An Integrated Monitoring Program for the Northern Prawn Fishery 2011

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AN INTEGRATED MONITORING PROGRAM FOR THE NORTHERN PRAWN FISHERY 2011

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Project objectives

a. To undertake a survey in January/February 2011 to provide recruitment indices and size data of the main commercial prawn species in the Gulf of Carpentaria

b. To undertake a survey in July 2011 to provide biomass, spawning indices and size data of the main commercial prawn species in the Gulf of Carpentaria

c. To spatially map the distribution of the main prawn and byproduct species in the Gulf of Carpentaria

d. To further develop statistical models to estimate abundance indices

e. To support the effective incorporation of survey information into stock assessment

Non-technical Summary

An international review of the Northern Prawn Fishery (NPF) tiger prawn assessment was carried out in 2001. The review drew attention to the high level of uncertainty in the assessment and recommended that the logbook data be augmented by fishery-independent survey data. In response to the review, industry funded a consultancy project in 2002 to investigate and design an integrated monitoring program for the NPF. Following an industry meeting, NORMAC decided to conduct a one-year pilot survey in 2002/03. The project (FRDC 2002/101) was funded through the FRDC, and included a spawning index survey in August and a recruitment index survey in January. The success of the pilot project led to subsequent FRDC-funded monitoring projects (FRDC 2003/075 in 2003/04, FRDC 2004/099 in 2004/05) and AFMA-funded projects (AFMA R05/0599 in 2005/06; AFMA R05/1024 in 2006/08 and AFMA R08/0827 in 2008/10). These projects (AFMA 09/0863 and AFMA R10/0822) are a continuation of the NPF prawn monitoring program and they are funded by AFMA, the industry and CSIRO.

Two surveys were undertaken during the 2011 calendar year, in January/February and July. The timing of the surveys matches key phases of the annual life cycle of the prawns. In general, the ‘effective spawning’ of commercial prawns in the Gulf of Carpentaria occurs from...
August to December. Postlarvae advect inshore and settle to shallow estuaries and embayments from September to March. Emigrant juveniles that contribute strongly to the subsequent fishery move from the inshore nursery habitats to offshore from roughly November to March, particularly November to January for banana prawns. Once offshore, they grow and move to deeper waters over time. The ‘recruitment survey’ in late January/February measures the abundance of smaller prawns that have emigrated from the nursery habitats and are found in the shallower regions of the fishing grounds early in the year. The ‘spawning survey’ in July (August prior to and including 2004) measures the abundance and spawning condition of large adults that are found on the fishing grounds just prior to the second fishing season. In the case of tiger prawns, they will be fished in the up-coming season. While in the case of banana prawns, they are a remnant spawning population from fishing during the first season (April-June).

For the ‘recruitment’ and ‘spawning’ surveys conducted in 2011, we used the sampling frames and randomly selected sites as in previous years. All surveys adopted the same stratification in which the strata are defined by subregion and water depth (for details see Ye et al. 2004; 2005).

Indices of prawn abundance are created from both surveys. The indices for tiger and endeavour prawns from both the recruitment and spawning surveys are incorporated directly into the NPF stock assessment. The size-frequency data from the surveys are critical to the recently developed size-structured model that supports the assessment. The spawning surveys also provide fishery independent data to monitor any change in fishing power in the NPF.

**Recruitment-Index Survey**

The recruitment-index survey is a substantial undertaking: two boats sampled a total of 300 sites in five regions (partitioned into 24 strata) between 25th January and 11th February 2011. To avert being caught in the potential path of Cyclone Yasi, we changed the order in which sites were sampled, and in spite of this disruption there was no loss of fishing time. Given the survey length, number of people involved and the wide geographic spread of sites to be sampled, the capacity to achieve this is testimony to the discipline, knowledge and experience of the survey team and vessel crews and management.

A regional Recruitment Index was produced for the seven commercial species. We have reported an index based on all sizes of prawn, for use in the current size-structured stock assessment model. However, for continuity with past reporting, we have focussed our interpretation on the index for prawns under 12 months old. We defined as recruits prawns smaller than 35 mm carapace length (CL) for males and 44 mm for females, respectively, of grooved tiger prawns (*P. semisulcatus*); under 34 mm CL for males and 39 mm for females, respectively, of all other species.

There were important differences in species composition, distribution and abundance between the regions (fully described in subsequent chapters). Fewer *P. semisulcatus* were found in some regions in 2008 and 2009; though their abundance rebounded in 2010, only to decline again in 2011 at Groote, while increasing in abundance at Weipa. Until 2010, there was a sustained increase in the abundance of *P. esculentus* recruits in the southeastern Gulf; though abundances declined in Mornington and Vanderlins in 2011. However, abundance in the Groote region declined for the 7th successive survey.

The global recruitment index for brown tiger prawns was high from 2008-10, and highest in 2009. It declined to about half those levels for brown tiger prawns in 2011, and only in 2004 was a lower index than this obtained. The global recruitment index for grooved tiger prawns was highest in 2006 (due to exceptionally high catches in the Vanderlins). In 2010 and 2011,
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the global index was at least 50% greater than the low values seen in 2008 and 2009. The global recruitment index for the blue endeavour prawns was highest in 2003. Blue-tailed endeavour prawns had their second-highest global recruitment index in 2010; but only about half that level in 2011. While 2003 and 2004 were the worst years for banana prawns, 2011 was the best year for the global recruitment index, along with 2008 and 2009 which were high also. In 2004, the global index was lowest for all species except for red endeavours and red-spot king prawns, which always have low catch rates in the recruitment survey.

This result clearly shows that the Recruitment Index can:

- be incorporated into the stock assessment as a fishery-independent index of abundance,
- be used for stock-recruitment relationship studies,
- assess the spatial extent of the prawns using fishery independent data, rather than relying on logbook data,
- provide good spatial maps of the distribution and abundance for the tiger and endeavour prawns.

**Spawning-Index Survey**

The spawning-index survey was completed during 29 June – 21 July 2011. The survey was originally designed to be carried out after the winter months when tiger prawns are more catchable, but before substantial catches have been taken by the fishing fleet. Since 2005, the surveys have been conducted in July due to the opening date of the second season being brought back from early September to 1 August. In July, both tiger prawn species are found in large enough numbers to survey. One boat sampled a total of 210 sites in three regions (Mornington, Vanderlins and Groote Eylandt) in 16 strata.

A regional Spawning Index was produced for the seven commercial species. We have reported an index based on all sizes of prawn, for use in the current size-structured stock assessment model. However, for continuity with past reporting, we have focussed our interpretation on the index for prawns of spawning age: prawns greater than 26 mm for males and 28 mm for females.

In the regions where tiger prawns and blue endeavours were caught in reasonable quantities, we generally achieved CVs in the range 10–20%, and the global index for these species was more precise (almost all CVs around 10% for tiger prawns, about 8% for blue endeavours). As a result of the good precision obtained, the survey has proved very useful as an index of Spawning abundance as part of an ongoing series.

Grooved tiger prawns (*P. semisulcatus*) were consistently more abundant offshore in Groote and the Vanderlins, where they had good catch rates. A few good catches of grooved tiger prawns also were taken at south Groote, close to North Vanderlin Island and west of Mornington Island. In contrast, brown tiger prawns (*P. esculentus*) were more numerous inshore than offshore in Groote (particularly at South Point) and the Vanderlins. However, in the Mornington region the deep waters of east Mornington consistently had the highest catch rates of brown tiger prawns.

Catch rates were generally more consistent among the three regions for *P. esculentus* than for *P. semisulcatus*, mirroring the regional profile observed in the Recruitment surveys. Catch rates of *P. esculentus* in the Mornington and Vanderlin areas dropped to about half the high
spawning index for brown tiger prawns has declined from 8 ha\(^{-1}\) in 2002 to less than 5.5 in 2004 and then recovered to \(-8\) ha\(^{-1}\) from 2005. It reached a peak of over 11 ha\(^{-1}\) in 2009 before dropping to just over half that density in 2011. Grooved tiger prawns had lower catch rates of 3–4 ha\(^{-1}\), interspersed with the highest catch rates of more than 5 ha\(^{-1}\) in 2002 and 2006. In 2011, the global index was 50% greater than the low values seen in 2007 and 2008. The global spawning index for blue endeavour prawns showed a similar pattern, with catch rates generally 50% higher than those of the grooved tiger prawn but equally low in 2007. For both species, the global index for 2011 was above average.

Global catch rates of *P. merguiensis* in the mid-year survey were generally low (2011 was no different, less than 0.5 ha\(^{-1}\)), reflecting both low recruitment to the three regions of the spawning survey and the fact that banana prawns are considerably depleted by fishing in the period April-June. 2006 (and 2008) had an unusually high catch rate, due to some exceptional catches in the Groote and Vanderlins regions. Western king prawns (*P. latisulcatus*) had their highest catch rates in 2002 and 2006. The catch rates of these were generally higher than for banana prawns, except for 2006.

The results of this survey were also used to evaluate the new spatial fishing power model. They have been shown to be extremely useful in comparing each year’s logbook data with biomass changes close to the time of fishing, irrespective of the spatial extent of the fishery in the year. This result clearly shows that the Spawning Index can:

- be incorporated into the stock assessment as a fishery-independent index of abundance,
- be used as a relative index of abundance for tiger and endeavour prawns in the fishing power model to reduce the confounding effect between fishing power creep and abundance variation in stock assessment models,
- be used for stock-recruitment relationship studies,
- assess the spatial extent of the prawns using fishery independent data, rather than relying on logbook data,
- provide good spatial maps of the distribution and abundance for the tiger and endeavour prawns.

**Spatial Modelling of Prawn Abundance**

A model-based approach (BayesX) was used to implement a Bayesian approach to modelling the tiger and endeavour prawns. The intention was to (1) to construct predictions for other sites not sampled; (2) to model changes more naturally than the sharp boundaries between strata that are applied in a typical design-based scheme such as the NPF prawn monitoring surveys; and (3) to obtain narrower and more realistic confidence intervals for abundance
indices. We have modelled the density of the two tiger prawn species (*P. esculentus* and *P. semisulcatus*) and blue Endeavour prawns (*M. endeavouri*) in recruitment surveys (January/February 2003–2011) and spawning surveys (June – July) (2002–2009, 2011).

Based on the posterior mean predicted log-density for each 2 nautical mile cell in the sampling frame, a spatial distribution pattern can be identified for each region, and its temporal variation can be monitored from year to year. For example, in North Groote predicted log-density of sub-adult *P. esculentus* is highest to the immediate northwest of Groote Eylandt, dropping away substantially in a direction to the northeast. There is a degree of similarly across years in this pattern. However, spatial distribution is relatively consistent over time in some regions more than others. For the adults, the analysis shows the changes in the extent of the high density patch to the west of Mornington Is and how it changes from year to year.

This investigation of penalized regression splines and their implementation in the BayesX package has shown that this is a promising tool for a model-based analysis of abundance data for commercial prawn species. The method is computationally more intensive than the design-based approach, but provides more credible abundance estimates that are not as heavily influenced by a few large catches.

**Recommendations and Conclusions**

1. It is recommended that future surveys retain the sub-region depth stratification. Analysis of variance on log-transformed catch rates for each species demonstrates the effectiveness of the stratification for both the January and August surveys. Regions account for an extremely high proportion of the variation, and strata within regions prove worthwhile partitioning for all species.

2. No region is representative of any another region. Since a survey index needs to be applicable to regions where most of the catch is obtained, it is recommended that the present spatial coverage (especially for the Recruitment Index survey) be maintained.

3. The Recruitment Index needs to be undertaken annually. Its value seriously declines if there is a break in the series or a major change in the timing of the survey. The stock and recruitment relationship in the NPF tiger prawn stock assessment is based on model-estimated recruitment and stock sizes. Recruitment and spawning stock indices and individual size data from fishery independent sources currently augment the existing catch and effort data and are integral to the new models that support the prawn stock assessment. Under TAC management, the augmentation from the Recruitment Index and size data is cost effective as it enables the setting of the most precise TAC (i.e. a higher TAC than one set incorporating greater precaution).

4. The Spawning Index can be used to help monitor any change in the fishing power of the fleet, and also can be used to estimate any changes in the spatial distribution of prawns in the fishery. It is incorporated in some model runs in the assessment. Its value is enhanced if undertaken annually. It is critical that the survey should be undertaken under TAC management or when there are significant changes in the fishing fleet or in seasonal fishing patterns.
5. Since the mid-year closure is currently of ~2 months duration, little fishery dependent data (logbook data) are available on brown tiger prawns at a time of year when spawners are most abundant. Under TAC management, it is of value to conduct the Spawning Index survey annually to provide distribution and abundance data for the period of the closure and hence improve the precision of the stock models.

6. It is recommended that future surveys of recruitment and spawning stock be undertaken at a similar moon phase and calendar month. For both recruitment and spawning stock surveys, the relative importance of including each fishing region as part of the survey will depend on the objectives and the species being targeted.

7. The NPF monitoring surveys provide valuable fishery-independent data that are useful for overcoming the serious confounding between fishing power and abundance. Consequently, these data reduce the uncertainty in the stock assessment.

8. A model-based approach based on penalised regression splines is being developed for the tiger and endeavour prawns that produces more stable indices in the presence of infrequent but very large catches. By explicitly aiming to model spatial variation in prawn abundance, this method may also allow historical surveys to be incorporated into the time series despite the lack of probability-based design and the fact that the areas covered in North Groote and Weipa differed somewhat from the present surveys.

9. Regional indices in the north west Gulf of Carpentaria for both recruitment and spawning for brown tiger prawns have shown a decline trend over the last 5 years. In the south west Gulf of Carpentaria, this trend is not seen, however, 2011 produced poor indices for brown tiger prawns in most regions. This is reflected in the global indices for brown tiger prawn as they trend lower over the last 2 years.
CHAPTER 1. INTRODUCTION

1.1 Background

The NPF is one of the Commonwealth’s most valuable and well managed fisheries. A recent FAO assessment has given the NPF world-class status as a ‘global model’ for the management of the worlds fisheries (Gillett 2008). The NPF Harvest Strategy with an MEY target defined its management (Jarrett and Dichmont 2007, Dichmont et al. 2010). Though from 2012, NPF management will transition to output controls (Total Allowable Catch (TAC)). In the early 2000’s, a stock assessment underpinning the Harvest Strategy used a delay-difference model for grooved and brown tiger prawn stocks (Dichmont et al. 2003). Dichmont et al. (2008) described a management strategy evaluation which considered stock, yield and economic contributions of both tiger and endeavour prawns; as well as impact of fishing on benthos, and performance indicators to develop a management strategy for the NPF. Management actions resulted in historically-overfished stocks recovering, particularly for brown tiger prawns (Dichmont et al. 2008). The 2011 Assessment incorporated a range of models that provided bioeconomic assessment of several stocks (Punt et al. 2010, 2011). The models computed a TAC for tiger prawns using the recruitment and spawning indices and length/frequency data from the fishery-independent surveys. As well, they extend the assessment to endeavour and red-legged banana prawns (Punt et al. 2011).

