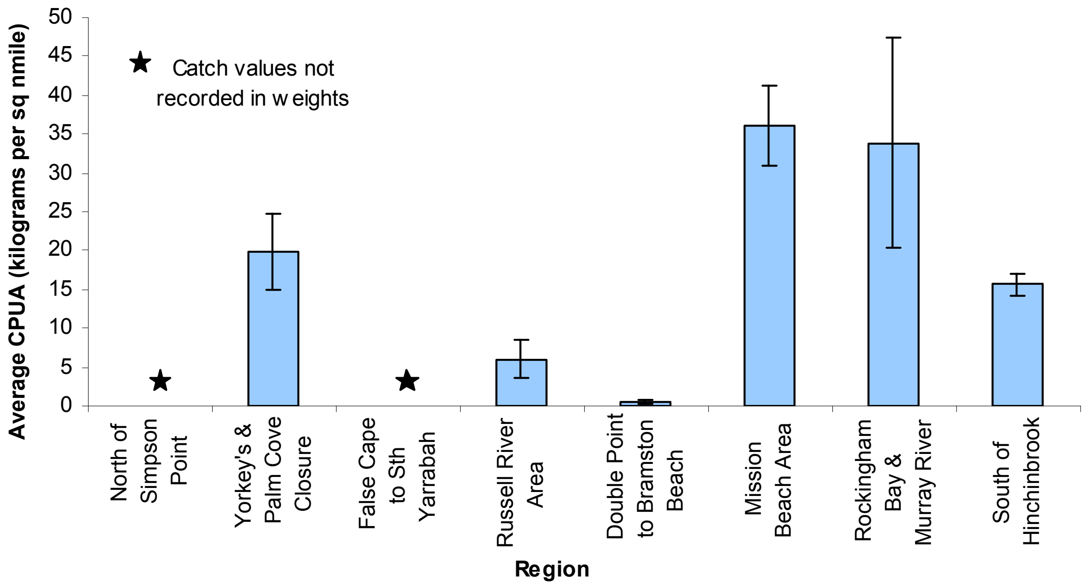


Figure 14. Average catch per unit area of P. monodon for clustered fishing grounds during research logbook survey, April to September 2000. Values are the average weight of P. monodon captured per square nautical mile (+- standard error).

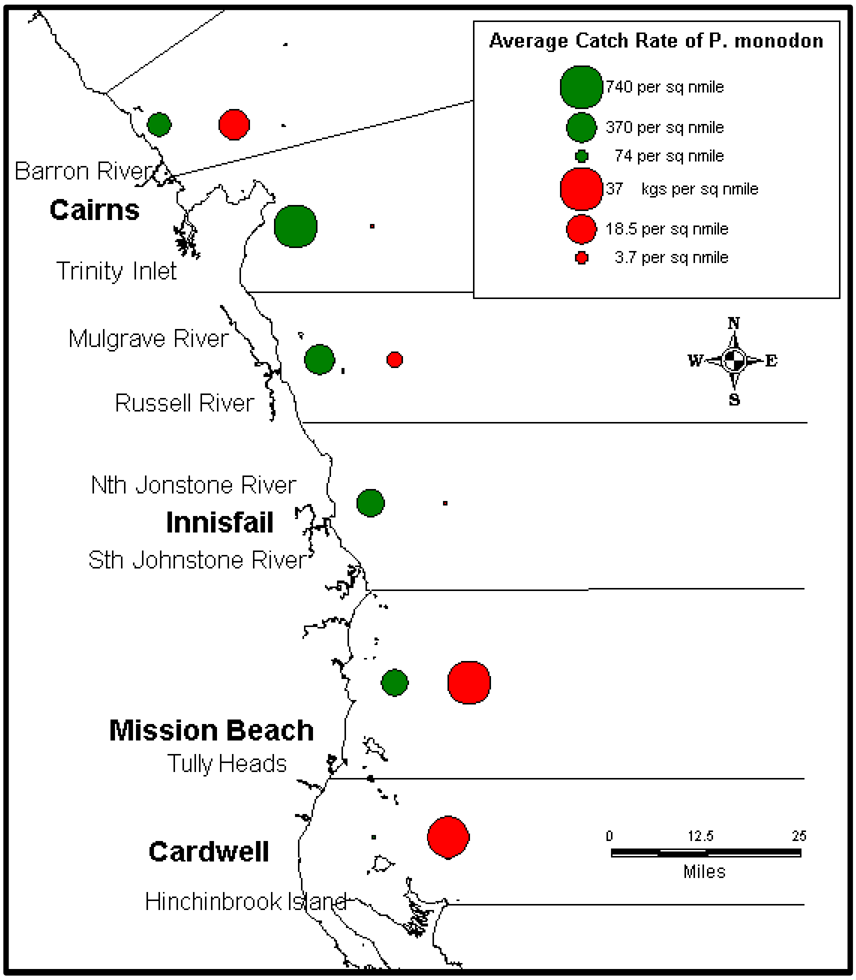


Figure 15. Map of the P. monodon fishing regions in North Queensland, showing a) the regions and their geographical boundaries; and b) their average reported catch per unit area (number and weight per square nautical mile). Catch information was collected during the research logbook survey, April to September 2000. Values are the average number or weight of P. monodon captured per square nautical mile per region.

Small Spatial Scale: Distribution of catch in the Cairns Region

c) QDPI Research Surveys: Trinity Bay

A randomised survey of prawn stocks conducted in Trinity Bay (Cairns) by beam trawl recorded a total of 17 individuals captured by 70, twenty-minute trawls. This survey recorded a concentration of catch in the south-east quarter of the closure, between Bessie Point and False Cape, although two other catches were recorded off the shore from the Barron River and Thomatis Creek estuary mouths (Figure 16). No *P. monodon* were captured in trawls north of Yorkey's Knob, although permitted broodstock collectors often target *P. monodon* in this region.

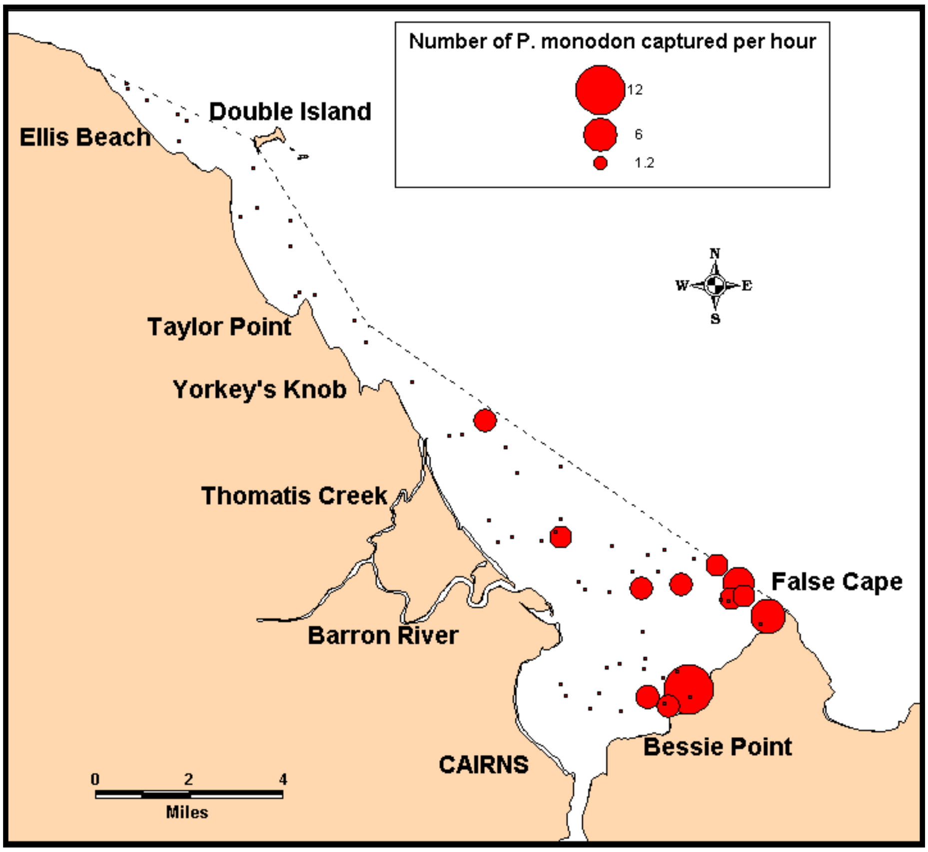


Figure 16. Distribution and catch frequency of P. monodon captured during a survey in the Trinity Bay Closure (May 2000). Circle size represents the number of P. monodon captured per 30-minute trawl. Small dark circles represent zero P. monodon catch.

Twenty-minute trawls recorded low and patchy catches of *P. monodon*, with up to 6 individuals per trawl (12 per hour) (Figure 17). Trawls conducted at the Bessie Point area recorded the highest catch rates of *P. monodon* (up to 12 individuals per hour, or 3087 per sq nmile).

The *P. monodon* captured were between 166 and 246 mm total length (39 and 61.3 mm carapace length).

A second (long-term) survey used these results and was conducted at Bessie Point, in the closure, and concentrated fishing effort in the area of highest catch rates recorded in May 2000. The survey recorded highest catch densities of *P. monodon* close to the estuary mouth of Trinity Inlet, with no *P. monodon* captured out near the fishing closure boundary at False Cape (Figure 17).

The survey recorded highest catch rates of *P. monodon* between 1 and 3 metres depth close to Trinity Inlet at Bessie Point. The site is covered by sparse to medium seagrass communities (Figure 17). Catch rates recorded up to 10 individuals per hour or 2469 individuals per sq nmile.

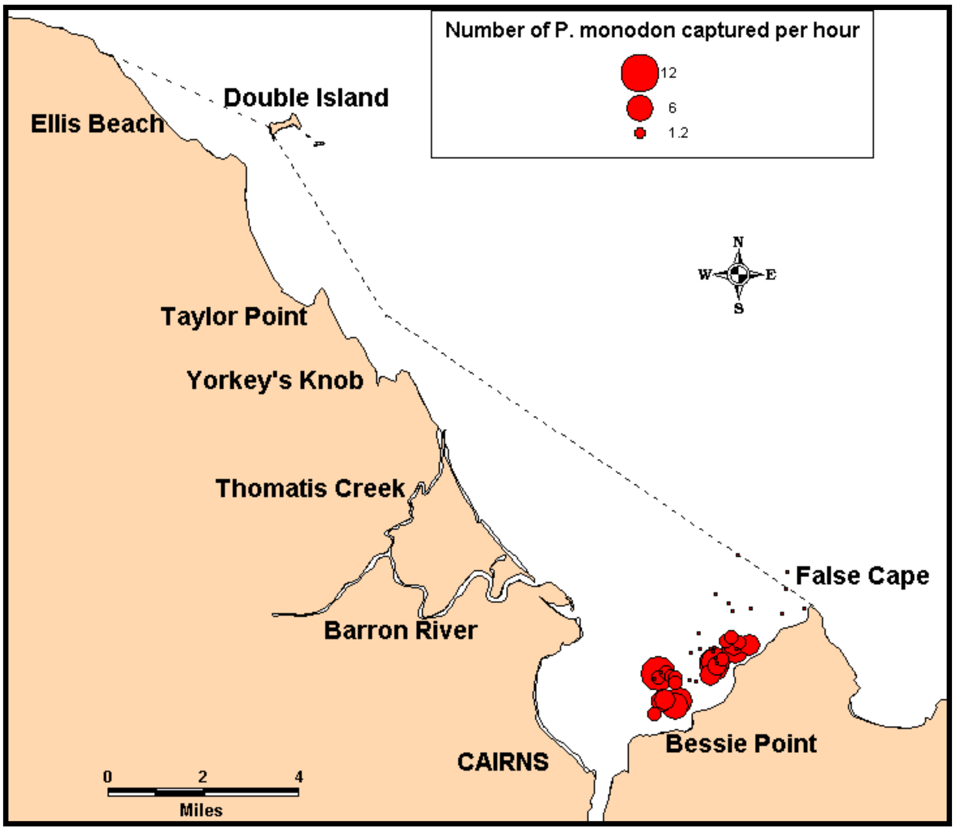


Figure 17. Results of a survey of adult P. monodon habitats in the southern region of Trinity Bay Closure in July 2000. Circle size represents the number of P. monodon captured per 30 minute trawl. Small dark circles represent zero P. monodon catch. Catch is displayed on the map at the position of the start of each trawl.

Figure 18. Size Class Frequency of female and male P. monodon captured by beam trawl in Trinity Bay, July 2000.

The survey captured a total of 45 *P. monodon* between 171 and 251 mm total length (41.5 and 66.5 mm carapace length) (Figure 18). The female *P. monodon* captured were larger than the males, although an equal ratio of females to males was recorded.

Regular sampling at six sites in the south-east section of Trinity Bay, between False Cape and Bessie Point, was conducted during the new moon phase period each month from July 2000 to December 2001. Catch rates were low and strongly seasonal.

The monthly monitoring surveys captured a total of 190 *P. monodon* over the 18-month period. Individuals captured ranged in size between 109 and 287 mm total length (23.7 and 76.2 mm carapace length) (Figure 19). Two major peaks in the size class distribution are observed for both males and females. The females had two peaks in length at 165 and 245 mm TL (37 and 58 mm CL), and males peaked in abundance at 150 and 185 mm TL (31 and 41 mm CL).

Obvious difference in the size of individuals was observed between the different sites, but the caveat is low sample sizes. Large broodstock-sized females were captured throughout the 6 sites, and the largest individual was captured from 1 metre depth (Site 3) (287 mm TL). Seasonal changes in the size of *P. monodon* in these sites are discussed later in Objective 4.

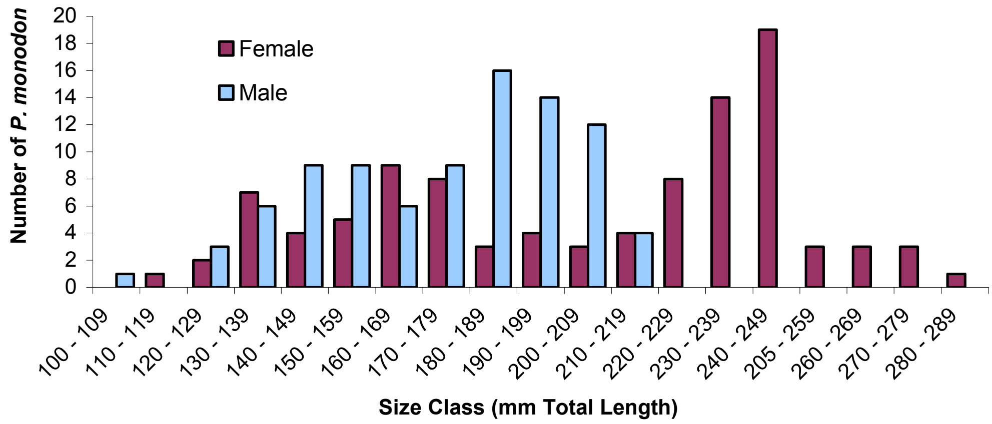


Figure 19. Size Class Frequency of male and female P. monodon between Bessie Point and False Cape, Trinity Bay, July 2000 to December 2001.

Temporal Distribution of adult *P. monodon* stocks.

Large Temporal Scales: Inter-Annual Patterns in Catch

Commercial Logbooks

The average annual catch of *P. monodon* reported in the ECTF was 7 295 kgs (1988 – 2001). Annual catches ranged between 2 423 and 20 587 kgs of *P. monodon* (Figure 20). Unusually high catches of *P. monodon* were recorded in 2001, with an annual catch of 20 587 kgs which was 5 times the previous years' catch.

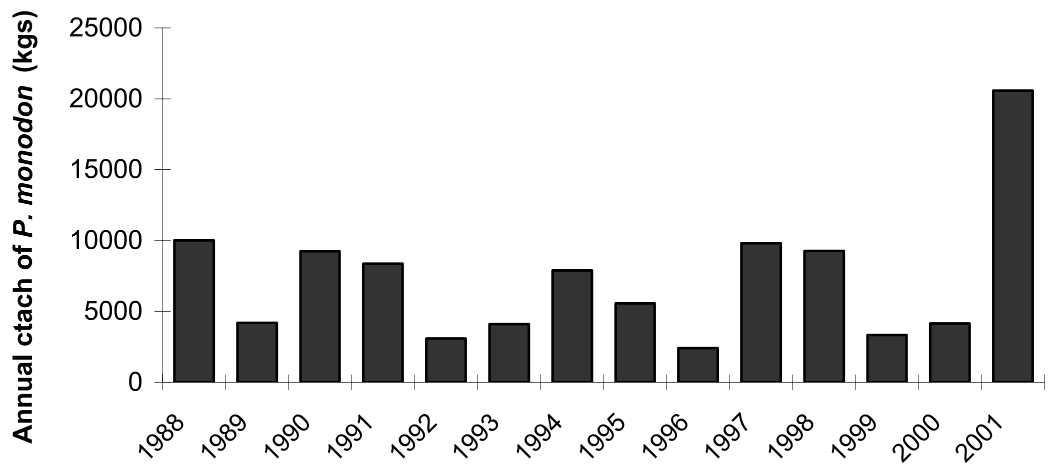


Figure 20. Total annual reported commercial catch of P. monodon in the East Coast Trawl Fishery from 1988 to 2001.

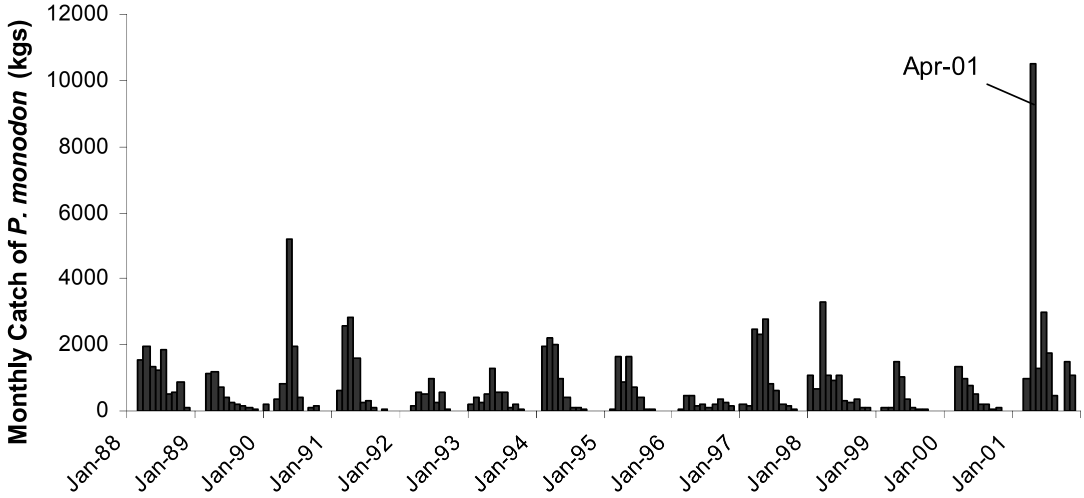


Figure 21. Total monthly catch of P. monodon taken in the East Coast Trawl Fishery between 1988 and 2001. Catch is the total number of kilograms of P. monodon captured per month.

The total monthly catch of *P. monodon* for this period followed a similar seasonal trend each year between 1988 and 2001 (Figure 21). For example, a peak in catch occurred in the first half of the year and reduced catch occurred in the second half of the year. An unusually high peak in catch occurred in April 2001 (10 504 kgs) with higher than average catches reported by a large proportion of vessels. This suggested that the higher reported catches recorded during 2001 were more likely due to a biological change in abundance, than due to a recent change in management implemented in 1999.

Medium Temporal Scale: Seasonal Patterns in Catch

Commercial Logbooks

The seasonal patterns in reported commercial catch demonstrate a post-wet season peak in *P. monodon* catch in April following with a slow decline throughout the later months of the year (Figure 22). A second much smaller peak in catch may be observed in October/November. Catches of *P. monodon* are almost zero during the month of December when the seasonal trawl closure is implemented from December 15 to March 1.

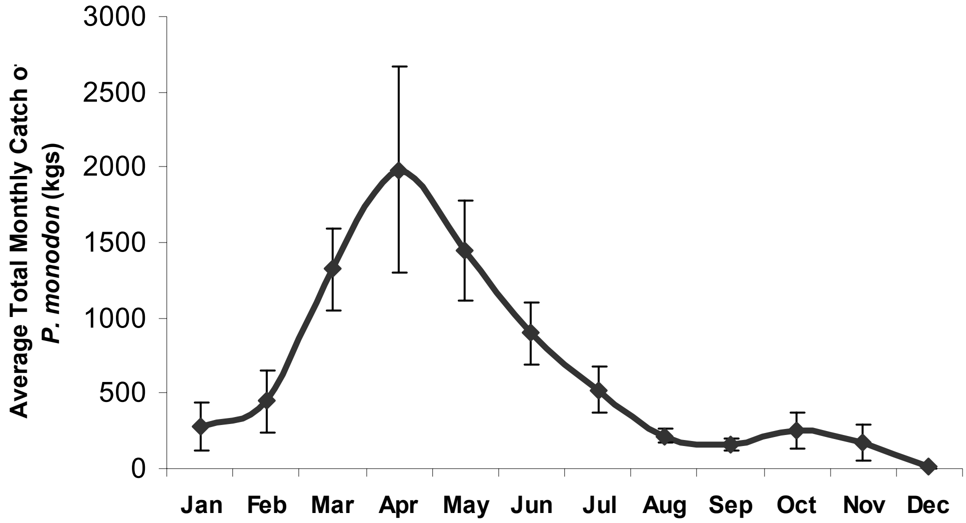


Figure 22. Average total catch per month of P. monodon based on commercial catch data from the CFISH logbooks between 1988 and 2001.

Research Logbooks

The catch of *P. monodon* was recorded as weights in the early part of the year in 2000 when fishers could target large number of individuals that have recently recruited from the coastal estuaries (Figure 23). Following this post-wet season period, *P. monodon* catch was recorded as numbers in logbooks most probably due to a reduction in their catch rates. The catch per unit area of *P. monodon* between Cairns to Cardwell reduced from April to September, and by September the average catch rates were consistently below 400 individuals per sq nmile.

During May, June, July and August, the highest daily catch rates (CPUA) of *P. monodon* for each month were recorded on or during a week before the new moon (Figure 23). During April, however, the highest catch rates were recorded in a week of the full moon phase. Broodstock collectors highlight that they target *P. monodon* during a two-week period around the new moon.

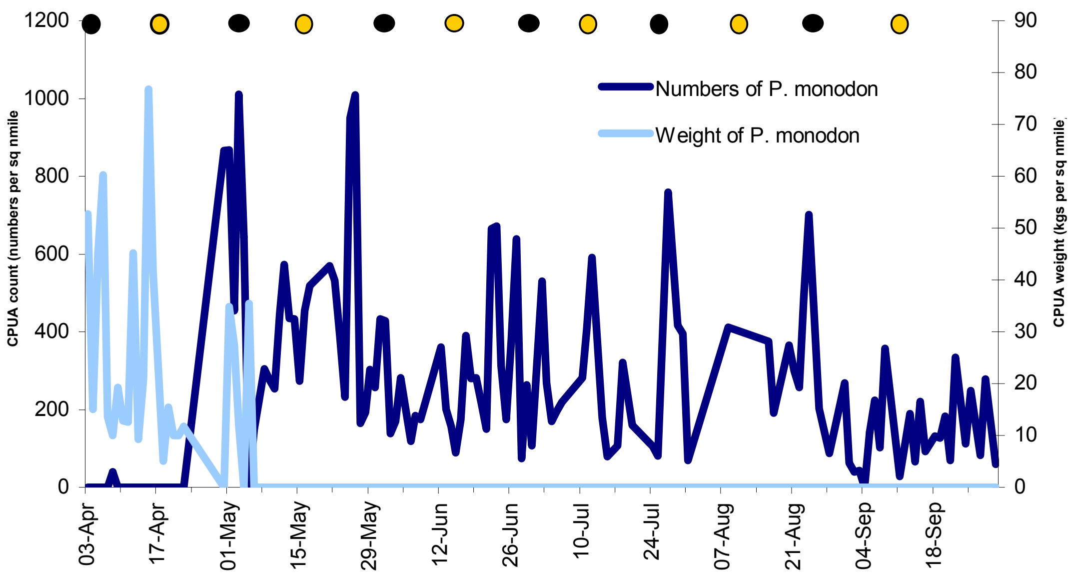


Figure 23 Seasonal patterns in the average daily Catch Per Unit Area of P. monodon during research logbook survey, April 2000 to September 2000. Catch was recorded in both weights and numbers and both are provided. Black circles indicate the timing of the new moon and the yellow circles indicate the timing of the full-moon during the survey period.

QDPI Research Surveys: Trinity Bay

P. monodon demonstrated strong seasonal patterns in catch in the six foreshore sites (Figure 24). Throughout a period of monthly monitoring (July 2000 to December 2001) by beam trawl, *P. monodon* peaked in catch rates in the wet to post-wet season of February to April. Catch rates slowly declined following this post-wet season until almost no prawns were captured at these sites in the pre-wet season of November and December of 2000 and 2001. The onset of northerly winds, warmer water temperatures, and lowered water turbidity are blamed for this absence of *P. monodon* in the broodstock fishery during these months.

The seasonal pattern in size of *P. monodon* corresponds with the timing of their recruitment from estuarine habitats during the wet season period, when small individuals emigrate from the creeks and rivers out onto the foreshores and fishing grounds. Smaller individuals dominated the catch in January and February in the foreshore habitats and individuals increased in average size over the following months as these new recruits grew. By September, large *P. monodon* dominated the catch (average size – 250mmTL). During September 2000, we also recorded a few smaller individuals in the foreshore sites.

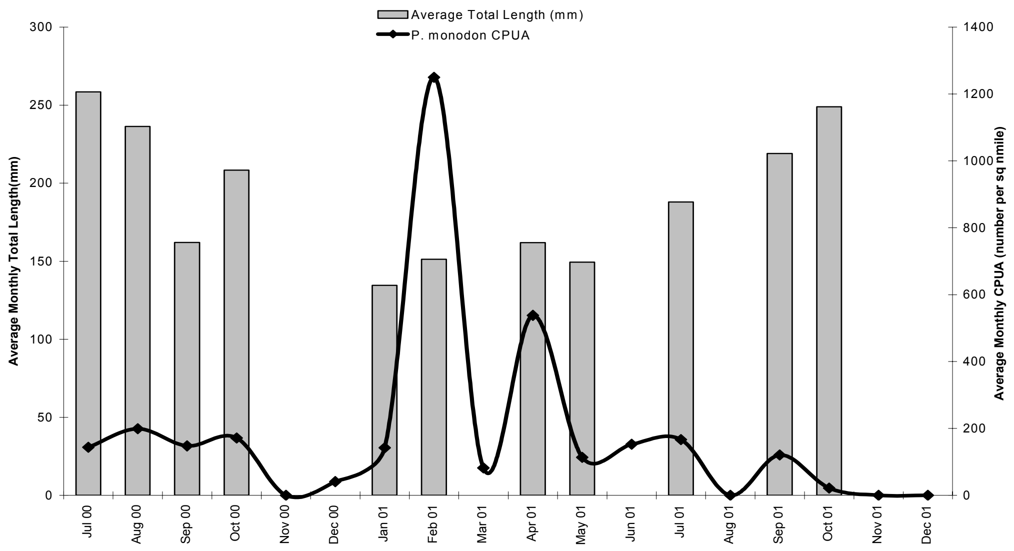


Figure 24. Seasonal change in the average size of P. monodon (total length mm) and Catch Per Unit Area (CPUA) during the monthly monitoring of six sites in Trinity Bay, July 2000 to December 2001.

Small Temporal Scales: Diurnal Patterns in Catch (CPUA)

Research Logbooks

There was no relationship found between the average catch rates of *P. monodon* in commercial trawls and time of the day recorded in research logbooks (Figure 25). However, the catch per unit area (number per square nautical mile) seemed to be more consistent during daylight hours (ie. low variability; small standard error bars). This pattern could be an artifact of the higher fishing effort during the day (and therefore greater number of trawls) that reduced the variability in the average CPUA value. Although we could not identify a relationship between catch and time of the day, the majority of fishing effort for *P. monodon* was conducted during daylight hours (Figure 25, dotted line).

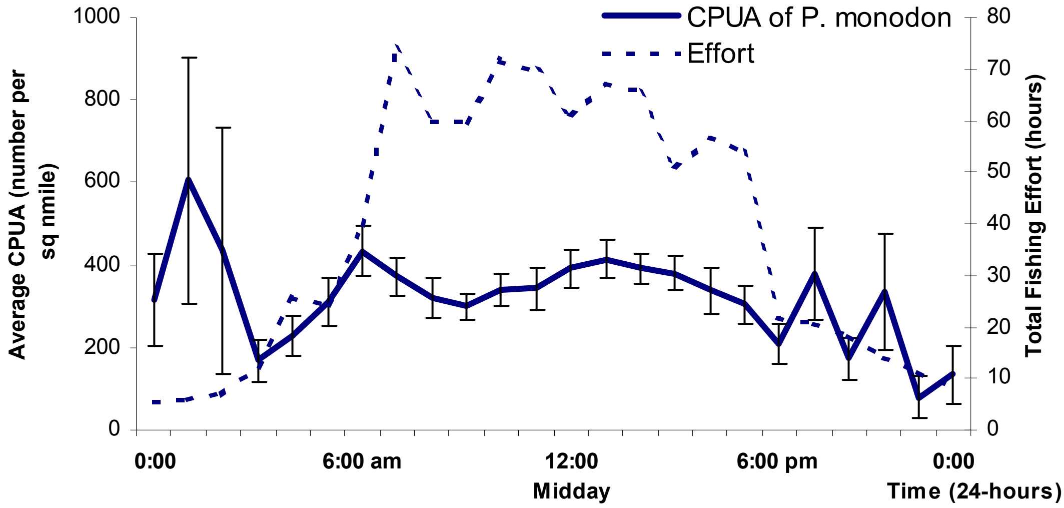


Figure 25. Catch Per Unit Area of P. monodon and total fishing effort over a 24-hour clock for trawls conducted during the research logbook survey, April to September 2000 (plus or minus standard error bars). Trawl times were calculated as a middle point between start and end time.

Contradictory to this information, anecdotal evidence provided by commercial broodstock collectors in North Queensland suggest that adult P. monodon catch rates are generally greater during the night. However, they report that during periods of high water turbidity catches may be more even across both day and night.

Fishing effort was highest during the day (Figure 25)- this is most likely due to the catch of banana prawns (P. merguiensis) being greatest during the day also. The catch of banana prawns is often used to supplement the catch of P. monodon and vice versa.

QDPI Research Surveys: Trinity Bay

The July 2000 survey was conducted across two night and two day periods. This included 27 ‘day’ and 20 ‘night’ trawls. *P. monodon* showed no significant difference in catch rates between day and night trawls, with an average of 462 and 571 individuals per hour for day and night periods respectively (Figure 26).

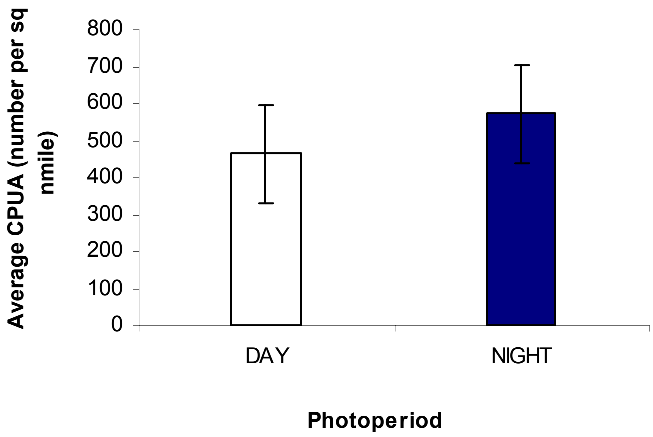


Figure 26. Average Catch Per Unit Effort of P. monodon during Day and Night photoperiods, Trinity Bay, July 2000.

Over a 24-hour clock (Figure 27). No pattern in catch can be observed to occur with the change in the light/dark cycle, as there was no change in catch around dusk and dawn. Penaeid prawns are known to bury in the sediment during periods of non-activity, and this strongly reduces their catchability in trawls. This suggests that the activity levels of *P. monodon* during July 2000 was not directly responding to light and dark phases, and that maybe other cues were influencing their activity levels, such as water turbidity, moon phase.

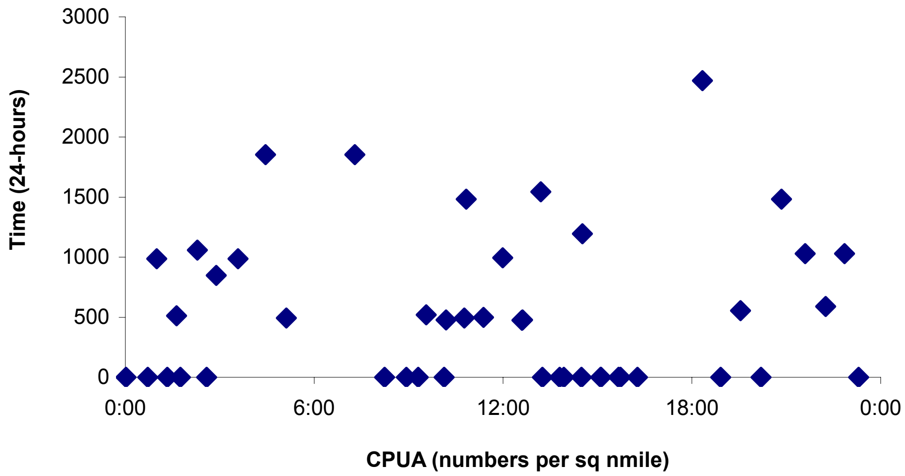


Figure 27. Diel distribution of Catch Per Unit Area of P. monodon in Trinity Bay, 3 to 6 July 2000.

The July 2000 survey was conducted from 3 to 6 July 2000. As the new moon phase occurred on 2 July 2000, we can assume that there was no or very little lunar light occurring during the night that could have affected the activity of *P. monodon*. Broodstock collectors in the region target *P. monodon* during the new moon period, but will fish for them during the day and night. There is no evidence for an effect of the day/night phase on catchability, however we cannot rule out that an effect could change with the timing of the lunar cycle and changes in water turbidity.

Spatio-temporal Patterns in Catch

Commercial Logbooks

Highest seasonal catches occur between the grids H16 (Cairns) and I19 (Cardwell), where catches peak from March to April (Figure 28). Outside of this latitudinal zone, average monthly catch is reduced (ie. in grids G14, G15, H15 & I20). A second seasonal peak is observed in October in H16 and in November in I18. Outstanding catches during 1988 and 1996 was responsible for the October peak in catch in H16 and the 2001 catch data was responsible for the November peak in catch in I18. There may be a latitudinal gradient in the timing of the peak catch on the North Queensland coast, where at high latitudes (ie. I20) the average peak in catch occurred during March, and at low latitudes (ie. G14) recorded peak catches were reported in April.