During the 1990’s and early 2000’s, management recognised a period of over-exploitation of the tiger prawn resource, particularly the brown tiger stocks, and reduced effort through a combination of seasonal fishing closures, gear reduction and overall structural adjustment and reductions (Jarrett and Dichmont 2007, Dichmont et al. 2008). Deriso’s (1) (2001) review of the tiger prawn assessment supported this conclusion and also drew attention to the high level of uncertainty in the assessment. To a large extent, the assessment was confounded because it was difficult to separate the effects of changes in fishing power (real fishing effort) from changes in prawn abundance when only commercial catch data are analysed (Dichmont et al. 2003; Deriso Review)). Deriso strongly recommended that the logbook data be augmented by fishery-independent survey data and that the survey should be designed both to provide an independent index of abundance for each tiger prawn species and to quantify fishing power changes.

In response to this review, an initial industry-funded consultancy was established to investigate and design an integrated monitoring program for the NPF (Dichmont et al. 2002). The initial design results were presented to a well-attended industry meeting in Cairns in February 2002. Suggestions from industry were incorporated into the project and a final report included a modular design and costing structure, which was presented to a special NORMAC meeting in March 2002. This meeting agreed to all components of the proposed program except the work in Joseph Bonaparte Gulf, which was seen as premature. As a result of this decision, a one year pilot test of the desk top design was undertaken incorporating two trawl surveys in 2002/03 (Dichmont et al. 2004), followed by an FRDC monitoring project in 2003/04 (Ye et al. 2004) and 2004/05 (Ye et al. 2005). AFMA funded the monitoring project in 2005/06 (Ye et al. 2006), 2006/08 (Milton et al. 2008) and 2008/10 (Kenyon et al. 2010). Nine consecutive years of monitoring surveys have now been completed and this growing fishery-independent time-

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1 Dr Deriso from Scripps Institution of Oceanography reviewed the NPF tiger prawn assessment in 2001
series of data (together with commercial catch and economic data) have underpinned the
management strategy developed for the NPF over the ensuing years.

The August survey to estimate a spawning index was undertaken in three regions of the Gulf
of Carpentaria (GOC). These data could also be used in future fishing power studies. The
February survey, aimed to produce an index of recruitment, was undertaken throughout most
of the fishing regions of the Gulf of Carpentaria.

The current projects (AFMA R09/0863 and AFMA R10/0822) aim to continue the recruitment
and spawning stock surveys, to further develop techniques that can effectively use the survey
data to improve the NPF tiger prawn stock assessment.

1.2 Need

In the early 2000’s, the international review of the NPF tiger prawn assessment agreed with the
conclusions of the 2001 assessment that tiger prawn stock levels were critically low, especially
for brown tiger prawns. The 2002 assessment further concluded that brown tiger prawn levels
were too low, but also emphasized the critical need for an independent monitoring program
given the confounding and complexities of the catch rate data that are used as the sole index of
abundance in the NPF assessments.

Over the ensuing eight years, the data from the Monitoring Surveys has supported the
development of internationally recognised fisheries management practices. The NPF
Assessment uses a range of models that provide bioeconomic assessment of several stocks
(Punt et al. 2011). The models compute a TAC for tiger prawns and extend the assessment to
endeavour and red-legged banana prawns. In the 2011 assessment, various models were run:
a) a mixed size (Punt et al. 2010) (two tiger prawn species) and Bayesian hierarchical biomass
dynamic model (Zhou et al., 2009) (one endeavour prawn species) and b) the Deriso model for
the three stocks (Dichmont et al. 2003). They will use the recruitment and spawning indices
and length/frequency data from the Monitoring Surveys to set a TAC from 2012 (Punt et al.
2011). The continuation of surveys provides precise independent size and abundance data for
these complex models and will enable the setting of the most precise TAC (i.e. a higher TAC
than one set incorporating greater precaution).

Moreover, during the drought years 2002-2007, environmental drivers that cause variation in
banana prawn stock abundance, and their survey indices, were steady. From 2008/09 to
2010/11, good rains in NPF river catchments produced flow-on effects to recruitment indices;
with the scope to explore variation in indices and their contribution to predict a TAC for
common banana prawns (Venables et al. 2011). The NPRAG has noted the recent variation in
both the environmental drivers and improved stocks and supported a continuation of surveys to
provide informative variation in data for the assessment.

In addition to the sustainability of exploited resources, prawn monitoring provides an
important opportunity to evaluate aspects highlighted by DEWHA’s Strategic Assessments
(AFMA 2003). Independent data can determine the status and trends of TEP species; and
bycatch and byproduct species. Valuable independent information can be obtained for species
at ecological risk (ERA & ERM processes and the By-Catch Action Plan).

1.3 Benefits and adoption

The majority of benefits of this project flow to the Northern Prawn Fishery, an AFMA
managed fishery in Northern Australia. The design of the integrated monitoring program,
which was started, tested and refined in early projects, has been adopted for current and future monitoring surveys for the NPF.

The surveys provide data and calculate indices that are unavailable from any other source. These size data and indices are currently incorporated in stock assessment and TAC setting for two tiger prawn species and the initial assessment for other prawn species (blue-tailed and red-tailed endeavour prawns). They are used to complement the log-book data to compute a TAC for tiger prawn species. The outcomes from the assessment have been adopted by NORMAC during season-by-season decision making, the development of the NPF Harvest Strategy, and transition to TAC output controls.

The time series of the annual indices refines the fishing power estimates for the main commercial prawn species. In addition, the abundance and spatial distribution data obtained for byproduct species can be used to assess the impact of fishing on these species and to provide advice on their long term sustainability. The species distribution maps provided to the industry promptly after each survey are also of immediate value to the fleet. They enable the entire fleet to assess the spatial distribution of each prawn species in the regions surveyed.

1.4 Further development

The current program of Prawn Monitoring Surveys in the NPF began in August 2002. The surveys have produced data on the annual abundance of recruitment and spawning stocks for commercial and byproduct species of the fishery. The data are independent of the commercial fishing activities. The monitoring surveys have now been carried out for ten years and will be undertaken for a further three years. The data have been used in the development of innovative new models to support the assessment of tiger prawns. They have been used to develop assessment for endeavour prawns. This work is on-going and contributes to the current exploration of TAC levels for several species. The data support the on-going exploration of fishing power.

Stock assessment relies heavily on time series data. Both recruitment and spawning stock surveys ideally should be continued for many years to allow the best use of the survey indices in stock assessment.

1.5 Planned outcomes

The project produced an integrated monitoring survey design; defining the objectives, scale, frequency and costs of the surveys. The implementation of the monitoring program produced quantitative descriptions of the spatial distribution and temporal variation of the populations of all commercial prawn and byproduct species.

The surveys provide data and calculated indices that include:
1. Prawn and byproduct abundance and distribution data for the major fishing grounds of the Gulf of Carpentaria,
2. Prawn and byproduct size data for the major fishing grounds of the Gulf of Carpentaria,
3. A recruitment index for seven species of commercial prawns in the Gulf of Carpentaria,
4. A spawning index for seven species of commercial prawns in the Gulf of Carpentaria,
5. Exploration of the link between prawn abundance indices and commercial catch.

The distribution information and the recruitment and spawning indices derived from the surveys have been incorporated into stock assessment models to reduce uncertainty, to evaluate the impact of fishing, and to better design management strategies and regulations.
The experience and design perspectives of the prawn monitoring surveys have made significant contributions to the design of long-term monitoring programs for any fisheries that involve multiple regions and multiple species.

1.6 Acknowledgements

This project was funded by the AFMA Research Fund and CSIRO Marine Research. We would like to thank the Northern Prawn Fishery Assessment Group for its invaluable comments during the project. Also, many thanks go to A. Raptis & Sons P/L, the skippers and crew of the charter vessels for their professionalism during the surveys. The NPFIO supported the project providing the charter vessel. Furthermore, the industry has given enormous support for this research to be undertaken and has provided much useful information and advice. Our thanks go to all those who went to sea as researchers, especially those not funded by this project. We are grateful for the efforts and expertise of anonymous reviewers who helped to proof, edit and produce the final report.

1.7 Project Staff

In Alphabetical Order of Surname:
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1.8 References


CHAPTER 2. SAMPLING GEAR AND DATA COLLECTED

2.1 Introduction

Our surveys are designed to generate a long-term set of fishery-independent data capable of providing key parameters to support the sustainable management of the Northern Prawn Fishery. A major issue for long-term research surveys is to use standard sampling gear so that the fishing power of the survey vessel can be kept as constant as possible over many years. Standardisation is important for a recruitment survey, but it is critical for any survey where changes in the fishing power of the fishing fleet are being estimated. To ensure standardisation, we used only NPF-based commercial vessels as a survey platform. They were chartered using a public tender process. In all cases, A. Raptis & Sons won the charter contract and, although we used several different vessels, they were mostly sister ships that were built at the same time using the same design e.g. length, draft etc.; maintaining fishing power as standard as possible.

Two new surveys are reported here: the January/February and July 2011 surveys. All surveys began and concluded at Karumba. The January survey was conducted from 25th January to February 11th 2011 (306 trawls) (FV Australian Pearl and FV Northern Pearl). The July survey was conducted from 30th June to 21st July (210 trawls) (FV Dolphin Pearl). The dates were chosen to standardise moon phase between years. Other environmental data were recorded and comprehensive information was collected on aspects of the trawl exercise: trawl locations and durations, trawl tracks and steaming tracks.

The schedule for the January/February 2011 survey was modified to avoid Cyclone Yasi (Category 5), but no fishing nights were lost. The first 7 nights of the survey (Karumba, east Mornington and Weipa) were conducted as usual. On day 8 the vessels steamed north to Groote Eylandt to distance themselves from the possible path of Cyclone Yasi. They continued the survey working north to south (Groote to the Vanderlins and one last night west of Mornington). The effect was to disrupt the usual sequence in which the regions of the Gulf of Carpentaria were sampled whilst maintaining the full complement of sampling sites.

2.2 Trawl gear description

For the January/February survey, two vessels were chartered and, as much as possible, worked in similar areas at the same time. Only one vessel was chartered for the July 2011 survey. All vessels used two 12-fathom tiger prawn nets manufactured for CSIRO by GNM Chandlery, Cairns.
Net and rigging specifications were as follows:

- 2 x 12Ftm Tiger Nets as per Samples of Nets (GNM nets)
- Made from; 2” 400/30 Brown Markwell Net
- Head Lines; 8mm S/S Wire wrapped in 6mm Silver Rope
- Foot Lines; 9.5mm S/S Wire wrapped 8mm Silver Rope
- Drops; 9 Links 8mm S/S Chain
- Ground Chain; 13mm S/S Chain
- Selvedged; 400/30Ply Orange Twine
- Seam; 400/30Ply Orange Twine Doubled
- Cod Ends; 17/8” 180Mr x 120Md with a 180mr x 30Md Skirt
- TEDS (no Bycatch Reduction Devices (BRD) were fitted)
- Frame; Using your Existing frames
- Bodies; 17/8” Black Braided Net with 13/4” 400/60 Double Flaps 10mm Silver Rope for Wrapping.

The GNM net and rigging specifications were as follows:

- 400d/30ply 2” stretched mesh net.
- Codend of 400d/4x16ply black braided 1⅝” stretched mesh net, 150 mr (meshes round) x 120 md (meshes deep).
- Fitted with 8mm S/S drop chains and 13mm regular link S/S ground chain.
- Headrope of 8mm S/S wire wrapped in 6mm PE rope.
- Footrope of 10mm S/S wire wrapped in 8mm PE rope.
- Fitted with 150 mr x 75 md skirt.
- An upward-excluding Turtle Excluding Device (TED) was fitted to each net but no Bycatch Reduction Devices (BRD) were fitted.

The nets were attached to Number 9 Bison Boards provided by the survey vessels.

### 2.3 Abiotic data collected

For each trawl, start and finish times and GPS locations, as well as the GPS plotter track of the vessel during each trawl were recorded. Trawling was commenced each night at about 30 minutes after sunset and the last trawl of the night was completed at least 30 minutes before sunrise. Each trawl was 30 minutes in length, unless trawling was interrupted due to rough bottom or gear problems. Descriptors relating to weather, tides, moon phase and details of problems with gear were also recorded. Vessel trawl speed was maintained at 3.2 knots, although occasionally this was not possible in strong tidal currents.

Salinity/Temperature: A small Diver datalogger was attached to one trawl net on each vessel during each survey (‘Diver’ water quality monitoring, Eijkelkamp Agrisearch Equipment, The Netherlands; www.eijkelkamp.com). The logger recorded conductivity (later converted to salinity), temperature and water depth at 1-minute intervals throughout the night and the data was downloaded to a computer at the end of each night’s work.

### 2.4 Biological data collected

In most cases, all commercial species of prawns, bugs and scallops were identified to species and total weights and numbers were recorded for each net. Up to 2007, all squid and cuttlefish had been frozen and later transported to CSIRO, Cleveland for identification and further processing. Commencing in 2008, all squid and cuttlefish were counted and weighed, but not
kept. Cephalopods were not kept during these surveys. Currently, the cephalopods are not differentiated to species level: the data accumulated from 2002 to 2007 provided enough information on cephalopod species distribution. Up to 100 individuals of each species of prawn, bugs and scallops (50 individuals for scallops) were measured to provide information on population structure. For the prawns, the spawning stage, moult stage and presence of any parasites was also recorded. When substantially more than 100 individuals of any prawn species were present in the catch, a randomly selected subsample was measured. The numbers and weights of the subsample and total catch were recorded to relate the subsample details to the total catch.

The vessel Skipper estimated the weight of the total cod-end catch of each net after each trawl.

During all surveys, data were collected on seasnakes (photographed) and sawfish (DNA sample). Species of syngnathids were photographed for other CSIRO staff working on TEP Bycatch in the NPF. These data will be reported separately.
CHAPTER 3. SURVEY DESIGN AND DATA ANALYSIS

3.1 Background

A major component of the design and initial analyses of these surveys is reported in Dichmont et al. (2002), Dichmont et al. (2004) and Ye et al. (2004). This chapter outlines the design of the two surveys and the method of analysis applied to the prawn catch data.

3.2 Prawn density

To enable comparison with historical survey data we calculate the prawn density (number per hectare of estimated swept area) since the configuration of nets has changed between historical and recent surveys. Standardizing by the area trawled also allows us to correct for differences in trawl speed that occurred between and during these surveys.

In estimating the swept area, we assumed a 30m wide path is swept by the pair of nets. For most trawls carried out after late 2003, we evaluated the trawled distance from computerised trawl tracks. Where this information was unavailable but speed had been recorded, we multiplied the speed by the recorded duration. If neither speed nor track data were available, we assumed a speed of 100m per minute and multiplied this by duration. Trawls of less than 15 minutes were discarded as being unrepresentative.

Most trawls swept an area of 8–10 hectares, with a modal area around 9 hectares (Figure 1). With increasing experience of conducting these surveys, especially now that we have identified and dealt with untrawlable sites, swept area has become more consistent than in the first few surveys.
Figure 1: Estimated area swept by trawls (in hectares) during the spawning and recruitment surveys.
3.3 The sampling frame

For each survey, three sets of information are needed when constructing the index for each prawn species for each region\(^2\). The three data sources are the sampling frame, the design information (stratum labels for sampled sites) and the number of prawns per hectare swept by the trawl.

The sampling frame is the full set of 2 n.mile cells from which sample sites are selected, each cell being uniquely defined by a 15-character grid reference representing the latitude and longitude at its centre (e.g. S17d15mE140d07m). Each cell is also assigned a region and a stratum label. The sampling frame is also used to evaluate the total area of each stratum, and from this is derived the weight given to each stratum when calculating each regional index. For both the Recruitment and Spawning surveys, the original sampling frame has been modified to reflect either the area that can feasibly be trawled, or to improve on the original design for reasons given below.

For the mid-year Spawning survey, the strata within each region were originally defined by fishing effort and water depth (Figure 2). However, to facilitate comparison with the Recruitment survey and to ensure compatibility with another project in the Eastern Gulf of Carpentaria that ran concurrently with monitoring surveys in 2003 and 2004, we retrospectively stratified the Spawning survey in a manner similar to the Recruitment survey, where the strata are defined by sub-region and water depth (Figure 3). With the new strata, no fewer than four sites were sampled in each stratum, and for the August 2003 survey we increased sampling rates in a couple of the weaker strata; those with the fewest sites. The two approaches to stratification produced comparable indices and expected precision (see Dec 2003 milestone report). At the same time, we reduced the overall extent of the Spawning survey by trimming the northern and eastern sections of the Groote region and removing an untrawlable corridor north-west of Mornington. One sample site (near the north-eastern tip of Groote Eylandt in the August 2002 survey) was excluded by the modified sampling frame, and that was allocated to the nearest grid inside the sampling frame.

For the Recruitment survey, the strata were originally defined by sub-region and water depth. The only changes to this sampling frame were minor: 18 cells in the west Karumba sub-region were re-assigned to the east Mornington sub-region for compatibility with the Spawning survey sampling frame. Even after this change, the east Mornington sub-region included a larger area in the Recruitment survey than in the Spawning survey as it covered cells in which, historically, there has been no tiger prawn fishing effort in the second season. In addition, five cells were included in the north-eastern part of Albatross Bay which was previously considered too shallow to trawl and three of these cells were sampled in the January 2004 survey. These extra cells and sample sites were added to ensure the survey did not miss out on potentially high catch rates of banana prawns (*P. merguiensis*) close to shore. The modified stratification for the January 2004 survey is shown in Figure 4.

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\(^2\) Additional offshore sites sampled in January 2003 for a bycatch monitoring project were not included in the calculation of the recruitment index.
Before calculating the number of prawns per hectare by species for a trawl, we took account of any sub-sampling whereby carapace length was only measured on a subset of a particular
species in a given net in a given trawl. This occurred when large numbers of a species were caught in one trawl. Usually, only a maximum of 100 prawns were measured to provide a good indication of the size structure of prawns in the trawl. These animals were partitioned into two age groups, using the survey-specific size thresholds described previously. These counts were then multiplied by the ratio of the total number in that net to the number in the sub-sample. For example, if half the brown tiger prawns (P. esculentus) prawns in the port net were measured then the counts for the two age groups in that net were doubled. The adjusted counts from the two nets for that species were then added together. If one net had failed (e.g. if the net was torn, or the catch was much smaller in one net than the other), the count from the suspect net was not used and the count from the remaining net was doubled. Finally, the adjusted total count (of adults or sub-adults) was divided by the estimated area swept by that trawl.

Figure 4: Modified frame for January recruitment index survey, stratified by sub-region and depth.

### 3.4 Calculating the indices of abundance

The estimated index for each region ($\hat{\mu}_R$) consists of a weighted sum of the sample mean number of prawns per hectare in each stratum ($\bar{y}_{R,j}$), where each stratum weight ($w_{R,j}$) is the proportion of the region represented by that stratum. There are $N_R$ strata in each region, and the stratum weights sum to 1 within a region.

\[
\hat{\mu}_R = \sum_{i=1}^{N_R} w_{R,j} \bar{y}_{R,j}
\]  

(1)

The variance of the index consists of a weighted sum of the stratum sample variances. In this calculation, the stratum weights used for the index are squared and hence no longer sum to 1. No finite population correction was applied as each trawl sweeps a very small fraction of the cell it samples.
The square root of this variance gives the standard error of the estimated index for that region. The coefficient of variation is the ratio of the standard error to the estimated index, multiplied by 100.

An overall (or ‘global’) index was also calculated for each species, by extending the approach used for regional indices to include all strata from all regions. The stratum weights now represent the real proportion of each stratum relative to the whole survey.

\[
\hat{\mu}_G = \sum_{i=1}^{N_G} w_{G,i} \bar{y}_{G,i}
\]

### 3.5 References


CHAPTER 4. RECRUITMENT INDEX

4.1 Purpose and design of Recruitment Survey

The Recruitment Survey is conducted in January or February (occasionally extending into early March, as it did in 2009). This survey provides a Gulf-wide index of recruitment with coefficient of variation (CV) for tiger, banana and endeavour prawns, and a catch rate distribution map made available on the AFMA web site.

It has also generated data for other projects at a particularly valuable time of year when no commercial catch data are available for the Northern Prawn Fishery due to the seasonal closure that runs from December to March.

This survey aims to catch young adult prawns as they migrate into fishery grounds from nursery habitat. The timing is intended both to capture the recruitment peak for the two tiger prawns and to pre-empt the period when banana prawns form large, dense aggregations. In order to collect all samples within a short period avoiding the full moon, we deploy two vessels. Trawls were carried out on the following nights: 25 January–12 February 2003, 12–28 January 2004, 3–21 February 2005, 21 January–6 February 2006, 8–24 February 2007, 30 January–14 February 2008, 15 February–5 March 2009, 2–18 February 2010, and 25 January–11 February 2011.

The sampling frame is partitioned into 24 strata (Figure 4). The size of each stratum (in 2 n.mile grids) and the number of successful trawls are given in Table 1.
<table>
<thead>
<tr>
<th>Depth stratum</th>
<th>Number of 2 nm sites for selection</th>
<th>2003</th>
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4.2 Size distributions of prawns in recruitment surveys

Based on trawls where a species was found, we calculated for each region the average size-dependent frequency per trawl for that species, separately for each sex. For each of these trawls, the number of prawns observed (zero or greater) was recorded for each of a full suite of observed carapace lengths (generally 10mm to 70mm), truncated to the nearest millimetre.

The regional length-frequency distributions in each survey for the four most important species (brown and grooved tiger prawns, blue endeavours and common banana prawns) are shown in Figure 5 to Figure 8. We have selected regions where the species was usually most abundant in the Recruitment Surveys. Superimposed on these figures is the size threshold below which prawns are considered to be less than 12 months old. Published growth curve parameters (Wang & Somers, 1996) were used to provide an estimated carapace length at 12 months: 44 mm for female Penaeus semisulcatus (grooved tiger) prawns or 35 mm for male P. semisulcatus; 39 mm (female) or 34 mm (male) for all other species. A strong mode at least 5 mm below the threshold represents the recruitment peak for the summer of the survey; a second mode just below the threshold points to a recruitment peak in the previous autumn; a mode to the right of the threshold represents prawns from the previous summer’s peak recruitment time.

For most species in most regions, the majority of the prawns caught are smaller than the 12-month size threshold, since animals greater than 12 months old have been subject to a prolonged period of natural and fishing mortality. However, in some years there was a surprisingly high density of male P. semisulcatus from the previous summer cohort in the Groote and Vanderlins regions, relative to the density of the current cohort – possibly a result of preferential targeting of larger (female) prawns during the previous year’s fishing season.

For most species-by-region combinations, the modal length for males recruiting in the current summer is several millimetres below that of the females. However, male and female P. semisulcatus (all regions) and P. merguiensis (Weipa) recruiting in the summer of the survey are quite homogenous in size distribution at the time of survey – though there is an obvious difference in modal length for the previous year’s cohort (whose mode exceeds the indicated threshold length).

The ratio of total male to female density is uneven in Recruitment Surveys (Figure 9 and Figure 10). For example, the ratio of male to female total density for P. esculentus nearly always exceeds 1 for region–by-year combinations with meaningful total densities, mostly in the range 1.1–1.3 across all regions. Most of the excess occurs for the current summer’s recruitment cohort (animals smaller than 12-month threshold in Figure 5). A similar dominance of males in the catch was observed for P. semisulcatus, but in this case this situation is mainly due to a higher density of males in the previous summer’s cohort (animals larger than 12-month threshold in Figure 6). A milder excess of males was observed for M. endeavouri. For P. merguiensis, on the other hand, sexes were equally balanced, with the male to female ratio mostly in the range 0.5–1.5. For this species, there are usually few survivors of both sexes from the previous summer’s recruitment cohort (animals larger than 12-month threshold in Figure 8).
Figure 5: Observed carapace length distribution of female (red) and male (blue) *P. esculentus* for high-density regions in 2003-2011 Recruitment Surveys, by year and region (G=Groote; M=Mornington; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns under 12 months old.
Figure 6: Observed carapace length distribution of female (red) and male (blue) *P. semisulcatus* for high-density regions in 2003-2011 Recruitment Surveys, by year and region (G=Groote; V=Vanderlins; W=Weipa). Dashed vertical lines indicate upper threshold for prawns under 12 months old.
Figure 7: Observed carapace length distribution of female (red) and male (blue) *M. endeavouri* for high-density regions in 2003-2011 Recruitment Surveys, by year and region (G=Groote; M=Mornington; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns under 12 months old.
Figure 8: Observed carapace length distribution of female (red) and male (blue) *P. merguiensis* for high-density regions in 2003-2011 recruitment surveys, by year and region (K=Karumba; V=Vanderlins; W=Weipa). Dashed vertical lines indicate upper threshold for prawns under 12 months old.
Regional sex ratio for each species

Groote  Karumba  Mornington  Vanderlins  Weipa

M. endeavouri

P. esculentus

P. semisulcatus

Male to female ratio

Combined count per trawl

Figure 9: Distribution of male-to-female density ratio across regions and surveys for three main species (M. endeavouri, P. esculentus, and P. semisulcatus).
Regional sex ratio for each species

<table>
<thead>
<tr>
<th>Species</th>
<th>Region</th>
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<tr>
<td>P. merguiensis</td>
<td>Groote, Karumba</td>
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<td>Mornington, Vanderlins, Weipa</td>
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</table>

Figure 10: Distribution of male-to-female density ratio across regions and surveys for *P. merguiensis*.

### 4.3 Spatial distribution of young prawns

Densities of prawns under 12 months old are shown in Figure 11 to Figure 14 for four important species (*P. esculentus* - brown tiger prawns; *P. semisulcatus* - grooved tiger prawns; *M. endeavouri* – blue endeavour prawns; and *P. merguiensis* – common banana prawns).

Brown tiger prawns have consistently had high densities in three main areas: near the mainland south-west of Groote Eylandt, in shallow waters west of Mornington Island and south-east of this island. Brown tigers had high densities in an east-west strip directly north of Groote Eylandt until 2010 and sometimes, brown tigers have been dense in shallow coastal waters in the Vanderlins region, but this is not consistent. They have always had low density in the Weipa region, in the south-east Gulf close to the mainland and in the deeper waters north of Mornington Island and the Vanderlins, and south-east of Groote Eylandt.

Grooved tiger prawns have consistently had high densities in a north-south strip north of Groote Eylandt, and in the Weipa region. In some years, there has been high density in shallow coastal waters in the Vanderlins, and in a small area directly west of Mornington Island. Density has consistently been low to the west and south-west of Groote Eylandt, and in the south-eastern part of the Gulf lying to the east of 139°E.

Blue endeavour prawns tended to have a similar density distribution to the brown tiger prawns, though usually with a lower density – highest abundance occurring north and west of Groote Eylandt, west and south-east of Mornington Island and in shallow coastal waters in the Vanderlins.

Banana prawns were generally found only in the Weipa and south-east Gulf regions, with occasional high densities to the west of Mornington Island or in very shallow sites around the Vanderlins.
Figure 11: Observed density (number per hectare) of < 12 month-old *P. esculentus* at recruitment survey sites.
Figure 12: Observed density (number per hectare) of < 12 month-old *P. semisulcatus* at recruitment survey sites.
Figure 13: Observed density (number per hectare) of < 12 month-old *M. endeavouri* at recruitment survey sites.
Figure 14: Observed density (number per hectare) of < 12 month-old *P. merguiensis* for recruitment survey sites.
4.4 Recruitment Index

Since the start of the NPF monitoring surveys, we have reported global indices based on both (1) the prawns under 12 months old and (2) all prawns. Since the size-structured stock assessment model was developed (Punt et al., 2010), the latter index has been considered a more appropriate input. However, for consistency with earlier reports we continue to present more detailed spatial and regional information on the younger prawns.

Prior to presenting the global Recruitment Index for each survey, we present separate regional indices for each species, together with 90% bootstrap confidence limits using the mirror-match method for design-based analysis of sample surveys (Sitter, 1992), which has been shown to have good properties in fishery surveys (Smith, 1997).