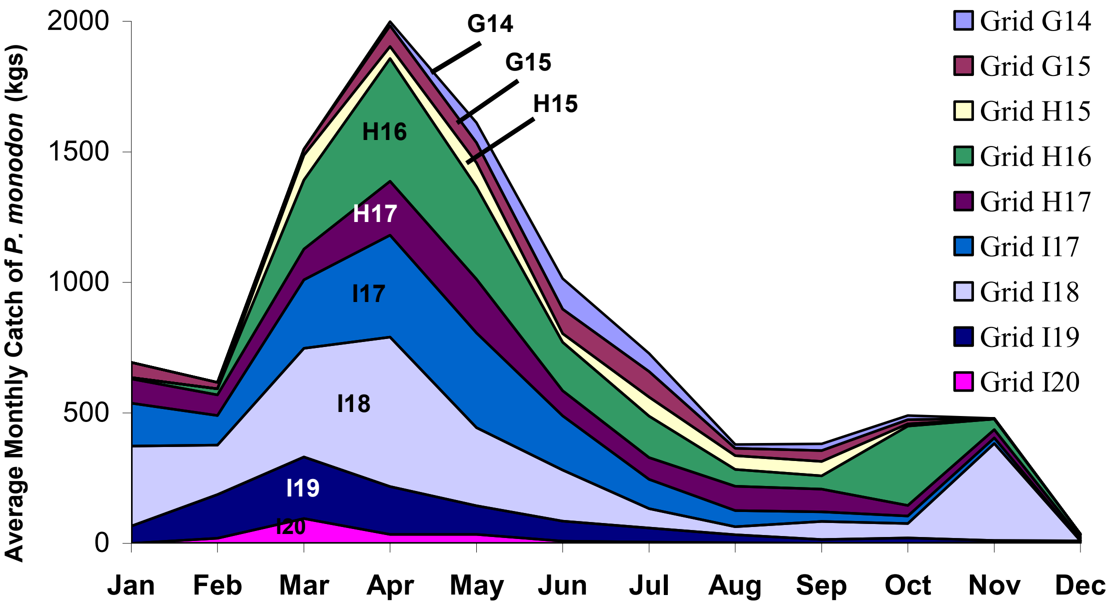


Figure 28. Spatio-Temporal distribution of the average monthly reported commercial catch of P. monodon for nine 30-minute reporting grids in the East Coast Trawl Fishery from G14 (ie. Bloomfield River; Helenvale) to I20 (ie. Ingham). Data used is the average monthly catch information from 1988 to 2001. Area layers in the plot are layered in latitudinal order (more northerly grids top; more southerly grids bottom).

QDPI Research Surveys: Trinity Bay

The seasonal patterns observed in Catch Per Unit Area (Figure 29) are mostly due to the changes in catch rates in just two out of the six sites (Figure 2). The catch recorded at sites 2 and 3 were 2.5 times greater than the other sites. These include sites 2 and 3, as they have similar seasonal patterns in catch to other sites from January to August, however they have high peaks in catch in February and April 2001. Although sites 1 and 6 also demonstrate these wet-season peaks in catch, it is Sites 2 and 3 that are responsible for the large seasonal peak when all sites are combined in a monthly average (Figure 24).

Sites 2 and 3 are the most shallow of the 6 sites, and border onto the seagrass communities off Bessie Point. They are also the closest sites to the estuary and mangrove communities off Bessie Point. On very low tides, Site 3 is no longer inundated by the tide and is exposed. Sites 2 and 3 also produced the highest catch rates of the banana prawn, *P.merguiensis*.

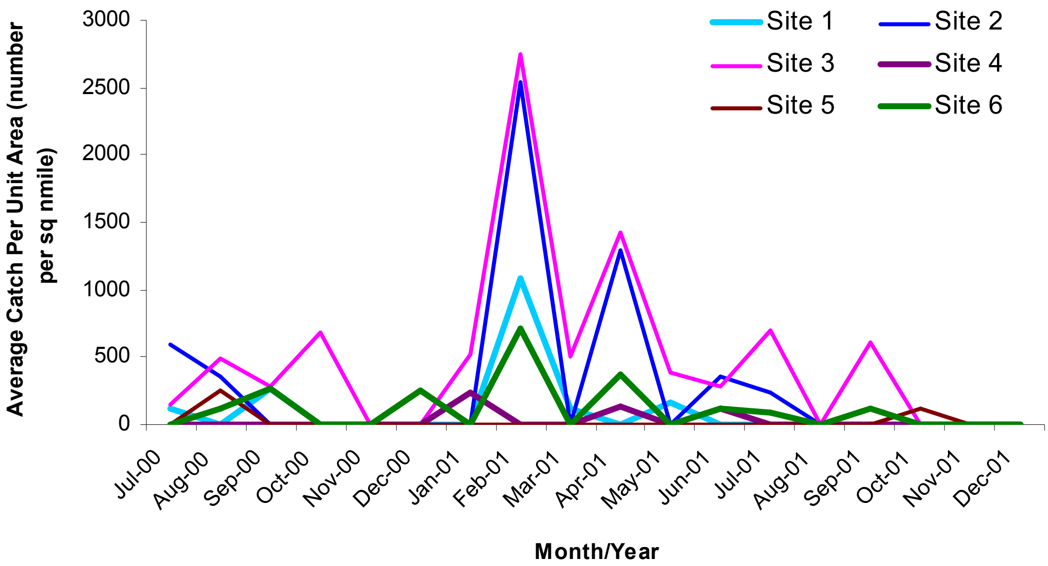


Figure 29. Spatial changes in the Catch Per Unit Area for 6 sites over the length of the survey period, July 2000 to December 2001.

Spatial and Temporal Distribution of adult *P. monodon* habitats.

Abiotic Habitat (non-biological components)

Depth

Research Logbooks

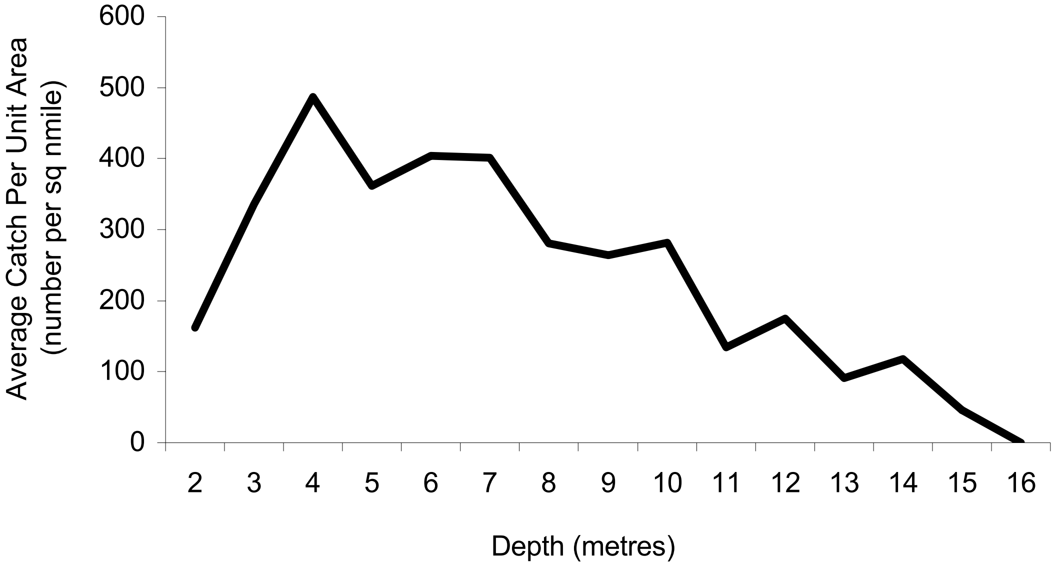


Figure 30. Average catch per unit area of P. monodon captured in commercial trawls recorded in research trawls April to September 2000

Average reported catch per unit area of *P. monodon* was greatest at 4 metres depth and declined with increases in depth (Figure 30). No *P. monodon* were captured in depths of 16 metres, and no trawls were conducted in depths greater than 16 metres in research logbooks during the survey period.

QDPI Research Surveys: Trinity Bay

Beam trawls sampled prawn communities at between 1.4 and 8.4 metres depth. The higher catches were recorded from shallower trawls (Figure 31). This trend may be an artefact of the sampling design, where more samples were conducted with shallow waters. The small depth range sampled in the closure would made it difficult to determine any depth-related difference in catch rates and abundance of *P. monodon*.

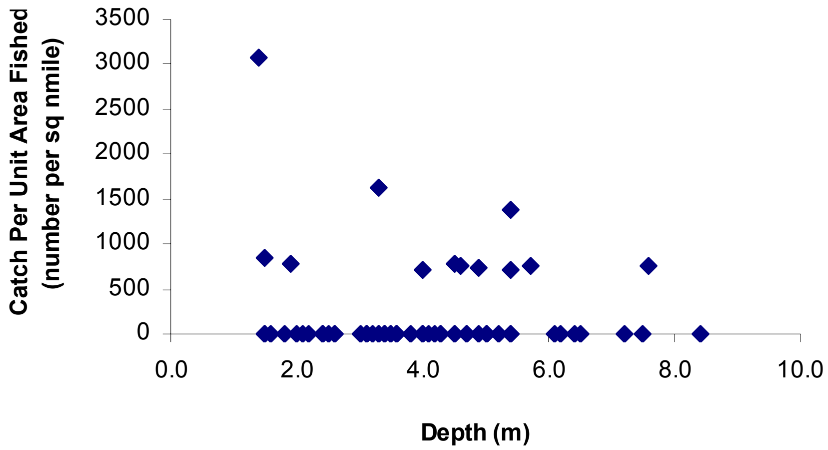


Figure 31. Distribution of catch rates with depth of seabed sampled by beam trawl during May 2000 survey of Trinity Bay.

Sediment

QDPI Research Surveys: Trinity Bay

During the May 2000 survey of the entire closure, three replicate sediment samples were collected at the start of each trawl samples. With only 17 individuals captured during 12 trawls out of a total of 70 trawls, a relationship between catch rates and sediment type could not be identified (with any statistical rigour).

Anecdotal information from broodstock collectors suggest that on the inshore fishing grounds of North Queensland, *P. monodon* prefer the soft mud sediments. As the vessels trawl over a more sandy mud, the number of *P. monodon* in trawls will decline. This information suggests that *P. monodon* adults prefer muddy sediments in the inshore fishing grounds.

Rainfall and Waterflow

Reported commercial catch was concentrated in the Cairns to Cardwell region of North Queensland. This Cairns to Cardwell region also has the highest rainfall in Queensland. The relationships between catch (cf abundance) of *P. monodon* and rainfall and/or waterflow are investigated/presented in the later Chapter on seasonality.

Weather and Water Conditions

The research logbook survey period was between April to September 2000. The weather for this dry-season period is dominated by strong south-easterly winds that regularly reach up to 30 knots. Due to these strong onshore winds, water turbidity is often high in the shallow inshore waters (<10m depth).

Anecdotal reports suggest that in times of low water turbidity, catch rates of *P. monodon* are often low. Conversely when the water turbidity is high, catch rates are often at their highest. Therefore the strength and direction of prevailing winds are possibly able to affect prawn catchability and therefore the supply of broodstock. At the "local" level, *P. monodon* broodstock collectors target patches of dirty water when the general water turbidity is low. Normally they find these pockets of dirty water at the southern ends of beaches along the North Queensland coast. This suggests that currents and tides, as well as wind, are also likely to affect the distribution of *P. monodon* on small spatial scales.

Water Quality

QDPI Research Surveys: Trinity Bay

Salinity

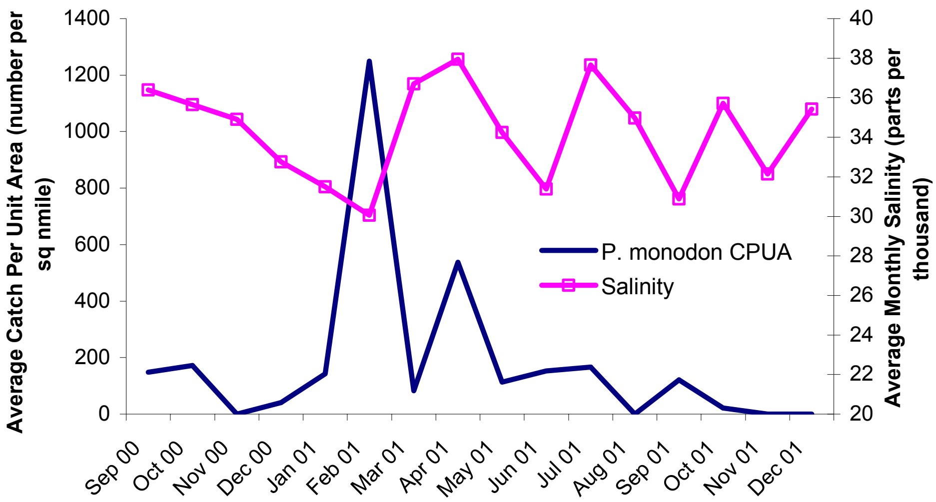


Figure 32. Seasonal average salinity and Catch Per Unit Area (CPUA) for six sites in Trinity Bay, September 2000 to December 2001.

Salinity did not follow a strong seasonal pattern throughout the research survey period (September 2000 to December 2001). A peak in *P. monodon* abundance occurred in February 2001 (1250 per sq nmile) when low salinity (30ppt) was recorded at the sampling sites (Figure 32). This is due to the emigration of new recruits from the estuary and freshwater flow from the estuary that occurred during the wet season (February). Following the wet-season in 2001, salinity fluctuated between 38 and 31 ppt, with peaks in April and July, and troughs in June and September. The fluctuating salinity through the 2001 dry season could be due to a combination of events such as periodic rainfall, strong winds and water currents, and tidal influences.

pH

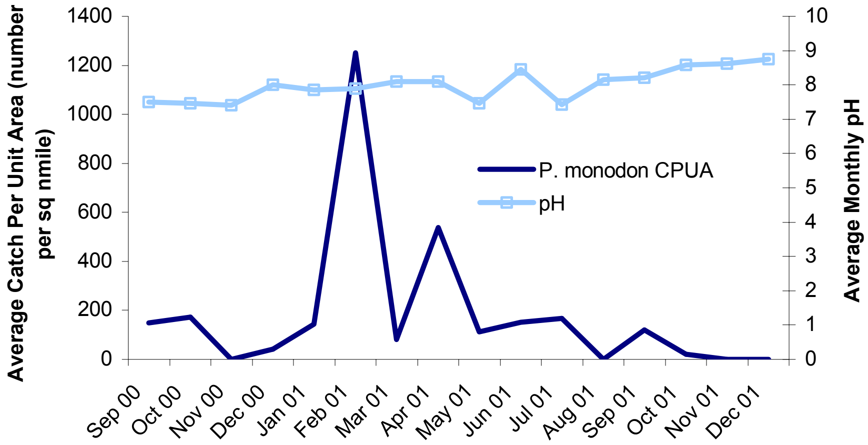


Figure 33. Seasonal average pH and Catch Per Unit Area (CPUA) for six sites in Trinity Bay, September 2000 to December 2001.

There was no seasonal pattern in the water pH from September 2000 to December 2001 in sites sampled by beam trawl. PH ranged from 7.41 to 8.7 during the survey period (Figure 33).

Turbidity

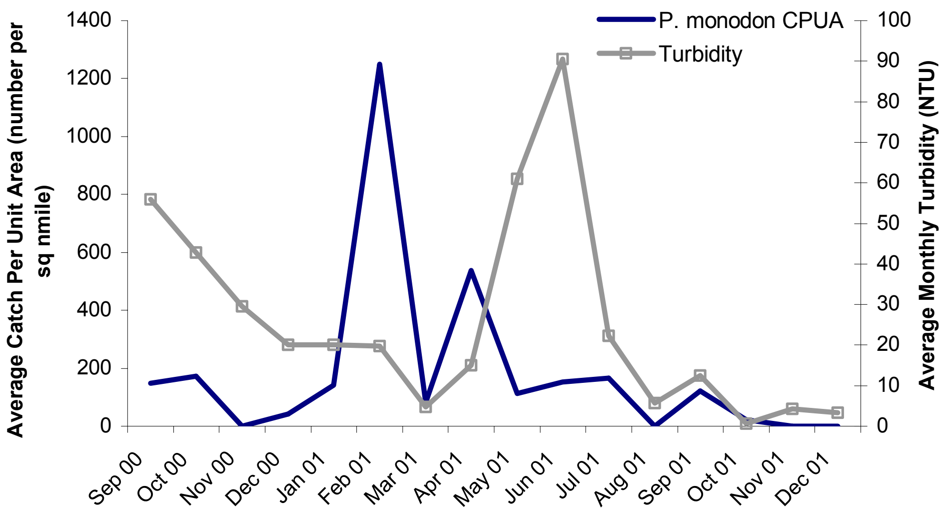


Figure 34. Seasonal average turbidity and Catch Per Unit Area (CPUA) for six sites in Trinity Bay, September 2000 to December 2001.

High water turbidity was generally recorded during the dry-season (September and October 2000; May-July 2001, Figure 34), when turbidity on the foreshore sites reached over 30 NTU, with readings up to 90 NTU recorded during June 2001 when strong winds prevailed. Low water turbidity were generally recorded during the wet-season between December 2000 and April 2001 and from August 2001. During the wet-season period, the predominant winds in general are slight northerly winds. The between-month pattern showed that high catches occurred during months of low water turbidity (Figure 34). However, anecdotal reports from *P. monodon* broodstock collectors suggest that in-month patterns (ie. on small temporal scales) show that high catch rates occur during periods when the water turbidity is high. This may simply be a difference in temporal scale or, more likely, a reflection of collector behaviour in seeking out (targeting) areas and "local" conditions that from their experience indicate concentrations of *P. monodon.*

Water Temperature

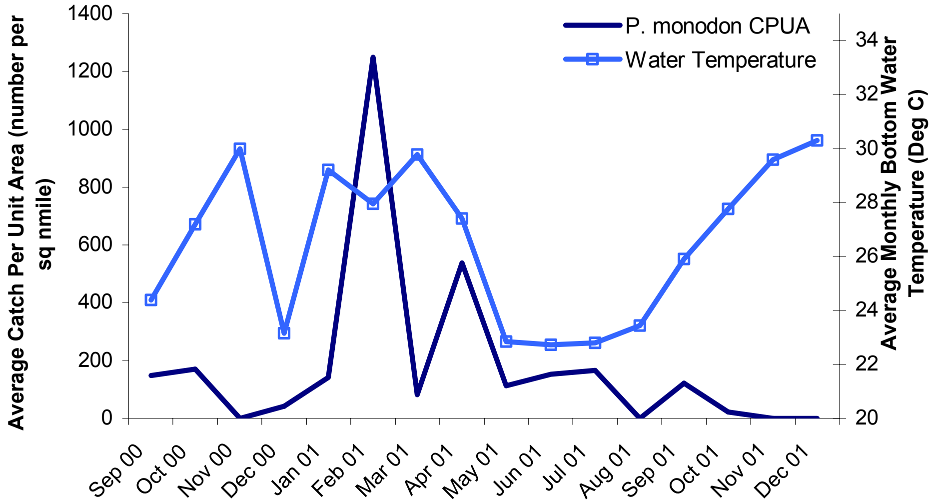


Figure 35. Seasonal average bottom water temperature and Catch Per Unit Area (CPUA) of six sites in Trinity Bay, September 2000 to December 2001.

Water temperature followed a strong wet-dry season pattern, with a peak in temperature occurring during the summer wet season (Figure 35). Some fluctuations in temperature occurred during this wet season period, most probably due to cooler freshwater influences from the neighboring Trinity Inlet estuarine system. The winter or dry season period (May to August) showed low and consistent water temperatures with temperatures reaching down to 22.7^{o}C in 2000 and 23.2 ^{o}C in 2001. Water temperatures began to rise during September for both 2000 and 2001.

Habitat (biological components)

Marine Vegetation

The presence or absence of marine plants in trawl samples was recorded for each trawl during the May 2000 survey of Trinity Bay (entire closure). Only 9 of the 70 trawls found seagrass present in the samples or in evidence on the trawl gear. Therefore was no strong relationship between the presence of seagrass and catch rates, however the highest catch rate of prawns was recorded where seagrass was present. This area included very shallow waters and was just outside the estuary. At best this simply demonstrates that *P. monodon* were not restricted in the lower limits of their depth distribution and could be captured both on and off the seagrass beds.

Associated Species

Community Composition

QDPI Research Surveys: Trinity Bay; and Anecdotal Information

Anecdotal information from broodstock collectors suggests that there is a strong relationship between the species composition of fin fish and prawns captured in trawls in the inshore fishing grounds and the magnitude of *P. monodon* catch. They highlight that many silver-coloured fish are captured from a muddy-bottom habitat when *P. monodon* can be captured in abundance (Table 2). A change to a species composition dominated by more coloured fish occurs on a more sandy-bottom habitat (Table 2) when *P. monodon* catch abundance is lowest.

This change in prawn catch with species composition was also observed during QDPI research surveys in 1-6 metres depth.

Table 2. List of key associated species that are associated with habitat where P. monodon *is captured and is generally not captured. The list of species was generated from anecdotal information from commercial broodstock collectors and QDPI research beam trawls, North Queensland.*

Community Composition	**Key Associated Species**
Species associated with habitat where *P. monodon* is captured	**In general: Silver-coloured fish** • Banana prawn: *P. merguiensis* • Dollar fish: Leiognathidae • Grunter: Pomadasys spp. • Jew Fish: Sciaenidae • Trevallies: Carangoidae • Bony bream: *Nematolosa come* • Hair tails: *Trichiurus lepturus* • Silver biddies: Gerridae
Species associated with habitat where *P. monodon* is generally NOT captured	**In general: More brightly coloured fish** • Endeavour prawn: *Metapenaeus ensis; M. endeavouri* • Small non-commercial prawn: *Trachypenaeus* sp. • Goat fish: Mullidae • Cardinal fish: Apogonidae • Lizard fish: Synodontidae

Note. Colour of bycatch fish used by collectors as an indicator of possible presence of *P. monodon*

Associations with the banana prawn, P. merguiensis

Commercial Logbooks

Between Year Patterns in Catch

The patterns in total annual reported catch of *P. monodon* and *P. merguiensis* are very similar during the period between 1988 and 2001 (Figure 36). The total annual catch of *P. merguiensis* was much greater than for *P. monodon* throughout the 14-year period and ranged from 121 085 to 777 910 kgs, with *P. monodon* catch ranging from 2424 and 20 587 kgs. Although captured in different quantities, very similar peaks and troughs in catch magnitude are observed. This suggests that similar between year processes may influence the biomass of both *P. monodon* and *P. merguiensis* in the commercial fishery.

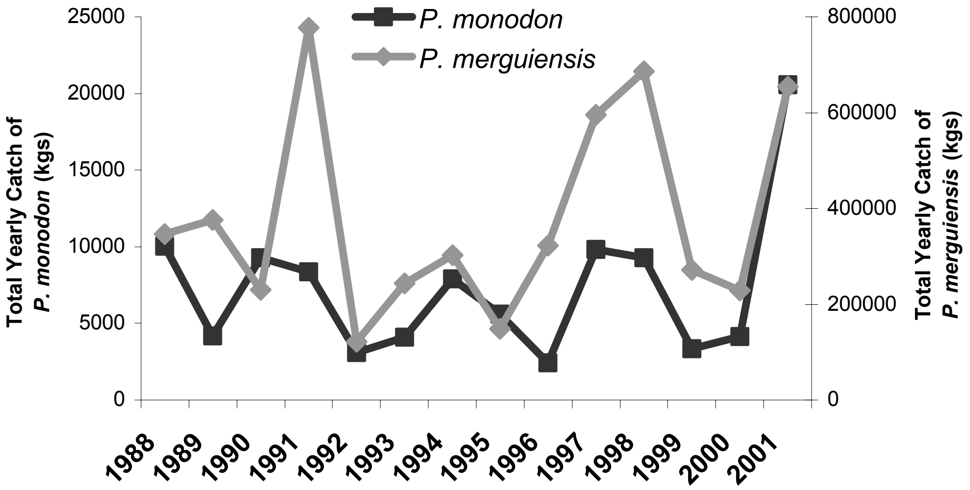


Figure 36. Annual commercial catch of P. monodon and P. merguiensis in the East Coast Trawl Fishery between 1988 and 2001.

Seasonal Patterns in Catch

Commercial Logbooks

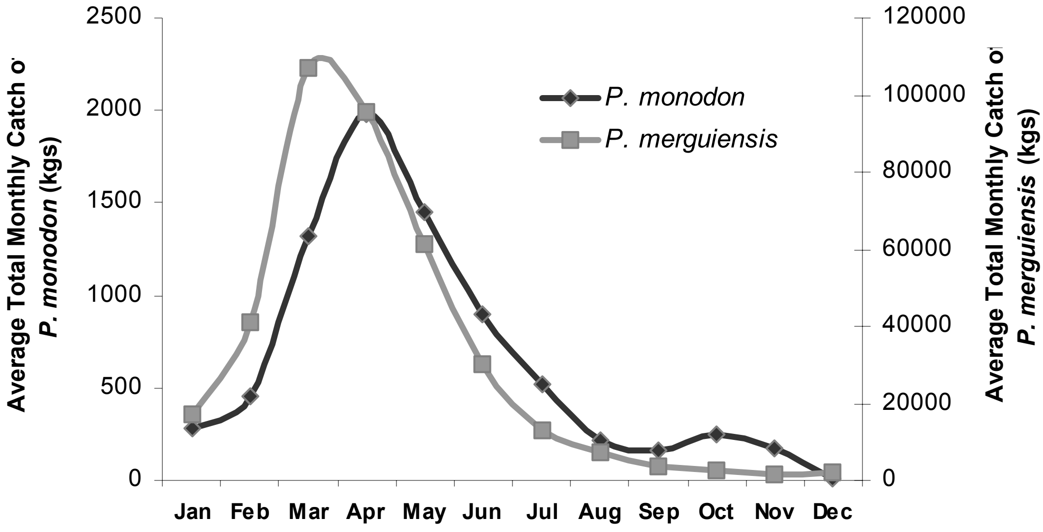


Figure 37. Average Monthly Catch of P. monodon and P. merguiensis in the East Coast Trawl Fishery between 1988 and 2001.

The average monthly reported catch of *P. monodon* and *P. merguiensis* follow a similar seasonal pattern with one large peak in catch during or near the end of the wet-season (March/April), Figure 37. Similarly, the catch of *P. merguiensis* reaches almost zero during late spring (pre-wet season- November, December). *P. merguiensis*, however did not demonstrate a second smaller peak in catch during October and November.

Magnitude of Catch

QDPI Research Surveys: Trinity Bay

P. monodon was captured at low catch rates in comparison to the banana prawn, *P. merguiensis*. On average, *P. monodon* was captured at a rough ratio of 1:40 with banana prawn in foreshores.

The magnitude of *P. monodon* catch was loosely correlated to the magnitude of banana prawn catch (*P. merguiensis*) (see Figure 36). For the monthly catch information from July 2000 to December 2001 the timing of both species catch in trawls was similar. ($R2 = 0.32$; N=360; $P = 0.053$).

Metapenaeus spp. are the endeavour/ensis penaeid prawns that are also captured in inshore waters of the Queensland coast. The catch of *Metapenaeus* was not significantly correlated to the catch of *P. monodon* (R2=0.11; N358)

Objective 3 Juvenile distribution and habitat

An inventory of juvenile *P. monodon* stocks and habitat assessment of their capture locations in North Queensland was conducted between November 1999 and December 2001 in freshwater, estuarine and foreshore areas. Methods included: field surveys using cast netting techniques; opportunistic surveys using alternate gears; information and data collected by recreational fishers; and collection of abiotic data (ie, *in situ* water quality, rainfall, water flow and habitat assessment). The objective of juvenile research was to determine distribution and abundance of animals, with resulting data to establish recruitment and age structure in nursery habitat. In summary juvenile *P. monodon* were found to inhabit all reaches of estuarine systems sampled (Figure 38). A total length size range of 16 mm to 198 mm (carapace length 3 mm to 50 mm) was found moving throughout the estuary, representing post larvae to adult *P. monodon* (refer to Figure 1 and Appendix 3.5). Post larvae (average total length 13.5 mm) tended to dominate the upper estuary with a graduation through to juvenile, adolescent and sub adult towards the lower estuary. This pattern of animal size structure in the estuarine reach was strongest during periods of high abundance (October to March) and particularly during recruitment of post larvae into nursery habitat (October/November). Juvenile *P. monodon* was found in extremely low and variable abundance (Figure 38), which created limitations in establishing methods to predict annual stock abundance and sustainability.

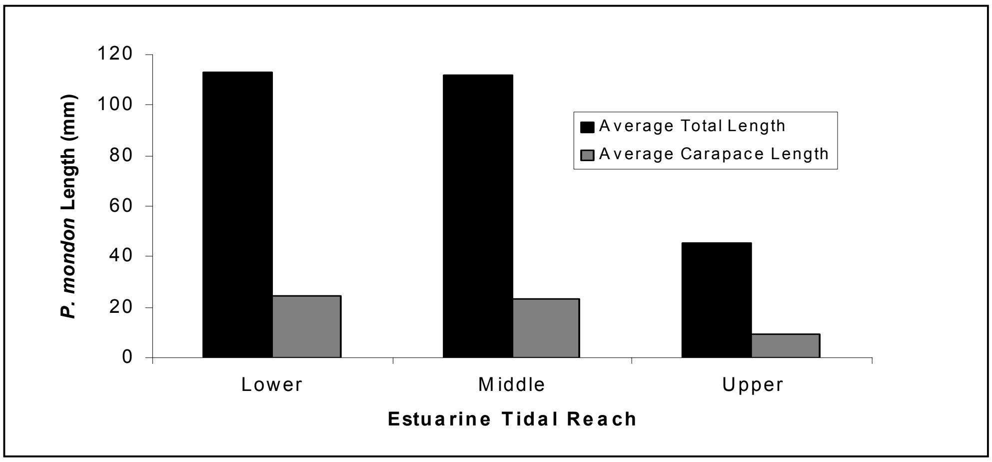


Figure 38.Average total and carapace length of juvenile P. monodon by estuarine reach

Alternate Gears

To establish the presence of juvenile *P. monodon* in nursery habitats a range of capture gears were used to. Primarily cast nets were used in distribution and abundance surveys, but these nets were unsuitable to capture post larvae animals. The habitat of this life history stage also caused cast nets to snag (e.g. on rocks and tree roots). Hence use of cast nets was limited to relatively clear shallow waters and required a large amount of effort to cover long stretches of bank habitat.

Descriptions of alternate gears (small beam trawl, fyke net, hand scoop net, drag net and back pack and boat electrofisher) used to establish distribution and abundance of juvenile *P. monodon* is outlined in the methodology section of this report. The presence of juvenile *P. monodon* was established in a number of habitats via the use of alternate gears, which would not have been possible using cast nets. The a size of prawns caught in each gear type is displayed in Figure 39.

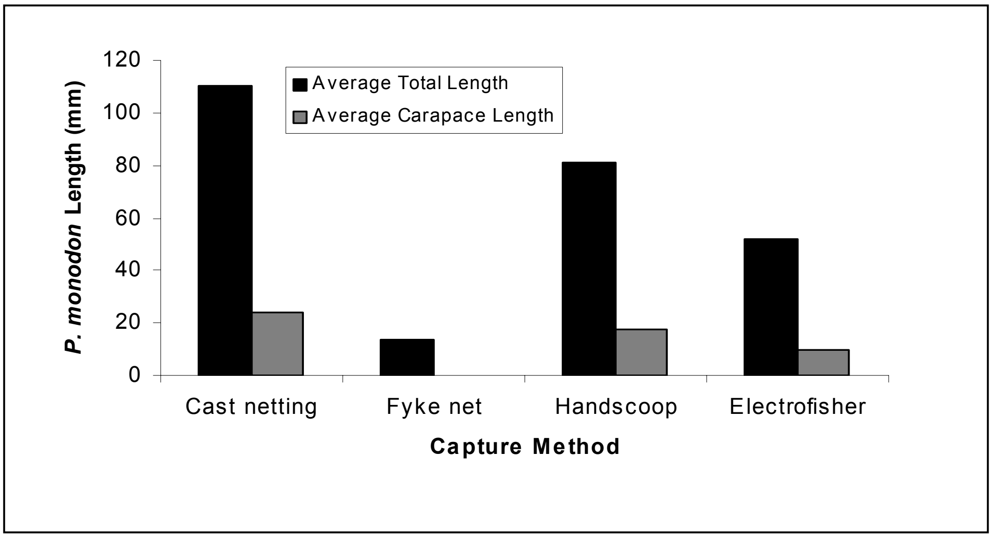


Figure 39 Average total and carapace length of juvenile P. monodon by capture method

Small Beam trawl

Two species of prawn were identified in the beam trawls samples. *P. monodon* were found to compose 18% of the prawn catch and *Metapenaeus ensis* 82%. The beam trawling exercise proved to be effective in establishing presence of post larvae *P. monodon* (approximate total length 13.5 mm), in two of the three upper estuarine sites (Thomatis Creek and upstream Freshwater Creek, see Appendix 3.2) of the Barron River in November 2000.

Fyke net

The fyke net study proved to effective in capture of post larvae *P. monodon* along side *M. ensis* and post larvae and sub juvenile estuarine fish (eg. mullet, gar fish, queen fish and toad fish), that were actively moving or drifting with currents through this upper tidal site. The average total length (± SE) of 45 post larvae *P. monodon* captured was 13.5 mm ± 0.6 mm. Figure 40, below, displays the CPUE of *P. monodon* in number caught per hour preceding the low tide. A rapid and significant rise in CPUE half way (3 hours and 15 minutes) into the rising tide is displayed, with catch peaking after two thirds of the rising tide and rapidly declining thereafter. The increase in capture of *P. monodon* with tidal rise indicates post larvae movement both in the water column and up and downstream in the system. The peak capture period could be attributed to the fyke net being at maximum capture efficiency during highest tidal velocities, that is mid to two – thirds of tidal run. Vance, D. J. *et. al*. (2002) studies of juvenile penaeid prawns use of mangrove forest displayed that prawns were most abundant as tide height inundated mangrove communities at the peak flooding tide. This sampling has shown similar results to Vance's work, displaying use of inundated river fringing mangroves by juvenile *P. monodon*, with the correlation between water depth and catch rate suggesting their use of water current and velocities to enter mangroves.

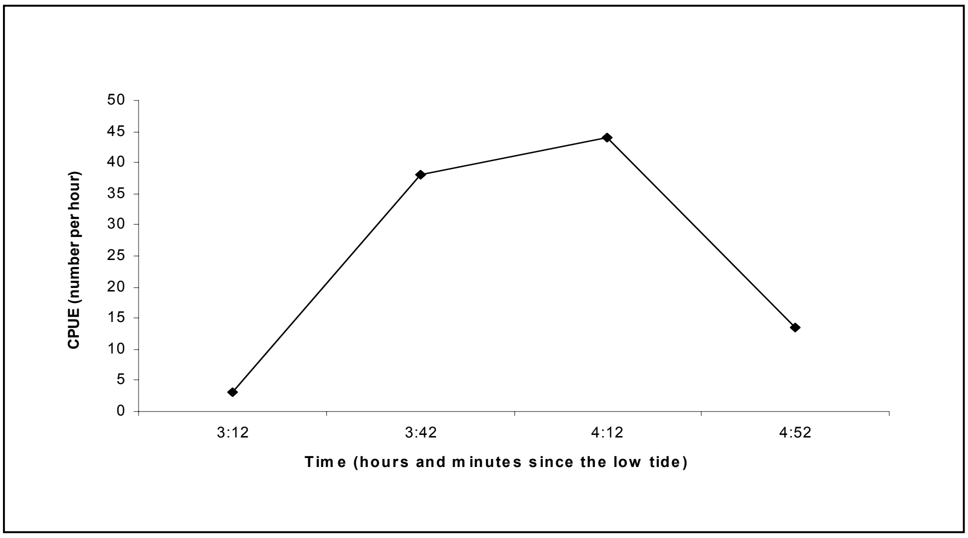


Figure 40. Variation in CPUE of post larvae P. monodon following low tide (sampled using a fyke net at site 1 on the Barron River).

Scoop Net

The hand scoop net proved to be successful in capture of juvenile *P. monodon* with a total length size range of 18 mm to 115 mm, averaging SE $\pm$ at 34.65 mm $\pm$ 18.81 (refer to Appendix 3). The hand scoop net was also successful in capture of *P. monodon* of a tagable size (> 55 mm total length) at the Johnstone River site (town boat ramp), which could not have been sampled via any other capture methods due to rocky substrates. In the Russell/Mulgrave River sites the hand scoop net was successful in capture of *P. monodon* of 30.63 mm $\pm$ 8.94 mm and established the presence of *P. monodon* in steep, hard, mud bank structures, not able to be sampled via other capture methods.

Drag Net

Due to the presence of marine stingers and crocodiles and with little success in application of the drag net from a vessel, it was deemed an unsafe practice to continue use of this capture technique.

Electrofishing

Back Pack

Presence of *P. monodon* was not established in sites surveyed (refer to Table 1 and Appendix 3.2) via this capture method. Presence of other prawn species was established and is listed in Table 1 below. Water quality and habitat varied between sites with Saltwater and Moody Creek classified as having high to extreme disturbance and low mangrove dominance and Half Moon Creek moderate disturbance with high mangrove dominance.

*Table 3: List of species captured at sites back packed electrofished (*denotes both sites)*

Species	**Site**
Metapenaeus ensis	Half Moon Creek and Saltwater Creek *
Macrobrachium. Mamillodactylus	Half Moon Creek and Saltwater Creek *
Caridina Spp.	Saltwater Creek
C. serraterostris	Moody Creek
Metapenaeid sp,	Moody Creek
Macro. Sp	Moody Creek
C. longirostris	Moody Creek
M. latydactylus	Saltwater Creek – Centenary Lakes

Vessel

Eight of the sixteen sites (refer to Table 3 and Appendix 3) sampled via this method recorded the presence of *P. monodon* in upper, middle or lower estuarine sites. Total length of animal found ranged between 60 mm and 220 mm, without displaying any size variation spatially; that is, between sections of the river, sites or systems. *P. monodon* were found only at one site (or reach of estuary) in each system when present, and in this same site where found on more than one sampling occasion. Seasonal pattern of *P. monodon* varied between systems and over the study period January 2000 to March 2002 and is displayed in Table 4, below. Effort varied between systems, with sites from the Herbet River and south being sampled quarterly and north of the Herbet sampled monthly. This variation did not allow extensive comparison of presence/abundance over seasons.

Presence of *P. monodon* was not established in any system during the dry winter months of May, June and July. Seasonal distribution displays presence of *P. monodon* for all sites was greatest during the pre-wet season (August to November) with a high catch rate continuing into February and March 2002 due to no wet season commencing. Presence of *P. monodon* was extremely variable between systems during the same sample period as well as seasonally, for example the first recordings of *P. monodon* in Baffle Creek was in March 2002 (after the first rains) when *P. monodon* was relatively abundance (approximately 200 per site).

Table 4: System and dates of P. monodon capture via boat Electrofisher (UE – upper Estuarine; ME – middle estuarine; LE – lower estuarine)

System	**Stream Salinity**	**Date of capture**
Baffle Creek	ME	March 2002
Daintree River	ME	April, September, October 2001
Herbet River	LE	April 2001 and March 2002
Mulgrave River	UE	November 2000 and August & October 2001
North Johnstone River	ME	January & November 2000, January & October 2001
O'Connell River	UE	March 2002
Russell River	UE	November 2000, August, September & December 2001 and February 2002
South Johnstone River	UE	October 2001

The habitat assessment varied between sites with half (four) the sites having low disturbance, and two with moderate and two high disturbances. Mangrove dominance was low at the majority of sites (six) and medium at the remainder (two), which was to be expected given the surveys were targeting Mangrove Jack habitat (snags and rocks), in areas of low conductivity (middle to upper tidal) for effective electrofishing. Disturbance was low at over half (five) the sites, moderate at two and high at one (contributed to by artificial structures used by Mangrove Jack for habitat). Bank structure was predominantly flat (low gradient) mud banks

Tidal and Diurnal Effects on Catch ability

Figure 41 displays average CPUE (catch per 20 casts with 100 % opening) for three Barron River sites (site one, two and three) (refer to 3.2) sampled. Sampling was conducted over 48 hours from 22:32 on 11 January 2000 until 23:05 on 13 January 2000, throughout the tidal range over this period. Peaks in catch were seen during the first night between 23:00 on 11 January 2000 to 07:00 12 January 2000, between 16:00 (12 January 2000) and 03:00 on the 13 January and again from the 16:50 until 23:00 on the 13 January 2000. The three peak catch periods correlate with the falling to low tidal period. Peak catch periods also appear to increase in the afternoon to early hours of the morning. With reference to our fyke net sampling, which displayed peak catches of post larvae *P. monodon* during the rising tide until the point at which prawns had access to mangroves, it would appear a more reasonable assumption to suggest that catch was primarily related to tidal height. With further reference to results of fyke net sampling, higher cast net catches on the falling and low tide could be associated with concentrated movement of prawns with the tide, out of the mangroves and into the water column directly adjacent to exposed mudflats.

Studies of juvenile penaeid prawns in mangrove forests by Vance *et al.* 2002, observed distribution patterns of penaeid prawns that were associated with tidal height and habitat. The greatest catches being closest to mangrove fringes with prawns concentrating in a narrow band (5 to 10 m) close to the waters edge. Vance's *et. al.* studies also observed higher catches of prawns on ebbing/falling tides than flood-tides, which was attributed to higher velocities in water flow on ebb tides in mangrove lined creeks.

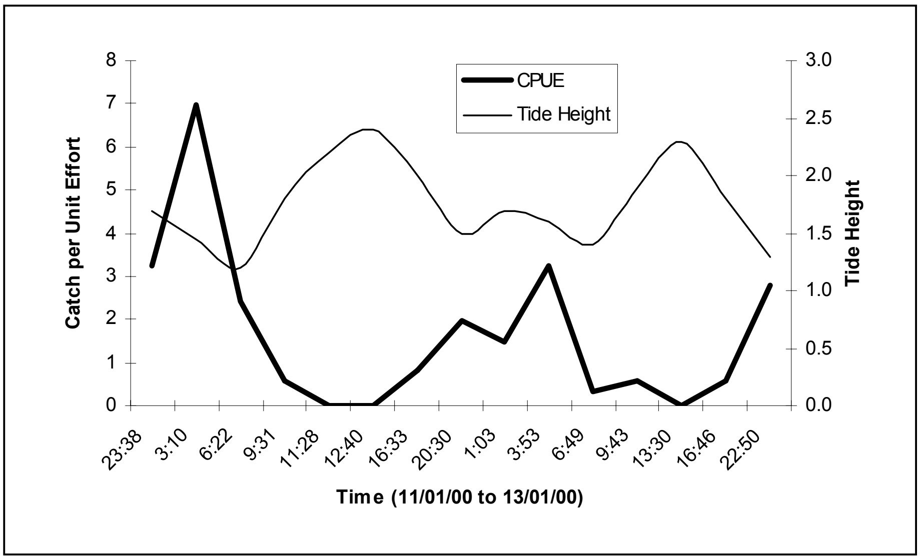


Figure 41.: Average CPUE for Barron River sites with tidal range over time (11 to 13 January 2000)

Stream Habitat

Habitat assessment results are displayed and discussed for *all sites* (all capture methods and surveys, refer to Appendix 3.4) as well as separately for sites sampled monthly (refer to Appendix 3.2 and 3.4) for seasonal patterns in the population structure surveys. Brief descriptions of less detailed site habitat assessments for alternate gear surveys have been given with distribution and abundance results of that survey.

In summary *P. monodon* were found to make use of all sections of the estuary from the upper tidal (freshwater) to the lower tidal (saltwater) reaches. Post larvae (< 29 mm) were predominantly found further upstream (upper to mid tidal, juveniles (29 to 56 mm) were found throughout, adolescents (56 to 134 mm) were found in mid to lower reaches and sub adults (134 to 164 mm) were found in lower estuaries (see Appendix 3.5). *Penaeus monodon* was also seen to make use of habitat structure, preferring mud banks vegetated by sparsely distributed mangrove peg roots to which they were seen clinging. Mud banks with low sloping gradients also recorded higher *P. monodon* abundance, with these banks becoming inundated by tides earlier than steep banks, allowing animals access to mangroves (refer to Appendix 3.5). Animals were seen to congregate in a narrow band adjacent to the water edge at low tide waiting for access back into shelter provided by vegetation. Shade also appeared to be important, with animals frequently being found in small patches of shade created by overhanging vegetation.

Stream type

All Sites

From research surveys and recreational fisher data, juvenile *P. monodon* were seen to inhabit all stream types (i.e., ephemeral to foreshore systems). No direct relationships could be established between stream type and catch abundance. Creeks directly open to foreshore and rivers were the predominant stream type sampled for juvenile *P. monodon* and comprised 33 % (30 sites) and 31 % (28 sites), respectively, as displayed in Figure 42. Fifteen sites (17 %) were sampled in complex mangrove inlet systems, for example Trinity and Mutchero Inlet, and six sites (7 %) were sampled in creeks systems. A small number of sites, seven or 8 %, were sampled on foreshores and three sites (3 %) in the tributaries of rivers and one in an ephemeral system.

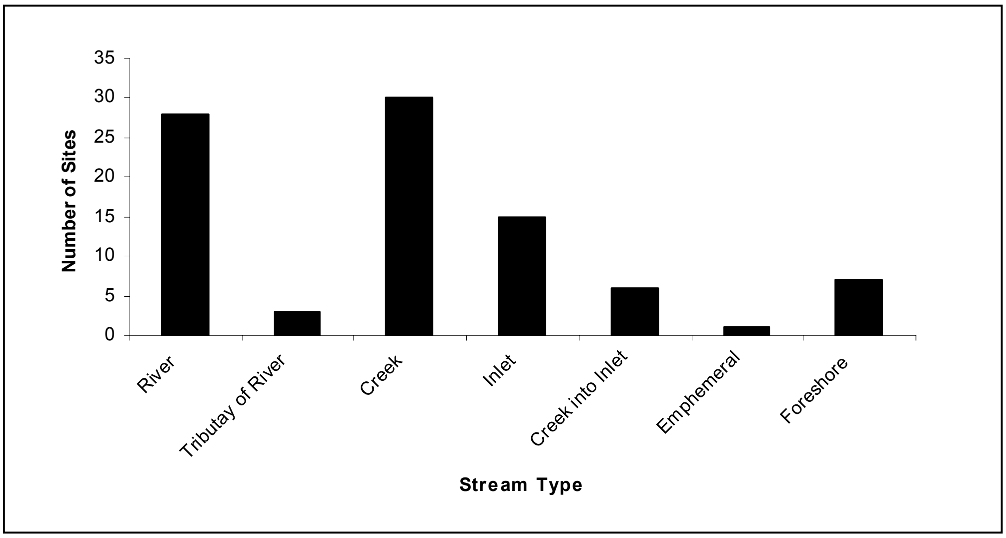


Figure 42 Stream Type at all sites sampled

Monthly survey Sites

The four Barron River sites were in the main channel of the river. Two of the Hills Creek sites (east bank and west bank) were on the main banks of the creek and the remaining site in a small tributary of the creek. *P. monodon* were found at all monthly monitored sites.

Stream Tidal Reach

All Sites

The presence of juvenile *P. monodon* were established in all tidal reaches of estuaries. Fifty two or 58 % of the 90 sites sampled were located in the lower estuary, see Figure 43. Initially the lower tidal reaches were targeted as having suitable habitat structure for cast netting, and due to findings from a literature review and anecdotal information. The foreshore reaches comprised 15 (17%) of the sites, with a similar 16 % (or 14 sites) of sites sampled in mid tidal reaches. The least sampling effort was in the upper tidal reaches comprising 10 % or nine of the sites sampled.

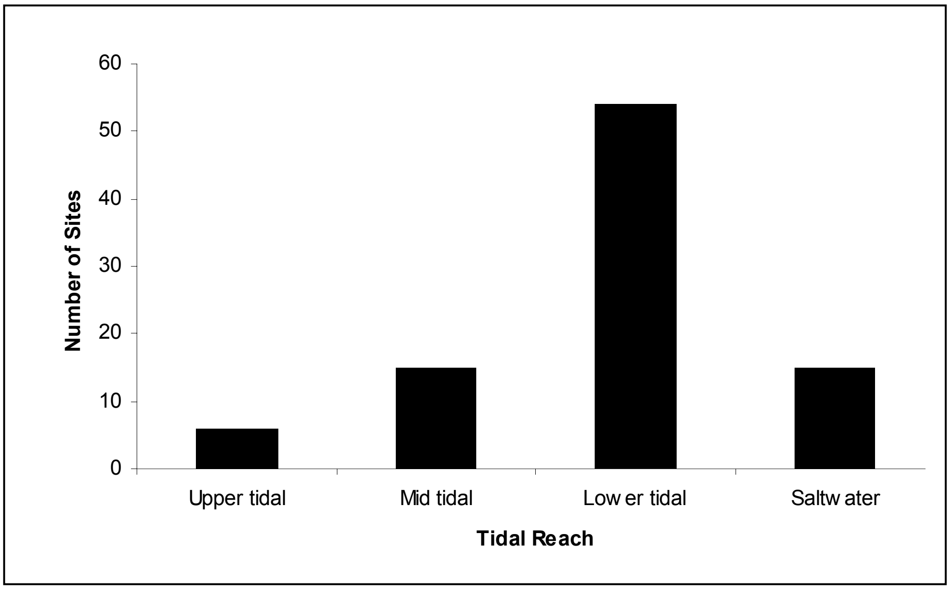


Figure 43 Stream tidal reach at all sites sampled

Monthly surveys.

Five of the seven sites were located in the lower tidal reach that is, Redden Creek and Rock wall sites of the Barron River and all Hills Creek sites. Site one and three of the Barron River were located in the middle tidal reach. Juvenile *P. monodon* were found present at all these tidal reaches.

Disturbance

All sites

Juvenile *P. monodon* appeared to have a strong relationship to habitat structure, yet was found to inhabit sites varying from extreme disturbance through to sites with no disturbance. This suggests adaptation to differing micro habitats that provide similar uses and benefits e.g. revetment walls provide pockets of shelters as does naturally occurring holes hard mud bank. Site disturbance for all 90 sites sampled showed that 39 (43 %) of the sites displayed low, 19 sites (21%) high, 18 sites (20%) moderate, and 11 sites (12%) undisturbed. Three sites (3%) displayed extreme disturbance (displayed in Figure 44, below). Sites of extreme disturbance were all channelled (drains), found at the top of systems surrounded by urbanisation in the Cairns region. The majority of the sites classified with high disturbances were encroached by farmland causing bank erosion, sedimentation, loss of riparian vegetation and with revetment structures to replace bank vegetation. Over half (eight) of the sites sampled in the Barron River had high disturbances, contributing to nearly half of this disturbance category. The high disturbance sites were distributed throughout reaches of systems. Man made structures (e.g. minor revetment work or bank access points) reducing or impeding riparian and bank vegetation was the dominating factor causing moderate disturbance at sampling sites.

Sites of moderate disturbance were mainly found in the lower and middle reaches of systems. Ninety percent of the sites with low disturbance ratings were found in lower or foreshore reaches of systems e.g. 17 of the Trinity Inlet sites. Low disturbances were predominantly caused by high levels of boat traffic and structures such as the the East Trinity Inlet bund wall which can impede fish and prawn movement and is upstream to many Inlet sites. The majority (8) of undisturbed sites were found in the lower estuarine reaches, with one undisturbed site in each other estuarine reach categories. All but 2 of the 11 undisturbed sites were found outside of the Cairns region, although the majority (81 %) of sites sampled were in the Cairns Region.

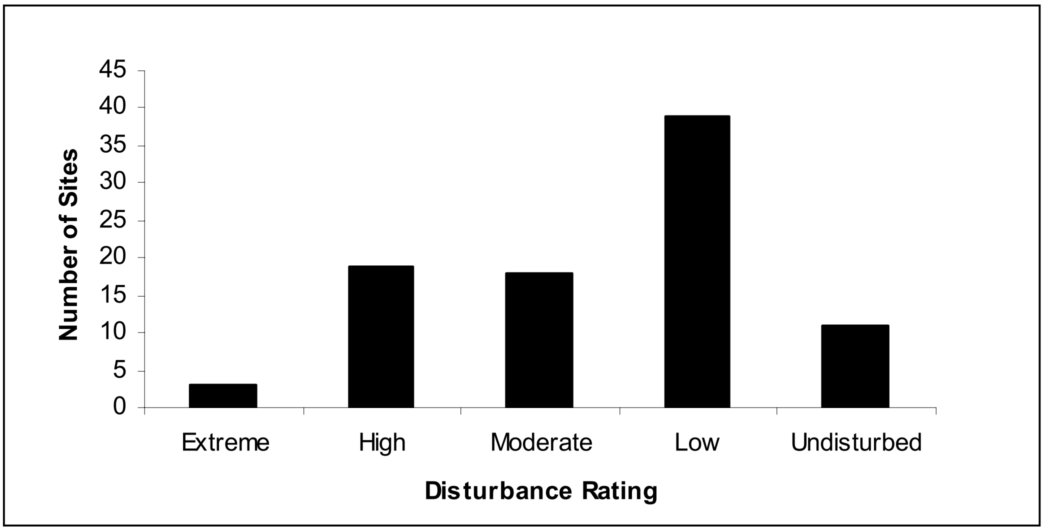


Figure 44 Disturbance rating at all site sampled

Monthly surveys

There was no difference in monthly catch rate could be attributed to disturbance rating level.

Mangrove Dominance

All Sites

Juvenile *P. monodon* were found to make use of sparsely distributed mangrove peg roots on submerged mud banks as well as water shaded by overhanging vegetation. Therefore there was some relationship between prawn abundance and presence of mangroves as they provided preferred habitat, although *P. monodon* was seen to make use of habitat provided by other plant species or artificial structures. Mangroves were present at 90 % of sites sampled with varying dominance, shown below in Figure 45. Sixty seven percent of sites displayed high mangrove dominance and were predominantly and logically in the lower estuarine and foreshore sites. Medium mangrove density sites comprised a small 4% of sites found in the middle estuarine or disturbed lower estuarine sites. Nineteen percent of sites were classified to have low mangrove density, found in natural densities in the upper tidal reaches and with altered densities in moderately or highly disturbed sites in middle or lower estuarine reaches of systems. No mangroves were found at 10 % of sites sampled, predominantly in foreshore sites or highly and extremely disturbed sites.

Mangrove species composition was recorded as either R*hizophrastylosa or Avicennia marina* as dominant and therefore either species always present.

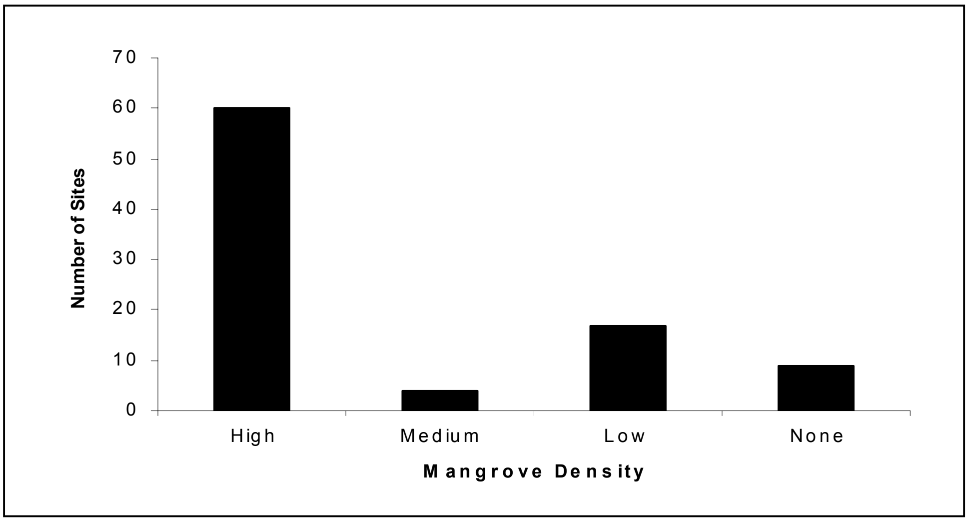


Figure 45 Mangrove density at all sites sampled

Monthly survey Sites

All but the Barron River, Site one was 100% dominated by mangroves in bank and riparian vegetation. Site one was differentiated by cottonwood, melaluca and terrestrial species composing riparian vegetation and intruding into bank vegetation. Bank vegetation of all seven sites was dominated by *A. marina*., which is a naturally widespread and dominant mangrove species found fringing banks and systems in wind and wave zones. It has small sparsely spaced peg roots that spread out beyond its canopy on to mud flats. The habitat provided by *A. marina* was preferred by juvenile *P. monodon* on other opportunistic sampling surveys in the Cairns to Innisfail region.

Water Quality

In summary there were no direct relationships established between individual *in situ* water quality parameters and *P. monodon* catch rates, with low and variable catch rates making such comparisons extremely difficult. Between systems that were monitored monthly, that is the Baron River and Hills Creek, there was a wide variation in average values for some water quality parameters, but the sites displayed similar CPUE's. Seasonal patterns in water quality for the monthly monitored sites is treated in a later chapter.

Ph: Monthly survey Sites

Figure 46 shows the average monthly pH (SE$\pm$) values found between sites and their deviation from the average pH for all sites combined (7.4 $\pm$ 0.2). By system the Barron River average (SE$\pm$) pH was 7.4 $\pm$ 0.3, which was equal to Hills Creek at 7.4 $\pm$ 0.1. pH values ranges were equal between sites with a minimum of 6.0 and maximum of 8.5, with site averages ranging between 7.2 and 7.8. There were no patterns displaying direct association with pH levels and catch rate that were evident in analysis. The tidal opening of a gate upstream of Hills Creek sites (see Figure 1) which allows water to flow to and from low lying acid sulphate soil areas appears to have had no effect on the pH at these sites at time of sampling.

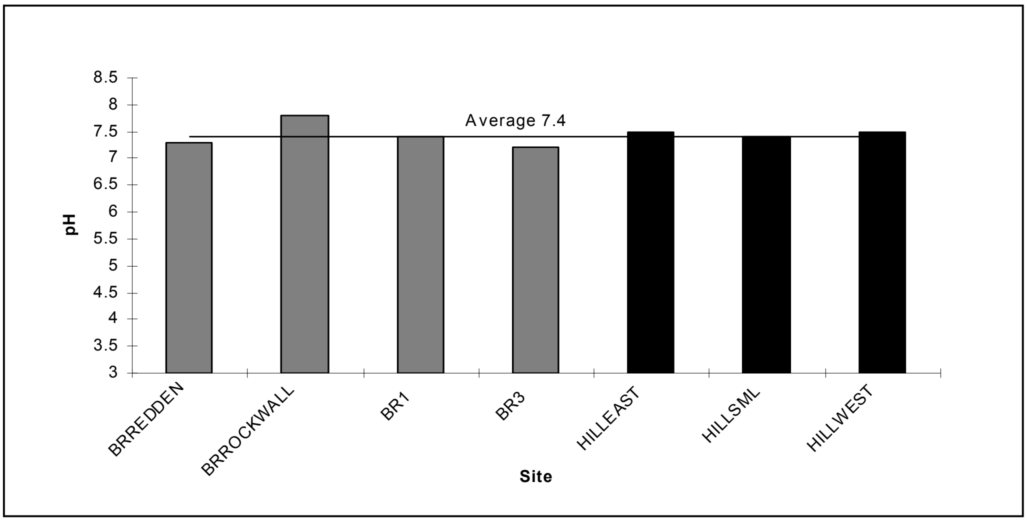


Figure 46 Average PH values at Monthly survey Sites

Conductivity

Monthly survey Sites

The distribution of average monthly conductivities found at sites is shown in Figure 47, with no direct relationship found between conductivity and catch rates. There was distinct variation in conductivity values between systems and less variation between sites in systems. The total monthly average of 29.82 ms cm^{-1} for all site combined had a standard error of $\pm$ 11.25, displaying large variation in conductivity. Hills Creek sites, clustered in the lower tidal reaches had a range of average monthly conductivities between 37.71 and 45.66 ms cm^{-1} and a monthly average ($\pm$SE) of 41.66 ms cm^{-1} $\pm$ 4.15 displaying strong saline influences. The Barron River sites distributed between the lower and middle reaches of the estuary notably displayed a slightly larger variation between sites 16.45 to 28.23 ms cm^{-1}, with a lower monthly average ($\pm$ SE) of 21.57 ms cm^{-1} $\pm$ 4.78, most likely due to regulated upstream freshwater supplies.

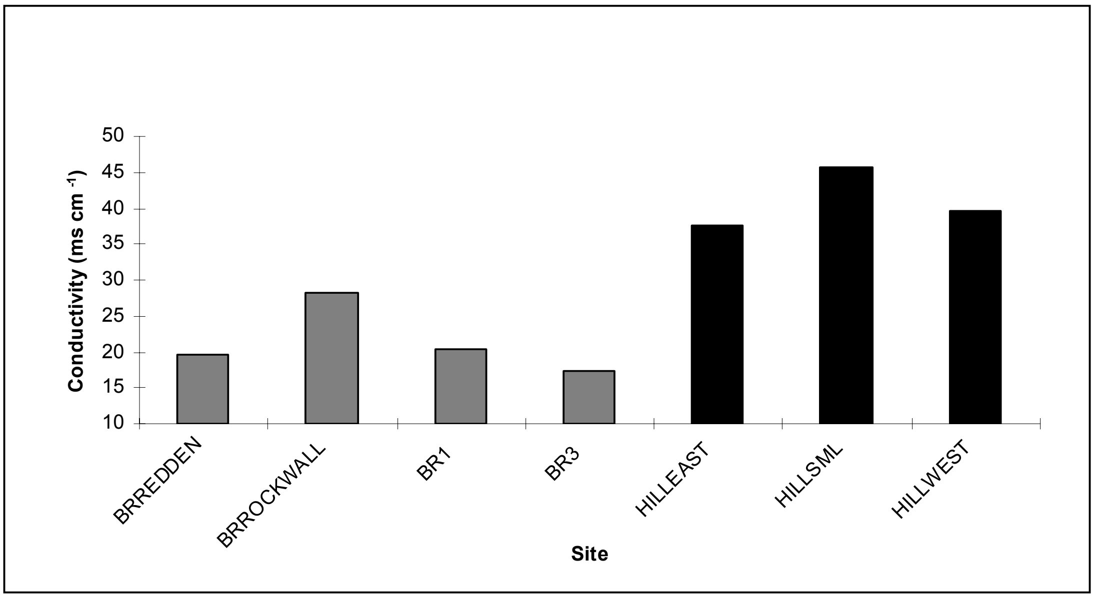


Figure 47 Average monthly conductivity (ms/cm) for Monthly survey Sites

Salinity

Monthly survey Sites

The distribution of average monthly salinities in parts per thousand (ppt) found at sites is shown in Figure 48. Following similar patterns as for conductivity there were distinct variations in salinity values between systems and less variation between sites. Average monthly salinity range for Hills Creek was varied between a close to freshwater of 0.9 ppt to a maximum of 35.9 ppt, while average monthly salinities displayed the strong foreshore salinity influences at 26.6 ppt. Average monthly salinity range for the Barron River varied between freshwater 0.0 ppt to a maximum of 29.9 ppt, while average monthly salinities at 13.6 ppt display upstream freshwater influences. Differences between salinity at lower tidal and middle tidal reach sites of the Barron River was minimal, for example maximum salinity differed by 4 p.p.t. Middle reaches of the Barron were sampled with saltwater influence, one and half to two hours later in the tidal rise than the lower reaches on all sampling occasions, creating the similar salinity levels.

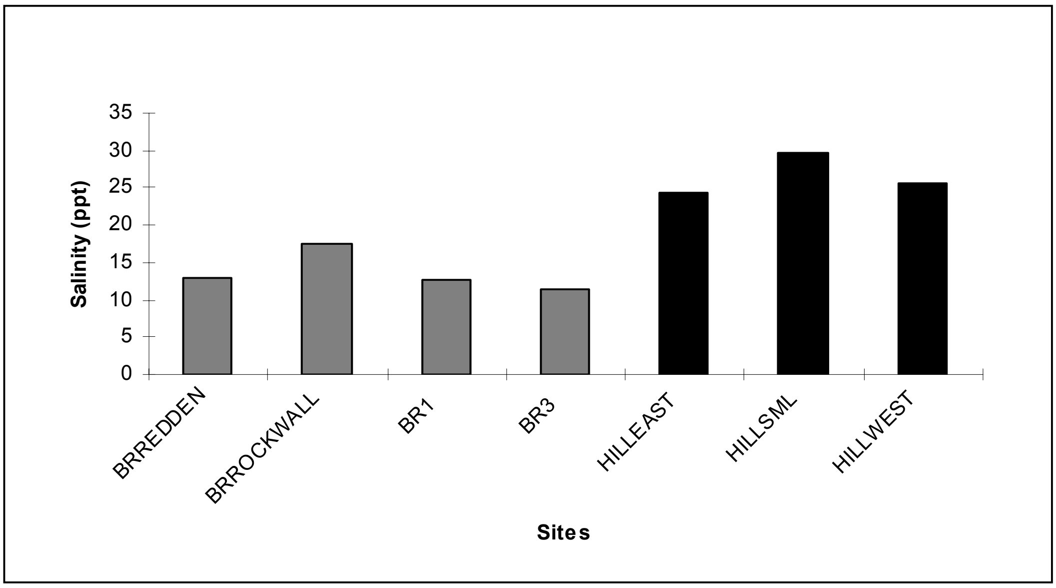


Figure 48 Average salinity (parts per thousand) for Monthly survey Sites

Temperature

Monthly survey Sites

Average monthly system temperatures were in 0.1°C of one another, with the Barron River average at 26.7°C and Hills Creek 26.6°C. The range of temperatures differed slightly, with the average Barron River minimum of 22.2°C and maximum at 31.8°c compared to Hills Creek higher average minimum of 22.8°C and maximum at 33.0°C. As displayed in Figure 12, compared to all other sites the east bank site displayed higher average temperatures by 0.8°C and the Small Creek site lower averages by 0.7°C. In relation to catch, these two sites at displaying highest and lowest temperatures averages both displayed below average CPUE, displaying no direct relationship between temperature alone and catch at a site.

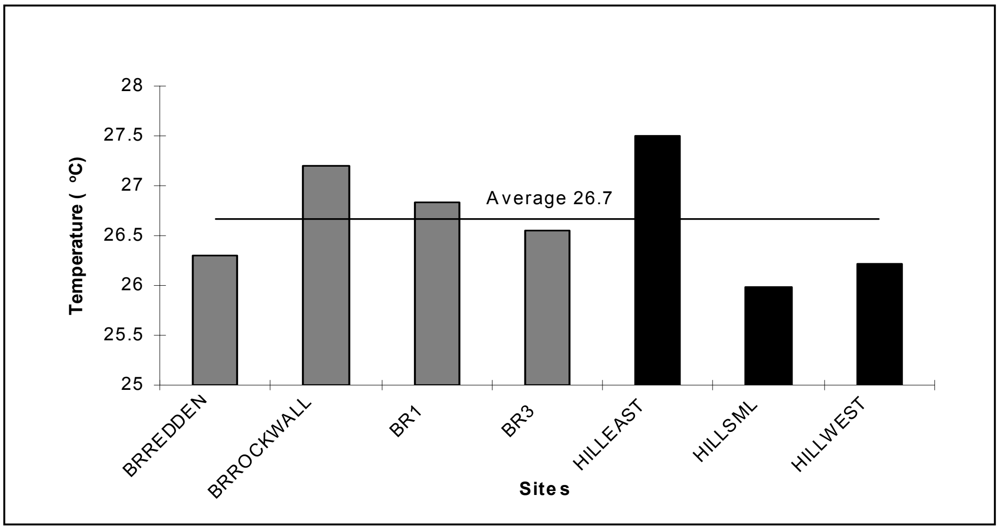


Figure 49 Average monthly temperature at Monthly survey Sites

Dissolved Oxygen

Monthly survey Sites

Average dissolved oxygen (± SE) in milligrams per litre (mg/L^{-1}) were higher at the Barron River sites (7.12 mg L^{-1} ± 0.96) than in the Hills Creek sites (5.03 mg L^{-1} ± 1.10) and can be seen by their deviation above and below (respectively) the average of 6.1 (mg L^{-1}) in Figure 50. Temperature was higher on average in Hills Creek sites, with increase in temperature having a direct abiotic influence by lowering dissolved oxygen, Hills Creek also displayed lower average dissolved oxygen levels. Relative narrow creek width with shallow and slow moving waters of the Hills Creek system influenced by warm sea waters would also have contributed to reduced dissolved oxygen levels, compared to the wider, deeper and faster flowing Barron River influenced from cooler, fresh headwaters upstream of sites with higher dissolved oxygen levels. There was no apparent direct relationship between dissolved oxygen levels and catch rates at given sites.

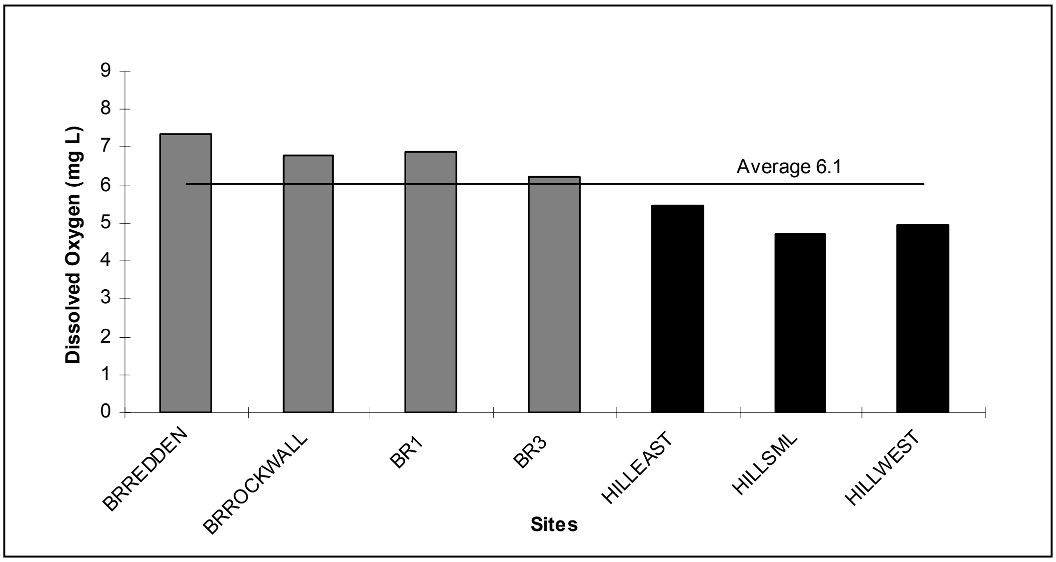


Figure 50 Average dissolved oxygen (mgL^{-1}) for Monthly survey Sites

Turbidity

Monthly survey Sites

The range of average monthly turbidities at monthly survey sites and average turbidity for all sites combined is displayed in Figure 51. Analysis of average turbidity by system displayed a higher average ($\pm$ SE) at Hills Creek of 54 $\pm$ 11.9 NTU than in the Barron River at 35 $\pm$ 7.9 NTU. In the Barron River the rock wall and site 3 showed lower than average turbidity of 26 and 32 NTU. The highest average turbidity levels were found at Hills Creek at the Small Creek (53 NTU) and west bank (67 NTU) sites. As with other water quality parameters no direct relationship was established wit turbidity levels and catch rates.