Graphical presentation underlines the consistency from year to year in the marked differences in density between regions for each species seen in maps (Figure 15 to Figure 18). It also demonstrates the considerable variation in regional density ‘profile’ among species – for example, *P. esculentus* and *P. merguiensis* have spatial distributions that are almost the complement of each other while *P. esculentus* and *P. semisulcatus* are both abundant in the Groote and Vanderlins regions but differ markedly in abundance in the Mornington and Weipa regions.

Another feature that emerges is the low density in 2004 across all regions for both tiger prawns, relative to other years. This survey was conducted under stormy conditions and this may have reduced the prawn capture efficiency of the gear. The high density of *P. semisulcatus* in the Vanderlins in 2006, with wide confidence limits, is mainly due to a couple of sites where the catch was an order of magnitude larger than normal. In most regions, catch rates of *P. semisulcatus* were fairly low in 2011, except for Weipa where the catch rates have shown a marked increase over the past four surveys.

Since 2005, *P. esculentus* has steadily declined in the Groote area and declines have been seen in Vanderlins and Mornington over the past three years. Catches of *P. esculentus* in 2008 in the Mornington region were more than double those seen in the previous five surveys, but by the 2011 survey much of that gain in the Mornington region was lost. Catch rates of this species for Groote and Vanderlins regions were also low in 2011. For Karumba, an increase in the index in 2011 ended a decline over the previous three years, rising from negligible catch rates to a mean similar to that in the Mornington region in previous years.

For *M. endeavouri*, catch rates in Groote and the Vanderlins in the first survey (2003) were more than double the regional indices seen in subsequent surveys. Though they were at fairly high levels in the Mornington region in the surveys of 2009–2010, the 2011 catch rate had dropped back to the 2008 level. The catch rate in Groote and Vanderlins regions was also relatively low in 2011. The catch rates over the last five surveys have been higher than in the first four surveys in the consistently low-density Weipa region.

For *P. merguiensis*, catch rates have shown no particular trend except for the Weipa region where catch rates in three of the past four years have been considerably higher than in the first five years – though the high density in 2008 was dominated by one site with an extraordinarily large catch even by the standards of banana prawns, which are known to form dense aggregations during the fishing season. A similar situation occurred in 2011.
Figure 15: Mean density (number per hectare) of < 12 month-old *P. esculentus* in each region over the recruitment surveys 2003-2011, with 90% bootstrap confidence intervals.
Figure 16: Mean density (number per hectare) of < 12 month-old *P. semisulcatus* in each region over the recruitment surveys 2003-2011, with 90% bootstrap confidence intervals.
Figure 17: Mean density (number per hectare) of < 12 month-old *M. endeavouri* in each region over the recruitment surveys 2003-2011, with 90% bootstrap confidence intervals.
Figure 18: Mean density (number per hectare) of < 12 month-old *P. merguiensis* in each region over the recruitment surveys 2003-2011, with 90% bootstrap confidence intervals. Note the square-root transformation for *P. merguiensis* due to the very large range of index values.
Finally, the recruitment index was evaluated for the entire sampling frame from a weighted average of the density in each stratum, each stratum being weighted by its area relative to the total area of the Recruitment Survey sampling frame (Table 1). The Recruitment Index based on prawns under 12 months old for the four main species is shown in Figure 19, and for all species is presented in Table 2. It is the main focus of interpretation here. In four cases (banana prawns in 2008 and 2011, and grooved tiger prawns in 2006 and 2011), one or two outstandingly large catches led to an exceptionally high mean, standard error and coefficient of variation, so these particular values should be interpreted with caution.

In most years (Table 2), the banana prawn index was much lower (1−4 per hectare) than for the tiger prawn species because much of the sampling frame covers terrain where little or no banana prawns are found – the exceptions being the south-east Gulf and the Albatross Bay (Weipa) region. Because this prawn is so patchily distributed, the CV is quite high: 17−44 percent over seven surveys, 51 percent in 2011 and as high as 71 percent in 2008 when one trawl in Weipa yielded an outstanding catch of 450 kg banana prawns in only one of the paired nets.

In contrast, the mean for the two tiger prawns was generally quite high, typically around 4−8 per hectare. For both these species, the CV was mostly 10 percent or less, the notable exception being for grooved tiger prawns in 2006 when a few exceptionally large catches were made in the Vanderlins region, and again in 2011 due to large catches in the Weipa region.

Blue endeavour prawns (M. endeavouri) almost always have the smallest CV even though the mean for this species is generally in the range 1−3 per hectare, after an impressive 5.60 per hectare in the first survey (2003) when they were particularly abundant in the Vanderlins region, and 4.37 per hectare in 2010.

Western king prawns (P. latisulcatus) have been consistently found in small quantities: 0.4−0.7 per hectare in seven out of nine surveys, following a maximum of 1.63 per hectare in 2003. The CV for these, the red endeavours (M. ensis) and red spot kings (P. longistylus) is rather higher than for the tiger prawns and blue endeavour prawns, understandable given their low densities and general scarcity. However, it is noteworthy that M. ensis have been much more abundant (> 0.7 per hectare) in 2010 & 2011, compared with < 0.4 per hectare in seven earlier surveys.
Figure 19: Mean global density (number per hectare) of < 12 month-old prawns for the four main commercial species over recruitment surveys 2003-2011, with 90% bootstrap confidence intervals.
An index has also been evaluated for prawns of all sizes (Table 3), as this is the version being assimilated in the size-structured version of the stock assessment model that has been developed for tiger and endeavour prawns in recent times. The relative variation in density from year to year tends to echo the patterns seen in and discussed above, though for some species the index is appreciably higher due to a substantial proportion of prawns being larger than the 12-month carapace length threshold applied to the Recruitment Index.

For *M. endeavouri* and *P. merguiensis*, prawns under 1 year old always accounted for at least 90% of the total prawn density, and often more than 95%. This is echoed by the regional length-frequency distributions where few prawns exceeded the threshold carapace length for these two species. We can also make an informal assessment of the percentage survival of a given year’s recruitment cohort from the ratio of ‘new recruit’ density in that year with ‘veteran’ density in the following year. This ratio seldom exceeded 5%, and never exceeded 10%, for blue endeavour and common banana species during all recruitment surveys in the period 2003-2011.

For the tiger prawns, the prawns under 1 year old generally represented a lower proportion of the total prawn density: for *P. esculentus*, 77–90% and for *P. semisulcatus*, 79–94%. These proportions are compatible with the regional length-frequency distributions where some regions had a notable quantity of older prawns. The ratio of ‘veterans’ to ‘new recruits’ during the 2003-2011 surveys ranged from 12% to 32% for *P. esculentus* and 10% to 26% for *P. semisulcatus*, somewhat higher than for endeavour and banana prawns.

Interestingly, 2004 was the season with the greatest percentage survival of the four most important species, even though that year the recruitment indices for all four species were the lowest seen in the nine surveys.

The ratio of the Recruitment Index to the index from all prawn sizes was generally much lower for the other three species, probably because these species are rarer (particularly *P. longistylus* and *M. ensis*) and also because the areas covered by the sampling frame were mainly chosen to provide solid information on the four commercially most important species.
Table 2: Mean number of prawns (<12 month-old) caught per hectare for nine annual Recruitment Surveys (2003-2011), with standard error (S.E.) and coefficient of variation (C.V.).

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Table 3: Mean number of prawns (all sizes) caught per hectare for nine annual Recruitment Surveys (2003-2011), with standard error (S.E.) and coefficient of variation (C.V.).

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4.5 Conclusions

1. The annual recruitment surveys conducted over 2003-2011 provide simultaneous comprehensive spatial coverage of all commercial prawn species in the Gulf of Carpentaria. This has enabled the spatial distribution of recruits under 12 months old to the current year’s fishery to be quantified, and the inter-annual variation in catch rates to be assessed.

2. Highest catch rates of the two tiger prawn species (\textit{P. esculentus} and \textit{P. semisulcatus}) were consistently found in the same three regions: Groote, the Vanderlins and either Mornington (\textit{P. esculentus}) or Weipa (\textit{P. semisulcatus}). For \textit{P. esculentus}, the median value for the Recruitment Index was similar across the three main regions of Mornington (6.9 ha\(^{-1}\)), Groote (5.9 ha\(^{-1}\)) and the Vanderlins (5.9 ha\(^{-1}\)). The highest catch rate observed in any region (17.5 ha\(^{-1}\)) occurred in the Mornington region in the 2008 survey. The global recruitment index for \textit{P. esculentus} in 2011 was about 50% of recent years.

3. For \textit{P. semisulcatus}, Weipa was the most productive region with a median of 19.8 ha\(^{-1}\) over the nine years and a maximum of 35.7 ha\(^{-1}\) in 2011. The Groote and Vanderlins regions had similar medians (6.9 and 7.4 ha\(^{-1}\) respectively). For both tiger prawn species, catch rates in the two least productive regions were generally an order of magnitude less than those in the best regions. The mean catch rate for \textit{P. esculentus} in the Karumba region was about one-third that in the Mornington region in the 2008 and 2011 surveys.

4. The blue endeavour prawn (\textit{M. endeavouri}), while generally less abundant than the two tiger prawn species, also showed clear regional profiles. The three best regions for this species echoed those of \textit{P. esculentus}: Groote, the Vanderlins and Mornington. In 2003, Groote and the Vanderlins had catch rates 5-6 times that in Mornington but in the following years the catch rates in these regions dropped to a level comparable with Mornington. Over the nine-year period, the median catch rate for Groote (3.2 ha\(^{-1}\)) was higher than for the Vanderlins (2.7 ha\(^{-1}\)) and Mornington regions (2.4 ha\(^{-1}\)). Weipa was the only region with non-negligible catch rates of \textit{M. ensis}, ranging from 0.3 ha\(^{-1}\) in 2005 to 7.9 ha\(^{-1}\) in 2010 and 7.3 ha\(^{-1}\) in 2011, a marked increase over the first seven surveys.

5. Banana prawns (\textit{P. merguiensis}) were consistently most abundant in Karumba and Weipa. Catch rates at Weipa were highly variable – 1.6 ha\(^{-1}\) in 2003 up to 101.3 ha\(^{-1}\) in 2008 (due mainly to one site with an astoundingly high banana prawn catch), with a median of 22.3 ha\(^{-1}\). The CV was usually much larger for this species than the other species, as it tends to form dense aggregations. The median catch rate in Karumba was 9.3 ha\(^{-1}\), with a minimum of 3.0 ha\(^{-1}\) in 2003 and a maximum of 54.3 ha\(^{-1}\) in 2011.

6. The global Recruitment Index was highest in 2009 for brown tiger prawns, in 2011 for common banana prawns, in 2006 for grooved tiger prawns and 2003 for blue endeavours and western king prawns. For all five of these species, 2004 had the lowest global index.

7. As the species profile varies from region to region, no single area seems able to represent another. Therefore, we recommend continuing surveys of all areas so that a Recruitment Index can be obtained for all species of commercial importance in the Gulf.

4.6 References


CHAPTER 5. SPAWNING INDEX

5.1 Purpose and design of Spawning Survey

The Spawning Survey is conducted mid-year and provides

a. an index of spawning abundance with coefficient of variation (CV) for tiger and
deadventure prawns over fishing grounds relevant to the second season,

b. data on the distribution, abundance and size composition of the main byproduct
species, and

c. a catch rate distribution map made available on the AFMA web site.

Apart from producing a relative abundance index of spawning-age tiger and deadventure
prawns, the survey provides useful data for other projects. The sampling frame (Figure 3)
reflects the areas of major commercial effort historically in the Gulf of Carpentaria during the
first six weeks of the second season. Originally, the survey was to be conducted in August,
during the mid-year closure. The surveys have all been conducted over a comparable moon
phase, but now take place in June or July due to the earlier start of the second season. Trawls
have been carried out on the nights of 16–26 August 2002, 31 July–14 August 2003, 21 July–4

The Spawning Survey is partitioned into 16 strata (Figure 3). The size of each stratum in 2
n.mile cells and the number of successful trawls carried out in each survey are shown in Table
4. In this survey, we focus on adult prawns with a carapace length of at least 26 mm (males) or
28 mm (females), which represent most of the prawn catch at this time of year.

5.2 Size distributions of prawns in spawning surveys

Based on trawls where a species was found, we calculated for each region the average size-
dependent frequency per trawl (per net) for that species, separately for each sex. For each
trawl, the number of prawns observed (zero or greater) was recorded for each of a full suite of
observed carapace lengths (generally 10mm to 70mm), truncated to the nearest millimetre.

The regional length-frequency distributions in each survey for the four most important species
(brown and grooved tiger prawns, blue endeavours and common banana prawns) are shown in
Figure 20 to Figure 23. For $P. semisulcatus$ and $P. merguiensis$, the distributions are given for
only two regions due to low densities in the third.

Superimposed on these figures is the size threshold below which prawns were previously
excluded from the Spawning Index (26 mm for males, 28 mm for females). In earlier surveys,
which were conducted in late July/August, there are few prawns below this. In recent surveys,
there are noticeably more small prawns (below the 26 mm/28 mm threshold) in the Vanderlins
for the tiger prawns. This is even more marked for the endavour prawns, in all regions.

For $P. esculentus$, the modal length for males is 7–10 mm below that of the females (Figure
20). In Mornington, there is a higher concentration of large females than in the other regions,
possibly due to a more compressed recruitment period in the summer. Both tiger prawn species
tend to have smaller animals in the Groote region, whereas the blue endavour prawn sizes
appear to be quite consistent across regions (Figure 22). These are generally smaller than the tiger prawns, and the separation between modal lengths for males and females is narrower.

Table 4: Spawning survey: stratum size and number of sites successfully sampled each year.