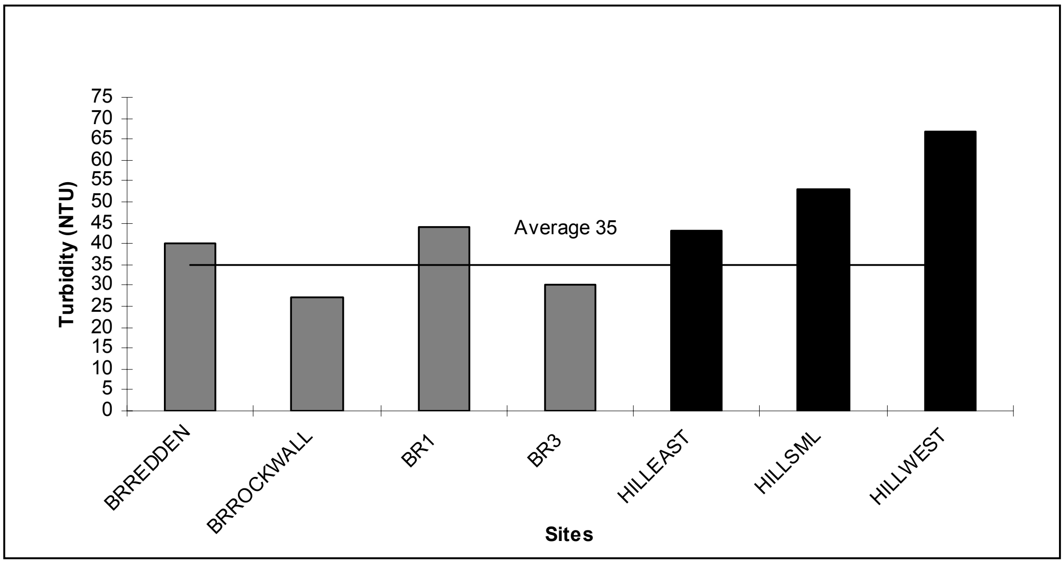


Figure 51Average monthly turbidity at Monthly survey Sites

Abundance and Distribution

Pilot cast netting surveys conducted between November and December 1999 displayed extremely low abundance and variable distribution of juvenile *P. monodon* (refer to Appendix 3.2 for sites surveyed). Juvenile *P. merguiensis* was established to be widely distributed and relatively abundant from recordings during this survey. Juvenile *P. monodon* were found present at 24 % (14 sites) of the pilot sites surveyed displayed, with a total of 27 individuals being captured (over half (15) coming from the Barron River). Juvenile's total length ranged between 80 mm to 174 mm (average 118 mm), with an average carapace length of 24 mm (range 10 mm to 36 mm).

From the survey of monthly monitored sites (Hills Creek and the Barron River) 234 individual juvenile *P. monodon* were captured. Total length of animals ranged between 48 mm to 198 mm and average at 116 mm. Carapace length of animals ranged from 9 mm to 45 mm and average at 25 mm. The Barron River and Hills Creek systems displayed equal average monthly catch per unit effort of 1.0, were effort was 20 cast throws (standard effort per individual site visit). Average monthly CPUE for *P. merguiensis* from the same survey displayed a much higher CPUE that varied between systems greatly, with Hills Creek averaging a monthly CPUE of 35.1 and the Barron River 17.24.

P. monodon – Cast net Effort

Figure 52 displays average catch at the monthly survey sites with distribution of cast effort (total number of casts thrown) as a percentage. Analysis of these two parameters displays that increased cast effort did not always increase average catch. This can be seen at Barron River site 1 which had the greatest cast effort but not the highest average catch. This highlights the extreme variability of catch and its unpredictable nature.

Note: This method of presenting and analysing data is different to that of catch per unit effort, in that it separates the two parameters, catch and effort. The ability to survey sites was at times restricted due to physical conditions (e.g.. heavy rain or tides) creating some differences in effort between sites; ie, number of times individual sites were visited. Extreme fluctuations in catch rate between consecutive months displayed in seasonal data, also shows that timing of a site visit could influence catch rate. Low catch rates (average catch was under one whole animal in all but one site) exacerbate these effects on average catch, size distribution and catch per unit effort.

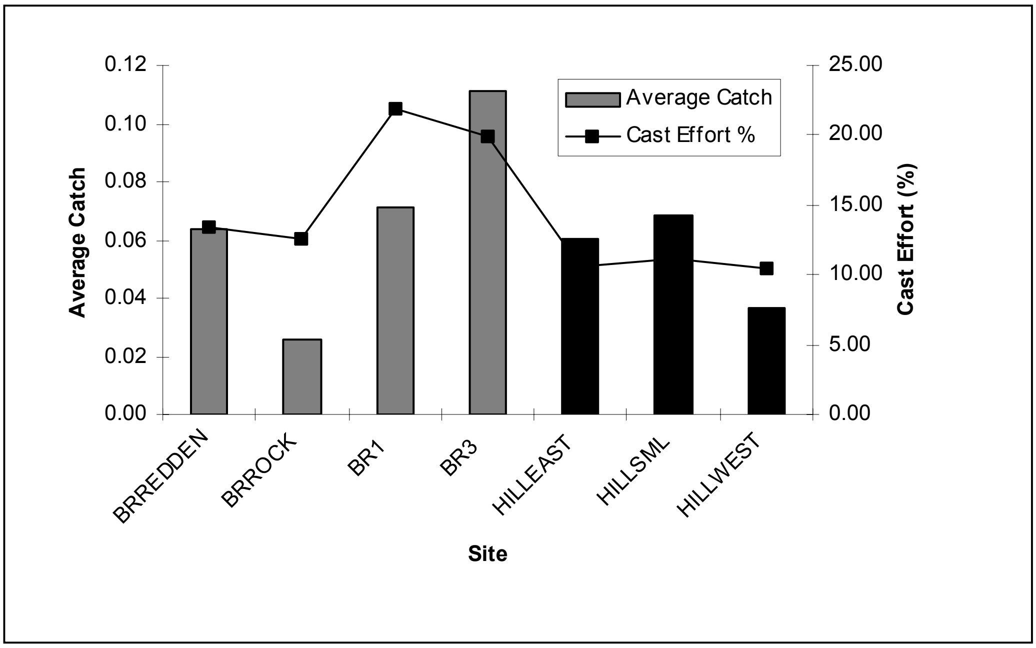


Figure 52 Average catch per monthly site with average cast effort (%)

Removal of data with missing surveys, allowed for standardization of cast effort. Figure 53 displays the increase in average catch for all sites and changes in rankings of average catch between sites when standardised cast effort was used for analysis.

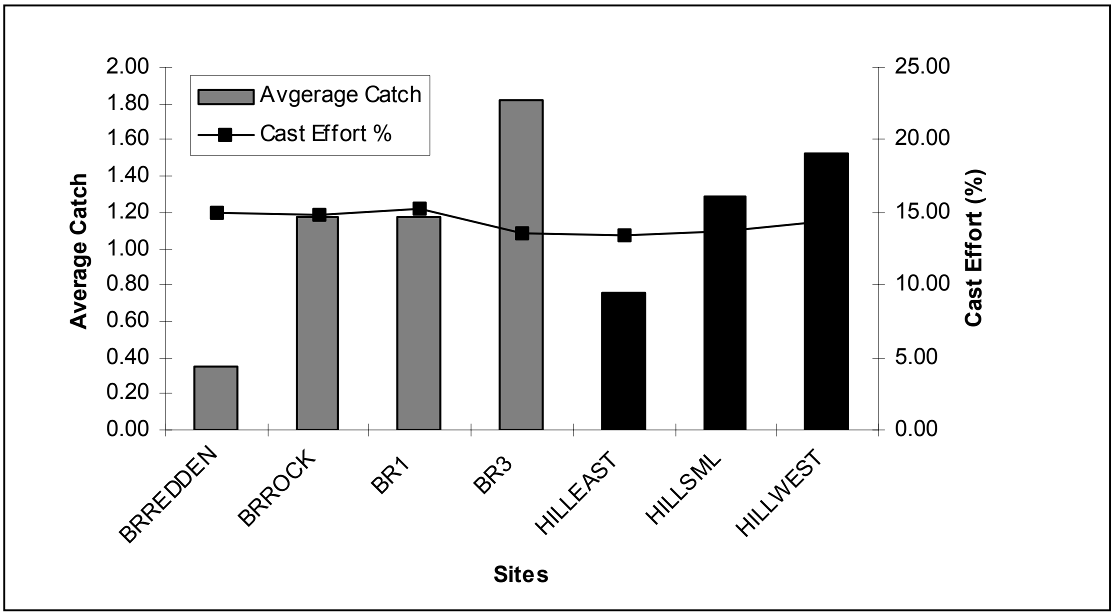


Figure 53 Average catch per monthly site with similar average cast effort (%)

Average CPUE (where effort was one cast) per monthly sites is displayed in Figure 54 and shows the values variation from the average CPUE, which was equal for the Barron River and Hills Creek systems, at 0.05 (which equates to one animal per site visit/20 cast throws). Figure 18 displays CPUE for monthly sites verses number of times *P. monodon* were found to be present at a site as a percentage. The Barron River Site3 displayed the highest productivity with an average CPUE of 0.08 with *P. monodon* present at 50 % of sample visits. The west bank and Small Creek sites in Hills Creek both displayed equal second highest average CPUE of 0.06 with *P. monodon* found 67 % and 39 % of the time, respectively, determining the most common place to find *P. monodon* was in Small Creek. The Barron River site one and rock wall displayed an equal average CPUE of 0.05, but with *P. monodon* more likely to be present at site one (39 % of visits) than the rock wall (28 % of visits). Thirty nine percent of visits saw capture of *P. monodon* on the west bank site of Hills Creek which displayed a lower than average CPUE of 0.04. The Barron River Redden Creek site displayed the least productivity with an average CPUE of 0.02 and was it was therefore also one of the least likely sites to capture *P. monodon* seen 28 % of the time.

Figure 55 displays that finding *P. monodon* at a site did not correlate to productivity levels, as discussed above with average CPUE. Distinct variation of number of times *P. monodon* were present at sites can be seen. Differences in number of times present between sites with similar CPUE are displayed with the Barron River site one and rock wall. Relatively high percentage of times presence is also displayed by a site with lower than average CPUE (Hills Creek, Small Creek site) and the site which produced the highest CPUE by far, had only slightly higher than average chance of finding *P. monodon* during sampling.

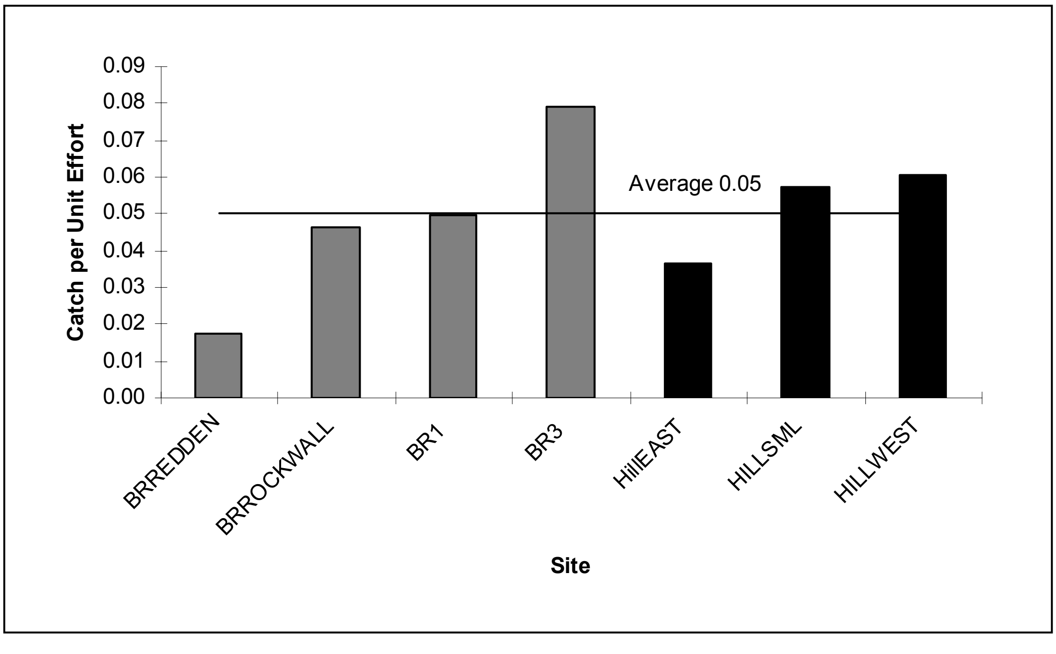


Figure 54 Average CPUE per monthly site compared to total average CPUE

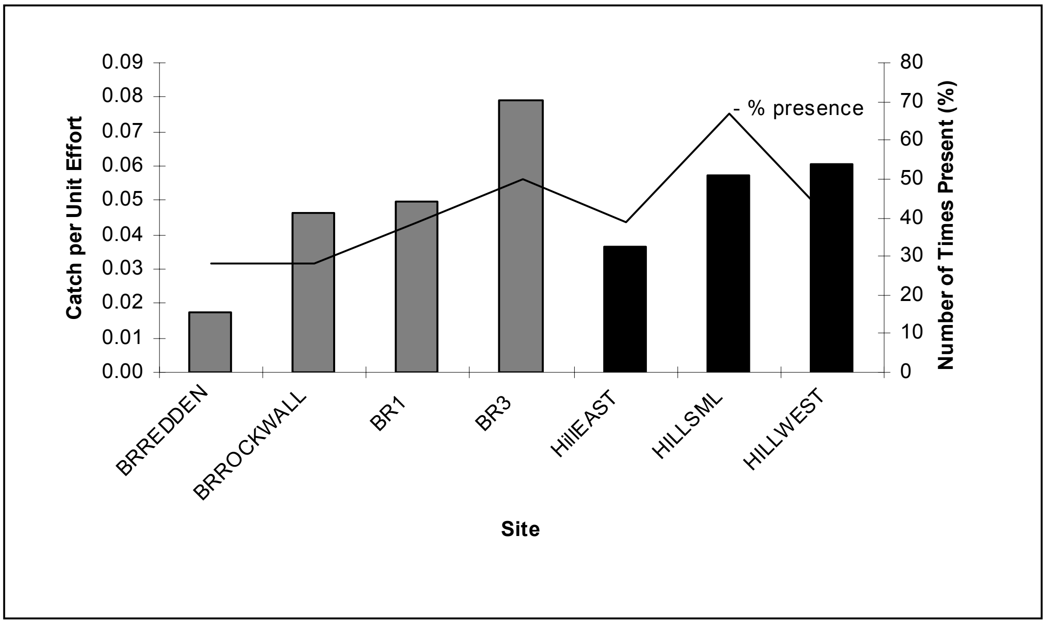


Figure 55 Catch per Unit Effort vs. number of times P. monodon were present

Figure 55 displays the actual number of *P. monodon* caught per monthly site visit (20 casts), with no *P. monodon* being found at the majority (52 %) of visits (not displayed in Figure 56). This result displays unpredictability and extreme variability in distribution and abundance of juvenile *P. monodon* and as well as the extremely low catch rates. When present, one *P. monodon* was found most commonly (21% of times), during 27 individual site visits. The greatest number of *P. monodon* found at any site on a visit was 12.

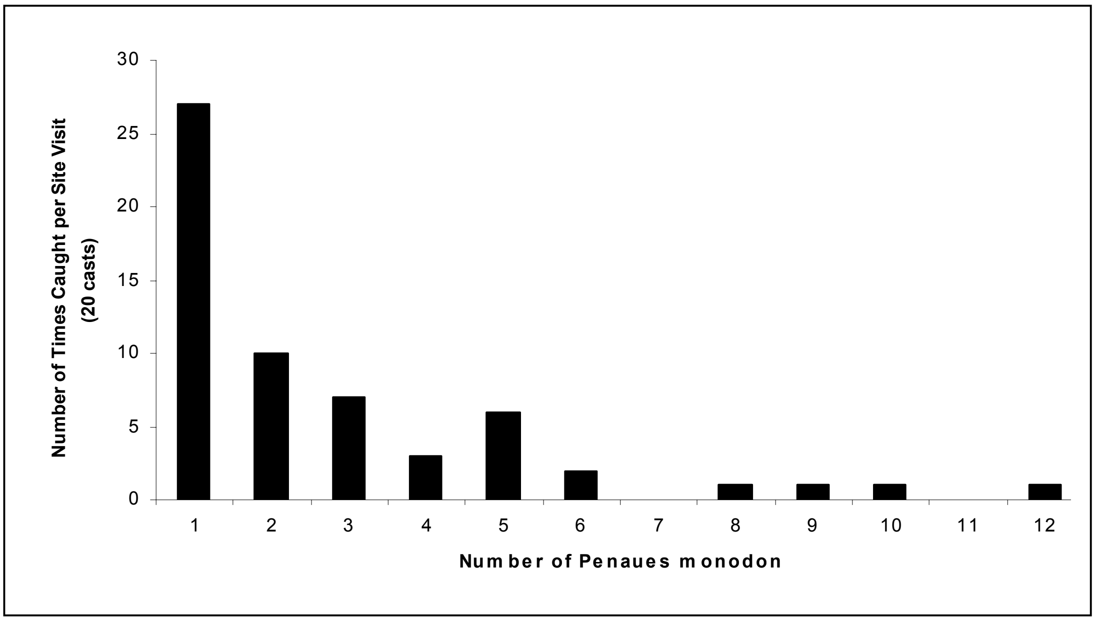


Figure 56. Number of P. monodon caught per monthly site visit

P. merguiensis – Cast net Effort

Figure 57 displays average CPUE for juvenile *P. merguiensis* at monthly sites, were effort was calculated as 20 casts (a site visit). The Hills Creek system displayed an average CPUE of 35.1 double the catch compared to the Barron River with an average CPUE of 17.24. The Hills Creek site Small Creek displayed the highest CPUE $\pm$ SE (43.7 $\pm$ 32.3), followed by the west bank (35.1 $\pm$ 26.2) and the east bank (26.6 $\pm$ 35.1). The average CPUE order between Hills Creek sites for *P. merguiensis* is similar to that for average CPUE *P. monodon* (refer to Figure 54), with the west bank and small creek displaying similar high CPUE. Other small drains off Hills Creek not sampled as part of monthly sampling, also displayed high but inconsistent catches of *P. merguiensis.* CPUE in the Barron River varied largely between sites with site one and the rock wall displaying the higher CPUE (22.5 $\pm$ 38.7 and 21.7 $\pm$ 23.7, respectively) and site 3 and Redden Creek much lower CPUE (11.8 $\pm$ SE 17.0 and 14.3 $\pm$ SE 24.4, respectively). Average CPUE effort patterns between sites for *P. merguiensis* differ than for *P. monodon*, with site three displaying the biggest difference (highest average *P. monodon* CPUE and lowest average CPUE). Juvenile *P. merguiensis* displayed higher abundance and less site specific distribution than juvenile *P. monodon.* Although found present during all *P. monodon* sampling, *P. merguiensis* was rarely found in the same individual cast possibly suggesting some territorial behavior between species.

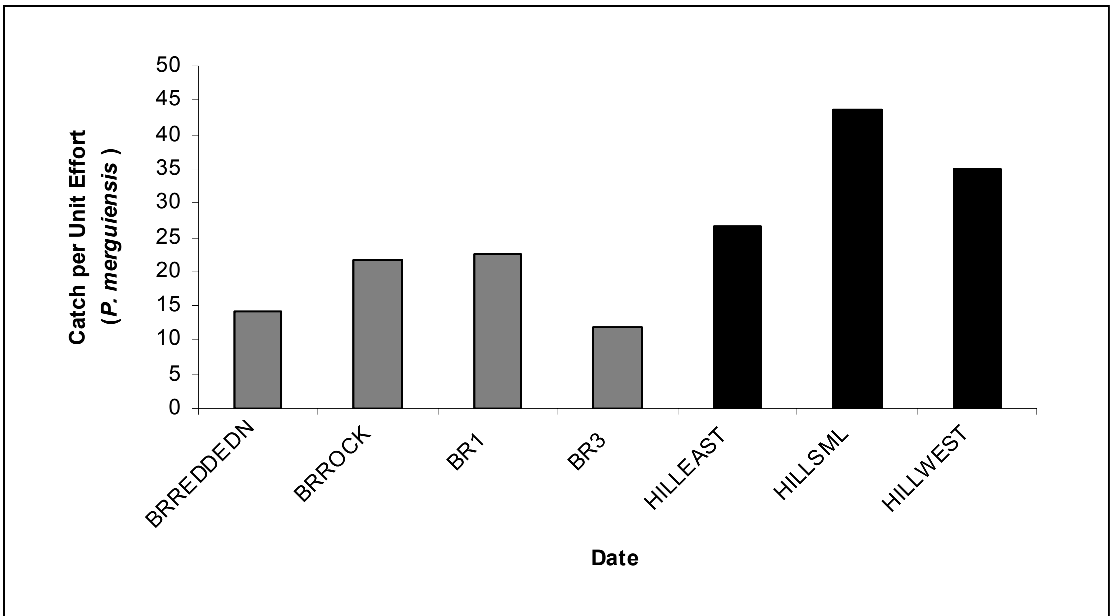


Figure 57. Average P. merguiensis Catch per Unit Effort for Monthly survey Sites

Seasonality

In summary there were no *direct relationships* established between individual *in situ* water quality parameters, rainfall and catch rates with season. Some trends and pattern*s* between water quality, rainfall and catch rates were seen seasonally, with fluctuations in catch and water quality parameters related to rainfall and temperature. As displayed by analysis of CPUE by sites, abundance and distribution of juvenile *P. monodon* is extremely variable and unpredictable over time.

Rainfall

Figure 58 displays total monthly rainfall (mm) seasonally for the Barron River and Hills Creek systems for the period between November 1999 and December 2001. The two systems displayed almost identical rainfall patterns for this period as would be expected given their close proximity (adjacent catchments) and with rainfall data calculated from coastal precipitation in each system. Figure 58 shows peaks in rainfall during February 2000 and 2001 in the study period, with these two events representing the annual wet season, which created flooding in systems, and continuous high rainfall through until April each year. The smaller peak in December 2000 prevented undertaking of sampling whereas the larger peak in February 2001 occurred after the monthly surveys. The two peaks seen in the 2000/2001 wet season displays the variation in wet period patterns over time when compared to the one concentrated rainfall peak in 1999/2000. Troughs in Figure 58 display little or no rain from May to November 2000 and May to December 2001 representing the dry season. Although not part of the study period it should be noted that no distinct wet season rains were seen for the 2001/2001 season, creating an extreme and extended dry season which is seen every few years on an irregular basis.

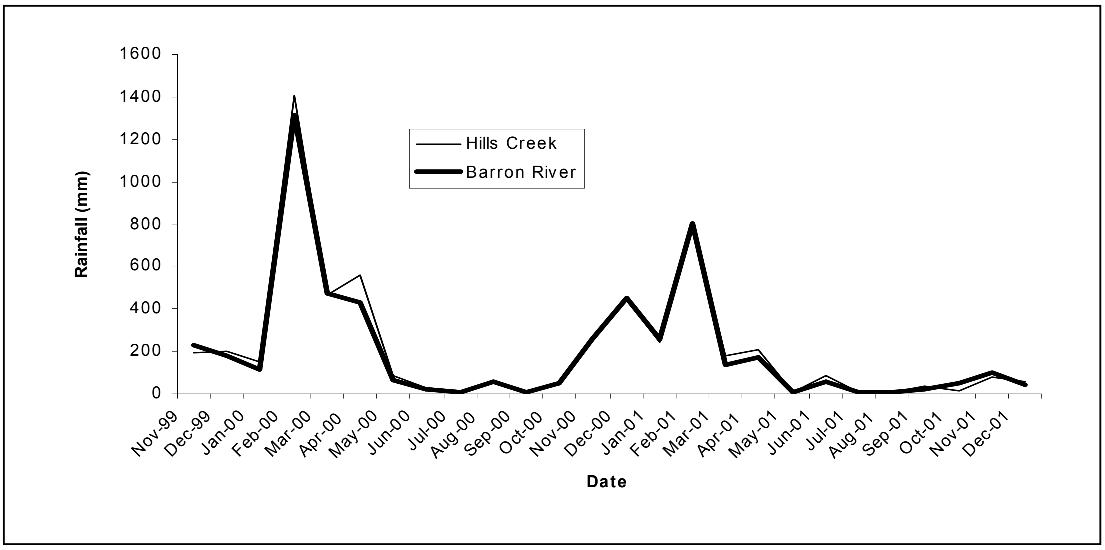


Figure 58. Rainfall (mm) at the Barron River and Hills Creek Catchments over the study period

Water Quality

pH

Figure 59 shows some slight seasonal variation in average monthly pH values over the study period, and was similar for both the Barron River and Hills Creek systems. The average monthly pH value was 7.3 and ranged between a minimum of 6.0 in February 2000 and maximum of 8.12 during November and December 2001. The wet season influenced sites with freshwater runoff and influenced lower than average pH values at sites e.g. during February and March. Reduction of freshwater during the dry season influenced sites by establishing the higher than average pH values. Variation between pH values over the two years can also be seen, with above average pH levels from July through until December 2001 caused by below average rain during the wet season for 2001/2002 season.

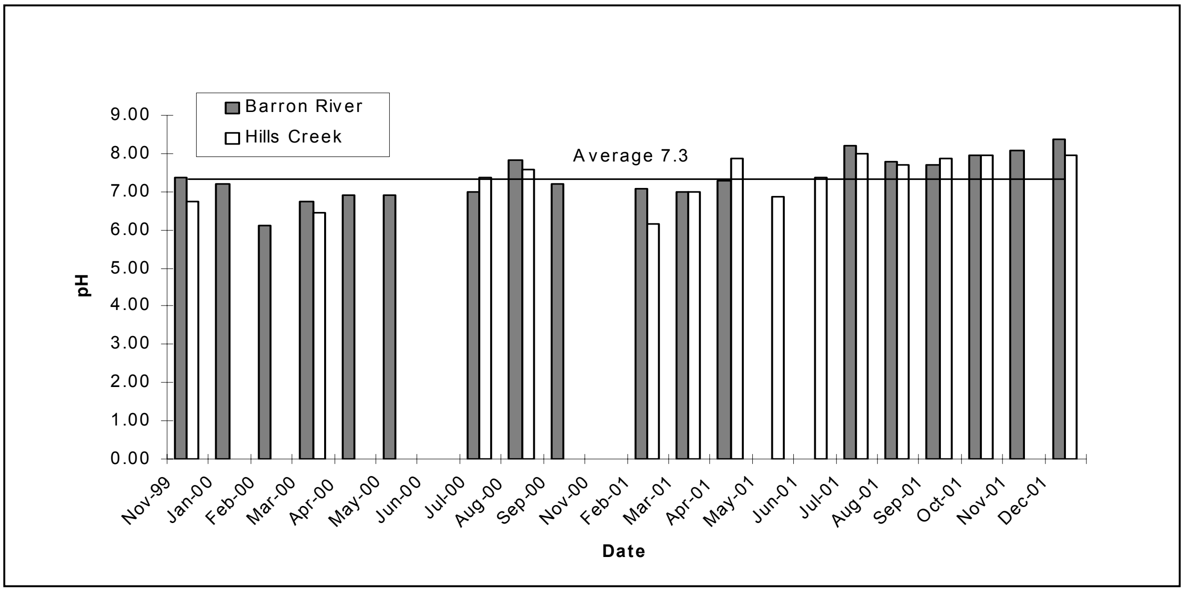


Figure 59 Seasonal average pH by system

Conductivity

The seasonal distribution of average monthly conductivities found in systems appears to be influenced by the wet and dry season, as would be expected. Figure 60 displays conductivity values (ms cm^{-1}) with lower than average conductivities displayed by troughs in the wet season between February to June

2000 and February to May 2001, followed by higher than average conductivity levels during the dry season between July to September 2000 and June to December 2001.

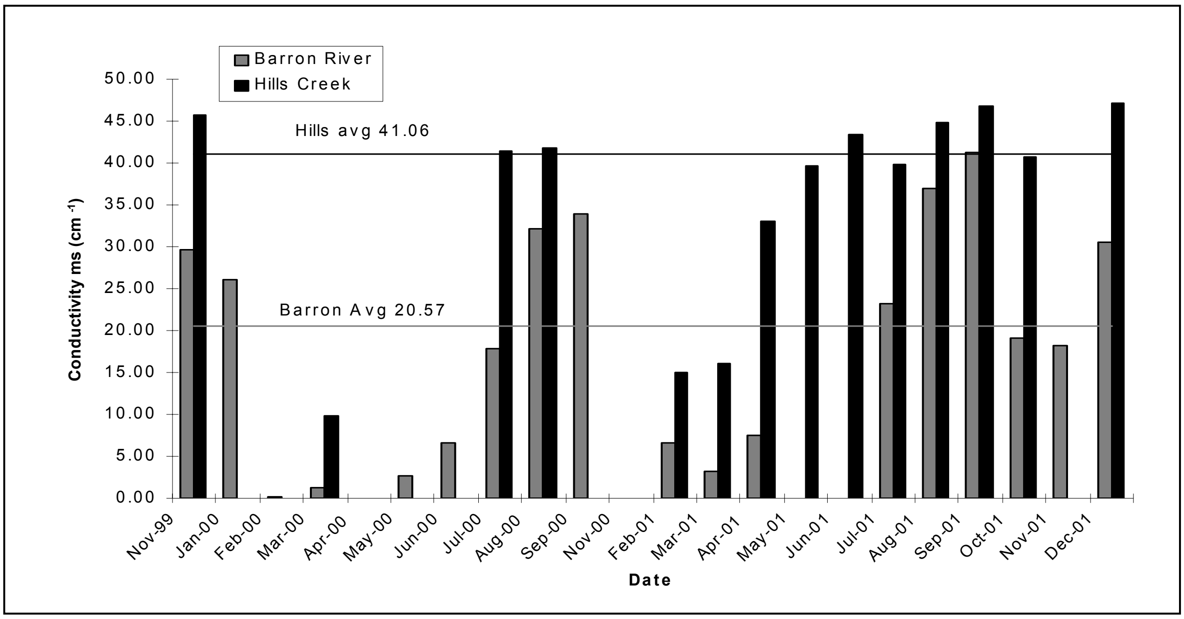


Figure 60. Seasonal average conductivities by system

Salinity

Salinity variations correlated well with seasonality influence from the wet and dry season. Lower than average conductivity levels were found in both the Barron River and Hills Creek systems during the wet and post wet period between February to June 2000 and February to May 2001 (see Figure 61). Above average salinities were displayed during post wet periods between July to September 2000 and July to December 2001.

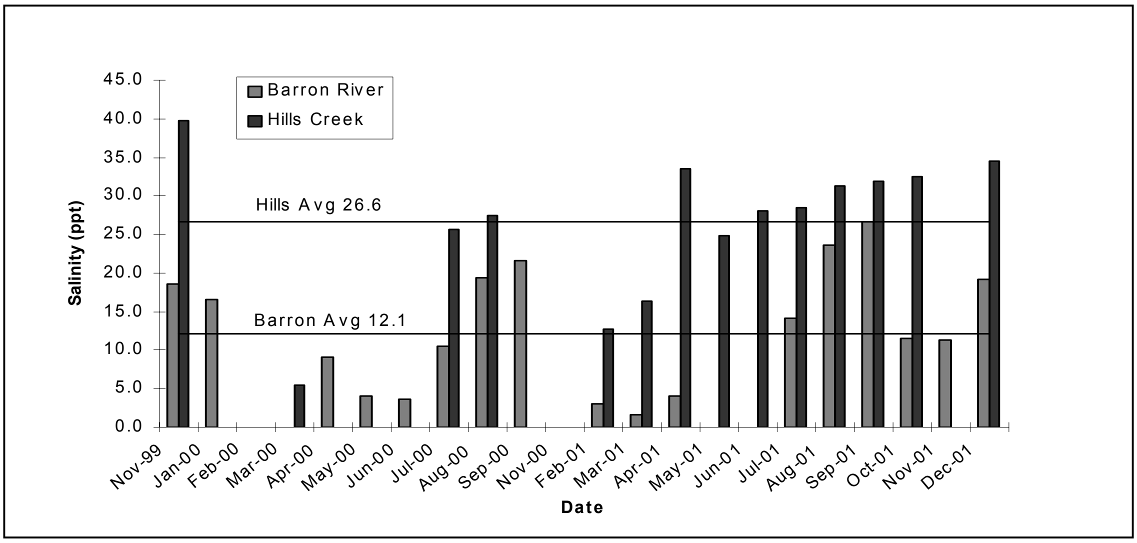


Figure 61 Seasonal average salinity by system

Dissolved Oxygen

Distribution of average dissolved oxygen values by system can be seen in Figure 62 for the period November 1999 to December 2001. Patterns coinciding with wet summer months and dry winter months were less distinct with dissolved oxygen than as for other *in situ* water quality parameters. Above average dissolved oxygen for both systems were generally found during cooler winter months with rainfall events, tidal height (water depth) and water temperature at time of *in situ* sampling is likely to have influenced levels. The Hills Creek sites displayed higher than average dissolved oxygen values more so in 2001 than 2000, whereas the Barron River sites saw the reverse with lower than average dissolved oxygen values in 2001 compared to 2000.

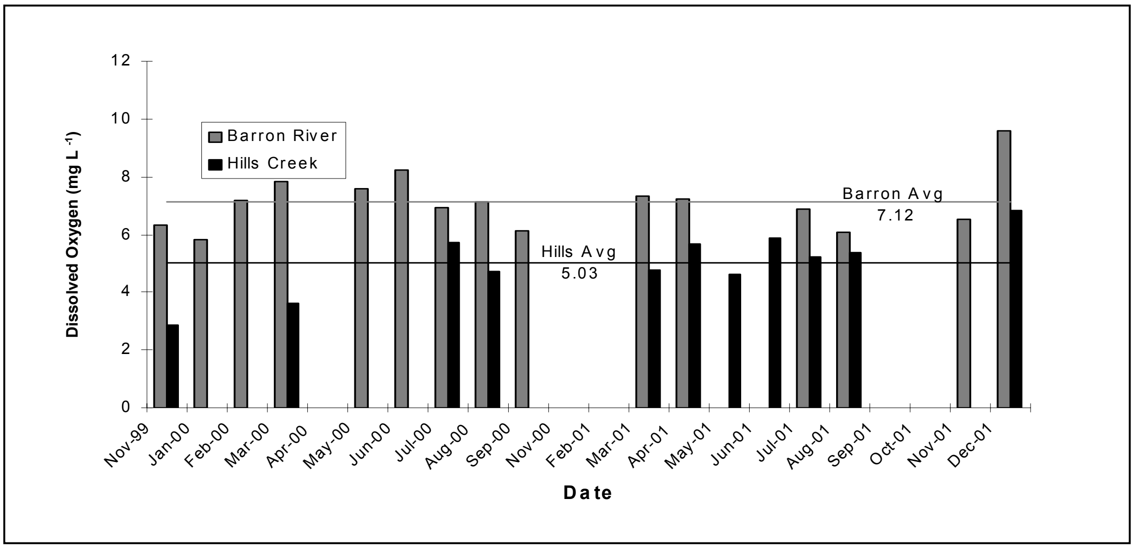


Figure 62. Seasonal average dissolved oxygen by system

Temperature

Temperature displayed seasonal fluctuations for both the Hills Creek and Barron River systems between winter and summer during the study period, as is displayed in Figure 63. Lower than average temperatures were displayed during winter months (for both systems), that is May to August 2000 (minimum average 21.8°C) and July to August 2001 (minimum average 24.0°C) also showing the cooler average seen in 2000. Higher than average temperatures were displayed in summer periods (for both systems) during November 2000 to May 2001 and October to December 2001. Heavy rains in the 1999/2000 wet season contributed to the less distinct peak in temperature for this period.

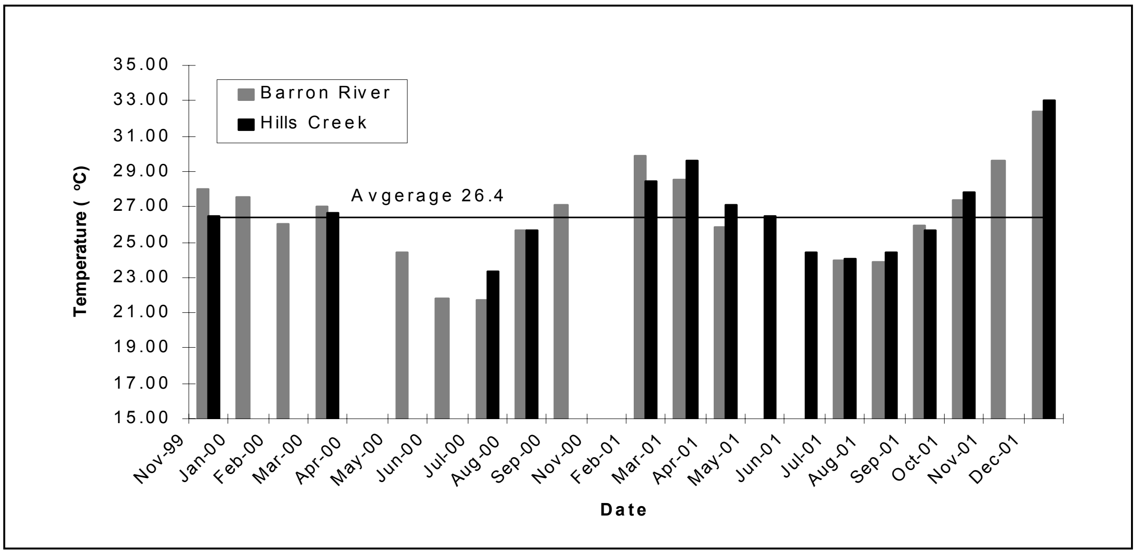


Figure 63 Seasonal average temperature by system

Turbidity

Average turbidity values by system over the study period are shown in Figure 64 below. No distinct patterns are concurrent with seasonality as was the case for other *in situ* water quality parameters, which suggests turbidity values often correlate to conditions at time of sampling such as rain and wind.

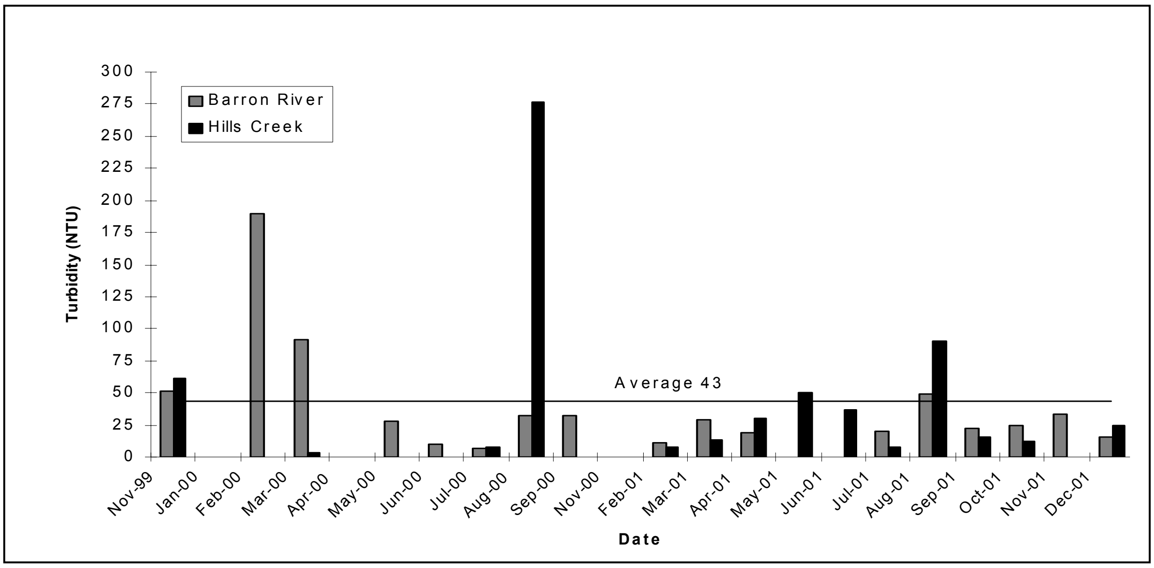


Figure 64 Seasonal average turbidity by system

There was an increase in turbidity in Hills Creek during February and March of 2000 associated during the wet season floods. An increase was observed in the Barron River after a small rainfall episode event in August 2000, which may have also been influenced by winds during this time of year.

Catch per Unit Effort

Abundance of juvenile *P. monodon* displayed strong seasonality patterns during the study period. Peak in catches of juvenile *P. monodon* were seen during summer months both pre wet and during the wet season; that is, from October through to March annually. The 1999/2000 season displayed a relative low average monthly CPUE of 0.4 (where effort is 20 casts) in comparison to the 2000/2001 season with an average monthly CPUE of 1.4. The project surveys were ceased before the end of the 2001/2002 season (December 2001) with pre wet surveys establishing juveniles in high abundance.

P. monodon

Figure 65 displays the variation in average monthly CPUE (where a unit effort is one cast throw and effort was similar) for juvenile *P. monodon* seasonally with the average monthly CPUE of 0.055 over the study period. A distinct increase in average monthly CPUE can be seen in the 2000/2001 season with an average monthly CPUE of 0.07, compared to that from the 1999/2000 season with an average monthly CPUE of 0.02. Above average catches were seen during early 2001 (January to March) and the beginning of the 2001/2002 season (October to December 2001), clearly displayed as peaks in Figure 24. Below average catches for 2001 was only seen in the winter month of June, displayed as plateaus below the average CPUE line, with establishment of juveniles throughout the whole year (that is between seasons). Below average catches were predominately seen throughout 2000 with above average catches only seen in two months, November 1999 to February 2000. The peak catches in the 2000 season were found proceeding rainfall, although increase in catch for the 2001 season from November 2001 did not proceed rain but drought.

Seasonal differences between systems varied with the Barron River having a higher average CPUE for 1999/2000 of 0.02 than Hills Creeks average CPUE of 0.01. The 2001 season showed opposite trends between systems with Hills Creek having the higher average CPUE of 0.1 opposed to the Barron River's average CPUE of 0.06.

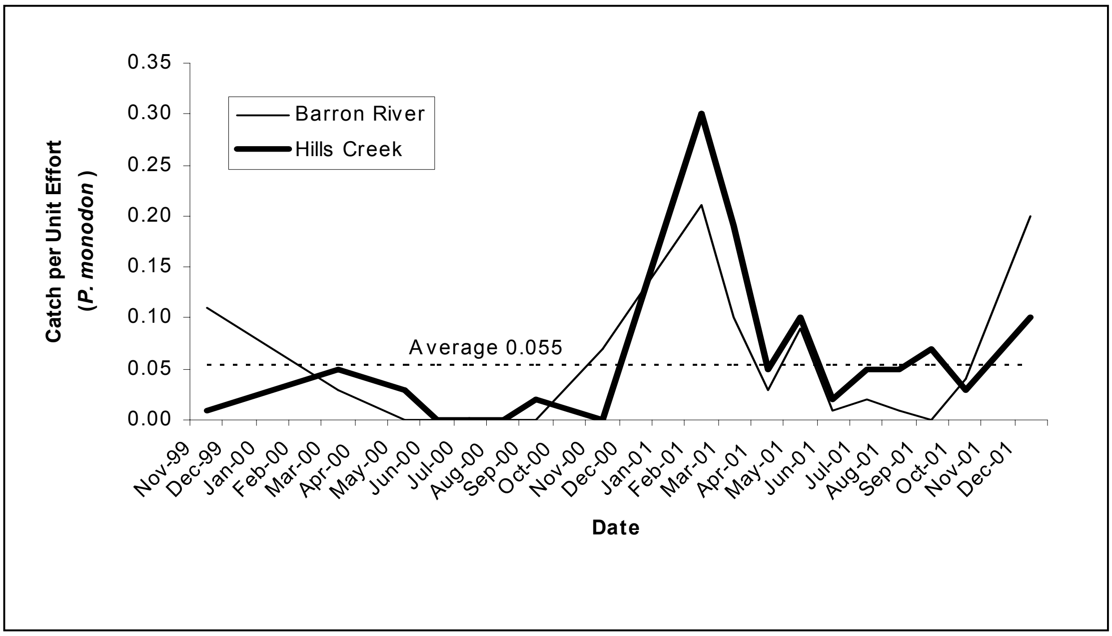


Figure 65: Seasonal P. monodon Catch per Unit Effort by system

Figure 66 displays average total length of juvenile *P. monodon* found during monthly monitoring over the study period. This data was analyzed to determine growth of juveniles to further establish seasonal cohorts, which may indicate timing of post larvae recruitment in to nurseries and migration of juveniles to foreshores. Data from November 2000 to December 2002 displays an entire season of juvenile's total length range, that is from summer, over winter and through to the following summer season. This period displays a pattern of growth of animals in estuarine nursery grounds from November 2000 (average 85 mm) through the winter months to August/September 2001 (average 140 mm) with smaller individuals found once again from November 2001 (average 85 mm). This pattern is based on a very limited number of individual animals (average CPUE of 1.4). Observations made from research surveys indicated relative mass abundance of post larvae (<29 mm total length) seen during October and November seasonally, with no other post larvae noted throughout other times of the year. Juveniles (29 to 56 mm total length) were seen to follow in abundance after first sightings of post larvae in mass. Due to low and variable catch rates only one period of post larvae recruitment in to estuarine nurseries was seen, occurring from October to November during the pre-wet period.

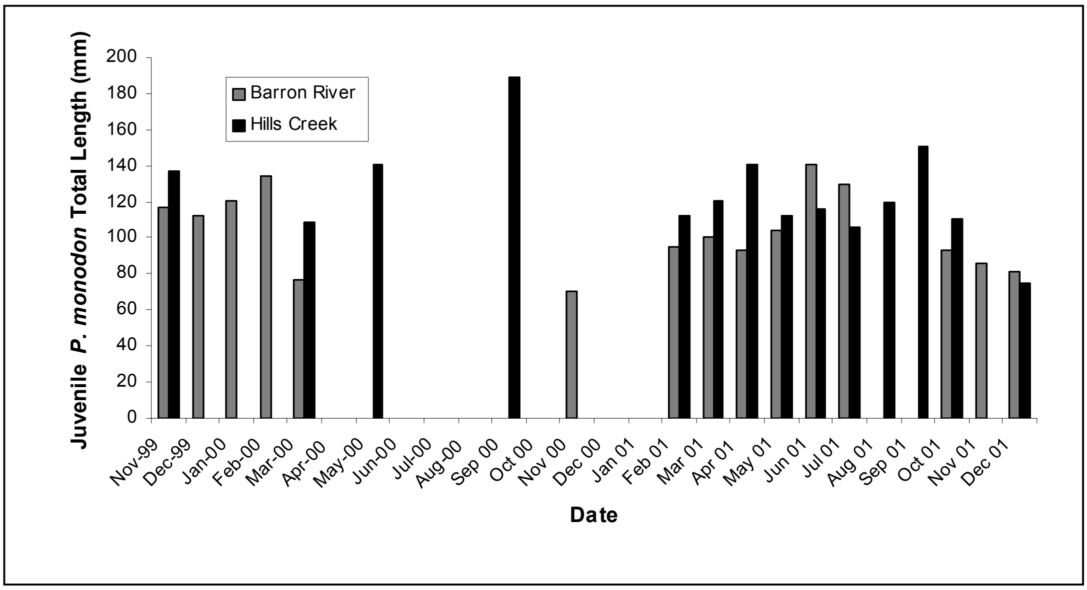


Figure 66 Total Length of Juvenile P. mondon seasonally in monthly monitored systems

P. merguiensis

Figure 67 displays the variation in average monthly CPUE (where a unit effort is 20 ca64st throws/a monthly site visit and effort is similar) for juvenile *P. merguiensis* seasonally. Average monthly CPUE was almost double for Hills Creek at 30.0 than that of Barron River at 16.4. Average monthly CPUE was greater in 2000 for the Barron River at 19.70 (59 % of total study catch) than in 2001, 13.44 (41 % of total study catch). Hills Creek average CPUE displayed an even stronger difference between years with CPUE at 38.88 (64 % of study catch) in 2000 and 21.94 (36 %) in 2001. Peak catches were over two distinct periods for Hills Creek between June and November 2000 and later in 2001 from October and December 2001. Catches of juvenile *P. merguiensis* in the Barron River displayed erratic, smaller peaks over a short time frame in June and July 2000 and November 2000 though to March 2001 with two smaller peaks in March and May 2001. No distinct relationship between catch and rainfall or *in situ* water quality could be made over the study period, although there was some display of peak catches in drier periods or proceeding rainfall events.

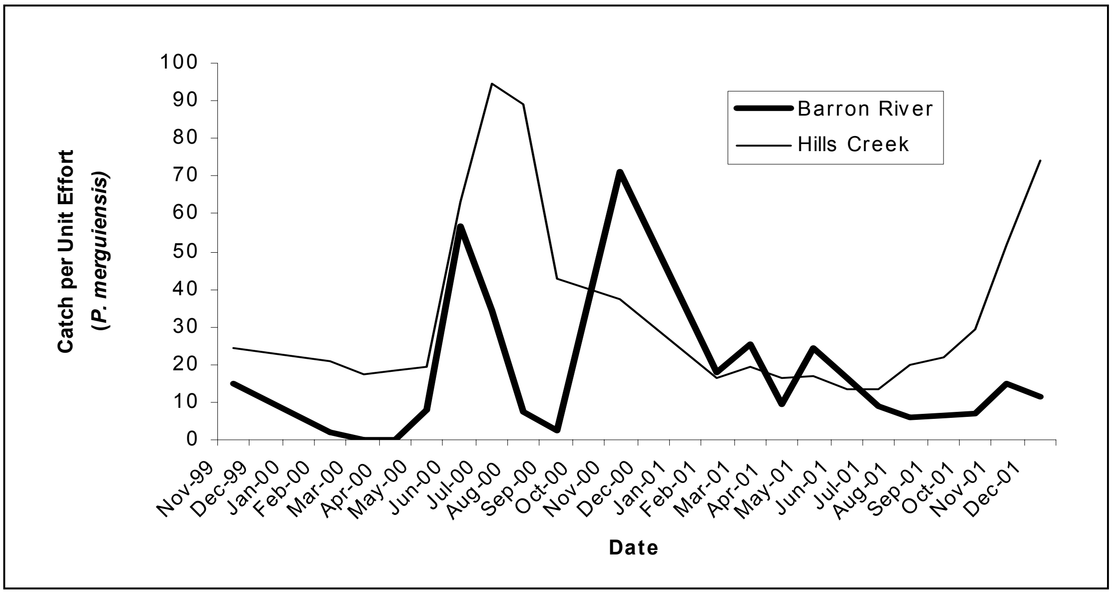


Figure 67 Seasonal P. merguiensis Catch per Unit Effort by system

Objective 4. Seasonality in the Population Dynamics of *P. monodon*

Background - The North Queensland Climate

The North Queensland climate is characterised by a distinct wet season with high volumes of rainfall, high ambient temperatures and mild northerly winds, followed by a dry season with cooler ambient temperatures, very low rainfall and strong south-easterly winds. Subsequently, the physics and chemistry of water in local estuarine, foreshore and inshore waterways can follow strong seasonal fluctuations.

Previous chapters have demonstrated that the distribution of *P. monodon* is concentrated in the wet-tropical regions between Cairns and Cardwell, North Queensland. Also, the abundance and size of *P. monodon* has been shown to change in synchrony with the timing of the distinct “wet” and “dry” seasons.

In this chapter we investigate these seasonal changes in *P. monodon* populations with changes in the abiotic environment that occur on a seasonal basis. The abiotic parameters that we investigated include rainfall, river water flow, salinity, water temperature, and turbidity.

We investigate these abiotic parameters and the timing of these in relation to the catch and size of *P. monodon*. This is done on both large spatial scales using commercial catch data and small spatial scales using catch data collected during QDPI surveys in estuaries and foreshores.

Large Spatial Scale Patterns

Seasonal Patterns in Waterflow

Water flow is monitored by the Department of Natural Resources at various stations in the catchment of most large rivers in Queensland. A complete dataset (or near to complete) has been collected in the North and South Johnstone, Barron, Mulgrave and Daintree Rivers of North Queensland. The water flow data for these rivers was collected in the freshwater reaches and is therefore useful in describing the volume of water that rainfall channelled into local rivers. It describes the downstream effect that the rainfall has on local waterways and estuaries.

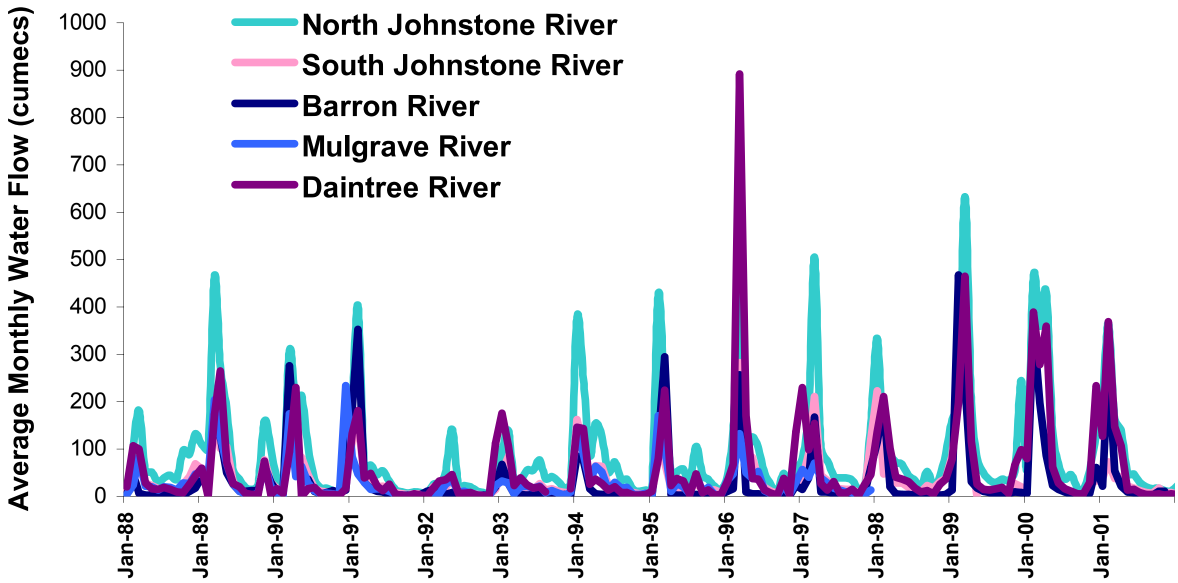


Figure 68. Seasonal changes in the average monthly water flow in the North and South Johnstone , Barron, Mulgrave and Daintree Rivers between 1988 and 2001.

Average monthly water flows (Figure 68) are highly seasonal, with highest average monthly flows between December and May. The yearly peak in average monthly flow most often occurs during the months of February and March, although there is a large variation in the timing and magnitude of the peak flows between years.

The Johnstone River water flow data recorded higher flows than the other rivers, which include the South Johnstone, Barron, Mulgrave, and Daintree Rivers. The greater flow of water in the North Johnstone River may be due to the relative positioning of the water flow meters in each system, and the distance upstream that they were permanently placed.

Previous chapters highlight that the commercial catch of *P. monodon* is geographically concentrated between Cairns and Cardwell in North Queensland. In this region, the highest catches were recorded in the commercial logbook reporting grids H16, I17, and I18, which includes fishing grounds located between the Tully Heads to just south of Port Douglas (between latitudes –18.0 and –16.5 deg South).

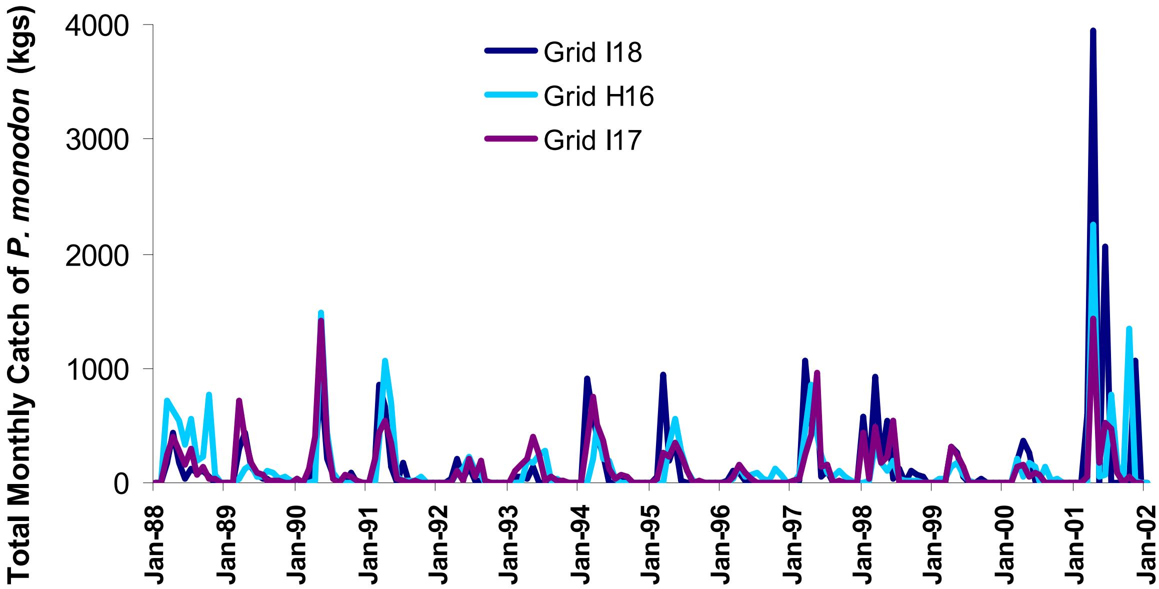


Figure 69. Seasonal changes in the total monthly catch of P. monodon in the Commercial Logbook reporting grids of I18, I17, and H16 between 1988 and 2001.

Monthly catch of *P. monodon* between Tully Heads and Port Douglas is highly seasonal, with the highest average monthly catches recorded during March to May (Figure 69). The yearly peak in average catch of *P. monodon* most often occurs during the months of March and April, although there is a large variation in the timing and magnitude of the peak catches between years. For example, most years between 1988 and 2001 have a short peak in *P. monodon* catch, however 1988, 1998 and 2001 recorded high catches throughout the year, and thus lacked the strong seasonal pattern in catch that occurred during most years.

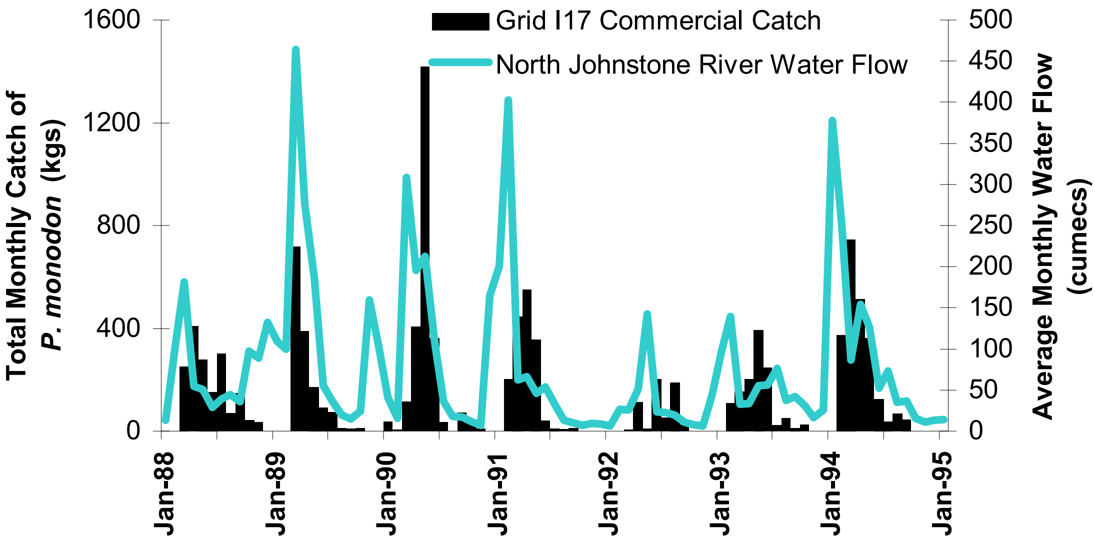
The distribution of catch between Commercial Reporting Grids H16, I17 and I18 varied between years, with no grid consistently catching the highest biomasses of *P. monodon*.

Comparison of commercial catch and water flow data

North Johnstone River

The commercial logbook reporting grid I17 is located outside the Johnstone Rivers with the south-eastern most corner of the grid beginning from the mouth of the Johnstone River mouth north up the coast (-17.5 deg south to 17.0 deg south; 146deg east to 146.5 deg east) (Figure 15). We used this grid to relate the seasonal changes in commercial catch to the seasonal changes in water flow in the North Johnstone River. This region was chosen due to the high flow volumes and continuous dataset of water flows in the river and continuous catch data for *P. monodon*.

a)



b)

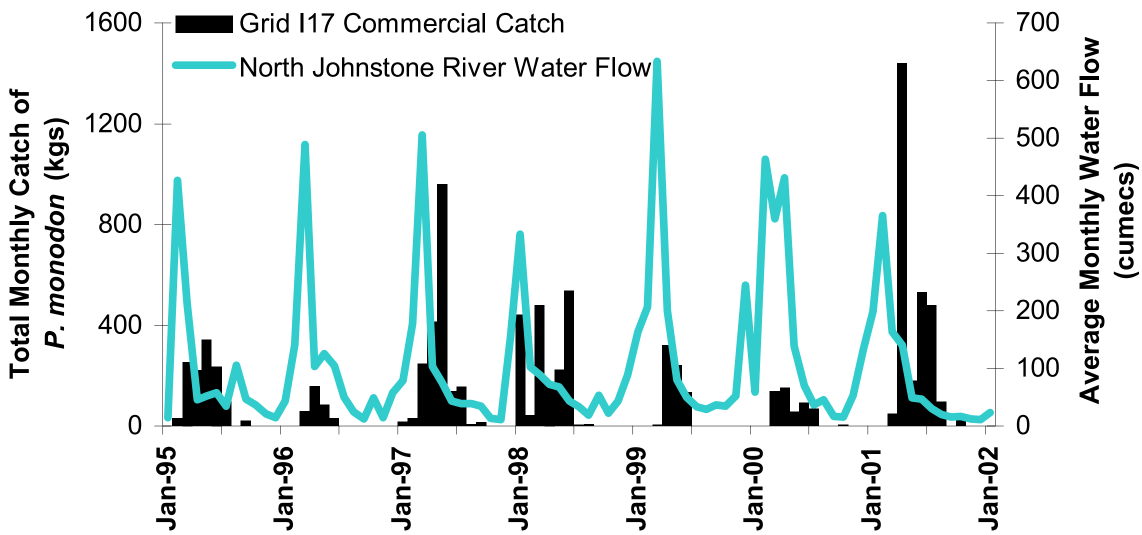


Figure 70. The seasonal changes in total monthly commercial catch in GridI17 with average monthly water flow in the North Johnstone River for a) 1988 to 1994; and b) 1996 to 2001.

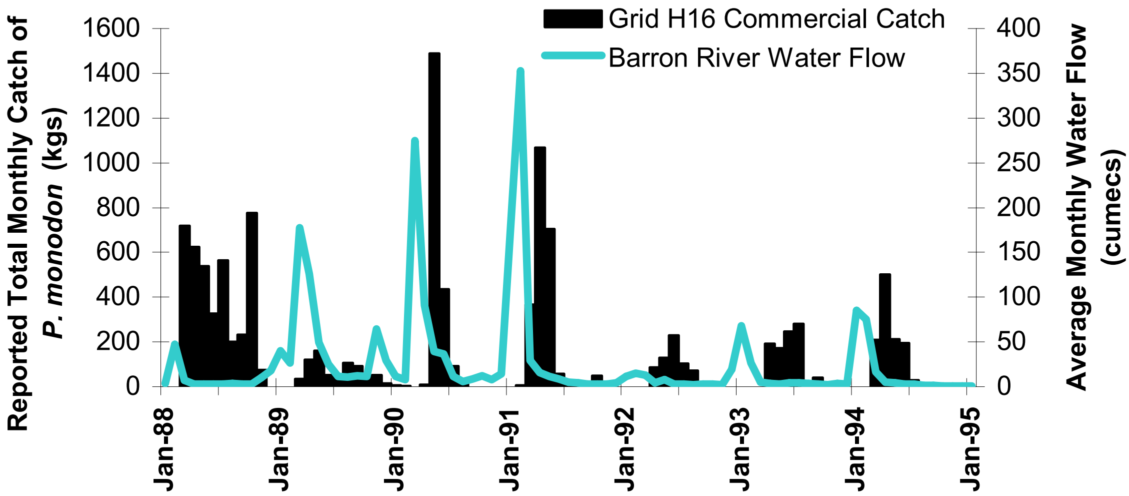
Both the average monthly water flow and the average monthly catch of *P. monodon* are highly seasonal, with at least one strong peak in catch and flow occurring each year. The peak in catch in Grid I17 occurred following the peak in river flow during most years with a lag of approximately 2 months. The peak in flow occurred mostly during the months of February to March, whilst catch peaked during the months of April to May.

There is a strong relationship between the magnitude and length of the peak in water flow in the North Johnstone River and the magnitude of catch in I17 during most years. For example, between 1988 and 1995 the seasonal pattern in water flow is similar in shape and magnitude to the seasonal patterns in catch. In the years, 1996 and 1999 to 2002, this pattern breaks down, and there is a much weaker relationship between water flow and catch with the timing similar to years 1988 to 1995, but the magnitude of the catch shows little correlation with water flow.

Barron River

The commercial logbook reporting grid H16 is located just off the coast of Cairns and Palm Cove, beginning from Oombunghi Beach (south of Cape Grafton), north to Yule Point (south of Port Douglas) (-16.5 deg south to 17.0 deg south; 145.5deg east to 146.0 deg east). We used this grid to relate the seasonal changes in reported commercial catch to the seasonal changes in water flow in the Barron River, which flows into the Grid H16.

a)



b)

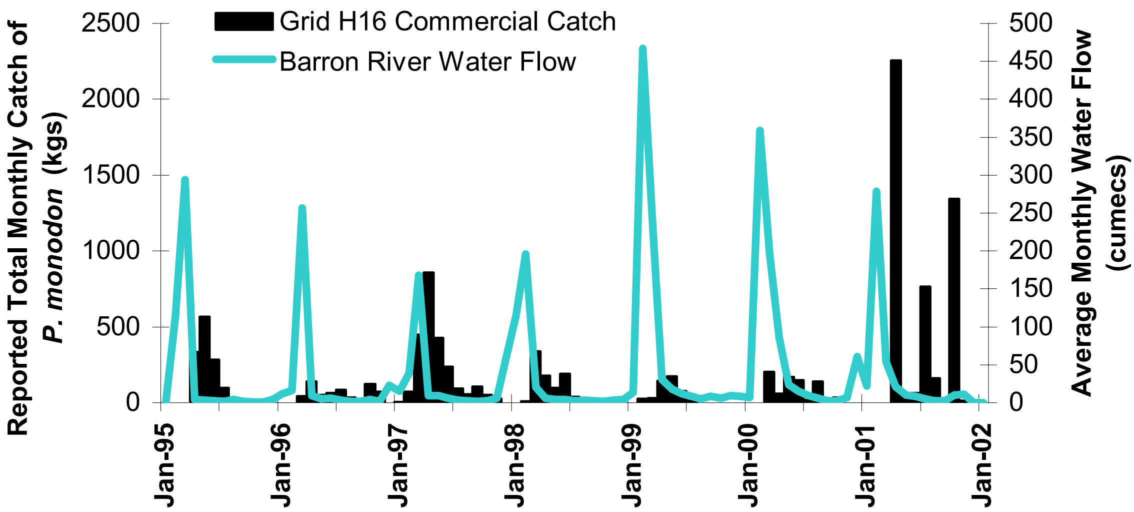


Figure 71. The seasonal changes in total monthly commercial catch in GridH16 with average monthly water flow in the Barron River, a) 1988 to 1994; and b) 1995 to 2001.

Both the average monthly water flow and the average monthly catch of *P. monodon* are highly seasonal, with at least one strong peak in catch and flow occurring each year (Figure 71). The peak in flow occurred mostly during the months of February to March, whilst catch peaked during the months of April and May. The peak in catch in Grid H16 occurred following the peak in river flow during most years with an average lag of 2 months. The year 1988 and 2001 recorded several large peaks in catch throughout the year, and lacked a strong seasonal peak as per other years. The seasonal peak in water flows preceding these high catch years, were not exceptionally high.

There may be a time-lagged relationship between the average monthly flow in the Barron River, and the catch in commercial grid H16. For example, in the years 1990 to 1995, and 1997 the seasonal pattern and magnitude of the water flows is similar in the pattern and magnitude to the catch in H16. In other years however, there appears to be no strong relationship between the patterns in catch and river flow.

Small Spatial Scale Patterns

Seasonal Patterns in Abiotic Environment in the Cairns Region

Water quality parameters were monitored on a monthly basis in sites that were monitored by cast nets in estuaries (Hills Creek and the Barron River), and by beam trawl on foreshores (Bessie Point to False Cape region). Together with seasonal data on rainfall and water flow, these parameters were used to describe the seasonal patterns in the abiotic environment occurring on a small spatial scale in the Cairns region.

Rainfall

High rainfall episodes were experienced in the Cairns region from November to April with a large wet-season peak in February and March. The 1999/2000 wet season had a shorter peak rainfall period (approx. 3 months) than the 2000/2001 season (approx. 5 months), however higher monthly rainfalls were recorded during the shorter 1999/2000 wet season. The dry season occurred from May to October with less than 90 mm recorded and an average of 31 mm per month during both years. The dry season rainfall did not differ between years.

Water Flow

The average monthly water flow in the Barron River and Hills Creek followed a similar seasonal pattern to rainfall at these two sites. Heavy water flows in the two freshwater systems occurred during February to May in 2000 and November to April in 2001 (Figure 6.4.5b). A small second peak in average water flow was recorded during September of 2000 and during October of 2001 in Hills Creek. No similar peaks were observed in the Barron River during these later months. Overall, the Barron River recorded greater water flows, with seasonal peaks in flow in the Barron River being 30 times the order of magnitude greater than the flows recorded in Hills Creek.

Water Temperature

A low dry-season trough in water temperatures was observed to occur in June to August when temperatures dropped down to 21.5^{o}C. Temperatures reached a high during the warmer wet-season period (November to April) with up to 33 ^{o}C recorded in Hills Creek in December 2001. A higher variability in the water temperature was recorded during the wet-season when rainfall and cooler runoff waters flood estuaries and foreshores. There was little difference in the water temperatures between estuaries and foreshores, although generally, temperatures were marginally higher in the estuaries. Water temperatures recorded were lower during 2000 than 2001, with water temperatures in the Barron River reaching down to 21.7 ^{o}C during 2000 and down to only 24.0 ^{o}C during 2001.

Salinity

There was an incomplete time series in the monthly water temperature and salinity due to problems with the *Horiba* water quality meters. This problem led to gaps in the data recorded during 2000 in particular.

Given these difficulties, salinity was consistent in the foreshore sites at Bessie Point to False Cape with salinities ranging between 30.05 and 37.94 ppt. Although these sites are situated close to the mouth of the estuary, little seasonal fluctuation in salinity was recorded. The salinity at the Hills Creek and Barron River estuarine sites varied greatly. Monitoring recorded salinities between 0 and 21.7 ppt for the Barron River and between 5.5 and 34.5 ppt in Hills Creek. The large differences in salinities between the Hills Creek and Barron River sites are due/attributable to the large differences in the stream types and sizes. The Barron River is a large system with a large catchment and has a high freshwater influence. Hills Creek runs directly onto the foreshore at the mouth of Trinity Inlet and therefore the salinity at these sites is more similar to the foreshore sites.

Seasonal wind direction and magnitude.

In the Cairns region there is a daily change in wind direction, ie, onshore and offshore breezes, hence data is presented for 9 am and 3 pm for average wind direction and daily wind-speed. Winds from the SE, SSE, ESE are reported anecdotaly by collectors to correspond with turbid waters in coastal habitats, and turbidity is believed to explain the increase in numbers of *P. monodon* available to be caught. Therefore prolonged south easterly winds were given as the explanation of the dramatic increase in the catch in 2001. Comparison of patterns from 1999, 2000, and 2001, however, showed no dramatic change in the direction nor amplitude of the wind in that year.