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<th>Number of sites sampled</th>
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<tr>
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The ratio of total male to female density differs considerably from 1 in spawning surveys (Figure 24 and Figure 25). For *M. endeavouri* it is typically in the range 1.1–1.3 and for *P. esculentus* and *P. semisulcatus* it is even higher than this with a range of 1.2–1.5. This skewed sex ratio is even stronger during spawning surveys than recruitment surveys for these three species, with only one occurrence of female prawns dominating in numbers over males (*P. semisulcatus* at Groote Eylandt in 2003). Judging from the length-frequency distributions, the difference arises from a single cohort. For *P. merguiensis*, the picture is less consistently biased, with the male-to-female ratio typically ranging from 0.5 to 2.0. The high variability in this ratio is a consequence of the low densities of this species at the end of the first season, during which banana prawns are the main target.
Figure 20: Observed carapace length distribution of female (red) and male (blue) *P. esculentus* for 2002-2011 Spawning Surveys, by year and region (G=Groote; M=Mornington; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns included in spawning index.
Figure 21: Observed carapace length distribution of female (red) and male (blue) *P. semisulcatus* for highest-density regions in 2002-2011 Spawning Surveys, by year and region (G=Groote; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns included in spawning index.
Figure 22: Observed carapace length distribution of female (red) and male (blue) *M. endeavouri* for 2002-2011 Spawning Surveys, by year and region (G=Groote; M=Mornington; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns included in spawning index.
Figure 23: Observed carapace length distribution of female (red) and male (blue) *P. merguiensis* for highest-density regions in 2002-2011 Spawning Surveys, by year and region (M=Mornington; V=Vanderlins). Dashed vertical lines indicate upper threshold for prawns included in spawning index.
Regional sex ratio for each species

Groote    Mornington    Vanderlins

Figure 24: Distribution of male-to-female density ratio across regions and surveys for three main species (M. endeavouri, P. esculentus, and P. semisulcatus).
5.3 **Spatial distribution of adult prawns**

For the tiger prawns and blue endeavours, raw densities are presented in Figure 26 to Figure 28. Generally, the brown tiger prawn distribution was similar to the recruitment survey. However, in the last few years, brown tiger prawn density has declined north of Groote Eylandt, in contrast to consistently good catches south-west of this island. The catches in the Vanderlins region, and north and east of Mornington Island, have tended to vary, yet in the last few years there regularly have been good catches in Vanderlins and east Mornington. In all but one year, high numbers of brown tiger prawns were caught west of Mornington Island. However, the larger catches are now closer to the island, whereas previously they were closer to the Tully inlet area, perhaps because surveys have been conducted earlier in the year than previously.

Across all spawning surveys, grooved tiger prawns have been most abundant in a north-south strip north of Groote Eylandt. The catches south of Groote Eylandt and around the Vanderlins area have been highly variable. Prior to 2011 there were very few grooved tiger prawns east of 139° longitude. However, during the 2011 spawning survey large numbers were caught west of Mornington Island. This was preceded by high numbers of grooved tiger prawns in both the 2010 and 2011 recruitment surveys.

The distribution of blue endeavour prawns tended to mimic that of brown tiger prawns, though usually with a lower density – highest abundance occurring north and west of Groote Eylandt, west and south-east of Mornington Island and in shallow coastal waters in the Vanderlins. High numbers of blue endeavour prawns are consistently found north of Mornington Island, whereas this area is quite unpredictable for brown tiger prawns.

![Figure 25: Distribution of male-to-female density ratio across regions and surveys for P. merguiensis.](image-url)
Figure 26: Observed density of adult *P. esculentus* at spawning survey trawl sites.
Figure 27: Observed density of adult *P. semisulcatus* at spawning survey trawl sites.
Figure 28: Observed density of adult *M. endeavouri* at spawning survey trawl sites.
5.4 Spawning Index

Since the start of the NPF monitoring surveys, we have reported global indices based on both (1) the adult prawns over 26/28 mm carapace length and (2) all prawns. Since the size-structured stock assessment model was developed (Punt et al., 2010), the latter index has been considered a more appropriate input. However, for consistency with earlier reports we continue to present more detailed spatial and regional information on the adult prawns.

Prior to presenting the global spawning index for each survey, we present separate regional indices for each species (Figure 29 to Figure 31), together with 90% bootstrap confidence limits using the (Sitter 1992) mirror-match method for design-based analysis of sample surveys, which has been shown to have good properties in fishery surveys (Smith and Tremblay, 2003).

Catch rates for *P. esculentus* in the Groote region show no decadal trend, but marked fluctuations from year to year. However, since 2006 there has been a decline trend from a maximum of 11.1 ha\(^{-1}\) that year to a minimum of 4.3 ha\(^{-1}\) in 2011. Catch has shown a fairly steady increase in the Mornington region from a low of 6 ha\(^{-1}\) prior to 2005 up to around 15 ha\(^{-1}\) by 2009, but there was a marked decline in 2011 to less than 10 ha\(^{-1}\). Likewise, catch rates in the Vanderlins were low in 2011; previously fluctuating between a minimum of 3.2 ha\(^{-1}\) in 2004 and a maximum of 11.0 ha\(^{-1}\) in 2009.

After a peak catch rate of 12.7 ha\(^{-1}\) for *P. semisulcatus* in the Groote region in 2002, catch rates dropped and oscillated between a minimum of 4.4 ha\(^{-1}\) (in 2005) and 7.7 ha\(^{-1}\) (in 2006). Although much smaller in the 2002 survey, the Vanderlins catch rate tracked the Groote catch rate quite closely in the other years, ranging between 2.3 and 6.7 ha\(^{-1}\) over the decade. Catch rates were negligible in the Mornington region, known to be marginal for this species, though increasing to a maximum of 1.9 ha\(^{-1}\) in 2011. No recent downtrend is evident.

For *M. endeavouri*, catch rates in the Groote region oscillated to a greater extent in the first four years, having started at 9.4 ha\(^{-1}\) in 2002 but from 2006 onwards the catch rates have all been between 4 and 6 ha\(^{-1}\) in Groote. In the Vanderlins, 2002 and 2006 were productive years, exceeding 7 ha\(^{-1}\) but otherwise all catch rates were less than 5 ha\(^{-1}\). Densities at Mornington Island have shown a similar trend to that in the Vanderlins, with ranges from 1.6 to 6.8 ha\(^{-1}\). The 2011 regional catches were above survey lows.
SPAWNING INDEX

Northern Prawn Fishing Monitoring

Figure 29: Observed density (number per hectare) by region of adult *P. esculentus* at spawning survey trawl sites.
Figure 30: Observed density (number per hectare) by region of adult *P. semisulcatus* at spawning survey trawl sites.
Figure 31: Observed density (number per hectare) by region of adult *M. endeavouri* at spawning survey trawl sites.
The global spawning index for adult prawns was evaluated for the entire sampling frame (Table 5) from a weighted average of the density in each stratum, weighting strata by their area relative to the total area of the Spawning Survey sampling frame. Figure 32 shows the trends for the four main species.

The banana prawn index was low (less than 1.5 per hectare), apart from 2006 and 2008 when there was a handful of fairly large catches. In 2011, it was the lowest in the time series. Because of these low densities, the CV was generally high (33–70 percent).

In contrast, the index for brown tiger prawns was generally quite high (typically 7–9 per hectare). It was lowest in 2004 (5.43 per hectare) and highest in 2009 (11.35 per hectare); and second lowest in 2011 (6.10). The CV ranged from 7–12 percent.

Grooved tiger prawns had lower densities than brown tiger prawns because they were generally not caught in the Mornington area or the eastern part of the Vanderlins region (the region with highest density in the Recruitment Survey — Weipa — is not surveyed mid-year). The index ranged typically from 3 to 5 per hectare, and the first survey (2002) produced the highest index of the nine surveys (5.09 per hectare). The 2011 index was above average. The CV ranged from 9–14 percent.

As in the recruitment survey, blue endeavour prawns (M. endeavouri) consistently had the lowest CV. The index for this species lies between those of grooved and brown tiger prawn indices: mostly 4 to 7 per hectare, with a low 2.76 per hectare in 2007. The highest abundance of this species, 7.83 per hectare, was found in the first survey (2002). The index for 2011 was consistent with 2008 and 2009.

Western king prawns (P. latisulcatus) were consistently found in small quantities: between 1 and 2 per hectare for most surveys, with the lowest index of 1.03 per hectare in 2004. The CV for this species was fairly good, given its lower abundance, ranging from 15–20 percent in most years. Red endeavours (M. ensis) and red spot kings (P. longistylus) had very low abundance and a high CV.
Figure 32: Observed density (number per hectare) by region of adult prawns of the four main commercial at spawning survey trawl sites.
An index has also been evaluated for prawns of all sizes (Table 6), as this is the version being assimilated in the size-structured version of the stock assessment model that has been developed for tiger and endeavour prawns in recent times.

For *P. merguiensis*, less than 2% of all prawns are excluded by the 26/28 mm threshold: the lowest ratio of adult index in Table 5 to total index in Table 6 was 0.98 for 2006. This is compatible with the regional length-frequency distributions shown earlier where all prawns exceeded the threshold carapace length in the first four surveys, with a few below the threshold in 2006 and 2007. Similarly, less than 6% of *P. esculentus* were below the threshold carapace length (lowest ratio of 0.94 in 2006), and for *P. latisulcatus* it was less than 7% (lowest ratio of 0.93 in 2004).

Higher proportions of sub-threshold prawns were observed for *M. endeavouri* (7–21%) and *P. semisulcatus*, (1–14%), particularly in more recent surveys which were conducted earlier in the year. This tendency was also observed in a more pronounced fashion (>20% of sub-threshold prawns) for the rarer species *M. ensis* and *P. longistylus*. 
Table 5: Mean number of adult prawns caught per hectare for nine annual spawning surveys (2002-2011), with standard error (S.E.) and coefficient of variation (C.V.).

<table>
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Table 6: Mean number of all-size prawns caught per hectare for nine annual spawning surveys (2002-2011), with standard error (S.E.) and coefficient of variation (C.V.).

<table>
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<tr>
<th>Statistic</th>
<th>Penaeus merguiensis (common banana prawn)</th>
<th>Penaeus esculentus (brown tiger prawn)</th>
<th>Penaeus semisulcatus (grooved tiger prawn)</th>
<th>Metapenaeus endeavouri (blue endeavour prawn)</th>
<th>Metapenaeus ensis (red endeavour prawn)</th>
<th>Penaeus latisulcatus (western king prawn)</th>
<th>Penaeus longistylus (red spot king prawn)</th>
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<tr>
<td>Mean</td>
<td>1.04 1.29 0.63 0.62 5.75 1.38 2.60 0.60 0.49</td>
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<td>7.92 5.07 5.03 4.46 7.06 3.35 5.54 5.38 5.80</td>
<td>0.25 0.10 0.09 0.03 0.09 0.15 0.05 0.10 0.15</td>
<td>2.17 1.32 1.11 1.64 2.48 1.41 1.39 1.17 1.30</td>
<td>0.04 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01</td>
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<tr>
<td>S.E.</td>
<td>0.73 0.43 0.20 0.22 3.21 0.72 1.82 0.29 0.17</td>
<td>0.74 0.49 0.57 0.61 1.06 0.83 0.63 0.95 0.59</td>
<td>0.54 0.39 0.32 0.30 0.55 0.28 0.36 0.42 0.40</td>
<td>0.70 0.32 0.38 0.27 0.53 0.27 0.32 0.37 0.38</td>
<td>0.05 0.03 0.02 0.01 0.03 0.04 0.02 0.03 0.04</td>
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<tr>
<td>C.V.</td>
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<td>10 9 9 10 10 9 14 11 10</td>
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Northern Prawn Fishing Monitoring
5.5 Conclusions

1. We were able to produce good indices of abundance of adult prawns (> 26/28 mm carapace length) at regional levels, and the CV for the global index was very low for both tiger prawns and blue endeavour prawns (M. endeavouri) (6–14%).

2. Grooved tiger prawns (P. semisulcatus) were consistently more abundant offshore in Groote and the Vanderlins, where they had good catch rates. In contrast, brown tiger prawns (P. esculentus) were more numerous inshore than offshore in Groote and the Vanderlins. However, in the Mornington region the deep waters of east Mornington consistently had the highest catch rates of brown tiger prawns. Catch rates among the three regions were generally more consistent for P. esculentus than P. semisulcatus, mirroring the regional profile observed in the Recruitment surveys. Catch rates of P. esculentus in the Mornington area have been better than, or comparable to, those in Groote since 2005. Meanwhile, the catch rate of P. semisulcatus in Groote was appreciably better in 2002 than any subsequent year, though remaining fairly steady since 2007 at Groote and in the other two regions. For the past seven years, the inter-annual variation in catch rates has been similar for the Groote and Vanderlins regions.

3. Like P. esculentus, blue endeavour prawns (M. endeavouri) on average had similar catch rates in all three regions, though the relative productivity between regions varied among years. While catch rates in the Vanderlins exceeded 7 ha\(^{-1}\) in 2002 and 2006, they ranged between 2 and 4 ha\(^{-1}\) in other years prior to 2011, reaching ~5 ha\(^{-1}\) in 2011. Meanwhile, catch rates in Mornington ranged from 4 to 7 ha\(^{-1}\) (including 2011) except for one very poor year (2007) where the catch rate was below 2 ha\(^{-1}\). A similar range was seen in the Groote region, except for the peak rate of nearly 10 ha\(^{-1}\) in 2002. Red endeavour prawns (M. ensis) are found in negligible quantities in the Spawning Survey as it excludes Weipa, their most abundant area in the Recruitment Survey.

4. Catch rates of P. merguiensis were modest (under 1.5 ha\(^{-1}\)), reflecting both low recruitment to the three regions of the spawning survey and the fact that banana prawns are considerably depleted by fishing in the period April-June. 2006 had an unusually high catch rate, due to some exceptional catches in the Groote and Vanderlins regions.

5. For brown tiger prawns, the global index declined from 8 ha\(^{-1}\) in 2002 to less than 5.5 in 2004 and then recovered to ~8 ha\(^{-1}\) from 2005, hitting a peak of over 11 ha\(^{-1}\) in 2009 before dropping to just over half that density in 2011. Grooved tiger prawns had lower catch rates of 3–4 ha\(^{-1}\) interspersed with the highest catch rates of more than 5 ha\(^{-1}\) in 2002 and 2006, a pattern similar to the blue endeavour prawns whose catch rates were generally 50% higher than those of the grooved tiger prawn but equally low in 2007. For both species, the global index for 2011 was above average. Western king prawns (P. latisulcatus) also had their highest catch rates in 2002 and 2006. The catch rates of these were generally higher than for banana prawns, except for 2006.

5.6 References


CHAPTER 6. SPATIAL MODELLING OF TIGER AND ENDEAVOUR PRAWNS

6.1 Introduction

In this chapter we report a Bayesian model-based approach to analysis of the abundance of both tiger prawns and blue endeavour prawns in both recruitment and spawning surveys, in contrast to the design-based approach presented in earlier chapters.

The design-based approach produces estimates of the population mean and variance in prawn abundance by taking account of the method by which sample sites were selected from a defined sampling frame. In principle, the appropriate analysis is fully defined by the method used to obtain the survey data. This approach makes no assumptions about how prawn abundance varies over space and time, unlike the model-based approach where we explicitly seek a stochastic distribution that suitably characterises the sample data.