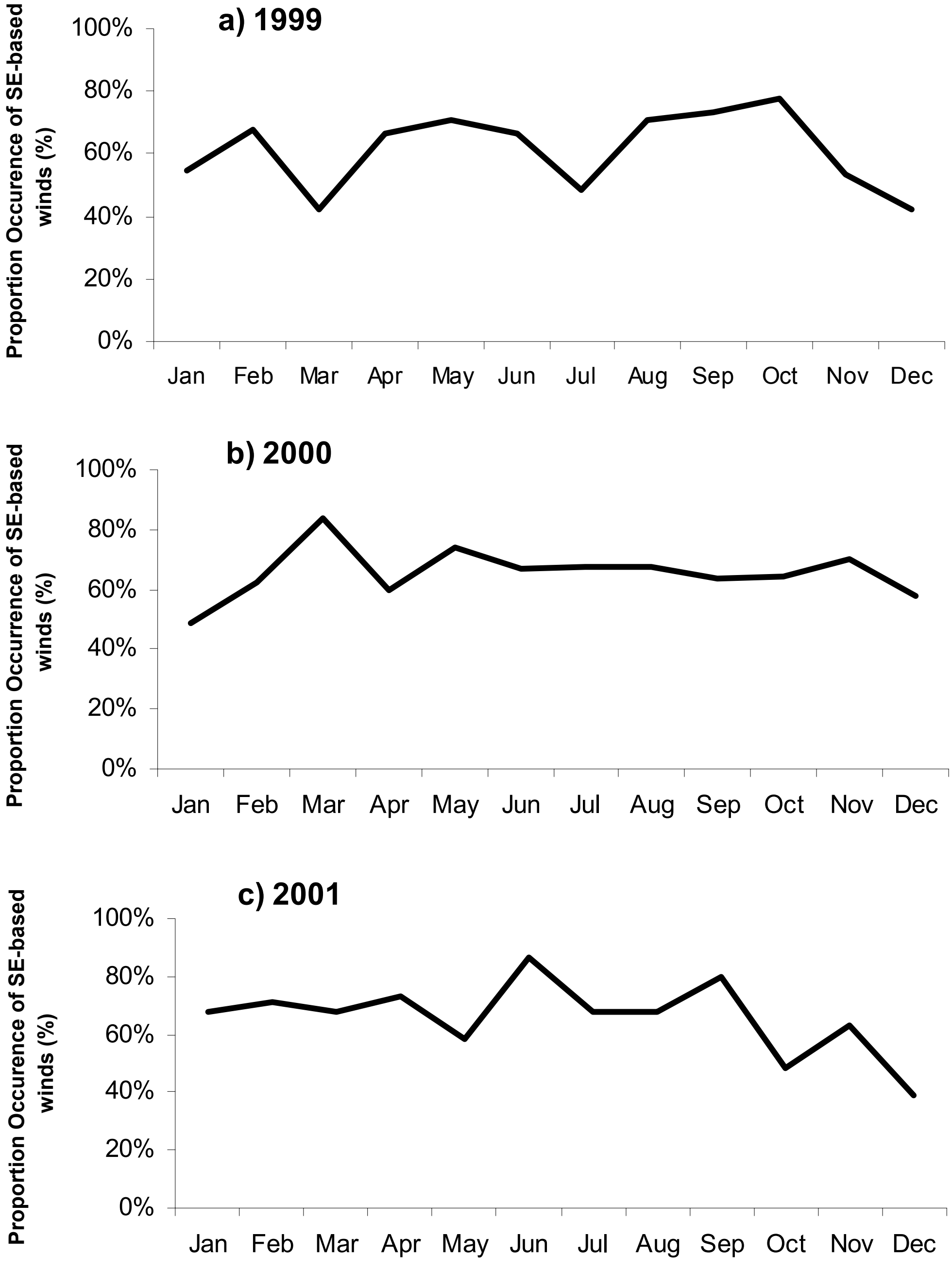


Figure 72. Proportion occurrence of SE, SSE and ESE winds at the Cairns Airport per month during a) 1999; b) 2000; and c) 2001.

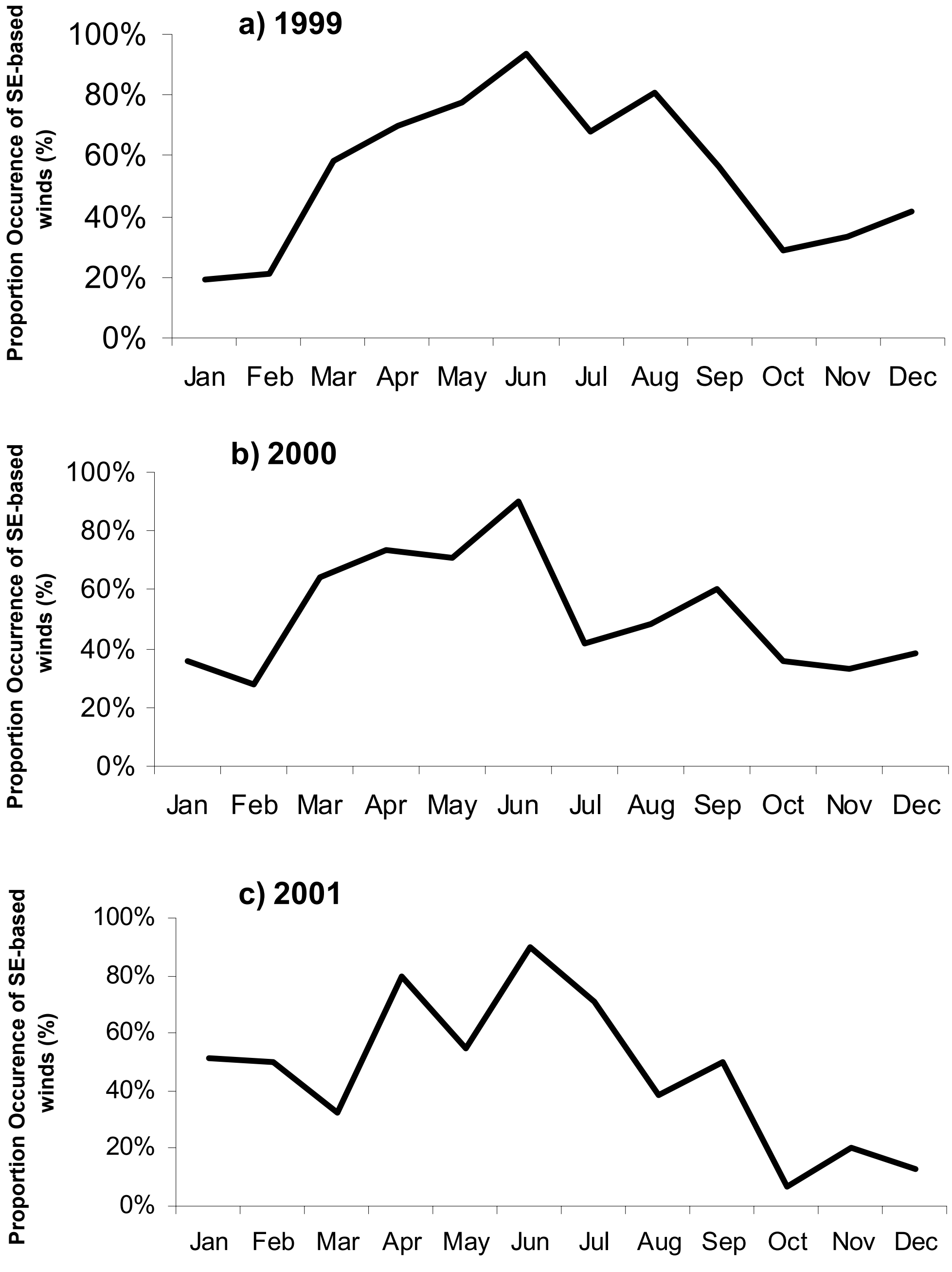


Figure 73 Proportion occurrence of SE, SSE and ESE winds at the Cairns Airport per month during a) 1999; b) 2000; and c) 2001.

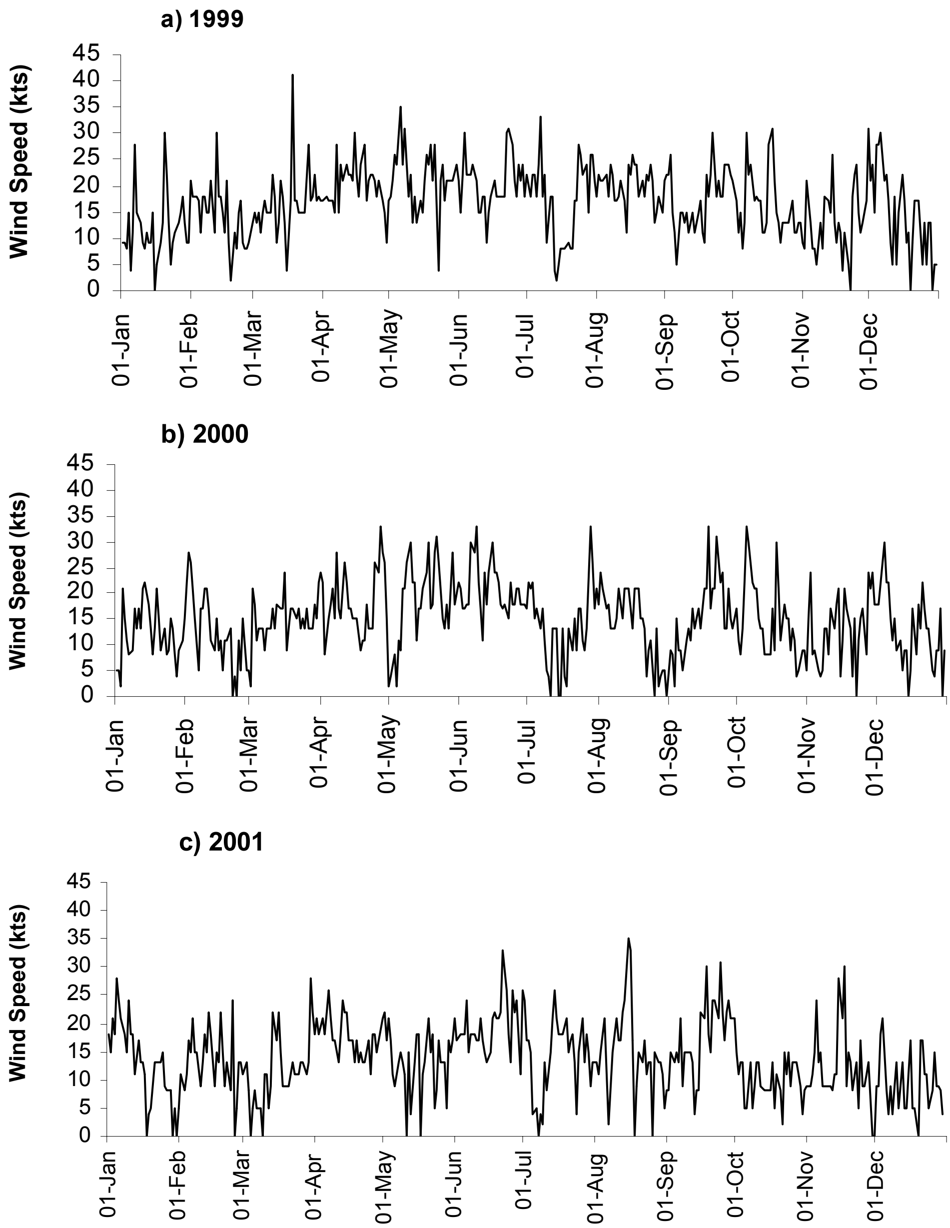


Figure 74. Daily recorded wind speed at the Cairns Airport at 9:00 am during, a) 1999; b) 2000; and c) 2001.

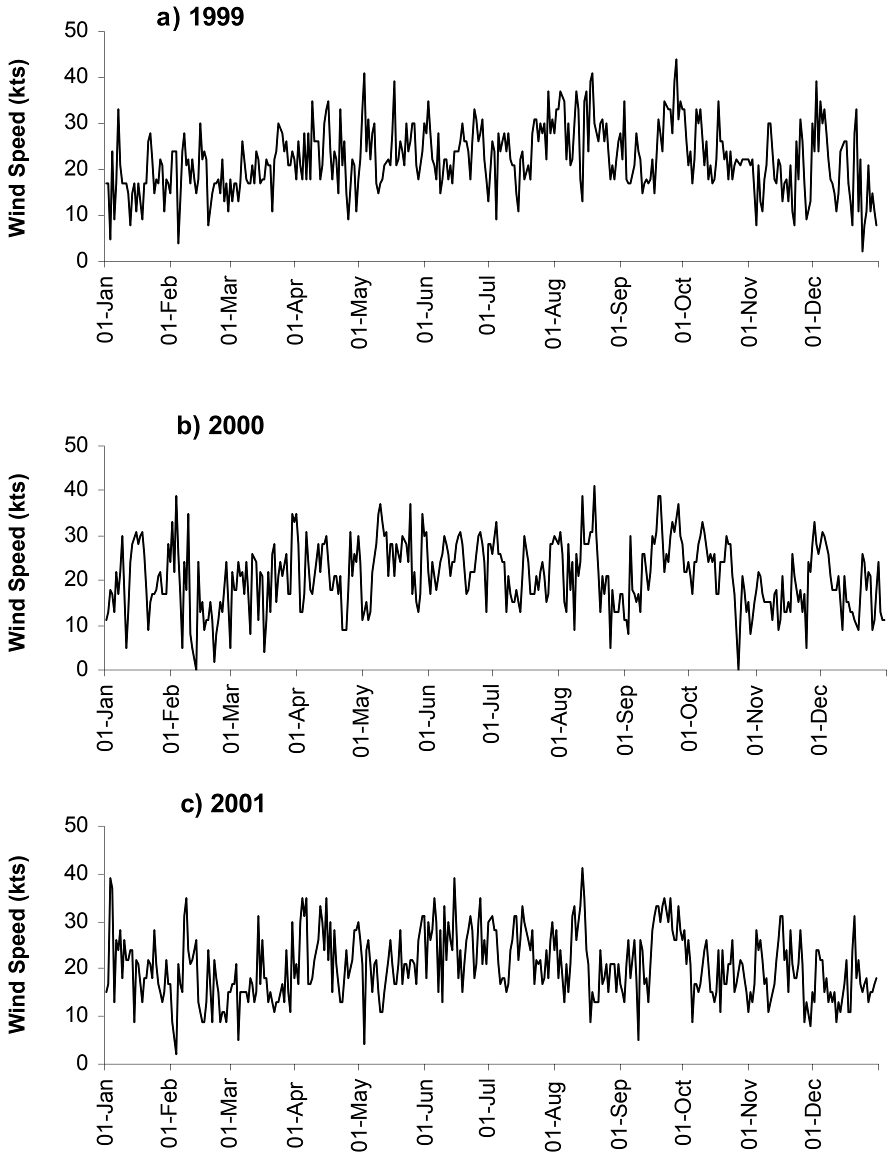


Figure 75 Wind Speed at 3pm (15:00) at Cairns Airport. Daily recorded wind speed at the Cairns Airport at 3:00 pm during, a) 1999; b) 2000; and c) 2001

Seasonal Patterns in Research Catch Data in the Cairns Region

Commercial Catch Abundance of P. monodon

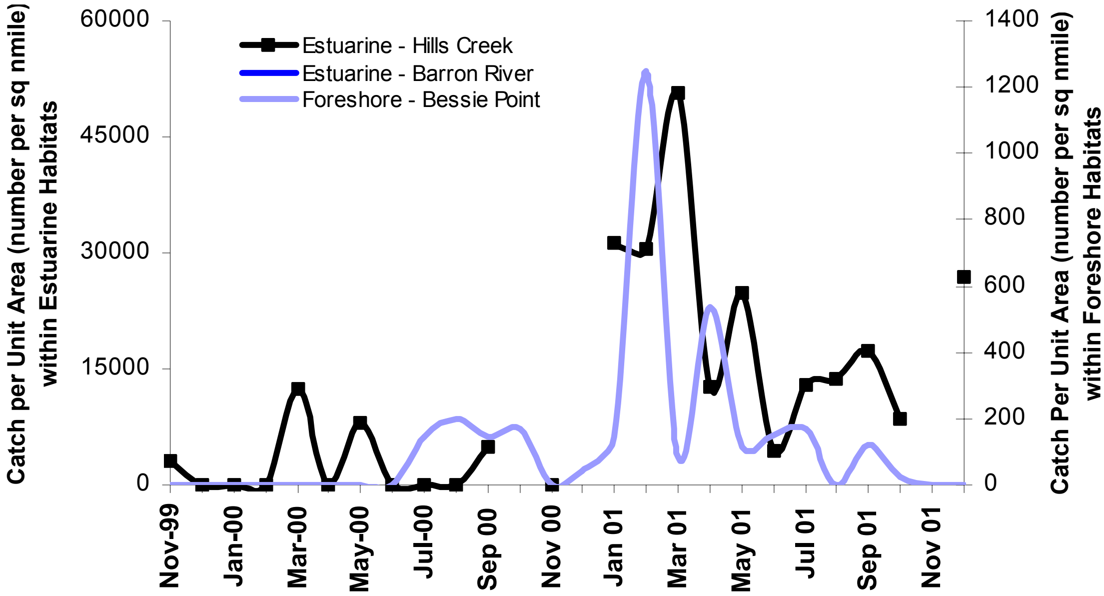


Figure 76. Seasonal changes in the Catch Per Unit Area in Foreshore sites monitored by beam trawl and Estuarine sites monitored by cast netting surveys, November 1999 to December 2001. Foreshore sites were not monitored between November 1999 and June 2000.

The catch of *P. monodon* was highly seasonal in estuarine and foreshore sites during monitoring surveys between November 1999 and December 2001 (Figure 76). The estuarine sites recorded large peaks in catch of juveniles, adolescents and sub-adults during January of 2000, February to March of 2001, and during November of 2001. Following this pre wet-season peak in catch, *P. monodon* abundances in estuaries declined, with very low catches recorded in both the Barron River and Hills Creek from June to November.

A very similar pattern was observed in foreshore sites at Bessie Point, where strong seasonal peaks in catch were recorded during the wet-season and very low abundances recorded in trawls during the dry-season.

In estuaries, there was a difference in catch rates recorded between years (Figure 76). Higher catch rates of *P. monodon* were recorded in estuaries in 2001. The difference between years occurred during both wet- and dry- seasons.

Size of P. monodon

Foreshores sites captured *P. monodon* that ranged in size between 109 mm and 287 mm TL. On a seasonal basis, the average size of *P. monodon* captured in foreshore habitats ranged between 134 and 258 mm TL (Figure 77). In these foreshore sites, small *P. monodon* were captured during and following the wet-season, when the average size reached down to 134 mm TL. Following the 2001 wet-season, the size of individuals on foreshores slowly increased through the dry-season, with average sizes reaching up to 249 late in the year (October 2001). The average length of *P. monodon* on foreshores during 2001 suggests that there was one major recruitment of small individuals out of the estuaries onto these foreshore sites during 2001.

A decline in the size of *P. monodon* during September 2000 was recorded in foreshore sites, with the average size of individuals declining from 258 mm TL in July to 162 mm TL in September. This suggests that recruitment of *P. monodon* occurred out of the estuaries onto foreshores during September, however only small sample sizes were recorded.

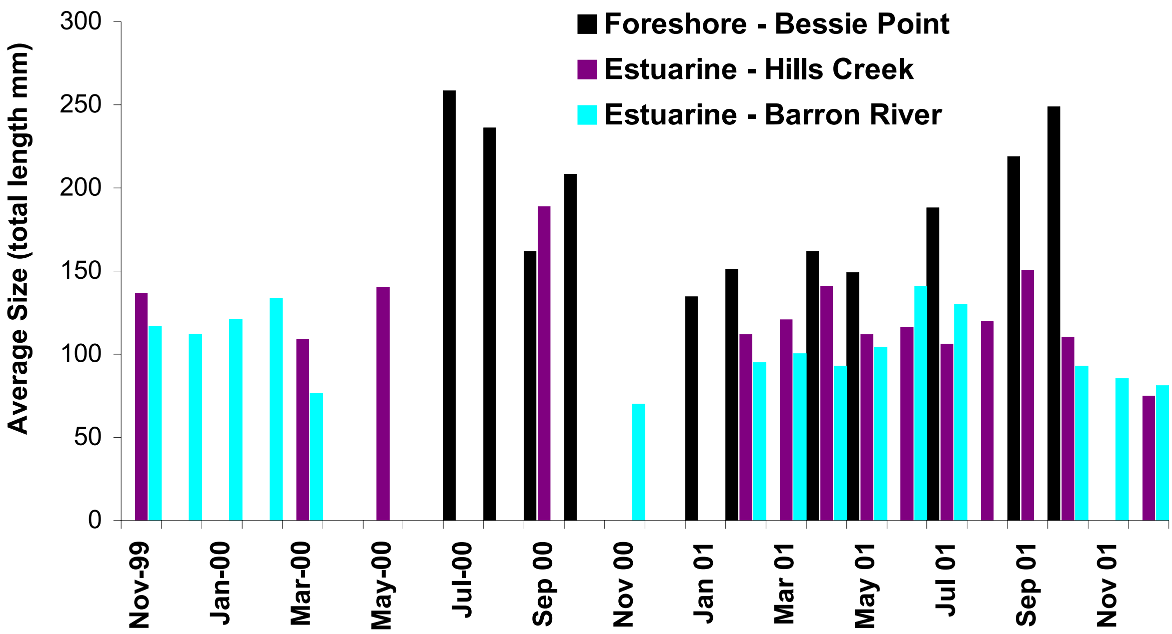


Figure 77. Seasonal changes in the average total length of P. monodon in Foreshore sites monitored by beam trawl and Estuarine sites monitored by cast netting surveys, November 1999 to December 2001. Foreshore sites were not monitored between November 1999 and June 2000.

The size of *P. monodon* captured in estuarine sites was lower than those captured in foreshore sites, with individuals captured ranging between 52 and 181 mm TL in Hills Creek and 25.6 and 186 mm TL in the Barron River sites. Due to the absence of *P. monodon* in estuarine sites during many months of the year, especially in 2000, it is difficult to detect a pattern in the seasonal changes in size of *P. monodon* in these sites. This absence of *P. monodon* in estuaries in the late months of 2000, suggests that there was little recruitment input from the estuaries into the fishery during this period.

In estuaries, the smallest *P. monodon* were captured during the pre-wet season period. Increases in size were observed during and following the wet-season, suggesting that individuals were recruiting out of estuaries during this time. In the year 2001, juveniles in an average size range between 93 and 150 mm TL were captured through the dry-season. A net increase in the size of *P. monodon* was not observed through this dry-season period. The average size in both estuarine sites varied considerably during this period. This suggested that the successful recruitment of post-larval *P. monodon* into estuaries occurred during the dry-season period between May to September 2001 and that recruitment out of estuaries may have occurred during this period.

Objective 5. *P. monodon* recruitment, movement, and growth.

Tag and Recapture Program

Objectives of the program were to identify the recruitment of juveniles from nursery to commercial grounds, determine movement of adult stocks in commercial grounds, and to evaluate survival of prawns following the process of tagging. The following chapter outlines results of the tag-release-recapture program in two parts, firstly tagged prawn statistics and secondly recapture results. Tagged prawn statistics provides distribution and abundance information obtained for *P. monodon* captured by various methods from associated grounds. The recapture results provide information on recruitment, movement and growth patterns.

Between 19 November 1999 and 12 December 2001, 2015 *P. monodon* were tagged and released. Adult prawns were captured on commercial grounds between Weary Bay and Mission Bay, and juveniles captured in nursery grounds between the Daintree River and Hinchinbrook Channel. In total 95 juvenile and adult prawns were recaptured establishing a 4.7 % recapture rate from all grounds combined.

Tagged Prawn Statistics

Capture Method and Fisher Type

P. monodon to be tagged were captured by several methods: commercial trawling; research beam trawling; research cast netting; recreational cast netting; and research hand scoop netting. A breakdown of ground fished by capture method is displayed in Table 5. The total number caught and number tagged is also displayed in Table 5, which displays many juveniles were caught and were unable to be tagged due to their small size. The greatest number of prawns were captured and tagged by commercial trawling methods and displays the support and time provided by commercial fishers, which formed the basis of the adult tagging program.

Table 5: Number of P.monodon caught and tagged by capture method, fisher, area fished

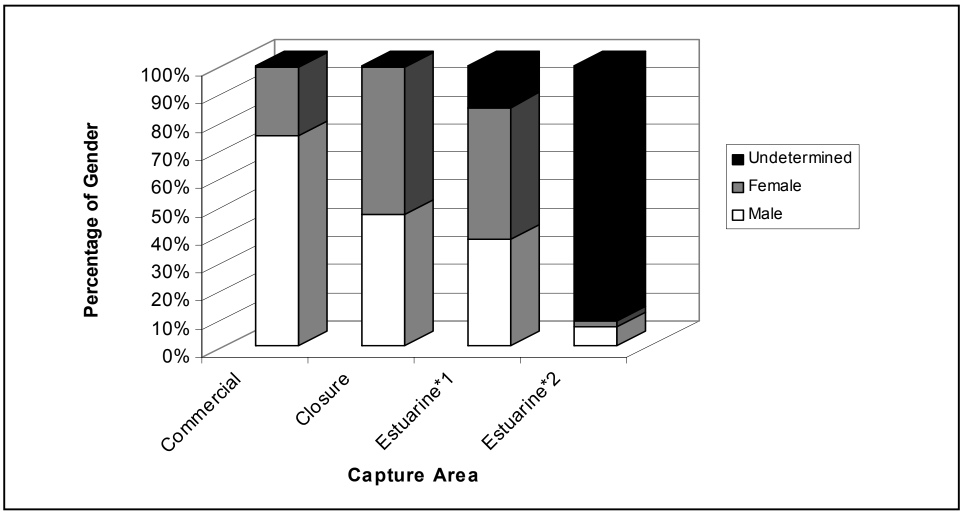
Capture Method	*Areas Fished*	*Number Caught*	*Number Tagged*
Commercial Trawl	Commercial Grounds	1 476	1 466
Research Trawl	Cairns Closure	195	192
Research Cast net	River	599	357
Recreational Cast net	River/lower tidal	76	0
Electrofishing	River/upper tidal	135	0
Hand scoop	River/upper tidal	44	4
Total		2 525	2 015

Note: visual assessment only was made of prawns seen using electrofishing practices.

Gender

The gender of prawns tagged was recorded where identifiable, with a breakdown given in Figure 1 by capture grounds. Commercially caught prawns that were tagged were generally unwanted broodstock product, predominantly prawns less than 220 mm total length and male. This selection of prawns generated bias in the data set for the commercially tagged prawns displayed by the higher percentage of males tagged (75 %, 1 103) than females (25 %, 370 animals) with a male to female ratio of 1:0.3. Lack of female prawns to tag and time and handling restrictions to process brood stock meant data could not be collected on reproduction e.g. ovarian development with size and seasonality. Some data was recorded on insemination of females in commercially caught prawns in April 2001 which indicated 58 % of females were inseminated at an average total and carapace length of 185.9 mm and 45.6 mm, respectively, with range of total length between 115 mm and 233 mm. Females not inseminated displayed a smaller average total 179.6 mm but similar average carapace 45.2 mm, with a much larger range of total length at 144 mm to 277 mm.

The percentage of female prawns tagged (53 %, 101 animals) by research trawls in the Trinity Inlet closure was slightly higher than that of males tagged (47 %, 90 animals), but displayed a relatively close male to female ratio of 0.9:1 (Figure 78). This approximately equal male to female ratio is believed to be a more representative account of adult stocks than that displayed by the unequal and biased commercial data set. The ratio of male to female prawns found in rivers by cast netting was 0.8:1, displaying a smaller percentage of males tagged (38 %, 128 animals) compared to females (48 %, 162 animals). The hand scoop net method used to sample prawns in upper estuarine habitat only captured four prawns in which gender could be determined, with 40 animals undetermined (91 %). Gender determination was more difficult for smaller sized individuals predominantly caught in upstream sites. At these small sizes (<50 mm) it was much easier to identify the petasma in males than detect the female thelycum.



Note: *1 (cast net) and *2 (hand scoop net)

Figure 78 Gender of P. monodon by grounds (capture method)

Size

Average total and carapace length

Figure 79 below displays the average total and average carapace length (mm) by ground captured for all tagged *P. monodon*. With reference to the *P. monodon* biology section of this report, the average sizes also indicate the average age and stage of life cycle of prawns tagged; that is post larvae (<29 mm, <3 weeks old), juveniles (29 to 56 mm, 3 weeks to 1.2 month old), adolescent (56 to 134 mm, 1.2 to 5 months old), sub-adult (134 to 164 mm, 5 to 6 months old) and adult (> 164 mm, 6 to 24 months old).

The average total length for prawns tagged in the Trinity Inlet closure (1 to 4.5 m depth) from research trawls was slightly larger at 190 mm $\pm$ 39.1 mm (but displayed a larger variation) than prawns from commercial grounds (184 mm $\pm$ 24.7 mm). The average total length indicates that the majority of prawns tagged from commercial and the closure grounds were adults. The prawns tagged from commercial grounds were those not required or unsuitable to be used as brood stock (usually less than 220 mm total length), therefore this data set is considered to biased. The commercial fishers catch would presumably display a larger average total length of animal, if the data set were to include all animals normally captured. Average carapace length of closure ground prawns was similar to commercial ground prawns, 45 mm $\pm$ 11.6 mm and 46 mm $\pm$ 6.0 mm, respectively, with closure ground prawns displaying more variation (indicated by standard error) possibly further displaying the biased data set of commercial ground prawn lengths.

Average total lengths for prawns tagged from cast netting (estuarine grounds) was 116 mm ± 27.1 mm and average carapace length 24 mm± 4.8 mm (Figure 79) . This displays an average increase in total length of 71 mm from nursery estuarine grounds to commercial and closure grounds and life stage change from adolescent to adult. To provide a true picture of average total length of prawns found from the hand scoop method in upper estuarine sites, the average was calculated from all prawns captured by this method as only four individuals (25 % of capture via this method) were of a large enough size to tag. The average total length of all prawns captured in hand scoop nets was 35 mm ± 18.8 mm and the average carapace length was 7.4 mm ± 4.1 mm. This reduction of average lengths found in hand scoops in upper estuarine grounds (averaging 82 mm smaller) from that of cast netting predominantly in middle to lower estuarine grounds indicates the upper estuaries were dominated by a smaller/younger class of animals, a pattern verified by researchers field observations. Average total length of animals captured in fyke nets (13.5 mm) has been included here to display the total range of animals captured

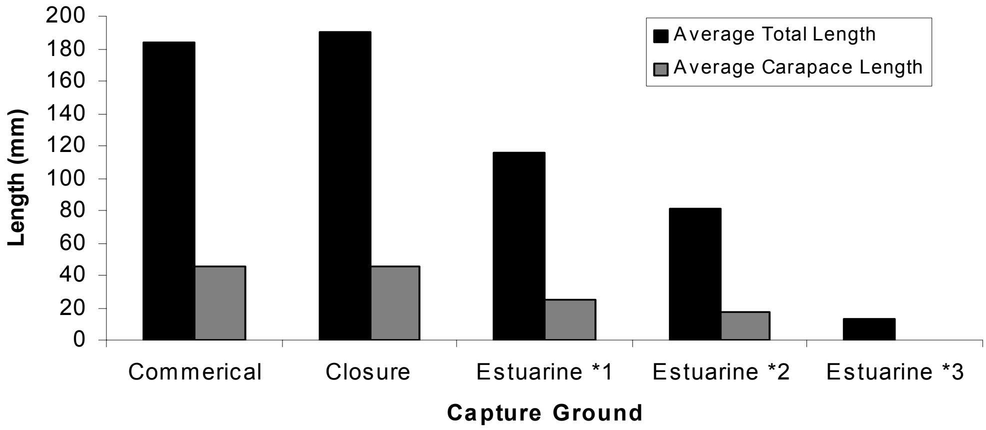


Figure 79 Average total and carapace length by ground captured

Figure 80 displays average total length for tagged male and female prawns separately by grounds captured.

Average total lengths of commercial ground tagged females was 189 mm ± 34.4 mm, while males were smaller but also with a smaller standard error (possibly due to greater numbers of males sample) at 182.4 mm ± 20.1 mm. Tagged closure female prawns displayed a larger average and ± SE at 204.5 mm ± 43.6 mm compared to males at 174.1 mm ± 25.7 mm, displaying a stronger difference between sexes than for commercial ground prawns (again possibly due to biased selection of prawns used from commercial grounds).

Prawns tagged from estuarine nursery grounds (cast netting) displayed an approximate equal average size between males at 124.1 mm ± 20.6 mm and females at 122.4 mm ± 27.6 mm.

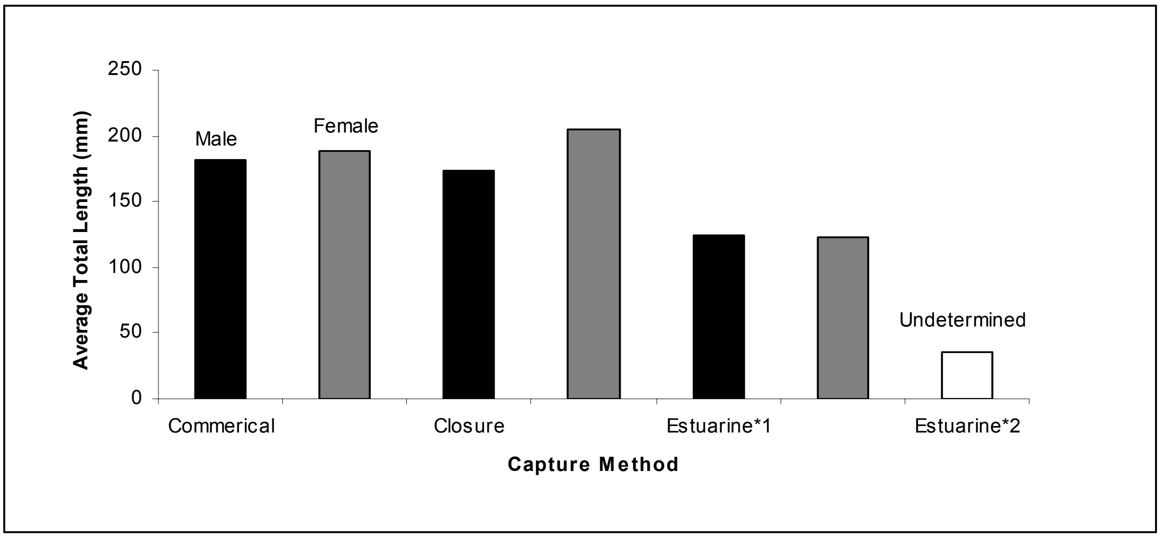


Figure 80 Average Total (mm) by Capture Grounds for Tagged P. monodon

Note: Estuarine *1 (cast netting) and Estuarine *2 (Hand scoop

Minimum and Maximum Total Length

Minimum and maximum total lengths by capture method are displayed in Figure 4, displaying similar patterns between capture grounds to that of average total length. The minimum and maximum total length of a closure ground prawn was 287 mm and 109 mm, respectively. Maximum total length of a commercial ground prawn was 260 mm and minimum was 97 mm (again, noting biased data set). The maximum total length of prawns tagged in estuaries via cast nets was 198 mm with a minimum of 98 mm. Hand scoop prawns were found (not tagged) in upper estuaries at a maximum of 115 mm and a minimum of 18 mm, displaying reduction size moving upstream.

Maximum total lengths of prawns captured by grounds and gender is displayed in Figure 81, with the largest tagged prawn being a female from each capture ground. This is a similar pattern as for average total length by capture ground and gender, with the exception of cast net/estuarine prawns which displayed an equal average total length between gender, but with a female producing the highest maximum total length (198 mm). Females were found to have relatively higher maximum total lengths than males for all capture grounds as follows: commercial ground male 222 mm and female 260 mm; closure male 217 mm and female 287 mm; and estuarine male 176 mm and female 198 mm.

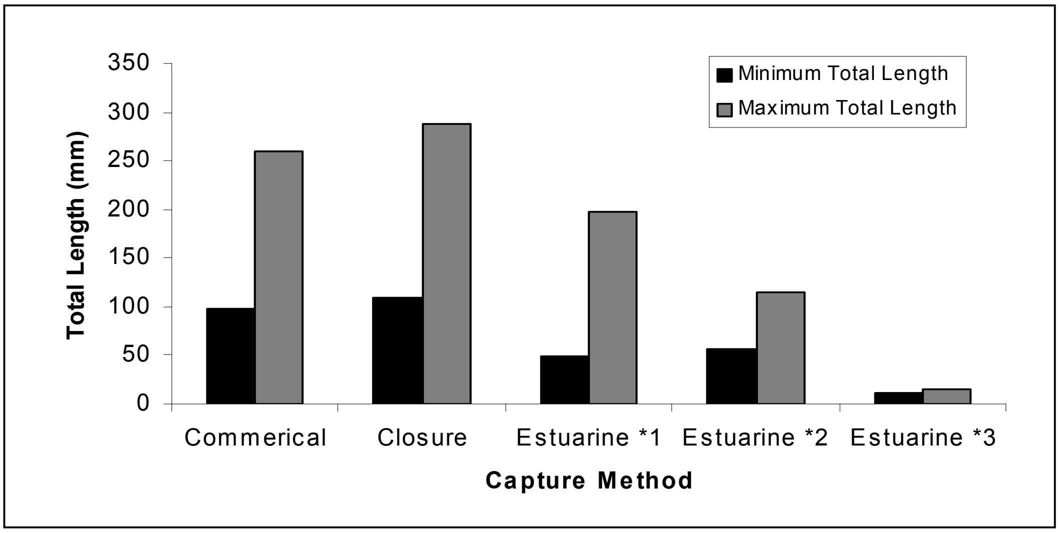


Figure 81 Minimum and maximum total length of P. monodon by capture grounds

Note: Estuarine *1 (cast netting), Estuarine *2 (Hand scoop), Estuarine *3 (Fyke net)

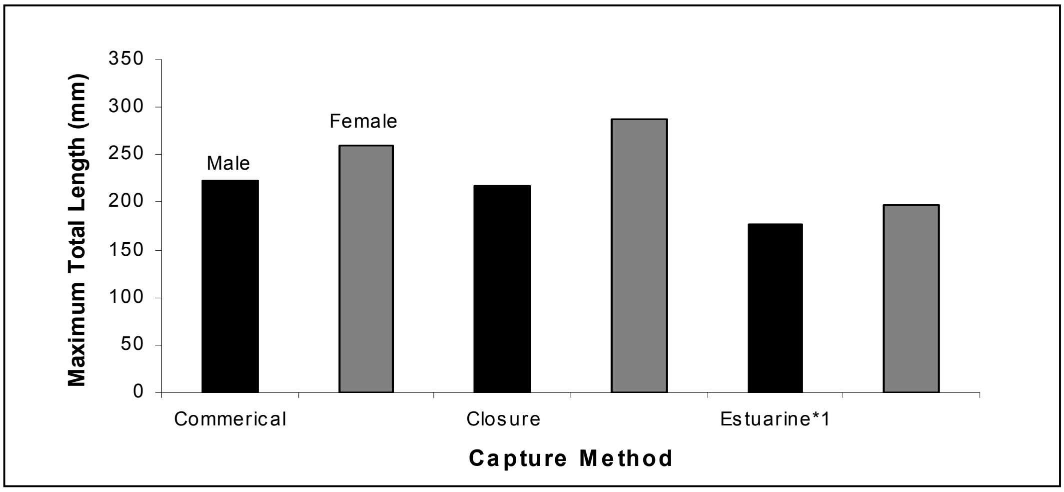


Figure 82 Maximum total length (mm) by capture ground and gender

Recaptures

Between 1 December 1999 and 28 April 2002, a total of ninety five tagged *P. monodon* were recaptured, a recapture rate of 4.7 % from the 2015 tagged and released prawns. Commercial broodstock fishers caught up to 80% of prawns recaptured showing that the success of this tag-release and recapture program depended heavily on commercial fishers. No recapture data was established from reported East Coast trawl fishery logbooks. Researchers recaptured 4 % of prawns (3 in estuaries and 1 in the closure) and recreational fishers contributed to 15 or 16 % of returns from cast netting in estuaries. Eighty six or 90 % of tagged prawns were recaptured once and 9 or 10 % were recaptured twice.

Movement and Growth

Recapture data was segregated by the location of original capture and the location of recapture, to investigate movement of prawns between systems in association with their life cycle history. Table 1 above displays the systems (areas fished) categorised as commercial grounds, closure, and estuarine reach.

Estuarine/nursery (cast netting) - movements and growth

Sixteen prawns were recaptured after being tagged in estuarine grounds. Three individuals were seen to recruit from the nursery grounds out onto commercial grounds displaying net movement north. Juvenile *P. monodon* were captured by cast net and tagged in 12 estuarine systems over the study period including the: Barron River; Cairns Harbour and Esplande; Trinity Inlet; Hills Creek; Half Moon Creek; Johnstone Rivers; Mulgrave River; Thomatis Creek; Saltwater Creek; and Chinaman Creek. The majority of tagging effort was in the systems of the Barron River and Hills Creek (monitored monthly) and contributed to 61% (217 animals) and 18 % (62 animals) respectively, of prawns tagged in estuaries, and all recaptures.

From the *P. monodon* tagged and released in the Barron River a recapture rate of 5.5 % was recorded. Ten of the 11 recaptures were produced from Site three (refer to Appendix 3.2), which also produced the highest cast netting CPUE and the highest number of tagged prawns (112 or 32 % of estuarine tags). The majority (10 animals or 83 %) of recaptures displayed no movement; that is they were tagged, released and recaptured at the same site (100 m stretch of bank). These estuarine prawns displaying no movement were of an equal ratio of male to female.

One prawn captured at Barron River Site one was tagged and released one kilometer upstream at Site three. Although displaced from its original capture location, this prawn was not seen to have returned to its original site of capture, when recaptured four days later. On average prawns were recaptured in 23 days of release, with the period at liberty ranging between 4 and 47 days. Growth of juvenile prawns during this period averaged at 26 mm total length and ranged between 2 and 85mm.

Two female adolescent prawns tagged and released from the Barron River displayed migratory movement patterns from the middle estuary (nursery habitat) out on to commercial fishing grounds (QFS CFISH grid 13-H16) north to Taylor Point, a distance of approximately 14 km. One adolescent tagged and released at 78 mm was recaptured as an adult at 106 mm displaying a total length growth of 28 mm over 97 days (January to April 2000). The adolescent tagged at 103 mm during March 2001 grew 85 mm during 187 days at liberty until recapture in August 2001 at 188 mm as an adult.

Hills Creek recorded a recapture rate of 9.7 %, that is 6 animals were recaptured from 62 juvenile tagging records in this system. All but one tagged prawn displayed no movement from the nursery release site. A 160 mm female tagged in February 2001 was recaptured 87 days later in April 2001 as an adult at 225 mm, displaying 65 mm total growth. This female moved from its nursery habitat, north to commercial adult grounds of Double Island Point, approximately 16 km from its original capture location. The four prawns that displayed no movement were adolescents and at liberty for an average of 23 days over a range of 6 to 46 days.

Trinity Closure (Research Beam Trawling) - movements and growth

Prawns tagged from the Trinity Inlet closure (captured by research beam trawls) recorded a recapture rate of 3.1 %, that is 6 recaptures from 193 animals, with one also recaptured twice. Five of the six prawns recaptured, moved out of the closure north onto commercial grounds. These prawns captured on commercial grounds were all tagged during May to July 2000 (32 % or 62 of closure prawns were tagged in this period) and recaptured between June and October 2000, with an average time at liberty of 74 days and range of 10 to 111 days. None of the prawns tagged in the closure for the rest of the survey period (August 2000 to December 2001) were recaptured (ie; the remaining 67 % or 131 animals).

The five prawns that displayed movement travelled an average distance north of 31 km (between 5 km to 100 km), moving to False Cape, Yorkeys Knob, Simpsons Point, Turtle Cove and Bailay Creek, with no movements recorded south. Growth of these adult prawns averaged 10 mm total length, ranging between 2 to 21 mm.

Commercial Grounds - movements and growth

Prawns tagged and released from commercial grounds (captured by commercial trawling operations) recorded a recapture rate of 4.6 % that is 74 animals from 1 466 tagged and released. The majority of prawns displayed no large scale movement in fishing grounds suggesting high site fidelity of this species once established in adult grounds. Many prawns were seen to make small movements of approximately 15 km north or south e.g. prawns captured and tagged along Oombunghi Beach were generally recaptured between Russell Heads and High Island. Some movement in grounds can be attributed to being tagged and released at a different site to the capture location as tag and release operations occurred while the vessel was making way.

Prawns were at liberty for an average of 33 days, ranging between 1 to 166 days. When analysed separately by gender, average time at liberty was 2.7 times longer for males (49 days) than for females (18 days). Growth ranged between 1 and 110 mm total length, over this time at liberty.

Several prawns from various commercial fishing grounds displayed homing behavior; that is returning back to original capture location when released at a different site. Again this movement suggested site fidelity in adults although time at liberty appeared to influence this movement.

One male prawn captured at Bailay Creek (Alexandra Bay) and released 70 km south at Double Island was recaptured back at its original capture location (Bailay Creek) 58 days later. Another male prawn captured and tagged at Bailay Creek and at released south at Yorkeys Knob was recaptured again five days later at Yorkeys Knob, showing no homing behavior in this short time. A prawn captured at White Cliff and released 15 km south at Yorkey Knob also displayed no homing behavior when recaptured only five days later. Several prawns captured at Bailay Creek and released south at Snapper Island moved the 12 km (approximately) back to Bailay Creek in 48 to 62 days. One male prawn captured at Yorkeys Knob and released 80 km north at Bailay Creek (shown above to be suitable *P. monodon* grounds) was seen to return back to Yorkeys Knob when recaptured 12 days later.

One hundred and sixteen prawns captured and tagged at Taylor Point on the same date, were released approximately 16 km south. Four of these prawns were recaptured displaying varying degrees of movement north and growth. The prawns were at liberty for an average of 41 days ranging between 29 to 60 days out. Three of the four prawns moved back to the approximate vicinity of their original adult grounds, 15 to 25 km north, with one prawn being recaptured at its release site. Growth varied between 2 to 31 mm total length and time at liberty or distance travelled did not appear to directly influence growth.

Von Bertalanfy equation.

A number of caveats need to be applied to this analysis:

- The number of prawns tagged and recaptured was relatively low.

- There was a definite bias in reporting recaptures by the commercial fishery, with an under-representation of the high-value large females.

- The tag return information in the majority of cases were reported from commercial fishers and the accuracy of measurement was variable (ie negative growth in some cases).

Table 6. Von Bertalanfy growth equation parameters derived from tag release and recapture of P. monodon *in northern Queensland (K = K per day).*

Parameter	Male	Female
Linf	207.23	327.78
K	0.00875	0.00339
t0	0	0

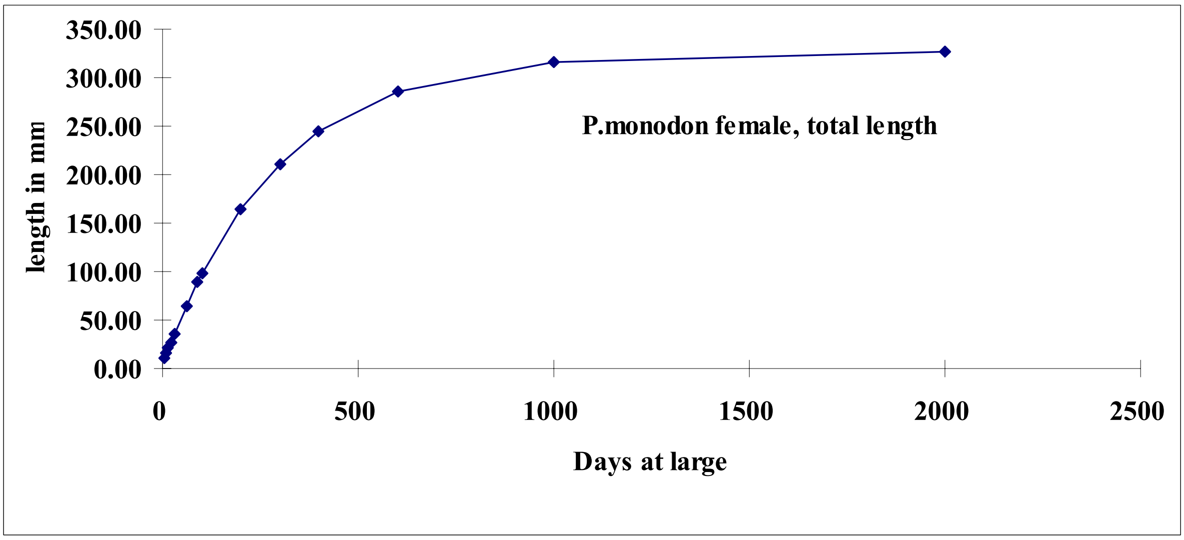


Figure 83. Growth curve (total body length) for P. monodon females in northern Queensland, based on Von Bertalanfy growth equation parameters derived from tag release and recapture data.

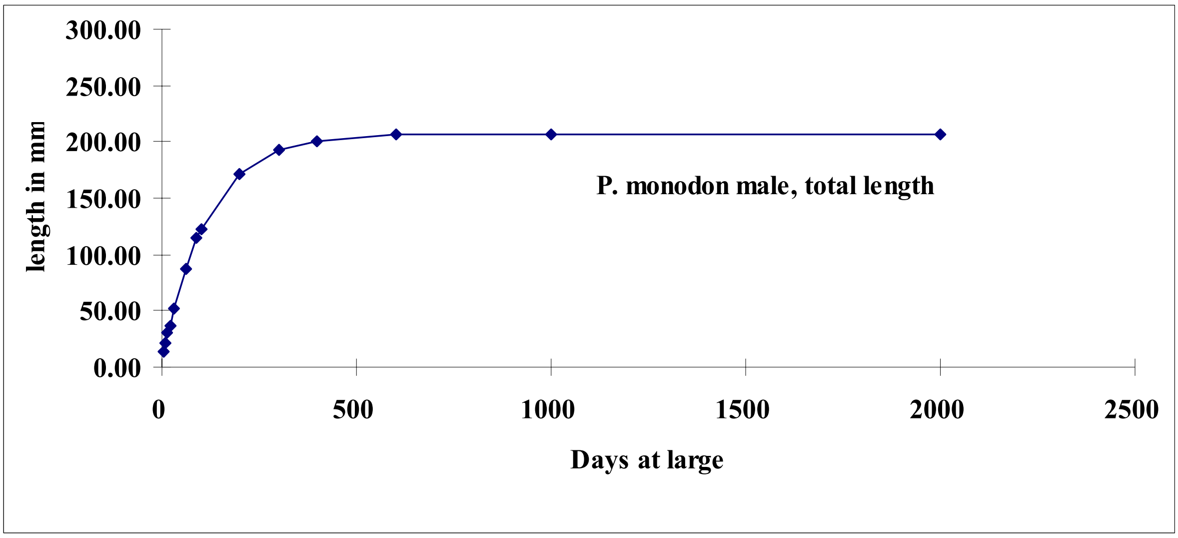


Figure 84. Growth curve (total body length) for P. monodon males in northern Queensland, based on Von Bertalanfy growth equation parameters derived from tag release and recapture data.

The general form of the growth curves is typical of penaeids, with the female attaining an ultimate size larger than the male. Growth appears to continue into the second and even third year for this species; up to 1000 days for females and 500 days for males (see figs 76 and 77).

Objective 6. Examine alternative capture techniques.

Preliminary Trials

LIFT NETS

During three nights' sampling in Darwin Harbour, a total of 53 prawns were caught. Trial results are given in Table 7.

The data were not comprehensive enough to support formal statistical analysis, but suggest that the only sampling gear type that offers any suggestion of worthwhile prawn catches was the collapsible lift net. The raw data also suggested that while banana prawns (*P. merguiensis*) and Yorke prawns (*M. eboracensis*) were abundant enough to offer some scope for further work on non-trawl gear, in terms of capture rates, black tiger prawns (*P. monodon*) appeared to be scarce and not vulnerable to capture.

Table 7. Grouped catches and catch rates for 4 gear types from two-four examples of each sampling device.

Trap type	**Total catches**				
Lift net	**Night 1**	**Night 2**	**Night 3**	**Total**	**Mean CPUE (prawns/pot/ night)**
P. merguiensis	9	10	8		
P. monodon	0	2	0		
M. eboracensis	6	4	3		
Total	**15**	**16**	**11**	**42**	**2.33**
Wooden trap					
P. merguiensis	0	0	0		
P. monodon	0	0	0		
M. eboracensis	2	0	0		
Total	**2**	**0**	**0**	**2**	**0.11**
Rigid-lift net					
P. merguiensis	2	3	0		
P. monodon	0	0	0		
M. eboracensis	0	0	0		
Total	**2**	**3**	**0**	**5**	**0.14**
Opera house trap					
P. merguiensis	3	0	0		
P. monodon	0	0	0		
M. eboracensis	1	0	0		
Total	**4**	**0**	**0**	**4**	**0.22**

POTS

AQUACULTURE PONDS

During four nights of trials with three trap types, a total of 632 banana prawns were taken. Of these, 570 were taken in Munyana traps, 62 in opera house traps, and none in top lifting traps. There were no significant difference in catch rates between nights (F_3=1.4, .2<P<.3), but the differences between treatments between gear types were clearly significant (P<.00001). The Munyana traps clearly took far more prawns than the other two types, and the top-opening trap was completely ineffective. We therefore abandoned its use in subsequent trials

MORETON BAY

Despite high prawn levels of abundance in the trial area, catches of prawns in traps from the trial area were consistently low. During 4 nights of field trials, with 40 trap sets per night, a total of 9 prawns (3 tiger prawns, *Penaeus esculentus*, 5 greasyback prawns *Metapenaeus bennettae* and 1 eastern king prawn *Penaeus plebejus* were taken. Catch rates averaged 1 prawn per 17 10-12 hour trap sets Catch numbers were insufficient to enable meaningful comparison between trap types or baits, and no trends were evident. (Table 8)

Table 8. Catch of prawns according to trap type and bait, from Moreton Bay.

	Opera house / Worm	Opera house / Pilchard	Munyana / Worm	Munyana / Pilchard	Total
Greasyback	0	1	2	2	5
King	0	0	0	1	1
Tiger	0	1	1	1	3
Total	0	2	3	4	9

Bycatch taken in traps was limited, with a maximum of 4 species (mean 1.93) being taken in any one trap lift. Average bycatch weight was 0.30kg/trap lift with an average of 3.28 organisms per trap lift. Analysis of bycatch take as a function of trap type and bait type suggested that both trap type and bait type had significant effects on bycatch weight. Mean weight from traps baited with pilchards was 0.47kg/trap lift, mean from traps baited with worm was 0.35kg /trap lift, mean weight from Munyana traps 0.44kg/trap lift and mean weight from opera house traps was.38kg/pot lift. Analysis of variance confirmed there were significant differences in bycatch weight as a function of bait type (F=5.26, P<0.05) and pot type (F=5.45, P<0.05). The interaction term between trap type and bait type was also significant (F=5.07, P<0.05).

Prawn catches from trammel nets were limited to three prawns from one set of a two panel net, (from the four night's samples) and an average of 3 prawns per set of the Indonesian nets, on the one night they were used. Bycatch take from the trammel net sets was highly variable – between 0 and 5kgs / set for the two and three panel nets, and 26-48kg / (4 hour) set for the Indonesian nets. Bycatch numbers and species numbers ranged between 0-20 (0-3 species) from the two and three panel monofilament nets, and 26-34 individuals (7-9 species) from the Indonesian nets. Catches from the Indonesian nets, in particular, included appreciable numbers of predatory fish such as sharks and catfish, suggesting the nets might have been acting as baited traps, to some degree. There was clear evidence that some fish and crustaceans meshed in the nets had been used as food by predators. The data set obtained from trammel nets was not extensive enough to support formal statistical analysis, but the preliminary data suggest that bycatch from the Indonesian nets was consistently high.

Prawn catches from the trawl samples were consistently high during the four nights on which sampling took place. Catches averaged 243 individual prawns per sample shot (mean weight of 2.45kg /shot). Catch ratios, by number, were 48% tiger prawns (*Penaeus esculentus*), 33% greasyback prawns (*Metapenaeus bennettae*), 15% eastern king prawns (*Penaeus plebejus*) 3 % hardback prawns (Trachypenaeus spp.) and <1% banana prawns (*Penaeus merguiensis*). Relative bycatch weight and numbers were low during this sampling program. There was an average of 19.9 bycatch species per trawl, with an average weight of 4.0kg. Target species (all prawn) to bycatch weight ratios averaged 1:1.64.

Trawl shots covered a mean distance of 1440m, and covered a width of 4m, i.e covered a swathe of 5760m ^{2} per sample shot. Assuming average gear efficiency of 35% (see Joll and Penn 1990), average density of prawns (all species) was approximately 1/0.12 m^2, or 1 prawn per 8 m^2. That is a remarkably high density for prawns that are not schooled up, and gave a more than adequate sampling basis for alternative capture gear.

Field Trials – Trinity Inlet

A total of 982 penaeid prawns (8 species / species complex) were taken during the four nights' field sampling in Trinity Inlet. Summaries of catch, by species and gear type, are given in Table 9. The data show, quite clearly, that banana prawns, *Penaeus merguiensis*, endeavour prawns, *Metapenaeus spp.* Dominated the catch of prawns, and that the majority of all prawns sampled (ca. 70%) were taken by trawl gear. As in Moreton Bay, prawn abundance was high enough to give a meaningful comparison between catch rates of trawl gear and other equipment.

Table 9 Summary of prawns taken in field trials, Trinity Inlet.

Gear Type	Banana *P. merguiensis*	Black tiger *P. monodon*	Brown tiger *P. esculentus*	Grooved tiger *P. semisulcatus*	Endeavour prawns *Metapenaus spp*	Rainbow prawn *Para-penaeopsis sculptilis*	Others – *Atypo-penaeus formosus, Trachy-penaus sp.*	Total
Opera house	19							19
Munyana trap	30	1						31
Lift net	3							3
Rigid lift net								0
Two panel trammel	2		1	6	54	1	3	67
Three panel trammel	4	2		6	154	2	4	172
Indonesian trammel								0
Trawl	288	28		8	339	16	11	690
Total	346	31	1	20	547	19	18	982

Prawns catches in traps from the Trinity Inlet trial area were somewhat higher than observed in Moreton Bay, despite real prawn densities being somewhat lower. During 4 nights of field trials, a total of 129 trap lifts were completed. Of these, 65 were with Munyana traps (31 with pilchard baits, 34 with prawn bait), and 64 with opera house traps (32 with pilchard baits, 32 with prawn bait). A total of 50 prawns (49 banana prawns, *P. merguiensis* and 1 black tiger prawn*, P. monodon*), were taken, i.e. a catch rate slightly less than 1 prawn per 12-16 hour trap set. Catch numbers were not significantly different between trap types (t=1.23, N.S.), but varied significantly between bait types (t=11.52, P<0.001) (Table 10).

Table 10 Catches of prawns by trap type and bait, from Trinity Inlet.

	Opera house / Pilchard	Opera house / Prawn	Munyana / Pilchard	Munyana / Prawn	Total
Banana	16	3	20	10	49
Black Tiger	0	0	1	0	1
Total	16	3	21	10	50

Bycatch from traps included 171 individuals (i.e. 1.4 organisms per trap lift), from 24 species or species complexes. Details of bycatch taken in the sampling program are given in Table 11. Nineteen of the 'species' were fish, 4 were crustaceans, and the last was a complex of gastropod species. The quantity of bycatch taken in pots was consistently low and, with the exception of mud crabs, had little or no commercial significance.

Catches from lift nets being trialed concurrently with pots were disappointing, particularly in the light of preliminary results obtained in Darwin Harbour. Three banana prawns were obtained from 34 lifts of the collapsible lift pot, and none were taken in 31 lifts of the rigid net. Bycatch was restricted to a total of 8 fish (7 species) and 3 crabs (see Table 11).

A total of 239 penaeid prawns (*P. monodon* – 2) were taken in 15 by 30 minute trammel net sets. Seventy two per cent were taken in the multipanel net. This net took larger numbers of small endeavour prawns than other gear. Bycatch levels were somewhat greater than the other gear types used, with a total of 668 organisms (23 species / species complexes) being taken in the 15 sets (Table 11). Total prawn to bycatch ratios were 1:2.8. All bycatch organisms taken during this sampling program were small, but our experience in Moreton Bay clearly demonstrated that trammel nets are not selective in terms of bycatch size, and large organisms, including sharks and rays, will be caught if they are present.

Table 11 Summary of bycatch taken (total individuals) against sampling gear type

Bycatch	Trawl	Munyana	Opera house	Indo-trammel	Multi-panel	Two-panel	Lift net	Rigid lift net
Ambassis verchelli	2							
Apogon poecilopterus	2	1			1		1	
Arius sp_	1	2		1	1	1		
Caranx sp.						1		
Cynoglossus sp_1	39	6		1	4	2		
Cynoglossus sp_2	3							
Dasyatidae	1							
Dexilichthys muelleri	59	5						
Drepane longimana	3							
Drepane punctata	2							
Eleutheronema tetradactylum	4					1		
Escualosa thoracata	5				133	201		
Gazza minuta	2							
Lagocephalus spadicious	1							
Leiognathus bindus	10			1		2	1	
Lutjanus malabaricus	1	2	1					
Monoacanthidae	0							
Mugilidae sp_1	1							
Nematalosa come	0			1				
Nibea soldada	77	2		1	10	3		
Otilithes ruber	10							
Paguridae	0	11	30					
Pelates sp.		1			1	1		
Platycephalus fuscus		1						
Platycephalus indicus	2							
Polydactylus multiradiata	4	1				1		
Polydactylus sheridani	8	1						
Pomadasys kaakan	2						1	
Pomadasys maculatum	2				4			
Pomadasys sp_1	31					1		
Psettodes erumei		1						
Scorpaenidae	1							
Sellachoidei (Sharks)		1						
Sillago sihama	7				1			
Sillago sp_	1	1		1	1			
Soleidae sp_ 1	1							
Stolephorus indicus	1						1	1
Sphyrna sp.		1			2			
Terapon sp.		4	4				2	
Terapon jarbua			1	2				
Terapon theraps	3	2	1				1	
Thryssa spp.				1	4	6		
Torchigena whitlei	1	2						
Trixipichthys webberi	18			3	2	1		
Valamugil buchanani	1							
Crab unidentified	3							
Portunidae sp_1	1							
Portuninae sp_1	2							
Portunus pelagicus	3	35	23		2	4	2	1

Portunus sanguinolentus	9	5	4	1	4	5
Scylla serrata		17				
Squilla spp.	9	1			8	1
Stomatopod	4					
Thenus indicus	1				1	
Gastropoda		3	1			

Sixteen trawl samples were obtained during the Trinity Inlet sampling program, with a total of 690 penaeid prawns being taken. Overall average prawn density was estimated at approximately 1 prawn per $33m^2$. Of the 690 prawns, 339 were endeavour prawns, *Metapenaeus spp*., 288 were banana prawns, *Penaeus merguiensis,* 28 were black tigers, *P. monodon*, 8 were grooved tiger prawns, *Penaeus semisulcatus*, with the remainder being *Trachypenaeus spp* and *Atypopenaeus formosus*. Black tiger prawn density was estimated to be 1 prawn per $800m^2$. Three hundred and thirty eight bycatch organisms, from 33 fish species / species complexes, and 8 species of crustacean species / species complexes (Table 11). Total prawn to bycatch ratios were 1:0.49, which is a remarkably low ratio for trawl gear.

We have estimated catch of black tiger prawns per person hour's sampling time on the basis of the time spent in the field during the Trinity Inlet sampling program. We have only referred to gear in which black tiger prawns were actually taken.

We estimated that the sixteen trawl shots absorbed 32 person hours (two persons by 2 hour's travel plus 2 hour's fishing and gear retrieval by four night's work). Setting and retrieving the 129 trap lifts took a total of 48 person hours (two persons by 4 hours travel (one trip to set, one to retrieve), 1.5 hours for setting time, 2.5 hours for retrieval time, by four nights). Setting, retrieving the multi-panel trammel net (the only one to catch a black tiger would have taken a minimum of 18 hours (one person by 2 hours travel time, 1.5 hours to set, fish and retrieve the net, and 1 hour to sort the catch by four night's sampling). In summary (Table 12), catch rates of black tiger prawns per person hour were extremely low for all gears other than trawl. The trawl catches were of the same order as taken in the commercial, directed fishery for black tiger prawn broodstock.

Table 12 Catch rates of black tiger prawns per person hour's sample with different gear types.

	Black tiger catch	Nominal person hours for sampling	Catch of black tigers / person hour
Trawl	28	32	0.875
Multi-panel trammel	1	18	0.055
Traps	2	48	0.042

Discussion of results.

We have conducted quite detailed and diverse trials of equipment that is used for taking prawns in various parts of the world. We have used conventional beam trawl as a basis for standardising and comparing catch rates between gears. By doing this, we were able to establish that catch rates observed in alternative gears had some meaning in terms of catch rates and were not confounded by absence of prawns.

There are two major conclusions from our work. The first is that capturing prawns in gear other than trawls resulted in very low catch rates under most circumstances. The economics of catching black tiger prawns in gear other than trawls, again, in most circumstances, would seem to be unworkable in our experience. This observation reflects the fact that black tiger prawns are, in general, a relatively uncommon and sparse component of the benthic fauna along the Queensland east coast.

The second is that bycatch from alternative gears was highly variable. Trammel nets took appreciable quantities (number, weight and species diversity) of bycatch, while taking very few prawns from the genus *Penaeus*. We are uncertain why one net type took such substantial numbers of endeavour prawns during the Trinity Inlet sampling phase, when trawl samples indicated the species complex was not highly abundant at the time of sampling. Bycatch to target species ratios of trawl gear was relatively low, but species diversity was the highest of all sampling gears used. Bycatch from traps and lift nets was minimal, but catches of target species were also extremely low.

Objective 7: Conduct economic cost/benefit analyses of various fishing patterns.

The Queensland prawn aquaculture industry currently produces about 2,500 tonnes of prawns a year (Lobegeiger 2002). Production statistics do not give a break down by species, but informal discussion with fisheries extension officers and prawn farmers indicates that black tiger prawns, *Peneaus monodon* accounts for approximately 70% of this production. Given prawn aquaculture (excluding kuruma prawn, *Penaeus japonicus*) production is worth approximately $37m annually, production and value of black tiger aquaculture is in the order of 1700 tonnes and $25m. This production is based upon a complex chain of production that originates with the supply of broodstock to hatcheries. All black tiger prawn culture in Queensland is currently based upon animals that originated from an open water, natural environment.

Production figures (Lobegeiger 2002) and industry estimates suggest that Queensland hatcheries use between 5,000 and 10,000 adult black tiger broodstock, the bulk of which are female.

All black tiger broodstock are taken by trawl, almost exclusively along the Queensland coast between Port Douglas and Cardwell. The broodstock collection industry is currently managed as an element of the Queensland East Coast trawl fishery, with specific elements of the East Coast Trawl Plan being directed towards the broodstock fishery. Black tiger prawns are taken as a byproduct in the fishery's general operation, in addition to being targeted by broodstock collectors. Q-Fish records (the compulsory Queensland fisheries catch and effort data collection system) indicate that catches of black tigers have averaged approximately 7.5 tonnes per year. If prawns are taken at an average weight of 100 grams, this represents an annual catch of ca. 75,000 individuals by the trawl fishery. We are aware, however, that the C-Fish system under-reports catches of black tiger prawns. There is no specific data column for entering catches of the species, and they are almost invariably taken as a byproduct in the fishery for banana prawns, *Penaeus merguiensis*. Catches are typically quite small – normally in the order of a few individuals to a few kilos per day, and much of the catch is boxed with and recorded as banana prawns, if noted at all. We cannot estimate the extent of under-reporting the total catch of black tiger prawns.

The broodstock collection fishery now operates under two clearly identifiable procedures. The first involves direct targeting of broodstock. Fishers operate small trawlers and work in areas where the bulk of their catch, in value terms, is made up of live black tiger prawns. They operate as single person enterprises and fish to fill orders of broodstock, rather than undertaking fishing operations to maximise total catch. The alternative procedure involves a 'subcontracting' process, wherein a contractor purchases live black tiger broodstock from trawl operators who are conducting conventional fishing operations for banana prawns. These operations may be slightly distorted, in spatial terms, in order that the operators take more black tiger prawns than they would if they were fishing solely for banana prawns. The contractor arranges a local schedule under which he collects the broodstock prawns from these trawlers via a speedboat, and on-sells them to hatcheries.

There is recent evidence that some operators are now starting to sell broodstock to markets in south east Asia as well as to Queensland hatcheries.

Economic analysis – methodology and outcomes

Data for economic appraisal of the black tiger prawn broodstock fishery has been derived from four sources. Information on total catches, catch rates and spatial distribution of catch for black tiger prawns has been obtained from the Queensland Fisheries Service catch and effort database C-Fish. An annual survey of the aquaculture industry (Lobegeiger 2002) and background interviews and discussions have been used to obtain information on the magnitude of the broodstock collection industry. Summary data from an as yet unpublished report to FRDC (Project 98/137, Economic Performance of the Queensland Trawl Fishery, Taylor-Moore, m/s) has been reviewed to obtain insight into the general economic performance of broodstock collectors and other east coast trawl fishers. Finally, an industry interview process directed towards a small number of broodstock industry participants was undertaken as an element of the current project. This involved a professional economist obtaining detailed data on revenue, costs, and depreciation and repairs of a typical broodstock collection business. These data were then analysed and presented, along with economic performance indicators including internal rates of return and benefit : cost ratios.

Revenue

The average beach price of black tiger spawners is approximately \$80 - \$100. This obviously varies with condition and there is some suggestion of price elasticity according to supply levels. The industry has experienced years of low broodstock supply that became a substantial bottleneck to the industry. In those years, prices of broodstock are reported to have risen, although price levels have not been properly documented. On average, however, the broodstock industry generates revenue of approximately \$800,000 to \$1m per year. At the same time, the mainstream east coast trawl fishery reports a take in the order of 7.5 tonnes (75,000 individuals) of black tiger prawn a year. While we know this is an under-estimate of total landing, it still represents a catch approximately ten times that of the broodstock fishery. Fishermen who sell black tiger prawns for human consumption receive an average price of about \$10-\$12kg, which suggest the revenue from black tigers used as part of conventional fishery landings is somewhat in excess of \$80,000 i.e. in the order of 10% of the broodstock prawn value. (We were not able to collect any information on the still very small export of live broodstock to Asia.)

Costs

The broodstock collection industry is quite small, with the bulk of supply coming from three or four consortia and individual operators. Queensland Fisheries Service has clear and consistent policies that prohibit the use of catch and effort data or results from economic surveys if the number of respondents is so low that individual operators can readily be identified. This is a negotiated strategy with industry to ensure confidentiality. Unfortunately this policy constraint has been triggered in our studies of the broodstock industry. While we have good cost and revenue data from a small sample, the data were obtained from such small numbers of individuals that we cannot release any details.

Economic performance

Again, our ability to comment on economic performance in the industry is constrained because of the small numbers of participants in the industry. All that can be offered is that the fishery as a whole appears to be profitable. It should be born in mind that the well-being of a $25m aquaculture industry is currently completely reliant on the supply of black tiger broodstock from open waters.

There is considerable interest in the concept of using black tiger prawns taken by the wider East Coast trawl fishery as broodstock. Trawl operators receive little for black tiger prawns taken incidentally to banana prawns, and there appear to be obvious benefits to both fishermen and the hatchery industry if these incidentally caught animals could be supplied to hatcheries.

While appealing this argument is not as simple as it first seems. Existing prawn trawlers are not set up for holding live prawns and some may not have the deck space to accommodate live-prawn tanks. The logistics of getting live prawns from operational trawlers to shore-based holding facilities can be complex, as most trawlers work well away from community centres that have the infrastructure to hold and freight live prawns. Finally, the level of demand and associated price structure in the industry need careful consideration before a significant expansion. The supply of 8,000 - 10,000 broodstock animals appears to meet market demands at this time, and the prawn aquaculture industry is not expanding rapidly (although this may change). Increasing local supply would almost certainly reduce prices of broodstock in the short term. Whether it would do so to such an extent that the viability of the existing industry and infrastructure might be threatened is an important consideration. The existing industry offers a reasonably stable supply to the hatchery industry, particularly in good years. Reducing prices to the point where the core area of broodstock supply becomes de-stabilised could act against the aquaculture industry's longer term interests.