In adopting the model-based approach, it is common for a variety of potential models to be considered. The modelling process has four components to specify: (a) an appropriate stochastic distribution for the response variable (prawn abundance), allowing for correlation between samples if necessary; (b) relevant/available explanatory variables (location, time, water depth, sediment type, salinity, etc); (c) the best functional form in which to express these; and (d) the most suitable function, or transformation, to map the response variable to the combination of prediction variables. This approach therefore offers greater flexibility but at the cost of greater complexity.

Model-based analysis has several advantages over design-based analysis. Firstly, such models can be used to construct predictions for other sites not sampled, on the basis of characteristics such as location, time of sampling and other covariates that are available for each site and/or time. Secondly, they offer an opportunity to model changes more naturally than the sharp boundaries between strata that are applied in a typical design-based scheme such as the NPF prawn monitoring surveys.

We have used a package called BayesX to implement a Bayesian approach to modelling. BayesX allows a wide variety of models to be fitted using a Markov Chain Monte Carlo (MCMC) algorithm (Fahrmeir, Kneib and Lang, 2004). This package offers a broad suite of models that is particularly suitable for analysing spatio-temporal data, can handle large datasets and whose MCMC code enables a large number of iterations to be run quite fast on a desktop computer. A further benefit of the MCMC approach is that it is straightforward to derive credible intervals for parameters and functions of these parameters.

6.1 Data

We have extended previous modelling of the density of sub-adult $P. esculentus$ in recruitment surveys (January/February) to two other major commercial species: $P. semisulcatus$ and $M. endeavouri$. We have also modelled the adult density of these three species in the spawning surveys (June-August). Observed densities of these species in the recruitment surveys have been shown in Figure 11 to Figure 14 in Chapter 4, and in the spawning surveys in Figure 26 to Figure 28 in Chapter 5.

The sampling frame for both surveys covers a long stretch of coastline in the Gulf of Carpentaria, in a number of segments that extend to about one degree offshore. A large central
area of the Gulf is not represented in the sampling frame as commercial operations are concentrated in coastal areas. In addition to gaps between sampling regions, two large islands (Groote Eylandt and Mornington) break the sample sites up into discontinuous components. Unlike the previous report, when we partitioned each survey into a number of sectors and modelled these independently from each other, we now fit one model to an entire survey. We still fit the data separately for each year, for each survey type.

If we simply fitted a two-dimensional surface using latitude and longitude, there would be considerable redundancy: more than half the knots would be positioned in areas with no data. It would also be computationally demanding if we wished to have a high density of knots in the regions where we do have data, in order to describe local trends. Therefore (Figure 33), we partitioned the (a) Recruitment Survey into six sectors and (b) Spawning Survey into four sectors that are as convex as possible with the minimum of holes. The number of samples in each sector ranges from 20 to 100 per survey, with most sectors containing 40–60 sites.

To stabilise model-fitting in each sector, we converted from the latitude/longitude coordinate system to orthogonal axes (pc1/pc2) obtained by principal component analysis of the centred geographic coordinates of the 2 n.mile cells in the sampling frame of each sector. The coordinate system used in model-fitting therefore varied from sector to sector, but in all cases was simply a rotation.

We did not include depth as a covariate, as this is highly correlated with latitude and longitude in each sector. Few other covariates have been sampled in a consistent manner across all sectors, but in principle these could be introduced at a later date.

6.2 Models

Counts for these species are over-dispersed relative to the Poisson, a common situation with marine catch data. One way to handle this would be to choose the Negative Binomial distribution. However, we have found that the mean-variance relationship of the Negative Binomial gives such flexibility when fitting regression splines that the predicted response can considerably exceed the highest observed density. Therefore, we log-transformed density, after adding a constant C=0.5 to all counts, i.e. log-density=log10 ((count + C)/trawled area) and fitted a Gaussian response distribution.

6.2.1 Specification of space-time models

BayesX offers two-dimensional versions of Penalised regression splines (P-splines; Lang and Brezger 2004), a form of flexible surface-fitting. P-splines use a design matrix derived from basis splines evaluated for each of the explanatory variables. The two-dimensional version allows for an interaction between the two explanatory variables by taking the tensor product of the two sets of basis splines. The regression coefficients are constrained to follow a first order random walk process whose variance ($\tau^2$) essentially acts as a smoothness penalty. This is assigned a diffuse prior based on the inverse Gamma distribution, and the MCMC process generates a posterior distribution for this parameter in addition to that for the residual variance, $\sigma^2$. The range of each explanatory variable is split into a pre-determined number of segments of equal length. Together with the chosen degree of the basis splines (usually 3), this determines the number of spline regression coefficients.
We specified the model for the expected value of log-density $Y_{is}$ at the $i^{th}$ site in the $s^{th}$ sector (in a given year) as follows:

$$E(Y_{is}) = \mu_N + \sum_{s=1}^{N} I(s) \left\{ \mu_N + \partial_{s(x_{is})} + ps2_{s} (pc1_{si}, pc2_{si}; k = 6; rwl(a = 0.001, b = 0.001)) \right\}$$
where \( I(s) = 1 \) for sector \( s \), and \( I(s) = 0 \) for all other sectors

\[ \mu_N \text{ is the mean log-density in the } N^{th} \text{ sector} \]

\[ \delta_s \text{ is the difference between the mean log-density in sector } s \text{ and that in the } N^{th} \text{ sector for the given year}, \]

and \( ps^2, (pc_1^a, pc_2^a; k = 6; rw(a = 0.001, b = 0.001)) \) is a two-dimensional penalised cubic spline with 6 internal equi-spaced knots each on the orthogonal axes centred in sector \( s \). For Vanderlins in recruitment surveys we set \( k=10 \), and for Vanderlins and West Mornington in spawning surveys we set \( k=12 \).

The parameters of the inverse Gamma prior for the P-spline variance, \( \tau^2 \), are given by \( a=0.001 \) and \( b=0.001 \). This is also the default prior for the residual variance, \( \sigma^2 \). Fixed effects such as \( \mu_N \) and \( \delta_s \) are automatically assigned a diffuse prior.

Effectively, separate penalised regression splines are fitted within each sector but the residual variance is pooled across all sectors.

### 6.2.2 Implementation of MCMC

MCMC is an iterative method that produces samples of the posterior distribution of all parameters in each cycle. Parameter space is frequently high-dimensional and early iterations tend to produce samples with high auto-correlation that give a biased representation of the posterior distribution. It is therefore necessary to discard a number of iterations (the ‘burnin’ period). As a further precaution to reduce correlation amongst retained MCMC samples, only every \( n \)’th iteration of subsequent sampling is retained (where \( n \) is the ‘step’ size). It is also necessary to have sufficient iterations to achieve convergence to the posterior distribution. We discarded the first 15,000 iterations and retained every 60th observation of the next 60,000 iterations, having found that a smaller step size gave high auto-correlations at substantial lags for the P-spline variance in particular. This produced 1,000 sets of parameter values from the posterior distribution.

### 6.3 Results

#### 6.3.1 Model convergence

Auto-correlations were negligible for all parameters (Figure 34 to Figure 39), indicating that the burnin period and thinning regime were appropriate and the MCMC fitting has converged to the appropriate posterior distribution for the parameters. Samples of the posterior distribution for the P-spline variance are a further diagnostic tool. Where the auto-correlations for the P-spline variance was low at all lags, both the local mean and the local variance for consecutive sets of samples were fairly stable (Figure 40 to Figure 42).
Figure 34: Auto-correlations for selected parameters for model fitted to log(density) of *P. esculentus* for the 2011 Spawning Survey.
Figure 35: Auto-correlations for selected parameters for model fitted to log(density) of *P. esculentus* for the 2011 Recruitment Survey.
Figure 36: Auto-correlations for selected parameters for model fitted to log(density) of *P. semisulcatus* for the 2011 Spawning Survey.
Figure 37: Auto-correlations for selected parameters for model fitted to log(density) of *P. semisulcatus* for the 2011 Recruitment Survey.
Figure 38: Auto-correlations for selected parameters for model fitted to log(density) of *M. endeavouri* for the 2011 Spawning Survey.
Figure 39: Auto-correlations for selected parameters for model fitted to log(density) of *M. endeavouri* for the 2011 Recruitment Survey.
Figure 40: Sampled values of log10-transformed P-spline variance for *P. esculentus* in the North Groote sector in the Recruitment Surveys. The red line gives the lowess mean smoother with a span of 2/3.
Figure 41: Sampled values of $\log_{10}$-transformed P-spline variance for *P. semisulcatus* in the North Groote sector in the Recruitment Surveys. The red line gives the lowess mean smoother with a span of 2/3.
Figure 42: Sampled values of $\log_{10}$-transformed P-spline variance for *M. endeavouri* in the North Groote sector in the Recruitment Surveys. The red line gives the lowess mean smoother with a span of $2/3$. 
6.3.2 Prediction surfaces

We evaluated the mean posterior predicted log-density for each 2 n.mile cell in the sampling frame. Back-transformation of these predictions onto the original scale and plotting against the original spatial coordinates gives a map of the median posterior predicted density for the three species of interest in Figure 43 to Figure 46.

In most sectors, predicted density of sub-adult *P. esculentus* in the recruitment surveys has shown consistent patterns over the nine years (Figure 43). It was high adjacent to the north-west of Groote Eylandt, mid-way between the west coast of Groote Eylandt and the mainland, and west and south-east of Mornington Island, where density appears to have been increasing steadily over the past few years. Density was consistently low in the Weipa region and South East Gulf. In the Vanderlins sector, highest densities typically occurred in shallow inshore waters, mostly to the south-east of the Vanderlins Islands. However, 2004 and 2007 did not fit this pattern – for 2004 the fitted surface had substantially fewer effective degrees of freedom than in other years because the observed densities were low and patchy.

The distribution of *P. esculentus* seen in the spawning survey is similar to that in the recruitment survey, except that in some years the brown tiger prawns to the south-east of Mornington appear to have partially migrated to the north of Mornington by the middle of the year, since the density in that area now equalled or exceeded that in the south-east (Figure 42). It is also clear that modelling in the Vanderlins is facilitated by having samples in the Tully region since there is a peak between 137.5°E and 138.5°E, an area not covered in the recruitment survey due to the need to cover Weipa and the South-East Gulf for banana prawns at that time of year.

Predicted density of sub-adult *P. semisulcatus* in the recruitment surveys has been consistently high in the North Groote and Weipa sectors (Figure 43), generally highest in the shallow coastal waters. There is a small strip west of Mornington where density tends to peak, but otherwise this species was absent in the Mornington/South-East Gulf sectors over the nine years. In the Vanderlins sector, highest densities tended to occur to the north-west of the Vanderlins Islands, but the predicted surface did not exhibit features that occurred consistently over the nine years.

The distribution of *P. semisulcatus* continued to be high in North Groote in the spawning survey, though generally peaking further offshore than in the recruitment survey (Figure 44). The density distribution was much more consistent in the Vanderlins, with high densities in the deeper waters in the north-western part of this sector.

In the recruitment surveys, the relative distribution of sub-adult *M. endeavouri* closely resembled that of *P. esculentus* over five of the nine years (Figure 45) being most abundant around Groote Eylandt and Mornington Island. Density was consistently low in the Weipa region and South East Gulf. After the first survey, density of this species in the recruitment surveys was low (averaging only 1–2 per hectare). In 2007, the combination of low density and probably some patchiness resulted in a poor model fit (large residual variance relative to other years). The fitted surface in the Groote and Vanderlins sectors was more-or-less featureless, with less than 3 effective degrees of freedom compared with 7–15 in other years.

The distribution of *M. endeavouri* in the spawning survey showed much more consistency across years (Figure 46), with peak densities in south-west of Groote, in the southern half of the Vanderlins and north of Mornington Island. There was variation in the distance offshore of peak densities in the Vanderlins from year to year. As seen for *P. esculentus*, modelling in the Vanderlins is facilitated by having samples in the Tully region.
Figure 43: Median posterior predicted density of Penaeus esculentus for the Recruitment Survey.
Figure 44: Median posterior predicted density of *Penaeus esculentus* for the Spawning Survey.
Figure 45: Median posterior predicted density of *Penaeus semisulcatus* for the Recruitment Survey.
Figure 46: Median posterior predicted density of *Penaeus semisulcatus* for the Spawning Survey.
Figure 47: Median posterior predicted density of *Metapenaeus endeavouri* for the Recruitment Survey.
Figure 48: Median posterior predicted density of *Metapenaeus endeavouri* for the Spawning Survey.
6.3.3 Posterior distribution for global recruitment and spawning indices

After some correspondence with Thomas Kneib, the BayesX package was modified to output the predicted response for every input record after each (selected) MCMC iteration. The input data consisted of two sets of records: (1) locations with catch data and (2) all cell-centres from the sampling frame with the response variable set to ‘missing’. Predictions were obtained for the latter set by performing weighted modelling, with a weight of 1 for locations with catch data and 0 for locations being predicted for. From this, the average back-transformed prediction can be calculated, yielding a sample from the posterior distribution of the global index from that survey. Sometimes the prediction for a given location was excessively large after back-transformation, so these were reduced to double the maximum observed density.

The posterior distribution for the global index is obtained empirically from the 1000 samples produced by the MCMC process: the median and 90% credible interval are shown in Figure 49 and Figure 50, along with the design-based estimate of the mean density from the entire sampling frame.

The Bayesian and design-based indices show similar patterns of variation from year to year, except that the Bayesian index is usually smaller because it represents the median of a skewed distribution. For *P. semisulcatus* in the 2006 recruitment survey, the Bayesian index is considerably smaller; the design-based index having been dominated by a couple of exceptionally large catches in the Vanderlins. On the other hand, in the 2003 and 2006 spawning surveys, the design-based index for *P. esculentus* was almost identical to the Bayesian index when in the other years it was about 25% higher.
Figure 49: Median (red solid squares) and 90% credible interval (red dashed lines) for MCMC global index of *M. endeavouri*, *P. esculentus*, and *P. semisulcatus* for nine years of Recruitment Surveys, compared with design-based global index (black diamonds) and 90% bootstrapped confidence interval (black dashed lines).
Figure 50: Median (red solid squares) and 90% credible interval (red dashed lines) for MCMC global index of *M. endeavouri*, *P. esculentus*, and *P. semisulcatus* for nine years of Spawning Surveys, compared with design-based global index (black diamonds) and 90% bootstrapped confidence interval (black dashed lines).
6.4 Discussion

The Bayesian penalised regression splines approach has not only enabled spatial aspects of the distribution of each species to be captured, it has provided overall measure of abundance, with a credible interval. The model-based approach appears to be less influenced by the presence of one or two excessively large densities in the catch data.