Discussion

Distribution, Abundance and Size

P. monodon occurred at low, highly variable densities and at variable spatial and temporal scales, in each of its life history stages.

Reported commercial catch information suggests that *P. monodon* was rare outside of its main commercial distribution on the east coast of Queensland in the Cairns to Cardwell region. Hotspots of *P. monodon* commercial catch were reported with the highest densities occurring around the Russell/Mulgrave and Johnstone River mouths. This distribution was supported by QDPI surveys and anecdotal information. We recorded only very low catch rates of juvenile *P. monodon* in estuaries outside of this Cairns to Cardwell region.

On smaller spatial scales *P. monodon* was patchily distributed in estuaries, foreshores and inshore fishing grounds. A strong bimodal pattern in abundance was recorded in estuaries with the abundance of *P. monodon* greater in the upper estuary and in the lower estuarine reaches. A size gradient was also observed in the estuaries. Large quantities of very small *P. monodon* were observed in the very upper reaches of estuaries during the pre-wet season. This gradient was not as pronounced, with greater mixing of *P. monodon* size classes observed in the different sections of each system.

In foreshore habitats surveyed in Trinity Bay, *P. monodon* were captured in highest densities in shallow waters between 1 and 3 metres depth. On inshore commercial fishing grounds, a strong relationship was identified between catch and depth. *P. monodon* was captured in highest densities at 4 metres depth, with declines in catch recorded with increases in depth. The capture densities were comparable between foreshore sites at 1-3 metres depth and important inshore fishing grounds at 4-7 metres depth.

P. monodon was captured in lower catch rates than the banana prawn, *P. mergiuensis*, which inhabits similar habitats in the mid to lower-estuaries, foreshore and inshore habitats in North Queensland. In the mid and lower-estuaries, juvenile *P. monodon* were captured in an average ratio of 1:39 to *P. merguiensis*, and on the foreshores, adult *P. monodon* were captured in an average ratio of 1:38 to 1:50. A relatively low abundance of *P. monodon* to *P. merguiensis* was therefore recorded throughout its life cycle. These ratios also support the anecdotal evidence from commercial trawlers that black tiger prawn (*P. monodon*) is caught in low numbers and on an irregular basis.

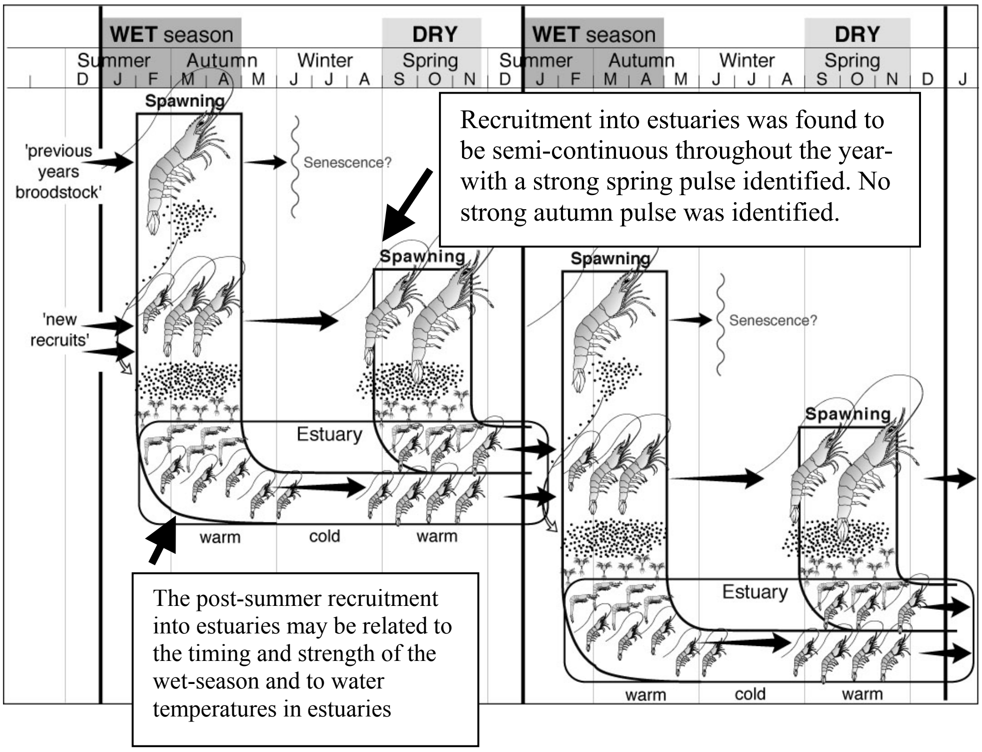
Life Cycle

P. monodon followed a typical penaeid prawn life-cycle, inhabiting estuarine nursery grounds during a juvenile to sub-adult phase, then migrating to foreshore and inshore grounds during the adult phase. Spawning occurs in foreshore and inshore habitats in North Queensland. The abundance and spawning potential of adult *P. monodon* in offshore habitats is undocumented. During the survey of estuarine habitats, no mature *P. monodon* were observed or reported. We therefore assume that, *P. monodon* only spawns in foreshore, inshore and possibly offshore locations as has been observed in other counties included in the species' distribution (Villaluz et al, 1969; Motoh, 1981; Rajyalakshmi et al, 1985).

P. monodon was captured in very low numbers. As a consequence, it was difficult to define distinct spawning periods for females captured in the foreshore habitats, monitored on a monthly basis. The settlement of post-larvae into estuarine habitats was observed to occur in one major pulse during the late winter period from August in the upper estuaries of large rivers such as the Russell, Mulgrave, North and South Johnstone Rivers. This presumably reflects an effective spawning period in July – early August. The numbers of small juveniles in these reaches increased during the spring period, when they migrated down to the lower reaches of estuaries by November and December. Subsequently, one large pulse of *P. monodon* was recorded to emigrate out of estuaries and onto foreshores during January and February.

Although the most significant recruitment was the pulse of recruits into estuaries during late winter to spring, a semi-continuous recruitment of juveniles was recorded in estuaries throughout the remainder of the season. A second, smaller pulse of recruitment was evident but was not strong and was difficult to pinpoint in terms of timing. Reported commercial catch information suggested that a second pulse of *P. monodon* catches, other than the known post-wet season peak in catch, occurred in commercial inshore fishing grounds in September to November. This pulse was not regular, occurring unpredicably over time and in differing locations. This second pulse in commercial catch would be attributable to a recruitment of post-larvae during the autumn period. An amended seasonal spawning calendar for *P. monodon*, adapted from Hall and Kenway, 1999 (Figure 85), diagrammatically demonstrates these patterns observed in North Queensland.

Tagging of *P. monodon* in North Queensland and anecdotal information from commercial broodstock collectors identified that individuals emigrating out of the estuaries during the wet season (ie. February) can be captured as late as the next year. These 1+ broodstock can be captured in very small numbers and have not been observed past the next winter period. Although the proportion of 1+ broodstock is low, their contribution to the successful spawning potential is unknown.



(Modified from Kenway and Hall, 1999.)

Figure 85. Summary of the seasonal spawning and recruitment of the black tiger prawn, P. monodon, in North Queensland.

Movement, Growth and Recruitment

Recruitment of *P. monodon* into the fishery occurred when late stage juveniles and sub-adults were recorded to emigrate from estuaries and shallow foreshores, in close proximity to the adjacent estuary mouth. Their dispersal occurred as a northerly movement out from these nursery areas onto inshore fishing grounds. No recruitment was reported to occur in a southerly direction. This suggests that estuaries south of particular fishing grounds may the source of new recruits.

Low abundance of the animal meant that only small numbers could be tagged (2015) and therefore caution is needed when drawing inference from the low numbers (95) of returned tags. Growth of the animal was typical of penaeids, with the female attaining an ultimate size larger than the male. Growth appears to continue into the second and even third year for this species.

A homing behaviour that was first identified previously by commercial fishers in a small scale tagging program was again observed during this project. "Homing Behaviour" or a return of dislocated individuals occurred where animals were tagged and replaced away from their original capture location.

Their *rapid* movement back to their original sites suggested that although the new locations were able to support *P. monodon* populations, individuals had a strong site fidelity once they had recruited out from estuaries onto the inshore fishing grounds. We are unaware of any parallel or similar observation for any other species of penaeid prawn. Tagging conducted on the foreshores resulted in few recaptures in these sites, and suggested that although large *P. monodon* could be captured on the foreshores, *P. monodon* did not settle at these sites long-term. This supports the catch information that *P. monodon* stocks in North Queensland consist of small, highly localised populations.

Commercial Data

The commercial CFISH logbook data analysed for this report is believed to be incomplete. (There was no observer catch validation of this data and under-reporting is also certain; see below). Therefore, the analysis of the data has several assumptions and its use has severe limitations.

There are two main considerations with respect to the commercial catch data for *P. monodon* in the East Coast Trawl Fishery. Firstly, *P. monodon* is not listed as a catch category on the logbook sheet. The reporting of *P. monodon* catch is reliant on the voluntary entry of the species in the "Other" category thus separating it from the "Tiger" catch category. Therefore the current logbook set up, and corresponding catch information, is highly likely to be an underestimate as a proportion of *P. monodon* catch will be reported as "Tiger". The second consideration is the accuracy of the commercial logbook. Analysis of the logbook data suggested that although low catches of *P. monodon* were being reported (less than 5 kg's), catches were most often reported in multiples of 5 kg's. This suggested that *P. monodon* are reported separately when a package carton has been filled, or half filled.

Other minor considerations include the inaccuracy of the spatial information reported. For example, many reported catches were in 100% land-based grids (both 30 and 6-minute grids) or in offshore grids that are "known" not to be trawled (B. Izzard Cairns Live Prawn, pers com; Appendix 2). A formal validation process during data entry might improve data quality or possibly a routine fisheries observer program.

The underlying assumption of using the data summaries and trend analyses is that the reported catch information is representative of the temporal and spatial trends in catch that occur in the fishery, and that these trends represent the underlying abundance of *P. monodon* stocks in Queensland. The corollary is that catch and effort may be temporally or spatially skewed by the data inadequacies. While there were obvious deficiencies in the reporting process we have no reason to believe this is the case. The data represents a sub-sample of the true commercial harvest following its general patterns in space and time.

Water Quality and Tolerances

P. monodon were found to inhabit a wide range of water qualities, particularly during the post-larvae to sub-adult phases in the estuarine systems of North Queensland. Salinity was the most variable water quality parameter recorded in estuaries, with *P. monodon* captured from water with salinities ranges between 0 and 36 parts per thousand (oceanic sea water is typically 35-36 ppt). In the upper estuaries where greatest densities of (small) *P. monodon* occur, salinity is largely less than 5 ppt. In the lower estuaries, salinity is less variable and closer to that of oceanic seawater. The foreshore sites followed a similar pattern. It is believed that salinity may be one of the most important triggers for the onset of maturation (Posdas 1986, In SEAFDEC, 1988).

There was no direct relationship found between water quality parameters and catch rates. The fact that catch rates were quite low made definition of a relationship more difficult.

Some relationship was shown between water temperature and prawn abundance on a seasonal basis, however many biological parameters change on this scale also. Anecdotal information from prawn farms suggests that water temperature is very important, with low temperatures and high variability of temperatures triggering disease and eventual mortality. Turbidity, pH, conductivity, wind strength and direction were highly variable both between and in each season, and were not consistent with strong seasonal patterns as seen with water temperature. The regular (monthly) monitoring of the stocks did not support examination of shorter-term environmental variables. However, anecdotal information suggests that wind-strength and direction have a direct link to water turbidity in the inshore fishing grounds. It is water turbidity that commercial fishers believe has the greatest influence on the distribution and abundance of *P. monodon*. The association of *P.monodon* and banana prawn catches suggests a preference for similar turbid habitats.

Habitat and Habitat Protection

P. monodon were found to utilise a large variety of habitat types throughout their life cycle. The variety of habitats was greater in their early life history, ranging from estuarine to fresh water.

In the upper reaches of estuaries, they were found to inhabit very low salinity waters in areas dominated by terrestrial vegetation. In the upper estuary proper they were found to live in weed beds, silt covered habitat such as snags, sticks, leaves, and rocks, and on hard, corrugated mud walls. In these reaches, a high structural heterogeneity appeared to be important to the small juveniles, as they were observed clinging tightly onto these structured habitats. Their dark colouration and shape mimics twigs or detritus, with the lighter coloured stripe down their dorsal side camouflaging them in with the silt-covered habitat.

Preferred habitats in the middle to lower reaches of estuaries were similar, where *P. monodon* seemed to prefer more open habitat. In these middle and low reaches they preferred shallow sloping mudbanks bordered by mangrove trees and was often found at low tide in shade that was provided by overhanging vegetation. At a mid-tide, *P. monodon* utilised the peg root systems of mangroves, particularly the grey mangrove *Avicennia marina*, where *P. monodon* took refuge in the structure that these root systems provide.

On the foreshores, *P. monodon* inhabited very shallow waters, with highest capture densities recorded in sparse seagrass beds that retained a high biomass of detritus such as mangrove leaves. Their utilisation of the seagrass communities has not been documented before, and the nature of their use of seagrass communities is unknown. The shallow waters (less than 3 metres) however, were utilised by sub-adults to large adults. Their high variability and low catch rates, particularly outside of the estuary meant that it was difficult to identify a relationship between other habitat descriptors such as sediment type and benthic structure.

Throughout the life cycle of *P. monodon*, the most important and fragile habitats are the estuarine habitats that include the upper, middle and low estuarine reaches of small, medium and large river systems. The fact that they depend upon all three parts (upper, middle and lower estuarine) of a system means that riparian/estuarine habitat degradation is a real threat to the continuing supply of broodstock to aquaculture.

The habitats preferred by *P. monodon* potentially include some of the most vulnerable habitats along the North Queensland Coast. These systems are potentially threatened by development, pollution, clearing, farming practices, land degradation, and waste disposal. The maintenance and care of these habitats is vital in ensuring sustainable *P. monodon* populations through providing adequate nursery grounds for juvenile stocks. In particular, the loss of very low salinity transition areas in Queensland estuaries has occurred in numerous locations as a consequence of water infrastructure construction.

The evidence we present suggests that these upper estuarine habitats are critical to species such as *P. monodon.* This may be of considerable value in giving natural resource managers a clear and unambiguous example of a species that could be potentially harmed through the construction of water reticulation systems in the lower reaches of river systems.

Alternative Capture methods for *P. monodon*

There is considerable interest in the use of equipment other than trawl gear as a means of capturing *P. monodon* and other prawns. We undertook quite extensive tests of alternative gear types for capturing *P. monodon* with little success.

Alternative gear for the capture of *P. monodon* broodstock was tested in Moreton Bay (Brisbane), Trinity Bay (Cairns) and Darwin Harbour. A total of 7 gear types were tested. We have used conventional beam trawl as a basis for standardising and comparing catch rates between gears. By doing this, we were able to establish that catch rates observed in alternative gears had some meaning in terms of catch rates and were not confounded by absence of prawns.

Gear types we trialed included various types of baited traps, lift nets and trammel nets. None produced catch rates of penaeid prawns that were comparable to the catch rates recorded for the beam trawl, despite the fact that all field trials were carried out in areas where penaeid prawns were abundant. Capturing prawns in gear other than trawls resulted in very low catch rates under most circumstances. This observation is particularly relevant in the case of *P. monodon* and reflects the fact that this species is, in general, a relatively uncommon and sparse component of the benthic fauna along the Queensland east coast. Catch rates of black tiger prawns in terms of catch per person-hour for fishing gears other than trawl gear were far too low to support economically viable operations, again reflecting the fact that alternative gears were not efficient methods of fishing for such a low-density prawn. The economics of catching black tiger prawns in gear other than trawls, in most circumstances, would seem to be unworkable in our experience.

Bycatch from alternative gears was highly variable. Trammel nets took appreciable quantities (number, weight and species diversity) of bycatch, while taking very few prawns from the genus *Penaeus*. We are uncertain why one net type took such substantial numbers of endeavour prawns during the Trinity Inlet sampling phase, when trawl samples indicated this species complex was not abundant at the time of sampling. Bycatch to catch (of target species) ratios for trawl gear was relatively low, but species diversity was the highest of all sampling gears used. Bycatch from traps and lift nets was minimal, but catches of target species were also extremely low.

Economics of the fishery for *P. monodon* broodstock

Given that we could not identify a viable alternative gear to trawl (see previous section) then the economic analysis defaulted to current methods of harvesting black tiger prawns. Our ability to comment on the economic performance of the *P. monodon* broodstock fishery, however, is severely constrained because of the small numbers of participants in the industry.

The hatchery industry uses between 5,000 and 10,000 broodstock animals (see Appendix 2) with a purchase value of approximately $1m. The financial well-being of a $25m aquaculture industry is at present, however, completely reliant on the supply of "wild" black tiger broodstock from open waters. We can give few details on the economic performance of the broodstock collection sector, other than observe that currently the fishery as a whole is viable and profitable.

There is some interest in increasing the supply of broodstock prawns to the aquaculture industry by increasing the proportion of live *P. monodon* taken in the capture fishery and supplying these to the hatchery sector of the industry. While such a process has intuitive appeal, we feel there is a real need to examine the economics of this strategy, particularly in terms of price elasticity in relation to supply levels. A complicating issue, however, is the development of a recent trend to export live broodstock, which again might adversely affect the hatchery sector and the aquaculture industry in general.

Sustainability

The over-riding objective for this project was to ascertain whether *P. monodon* stocks in Queensland were sustainable. Reported commercial catch data showed unpredictable and high between-year variability, but with no major sustained decline in catch over time. This is consistent with the species being at or about the geographic limit of its distribution. Although not validated, this reported commercial catch suggested that the species is reasonably sustainable at current levels of fishing effort. As with many crustacean species, particularly penaeid prawns, *P. monodon* is an r-selected species that has a short life span (up to 3 years) and can produce large numbers of offspring. It is believed that the survival success each year is highly related to the prevailing environmental conditions rather than to spawner stock abundance, (ie. the spawner potential). However, progressively larger proportions of the biomass taken each year by a combination of the commercial trawl fishery and the broodstock collectors may not be sustainable.

We tested for relationships between catch and the abiotic environment, including rainfall, water flow and water quality, but found no significant correlations. We did identify a temporal relationship between water flow and commercial catch, however this was not strong for all years and there was no basis for prediction of catch. We were therefore unable to find a method for prediction of commercial catch.

A possible explanation for the anecdotal reports of *P.monodon* occurring sporadically over an apparently wide area is that in "good" years, when survival success is good and the abundance is high, there is also an extension in range of the species up and down the coast. In "bad" years there is both a reduction in abundance and a contraction in this range. Such a relationship would be in keeping with the known spacing behaviour of the species; they occur in relatively small numbers and widely spaced.

Management Considerations for *P. monodon* Fishery

There are a number of issues for consideration in the management of *P. monodon*. These include resource allocation and collection of more accurate commercial catch and effort information.

Given that the species may be considered sustainable at current levels of fishing effort, it is the allocation of the current catch and effort that is the issue. Reported commercial catch in the East Coast Trawl Fishery is on average 7, 295 kgs of total product per year (1988 to 2001). This includes both frozen and live *P. monodon* products. This equates to approximately 75,000 *P. monodon* individuals if an average weight of 100 gms is used. Most of the product is taken during April to May following the recruitment of *small* adults onto the inshore fishing grounds, and accounting for a 1:1 ratio of males to females. It was estimated during the workshop on the 17th June 2002 (Appendix 2) that approximately 5,000 -10, 000 individuals (best estimate 8,000) are sourced for the aquaculture industry each year, including both male and female broodstock. The aquaculture demand accounts for in the order of 10 – 15% of the reported commercial catch each year. Under-reporting of the commercial catch, because of deficiencies in the current logbook (see below), means that in reality the figure is probably lower than this nominal 10-15%.

However, it is the low catch years when *P. monodon* broodstock availability becomes critical for the aquaculture industry and resource allocation of *P. monodon* is an issue. As the majority of *P. monodon* are taken during April to May, during a low catch year the lack of supply is only felt later in the year between September to December. The stocking of aquaculture ponds over the summer is dependent on the supply of broodstock during this later period. Again this is an allocation rather than stock sustainability issue that needs to be addressed.

The second management consideration is the availability of accurate commercial catch and effort information. Currently, *P. monodon* is not listed as a catch category in the ECTF official logbooks, but is entered in the "other" species category on the logbook sheet. Subsequently, the accuracy of reporting of *P. monodon* catch is reliant upon the use of this "other" category. Future management of the *P. monodon* fishery, for both frozen and broodstock sectors, requires the use of more accurate catch information. *P. monodon* must be listed as a catch category in the ECTF logbooks in order to increase the accuracy of catch information, and therefore provide a better understanding and more informed management decisions for the sustainability of the species for long-term management.

It would also be beneficial if a broodstock collectors logbook was introduced. It was apparent from the workshop on the 17th June 2002 (Appendix 2) that some collectors are not filling out the current trawl logbook as they feel it is inappropriate to their operations.

Summary

The black tiger prawn (*P.monodon*) broodstock collection for aquaculture has been carried out in northern Queensland for at least 15 years and has matured as a commercial enterprise. The number of players is still very small but recent developments in Cairns has seen the networking of a number of commercial Trawlers supplying by-product black tiger broodstock through a single broodstock collector (B. Izzard, Cairns Live Prawns, pers com; see also Appendix 2).

Given the length of time the collection industry has been operating and the increasing demand created by an expanding aquaculture sector, the action of normal commercial forces would suggest that readily available supplies of broodstock would have already been discovered and exploited. In this regard we have been able to document and verify a considerable amount of anecdotal "wisdom" about the distribution of black tigers and dispel some misconceptions.

Two such misconceptions were; that there are large unexploited grounds within easy access (centred on Cairns-Cardwell), and, that there was a second major peak in spawning that would allow a reliable summer stocking of aquaculture ponds. **In both cases we found that the most likely situation is that in "good" years the geographic range of the species increases up and down the coast, and in these years there is an increase in overall numbers spawning. In turn this would result in proportionately more individuals spawning later in the year; i.e. the tail of a normal distribution.** The reverse would occur in normal to bad years.

What we did <u>not</u> determine is how to predict "good" years. The number of black tiger prawns caught was too low and inter-annual variation too high to allow any reliable forecasting, particularly when based on only two years research sampling. A longer time-series of reliable catch and effort information from both the commercial trawl fishery and the broodstock collectors is a must.

It must be remembered that the alternate name for black tiger prawn is the "leader" prawn. This came about because normally one or two black tigers would be caught in a school of banana prawn, and by fishermen's logic if a prawn was bigger and blacker than the rest it had to be the leader. This anecdotal evidence points out that black tiger prawns historically have been caught in low numbers and on an irregular basis. Our study corroborates this.

A further misconception was that there were large numbers of broodstock within the inshore areas currently zoned as closed to trawling. We did find reasonable quantities of black tiger prawns in this zone but our tagging suggests that this habitat is a staging area for sub-adults moving out to deeper "commercial" grounds to the north. It is probable that these animals would ultimately be caught, at a larger size, on the recognised trawl grounds.

We also documented for the first time that high-rainfall coastal wetlands are the juvenile habitat of black tiger prawn. As with many other coastal species (Cappo 1998), this finding raises the issue of conservation of these habitats as a vital requirement for the longer-term sustainability of the stock and the industry.

Benefits

- The major benefit of this research project has been to document the underlying variability in the abundance of Black Tiger prawn stock and hence in the supply of broodstock to the aquaculture industry. The surveys have also dispelled a series of myths about the existence of unexploited grounds (and the potential of inshore closed/protected areas). In Queensland the current harvest levels, and areas that have traditionally produced that harvest, are what the industry have to work with. This reality gives industry a more rational base from which to plan future expansion.

- The collation of available fisheries information Black Tiger prawn across northern Australia identified a number of possible alternate areas in Australia and PNG that may be viable sources of broodstock. These include Weipa on the Queensland coast of the Gulf of Carpentaria, sites in Northern Territory, and some Torres Strait Islands.

- Advice on management strategies: In North Queensland the commercial trawl fishery harvest of black tiger prawn as frozen product is approximately ten times that harvested as live broodstock for aquaculture. As shown in this study, the capture of black tiger prawn by non-trawl apparatus is far from economically (or environmentally) viable in Queensland. Therefore there are two strategies whereby the supply of live broodstock can be enhanced:
  - Aquaculture industry to work closely with the trawl fishery to utilise the catch as live product before it becomes frozen product, (this would potentially increase broodstock supply tenfold at a minimum), and;
  - ensure that maximum benefit is gained from every broodstock prawn received by prawn hatcheries.

  For the same fishing pressure on the stock the aquaculture industry would get greater benefit from the harvest.

The outputs from this project, in the form of the Literature Review (appendix 1), the proceedings of the second workshop (Appendix 2), and draft copies of this final report, have been provided to industry and management for inclusion in negotiations for the Queensland East Coast trawl management plan and amendments, for consideration in the GBRMPA rezoning of the northern region and the current zoning of the Marine Representative Areas, and for inclusion in Environment Australia assessments for sustainability of the East Coast Prawn Trawl Fishery.

Project information has also been requested and used successfully by ECOFISH, a North Queensland marine industries cluster group, in lobbying for a restriction in size of trawl gear in the Cairns region banana and black tiger fishery, and for the preliminary third-party assessment of the Cairns region trawl fishery for Marine Stewardship Council accreditation.

Further Development

For the future:

Research.

- Weipa in the Gulf of Carpentaria was identified as a possible alternative source of broodstock (Appendix 1) and it may be useful to investigate the productivity of this area further.
- Potentially the current work by AIMS on pheromone attractants for pot capture of prawns may have application to the black tiger fishery. Our work showed that conventional baits and traps were not practical given the very low number of black tiger prawn per area of sea floor. Any attractant will need to be highly effective over a considerable distance, and in situations of shallow inshore cross-currents.
- This project could not explore the deeper water sites (between reefs or off the shelf) where very large broodstock have been obtained overseas (B. Izzard, Cairns Live Prawns, pers com). If there was evidence from industry that this was the case off Cairns then deeper water habitats should be investigated.

Industry development

- There is a high-priority need to facilitate networking of commercial trawler operators with broodstock collectors, to ensure more "frozen product" becomes live broodstock. Particularly in "bad" years and during the critical later part of the year.
- There is also a need to provide assistance to industry with the design of appropriate logbooks for the collection fishery and broodstock quality control tracking data.

Planned Outcomes

Outcomes Achieved (meeting performance indicators as per contract)

1. Two industry/management workshops were held. The initial workshop to inform the stakeholders of the project objectives, ensure that all sectors were included in the process, and to enlist the assistance of broodstock collectors in the gathering of data. The second workshop was held prior to the completion of the project to explain the research results and obtain feedback from all sectors of the industry. Proceedings from the latter workshop were published and circulated to stakeholders separately.

2. All programmed fieldwork was completed and results have been reported progressively to the steering committee, through progress reports, and through the second industry/management workshop.

3. A full-scale study on alternate capture techniques was carried out in NT, Moreton Bay and finally in Trinity Inlet, Cairns. Some potentially usefull methods were identified, however comparative trials on *P. monodon* grounds in Cairns showed that trawl (either Otter trawl or beam trawl) was orders of magnitude more effective than any other method.

4. The published reports from this project, in the form of the Literature Review (appendix 1), the proceedings of the second workshop (Appendix 2), and draft copies of this final report, have been provided to industry and management.

5. Although a model for forecasting annual abundance proved difficult due to the inherent variability in the stock, we were able to suggest a management model to enhance the viability of *P. monodon* broodstock fishery and hence the aquaculture industry dependent on that supply. The core concept is the networking of broodstock collectors with commercial trawlers to collect *P. monodon* prior to it becoming frozen product. Potentially this would make the 10 tonne of frozen prawns currently harvested available to the aquaculture industry, increasing the broodstock supply 10-fold.

Conclusion (Take-home message)

Crustacean populations are renowned for their resilience to fishing pressure; worldwide it has been shown to be difficult to "crash" such populations. Black tiger prawns (*Penaeus monodon*) in North Queensland, however, are on the margin of their geographical distribution and hence can be expected to display exaggerated variability. Therefore the Black tiger prawn in Queensland although persistent is relatively rare at best, and displays a highly variable abundance both in time and space

The Queensland commercial trawl catch of black tiger prawn in 2001 was five times the catch in 2000, occurring mainly during April. This increase in 2001 was also reflected in the juvenile and sub-adult research surveys, and recorded in research logbooks by broodstock collectors. One question asked by the research team was "Given everything what we knew and the sampling that was conducted in 2000, could we have predicted what happened in 2001?". We had looked for patterns of wind (cf, water turbidity), rainfall, river flow, and in past catches at various spatial and temporal scales. Despite our field sampling, a thorough search of the scientific literature, as well as canvassing anecdotal information from long-time fishers; the answer was NO we could not have predicted this event.

Inherently the population dynamics of black tiger prawn in North Queensland are close to unpredictable. In general terms, we know that in areas of high tropical rainfall you are likely to find black tiger prawn. We can also say that the peaks in abundance are seasonal and are generally matched with the timing of rainfall and river flow. But on a finer temporal scale we cannot really use either rainfall or stream flow in any one year to predict prawn abundance. An added difficulty is the relative rarity (low catch rate) of black tiger prawn and the high variability in these numbers, which means that it is very difficult to draw meaningful conclusions from the information we are able to collect.

The bottom line from an industry perspective is; it is a rare animal (compared to any other commercially trawled prawn species), and is sporadic in its occurrence. Sometimes you'll get good catches, sometimes you will not. From the data we've been able to collect, we cannot establish a model that will allow us to reliably forecast the availability of the species.

The best illustration for this type of life-history strategy is the banana prawn in the Gulf of Carpentaria. After twenty years or so of research, CSIRO have not been able to develop a reliable model to predict banana prawn catches. Although apparently dependent on monsoonal rains, the animal is very close to unpredictable on any finer scale. Black tiger prawn is even more difficult to predict because the numbers caught are far fewer.

The second point is that we did **NOT** find any new unexploited grounds on the Queensland East Coast and the reproductive timing of these animals in the wild does **NOT** seem to fit the needs of aquaculture. We did not find that major second spawning that would allow aquaculturalists to reliably stock ponds over the summer months. There was a slight hint of two spawnings in some years, however this occurred irregularly between regions and between years. We found one major peak early in the year with a much smaller and erratic pulse later in the year, with a low level of spawning in between.

The overriding questions for the project were "Are black tiger prawn populations sustainable?", and therefore, "Is the supply of black tiger prawn broodstock to the aquaculture industry sustainable?". Unfortunately the answers are not simple. There has been a reasonably stable commercial harvest of black tiger prawn through time; (that is, the fishery has not fallen over as yet!) Given that longer-term stability in catch indicates stock sustainability, then the black tiger prawn stock appears reasonably stable long-term. However we would not like to see the current harvest increase, based on the short-term variability that appears to be inherent in the stock. Better utilisation of the current harvests maybe the most effective strategy.

In North Queensland the commercial trawl fishery harvest of black tiger prawn for frozen product is approximately ten times that harvested as live broodstock for aquaculture. As shown in this study, the capture of black tiger prawn by non-trawl apparatus is far from economically (or environmentally) viable in Queensland. Therefore there are two ways that the supply of live broodstock can be enhanced:

- Prawn farmers and hatcheries to work closely with the trawl fishery to utilise the catch as live product before it becomes frozen product, (this would potentially increase broodstock supply tenfold at a minimum), and;
- ensure that maximum benefit is gained from every broodstock prawn received by prawn hatcheries.

For the same fishing pressure on the stock, or preferably lower pressure, the aquaculture industry would be getting greater benefit from the harvest.

Finally, major concerns were the absence of black tiger prawn as a catch category in official QFS logbooks for the East Coast Trawl Fishery, the absence of a specialised logbook for broodstock collectors, and an apparent disagreement within the hatchery side of the industry as to the number of broodstock used per year. Future stock assessments and sustainable management practices for the black tiger prawn fishery, both for the frozen and broodstock sectors, require more accurate catch information. This can only be achieved if black tiger prawn is firstly listed as a catch category in the Queensland ECTF logbooks, and secondly if more accurate records are made of the number and fate of broodstock caught. In terms of quality control, a system is needed to allow back-tracking of broodstock prawns from hatchery, through the collector, back to the area from which it was caught.

Conclusions and management implications for each project objective:

1. *Collate fisheries information currently available on P. monodon across northern Australia from grey literature, fisheries databases, research projects, and from indigenous communities*. This objective was met as phase one of the project and published separately (see Appendix 1). The distribution of Black Tiger prawn (*P. monodon)* throughout Northern

Australia was described and it highlighted that the Queensland east coast population was at the southern extreme of the species' geographic distribution. At extremes in the range large fluctuations in abundance are to be expected, as was found during our research surveys.

2. *Define the distribution of adult P. monodon stocks and habitats*. The commercial logbooks, broodstock collector logbooks and research trawl catch and effort information indicate that the major concentration of black tiger populations in Queensland are in high-rainfall regions, adjacent to tropical mangrove coasts, between latitude 16° 30' S and 18° 30' S on the East Coast. This region is the "traditional" harvest area that has supplied the majority of broodstock; no new areas of unexploited populations were identified. The implication is that better management of the currently harvested populations is a more practical option than exploring for new "undiscovered" areas along the East Coast.

3. *Define the distribution of juvenile P. monodon stocks and habitats.* The juvenile habitat in Queensland was documented for the first time in this study. As with many other tropical species the coastal mangroves, wetlands and swamps are important nursery areas, and this finding reinforces the need for protection of these habitats. Loss of critical habitat through coastal development may be a bigger threat to the future supply of broodstock than overfishing.

4. *Determine seasonal patterns in P. monodon population dynamics (abundance, population structure).* A main summer spawning was documented but no reliable second spawning was identified in the Queensland populations. The most likely situation is that in "good" years the geographic range of the species increases up and down the coast, and in these years there is an increase in overall numbers spawning. In turn this would result in proportionately more individuals spawning later in the year; i.e. the tail of a normal distribution.

5. *Identify P. monodon biology (recruitment, movement, growth, reproduction) in Queensland*. The black tiger growth curve is typical of penaeids, with the female attaining an ultimate size larger than the male. Growth appears to continue for longer for this species than most prawns; up to 2.7 years for females and 1.4 years for males. Sub-adults recruit from the shallower inshore grounds (currently closed and/or protected) out to the recognised offshore grounds. The implication is that it is not imperative to open these protected areas to sustain the supply of broodstock to aquaculture.

6. *Examine alternative capture techniques and the associated stress testing of caught broodstock in particular for inshore and shallow water habitats which may contain useable quantities of currently unexploited broodstock*. Pots, lift-nets, trammel-nets and beam-trawling was tested on an established inshore prawn grounds against industry-standard Otter trawling. Trawling was significantly more effective than any other method and consequently the bycatch-to-prawn ratios were not

significantly improved using alternate methods. In the case of trammel nets they were significantly worse. The management implication is that routine capture of black tiger prawn by non-trawl apparatus is currently not economically (nor environmentally) viable in Queensland.

7. *Conduct economic cost/benefit analyses of various fishing patterns, capture techniques and handling protocols.* The assessment of alternative methods of capture (see Objective 6, above) showed conclusively that trawling was currently the only practical method for supplying the quantities of broodstock required by aquaculture. The small fleet of trawl based collectors co-operated fully but data were obtained from such a small numbers of individuals that to respect confidentiality details cannot be released. All that can be offered is that the broodstock collection fishery as a whole appears to be viable and profitable. No assessment was possible on the implications of sale of broodstock into overseas markets.

The end.

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(see also references at end of Appendix 1)

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Intellectual property

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See attached CD for:

Appendix 1. Report on Collated Information

Appendix 2. Proceedings of workshop

Appendix 3. Data files