This approach is computationally much more demanding than the design-based approach, as it currently takes about 10 minutes to fit a given model to each species × year × survey combination, even with a Gaussian choice of response distribution. This could be speeded up by allocating fewer knots, especially as the effective degrees of freedom per sector was always less than half the number of knots allocated in two-dimensional space. However, there is the risk that interesting features of the surface will be missed. Of more concern are the instances where the fitted surface had less than 6 degrees of freedom – the reasons for this are not yet fully understood.

The Bayesian modelling perform better in the Vanderlins for the spawning survey than for the recruitment survey, because the Tully area (137.5°E–138.5°E) has high densities of a productive region that spans several degrees of coastline east of the Vanderlins Islands and spreading into the area west of Mornington Island. There are hints that closing the gap between south Groote and the Vandelsins would also reveal a similar “island” of high density for *P. semisulcatus*.

6.5 References


CHAPTER 7. PRAWN SIZE COMPOSITION, MATURITY AND PARASITES

7.1 Introduction

It is important when analysing the prawn catch data from these surveys and in using the results to comment on the status of stocks, to have an understanding of the size and reproductive status of the prawns caught during the surveys. For the annual recruitment survey (February), we need to know that our survey has adequately sampled the smaller, new recruits to the fishery, whereas for the July spawning survey, we need to adequately sample the prawns that are contributing to the fishery and to the spawning stock at that time of year.

7.2 Methods

For most trawls, we measured all individuals of the commercial prawn species that were caught. In some trawls where the prawn catch was large, not all prawns were measured. In these cases a subsample of around 100 prawns was measured and this was taken as being representative of the size composition of the whole catch for that sample. The carapace length (CL) (head length) was measured using digital vernier calipers to the nearest 0.01 mm and recorded on a laptop computer. In order to calculate the size-frequency, we aggregated the measurements into 1-mm size categories and pooled all measurements for each species, region and depth stratum.

7.3 Results and Discussion

7.3.1 Size composition

A large number of prawns were measured in the two surveys. In July 2011, 16,140 prawns were recorded, the majority being measured. In February 2011, 61,418 prawns were recorded. Other than for banana prawns, the majority were measured. Except for brown tiger prawns (*P. esculentus*), the number of prawns measured was consistently high relative to past surveys. In February 2011, ≤70% of the usual catch of brown tiger prawns were recorded, while in July 2011 ~ 50% was recorded.

As in most other years since 2005, good catches of grooved tiger prawns were taken in July 2011 (4096 prawns) and February 2011 (13690 prawns). 2005 was the first year when the survey was undertaken in July rather than August. There was concern that grooved tiger prawns may remain offshore in July on their annual migration to deeper waters (Somers and Kirkwood 1991). However, the greatest number of grooved tiger prawns of any survey was measured in July 2006 (8138 prawns). Less than 3000 grooved tiger prawns were caught in 2008, which was about half caught in most other years.

The mean size of the prawns reported in July 2009 and caught in July 2011 was similar (Table 8). Grooved tiger prawns averaged 1 mm CL larger in 2011 than 2009. Red spot king prawns averaged 7 mm CL larger in 2011 than 2009. Significantly, the average size of the prawns caught in July seems to be smaller than prawns caught in August prior to 2005. For example, the size of both species of tiger prawns was > 37 mm CL in 2002-2004. Since 2005 their average sizes have been < 37 mm (except for brown tiger prawns in 2005) (Table 7 and Table 8). Similarly, the size of endeavour prawns caught in July 2005-2011 is mostly smaller than
those caught in August 2002-2004. In 2011, the size range of prawns measured was large (Table 8); the smallest tiger prawns (both *Penaeus esculentus* and *Penaeus semisulcatus*) measured were about 13 mm CL and the largest were about 57 mm CL. The mean size of all prawn species measured in July was larger than in the previous January; demonstrating that the stock has grown over the year; as would be expected given the life cycle of prawns in the NPF (Rothlisberg et al. 1985, Somers et al. 1987). The smallest prawns were caught during the ‘recruitment’ survey in January each year, following their spawning in the previous spring.

Table 7: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in July 2007 and July 2008.

<table>
<thead>
<tr>
<th>Species</th>
<th>July 2007</th>
<th>July 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number measured</td>
<td>Mean</td>
</tr>
<tr>
<td><em>Penaeus esculentus</em></td>
<td>9333</td>
<td>35.8</td>
</tr>
<tr>
<td><em>Penaeus semisulcatus</em></td>
<td>5694</td>
<td>34.1</td>
</tr>
<tr>
<td><em>Metapenaeus endeavouri</em></td>
<td>5675</td>
<td>31.3</td>
</tr>
<tr>
<td><em>Metapenaeus ensis</em></td>
<td>499</td>
<td>31.8</td>
</tr>
<tr>
<td><em>Penaeus merguiensis</em></td>
<td>1052</td>
<td>33.5</td>
</tr>
<tr>
<td><em>Penaeus latisulcatus</em></td>
<td>2002</td>
<td>36.3</td>
</tr>
<tr>
<td><em>Penaeus longistylus</em></td>
<td>24</td>
<td>34.8</td>
</tr>
<tr>
<td><em>Penaeus monodon</em></td>
<td>4</td>
<td>46.9</td>
</tr>
</tbody>
</table>
Table 8: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in June/July 2009 and July 2011.

<table>
<thead>
<tr>
<th>Species</th>
<th>June/July 2009</th>
<th>July 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number measured</td>
<td>Mean</td>
</tr>
<tr>
<td><em>Penaeus esculentus</em></td>
<td>9646</td>
<td>35.2</td>
</tr>
<tr>
<td><em>Penaeus semisulcatus</em></td>
<td>3653</td>
<td>33.2</td>
</tr>
<tr>
<td><em>Metapenaeus endeavouri</em></td>
<td>5200</td>
<td>30.7</td>
</tr>
<tr>
<td><em>Metapenaeus ensis</em></td>
<td>162</td>
<td>28.3</td>
</tr>
<tr>
<td><em>Penaeus merguiensis</em></td>
<td>563</td>
<td>33.0</td>
</tr>
<tr>
<td><em>Penaeus latisulcatus</em></td>
<td>966</td>
<td>34.7</td>
</tr>
<tr>
<td><em>Penaeus longistylus</em></td>
<td>7</td>
<td>29.6</td>
</tr>
<tr>
<td><em>Penaeus monodon</em></td>
<td>7</td>
<td>46.0</td>
</tr>
</tbody>
</table>

The sizes of prawns caught in February 2011 were not substantially different from those caught in February 2010 (Table 10). The exceptions were grooved tiger prawns (*P. semisulcatus*) and red-tailed endeavour prawns (*M. ensis*) which were 2 mm CL smaller and 4 mm CL larger in 2011 than in 2010 (respectively). Also, red spot king prawns averaged 3 mm CL larger in 2011 than 2010.

A review of the length/frequency information for each prawn species shows the contribution of the annual recruitment of stock to the fishery later in 2011 (no survey was undertaken in July 2010). For both species of tiger prawns, in 2011, the contribution of the summer recruits to the winter/spring fishery stock can be seen from the survey results for January and July. The prawns have grown from about 20-36 mm CL for males and 20-39 mm CL for females in summer, to about 27-37 mm CL for males and 32-46 mm CL for females in July (Figure 51). For both species, there were larger cohorts of females in January, but few remained by July. For grooved tiger prawn, likely three cohorts of both males and females were evident in some regions in January.

The size composition of prawns caught for each species is slightly different for each region, but the predominant seasonal patterns can be clearly seen at north Groote Eylandt. In January 2010 and 2011, the majority of brown tiger prawns (*Penaeus esculentus*) in the population were small (length frequency mode of 28/29 mm CL for males and 34 mm CL for females). These prawns were derived from spawning occurring in the last half of the previous year (Figure 51a and Figure 51e). By July of each year, the length frequency mode of the prawns
had increased to 30/31 mm CL for males and >39 mm CL for females at the shallow sites, and 33 mm CL for males and >38 mm CL for females at the deep sites. The increase in size represents the subsequent growth of the prawns that were present in the population in January (indicated by the arrows on Figure 51). This can clearly be seen from the survey samples in July (Figure 51e and Figure 51f). The male grooved tiger prawns at the shallow strata are about 2 mm CL smaller than those in the deeper strata. The arrows indicating growth of the cohorts need to be treated with caution; they are an estimate of likely growth, in addition to migration of prawns between shallow and deep water sites.

As in previous years, some large year-old prawns were present in the population in January. Examples can be seen for both brown and grooved tiger prawns from January 2010 and 2011. Grooved tiger prawns at north Groote and brown tiger prawns at east Mornington provide the best examples (Figure 52 and 51). In January, two to three cohorts of both male and female prawns are present in the population. The oldest cohort represents a small portion of the population; the majority of prawns being new recruits from the previous spring spawning (Figure 51 and Figure 52).

Table 9: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in February 2008 and February 2009.

<table>
<thead>
<tr>
<th>Species</th>
<th>February 2008</th>
<th>February 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mean</td>
</tr>
<tr>
<td>Penaeus esculentus</td>
<td>11116</td>
<td>30.8</td>
</tr>
<tr>
<td>Penaeus semisulcatus</td>
<td>11431</td>
<td>29.8</td>
</tr>
<tr>
<td>Metapenaeus endeavouri</td>
<td>5526</td>
<td>28.1</td>
</tr>
<tr>
<td>Metapenaeus ensis</td>
<td>1568</td>
<td>30.1</td>
</tr>
<tr>
<td>Penaeus merguiensis</td>
<td>4487</td>
<td>29.8</td>
</tr>
<tr>
<td>Penaeus latisulcatus</td>
<td>1186</td>
<td>33.8</td>
</tr>
<tr>
<td>Penaeus longistylus</td>
<td>31</td>
<td>33.1</td>
</tr>
<tr>
<td>Penaeus monodon</td>
<td>111</td>
<td>39.6</td>
</tr>
</tbody>
</table>
Table 10: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in February 2010 and February 2011.

<table>
<thead>
<tr>
<th>Species</th>
<th>February 2010</th>
<th>February 2011</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Number measured</td>
<td>Mean</td>
</tr>
<tr>
<td><em>Penaeus esculentus</em></td>
<td>10643</td>
<td>30.3</td>
</tr>
<tr>
<td><em>Penaeus semisulcatus</em></td>
<td>13988</td>
<td>29.4</td>
</tr>
<tr>
<td><em>Metapenaeus endeavouri</em></td>
<td>5902</td>
<td>27.8</td>
</tr>
<tr>
<td><em>Metapenaeus ensis</em></td>
<td>2111</td>
<td>22.6</td>
</tr>
<tr>
<td><em>Penaeus merguiensis</em></td>
<td>8250</td>
<td>25.6</td>
</tr>
<tr>
<td><em>Penaeus latisulcatus</em></td>
<td>1057</td>
<td>33.8</td>
</tr>
<tr>
<td><em>Penaeus longistylus</em></td>
<td>59</td>
<td>30.3</td>
</tr>
<tr>
<td><em>Penaeus monodon</em></td>
<td>66</td>
<td>44.1</td>
</tr>
</tbody>
</table>

The pattern of size and growth for grooved tiger prawns (*P. semisulcatus*) at North Groote was different to those for brown tiger prawns (*P. esculentus*). In both January 2010 and 2011, the grooved tiger prawn population was comprised of both a majority of new recruits and some large individuals from the previous year. Compared to the size range of brown tiger prawns, there was a much larger proportion of small recruits (< 28 mm CL) in January in both years (Figure 52). The smaller grooved tiger prawn recruits may be determined by the smaller size that they leave their seagrass nursery habitats (Kenyon et al. 2004). Annually, the January recruits grow and contribute to the population of large prawns in July.

The size of prawns in the population of each region varies little annually. For example, the size of large female grooved tiger prawns (*P. semisulcatus*) at North Groote has varied by 1-2 mm over the 10 years of study. In July 2011, the mode in the deep water sites was 39 mm CL. In 2008, the mode was 38 mm CL, while 2009 had two modes at 36 and 40 mm CL. In 2005 the mode was 38 mm CL. Male prawns show similar low variation. The size is smaller compared to trawls undertaken in August in 2002, 2003 and 2004 with a mode of 40, 45 and 42 mm CL, respectively. The 2005-11 surveys were conducted in July, not August as for the early surveys, so animals had less time to grow. Given consistent trawl months, the size of grooved and brown tiger prawns varies by 1 to 2 mm CL only between years.
Figure 51: Percentage length frequency distribution of brown tiger prawns (*Penaeus esculentus*) at shallow and deep sites at North Groote in January 2010, January 2011 and July 2011. Note the different scales for each six-monthly set of data.
Figure 52: Percentage length frequency distribution of grooved tiger prawns (*Penaeus semisulcatus*) at shallow and deep sites at North Groote in January 2010, January 2011 and July 2011. Note the different scales for each six-monthly set of data.
Figure 53: Percentage length frequency distribution of blue endeavour prawns (*Metapenaeus endeavouri*) at shallow and deep sites at North Groote in January 2010, January 2011 and July 2011. Note the different scales for each six-monthly pair of figures.
At north Groote Eylandt, the pattern of recruitment for blue endeavour prawns 
(*M. endeavouri*) were similar to the two tiger species (Figure 53). Blue endeavour prawns 
(*M. endeavouri*) recruit to the fishing grounds in summer, following a spring/early summer 
spawning during the previous year. Endeavour prawns are generally smaller than tiger 
prawns, reflected in their size frequency distribution. In January 2010 and 2011 there were 
two cohorts of recruits at the shallow and deep water sites, although the trend was less clear at 
the deep water sites. In 2010, the presence of three cohorts of females was clear. The pattern 
suggests that two major peaks of recruitment can occur in the fishing grounds from inshore 
nursery grounds. In July 2011, the growth of the January recruits is evident by the presence of 
a strong cohort of significantly larger adult prawns in the fishery population in July. Unlike 
the tiger prawn populations, only a handful of large females survived for longer than one year 
of age; i.e. from the July survey to the following January survey.
Figure 54: Percentage length frequency distribution of brown tiger prawns (*Penaeus esculentus*) over all shallow and deep sites at East Mornington Island in January 2010, January 2011 and July 2011. Note the different scales for one six-monthly set of figures.
The size composition of prawns in the brown tiger prawn (*P. esculentus*) population around Mornington Island in January shows both new recruits and larger prawns from the previous year in all areas. At east Mornington, there was a higher proportion of large prawns in the population in both January 2010 and 2011 (Figure 54). The larger prawns are survivors from the fishery the previous year. By July each year, the January recruits had grown and contributed to the fishery stocks, both in the shallow and the deep strata.

At both east and west Mornington, the size distributions of brown tiger prawns (*P. esculentus*) showed there were two cohorts of recruits in both the male and female populations in the January of both years (Figure 55). This seems to be from two distinct cohorts of recruits in respective years, not surviving prawns from the previous years. At east and west Mornington in 2011, the contribution of the January recruits to the fishery stock in July is clear. The size distribution of the stock is larger in July due to growth of individual prawns, and the distribution of females and males separate as females grow larger.

In January during 2010/11, the north Mornington sites had the lowest number of brown tiger prawns and the lowest proportion of new recruits in the vicinity of Mornington Island. North Mornington is generally a deeper region than either east or west Mornington. In both years there were both recruits and large prawns at north Mornington (a broad spread of size classes). The low numbers of prawns, including recruits, suggest that the brown tiger prawns move to this area from elsewhere over the period from January to July. By July, relative high numbers of large prawns are found at both the shallow and deep sites (Figure 56). The tight July cohort for both males and females shows that small prawns are not common in these relatively deeper waters at north Mornington. The differentiation between the modal size for males and females shows the differing rates of growth between the sexes.
Figure 55: Percentage length frequency distribution of brown tiger prawns (*Penaeus esculentus*) over all shallow and deep sites at West Mornington Island in January 2010, January 2011 and July 2011. Note the different scales for each six-monthly set of figures.
Figure 56: Percentage length frequency distribution of brown tiger prawns (*Penaeus esculentus*) over all shallow and deep sites at North Mornington Island in January 2010, January 2011 and July 2011. Note the different scales for one six-monthly set of figures.
7.3.2 Prawn maturity

A large proportion of the female prawns of each species that were measured in July 2008, June/July 2009 and July 2011 had visible (ripe) ovaries indicating that they were in reproductive condition (Table 11). The proportion of female brown tiger prawns (*P. esculentus*) that had visible ovaries was >50% except at the Vanderlins in 2008 and at East Mornington in 2011. In many regions 70-80% of prawns had visible ovaries. The proportion of female blue-tailed endeavour prawns (*M. endeavouri*) that had visible ovaries was variable over the regions and depths; at East Mornington only 9% had ripe ovaries in 2011; but most had from 20% to ~60% ripe. During 2008 to 2011, the proportion of female grooved tiger prawns (*P. semisulcatus*) that were ripe was lower than brown tiger prawns (i.e. often 20-50%); and lower than the proportion of ripe female grooved tiger prawns measured in the surveys that were undertaken in August (2002-2004) (see Ye *et al*. 2006). The lower proportion of ripe grooved tiger prawns caught in July compared to August is expected, given that Crocos (1987) showed that the months of peak spawning for grooved tiger prawns spawn were August/September each year. There was a higher proportion of ripe female grooved tiger prawns at the deep water sites, while the proportion of brown tiger prawns that were ripe did not differ markedly between the shallow and deep sites.

Table 11: The percentage of females measured with visible ovaries at each group of sites in July 2008, June/July 2009 and July 2011. Percentages were only included if at least 50 females were measured.

<table>
<thead>
<tr>
<th></th>
<th>Brown tiger prawns</th>
<th>Grooved tiger prawns</th>
<th>Blue endeavour prawns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Penaeus esculentus</em></td>
<td><em>Penaeus semisulcatus</em></td>
<td><em>Metapenaeus endeavouri</em></td>
</tr>
<tr>
<td>Shallow</td>
<td>Deep</td>
<td>Shallow</td>
<td>Deep</td>
</tr>
<tr>
<td>08 09 11</td>
<td>08 09 11</td>
<td>08 09 11</td>
<td>08 09 11</td>
</tr>
<tr>
<td>North Groote</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>83 59 72</td>
<td>- 72 83</td>
<td>60 37 42</td>
<td>72 54 61</td>
</tr>
<tr>
<td>South Groote</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>87 71 74</td>
<td>-  - -</td>
<td>46 11 33</td>
<td>57 59 44</td>
</tr>
<tr>
<td>W. Vanderlins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77 83 95</td>
<td>-  - -</td>
<td>27 20 28</td>
<td>61 47 72</td>
</tr>
<tr>
<td>Vanderlins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46 77 93</td>
<td>- 68 -</td>
<td>3 2 -</td>
<td>48 33 68</td>
</tr>
<tr>
<td>E. Vanderlins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82 87 85</td>
<td>80 89 90</td>
<td>-  - 48</td>
<td>71 68 74</td>
</tr>
<tr>
<td>W. Mornington</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>68 76 60</td>
<td>64 78 63</td>
<td>- 41 49</td>
<td>44 57 57</td>
</tr>
<tr>
<td>N. Mornington</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71 86 74</td>
<td>64 80 61</td>
<td>-  -  -</td>
<td>-  - 87 84 60</td>
</tr>
<tr>
<td>E. Mornington</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>69 67 47</td>
<td>87 76 75</td>
<td>-  -  -</td>
<td>-  - 13 17 9</td>
</tr>
</tbody>
</table>

In February 2009, 2010 and 2011, the proportion of ripe females of each species was generally less than that found in the July surveys, particularly for grooved tiger prawns (*P. semisulcatus*) in the shallow strata (Table 12). There was no consistent pattern across regions from 2009 to 2011. Compared to the July surveys, the lower proportion of ripe females in the populations is consistent with the high number of immature recruits in the populations in January. Banana prawns (*P. merguiensis*) were only sampled extensively in January and the proportion of ripe females varied considerably between year and region (0.5-66%). The differences in the proportions of spawners between brown tiger prawns (*P. esculentus*) and grooved tiger prawns...
were consistent with the results of the CSIRO study at Groote Eylandt in 1983 to 1985, where brown tiger prawns were shown to mature at a smaller size and have a less seasonal pattern of spawning (Crocos 1987).

Table 12: The percentage of females measured with visible ovaries for brown tiger prawns (*Penaeus esculentus*) and grooved tiger prawns (*Penaeus semisulcatus*) at each group of sites in February 2009, 2010 and 2011. Percentages were only included if at least 50 females were measured.

<table>
<thead>
<tr>
<th></th>
<th>Brown tiger prawns</th>
<th>Grooved tiger prawns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Penaeus esculentus</em></td>
<td><em>Penaeus semisulcatus</em></td>
</tr>
<tr>
<td>Shallow</td>
<td>Deep</td>
<td>Shallow</td>
</tr>
<tr>
<td>North Groote</td>
<td>64.3 73.6 68.5</td>
<td>25.5 33.3 31.0</td>
</tr>
<tr>
<td>South Groote</td>
<td>60.8 64.3 77.8</td>
<td>60.9 55.5 76.9</td>
</tr>
<tr>
<td>West Vanderlins</td>
<td>67.6 65.2 47.8</td>
<td>34.8 47.5 18.4</td>
</tr>
<tr>
<td>East Vanderlins</td>
<td>76.4 55.0 44.1</td>
<td>31.3 31.4 12.2</td>
</tr>
<tr>
<td>West Mornington</td>
<td>58.4 51.6 33.3</td>
<td>56.2 58.7 38.7</td>
</tr>
<tr>
<td>North Mornington</td>
<td>52.3 40.5 -</td>
<td>35.4 50.0 18.7</td>
</tr>
<tr>
<td>East Mornington</td>
<td>30.7 31.3 37.9</td>
<td>42.8 31.6 58.9</td>
</tr>
<tr>
<td>West Karumba</td>
<td>- 0.0 2.5</td>
<td>25.7 6.9 45.2</td>
</tr>
<tr>
<td>East Karumba</td>
<td>- - -</td>
<td>57.1 6.6 64.</td>
</tr>
<tr>
<td>South Weipa</td>
<td>- - -</td>
<td>- - -</td>
</tr>
<tr>
<td>North Weipa</td>
<td>- - -</td>
<td>- - -</td>
</tr>
</tbody>
</table>

Table 13: The percentage of females measured with visible ovaries for blue endeavour prawns (*Metapenaeus endeavouri*) and banana prawns (*Penaeus merguiensis*) at each group of sites in February 2009, 2010 and 2011. Percentages were only included if at least 50 females were measured.

<table>
<thead>
<tr>
<th></th>
<th>Blue endeavour prawns</th>
<th>Banana prawns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Metapenaeus endeavouri</em></td>
<td><em>Penaeus merguiensis</em></td>
</tr>
<tr>
<td>Shallow</td>
<td>Deep</td>
<td>Shallow</td>
</tr>
<tr>
<td>North Groote</td>
<td>38.4 75.8 54.3</td>
<td>40.0 58.7 29.5</td>
</tr>
<tr>
<td>South Groote</td>
<td>26.9 48.0 47.8</td>
<td>44.6 53.5 63.7</td>
</tr>
<tr>
<td>West Vanderlins</td>
<td>48.5 74.0 46.7</td>
<td>44.0 34.6 40.0</td>
</tr>
<tr>
<td>East Vanderlins</td>
<td>41.8 75.8 49.2</td>
<td>56.8 29.0 50.0</td>
</tr>
<tr>
<td>West Mornington</td>
<td>61.2 66.0 38.8</td>
<td>50.0 58.3 28.8</td>
</tr>
<tr>
<td>North Mornington</td>
<td>53.6 39.1 64.6</td>
<td>33.8 36.1 58.3</td>
</tr>
<tr>
<td>East Mornington</td>
<td>45.7 45.9 55.3</td>
<td>40.2 14.3 46.3</td>
</tr>
<tr>
<td>West Karumba</td>
<td>29.3 2.8 46.4</td>
<td>14.3 - 35.8</td>
</tr>
<tr>
<td>East Karumba</td>
<td>- - -</td>
<td>- - -</td>
</tr>
<tr>
<td>South Weipa</td>
<td>- - -</td>
<td>38.5 6.3</td>
</tr>
<tr>
<td>North Weipa</td>
<td>- - -</td>
<td>59.5 26.5 42.1</td>
</tr>
</tbody>
</table>

7.3.3 Parasites

Bopyrid parasites can potentially have an impact on prawn populations as they make the prawns that they infest sterile (Somers & Kirkwood 1991). Two prawn species commonly
were found with bopyrid parasites (grooved tiger prawns (*P. semisulcatus*), banana prawns (*P. merguiensis*, Table 14). Data for brown tiger prawns (*P. esculentus*) have also been tabulated. The infestation rate of brown tiger prawns is less than 0.6%; which is low, but infestation was more widespread than red-tailed endeavour prawns. As in past reports, in both January and July 2009-2011, grooved tiger prawns (*P. semisulcatus*) had the highest infection rate in the shallow waters of North Groote. The highest percentage infected was in January 2009 (13%).

Over recent years, very few red-tailed endeavour prawns (*M. ensis*) were infected with bopyrid parasites (0.7% and 0.5% at north Groote in January 2009 and July 2011). In the early 2000’s, up to 12% of red-tailed endeavour prawns had bopyrid parasites. From July 2008 to July 2011, very few blue-tailed endeavour prawns (*M. endeavouri*) in the regions surveyed were infested, and the percentage infestation was very low, mostly from 0.1 to 0.5%. In July 2011, one of 14 (7%) banana prawns (*P. merguiensis*) was infected.


<table>
<thead>
<tr>
<th></th>
<th><em>Penaeus semisulcatus</em></th>
<th></th>
<th><em>Penaeus esculentus</em></th>
<th></th>
<th><em>Penaeus merguiensis</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>February</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Groote</td>
<td>13.2</td>
<td>4.7</td>
<td>9.1</td>
<td>5.8</td>
<td>0.7</td>
</tr>
<tr>
<td>South Groote</td>
<td>-</td>
<td>-</td>
<td>3.6</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>West Vanderlins</td>
<td>0.1</td>
<td>-</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>East Vanderlins</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>West Mornington</td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Mornington</td>
<td></td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Mornington</td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Karumba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Karumba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Weipa</td>
<td>5.4</td>
<td>2.0</td>
<td>1.0</td>
<td>1.4</td>
<td>0.8</td>
</tr>
<tr>
<td>South Weipa</td>
<td>5.4</td>
<td>2.2</td>
<td>1.0</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>July</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Groote</td>
<td>5.3</td>
<td>4.1</td>
<td>3.9</td>
<td>5.9</td>
<td>3.4</td>
</tr>
<tr>
<td>South Groote</td>
<td>1.2</td>
<td>0.8</td>
<td>0.4</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td>West Vanderlins</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>East Vanderlins</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td>West Mornington</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>North Mornington</td>
<td>-</td>
<td>-</td>
<td></td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>East Mornington</td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4 Conclusions

1. The January survey has been successful in sampling smaller prawns recruiting to the fishery.
2. Both the January and July surveys show low numbers of brown tiger prawns that are reflected in a low spawning index for July 2011 (see Chapter 5).
3. The July survey has been successful in sampling mature and spawning prawns in the fishery. The numbers of grooved tiger prawns found during the July 2008 and 2009 surveys were the lowest caught in any mid-year survey. Numbers increased in 2011. The proportion of grooved tiger prawns that are mature and ripe in July seems to be less than a month later in August.
4. Although January is a time of recruitment of new prawns to the fishing grounds, there are still some year-old prawns present in the populations.
5. For tiger and endeavour prawns in both 2008 and 2009, a clear relationship between recruitment in January and the growth of these animals to contribute to the subsequent August fishery population exists in many regions.
6. A long term series of the two surveys provides a good link between recruitment and subsequent stock.
7. The size frequency distributions of each prawn species were remarkably similar between years for recruitment in January, suggesting that there was consistency in the timing of recruitment to the fishery between years in 2010/11.

7.5 References


Ye, Y., Dichmont, C.M., Kenyon, R., Burridge, C., Pendrey, R., Van Der Velde, T., Vance, D., Bishop, J., Evans, F. and Donovan, A. 2006. An integrated monitoring program for the Northern Prawn Fishery: assessing the design and developing techniques to incorporate survey results into fishery assessment. FRDC 2004/099. CSIRO Marine Research, Cleveland, Australia.
CHAPTER 8. BYPRODUCT SPECIES

8.1 Introduction

The NPF monitoring project conducted two surveys during summer and winter 2011 to estimate prawn recruitment and spawning stock abundance. These surveys were designed to obtain reliable indices of abundance for six species of prawn. However, several species other than prawns were also caught. Information on these “byproduct” species were recorded to characterize the ecosystem associated with the prawn fishery in the Gulf of Carpentaria, as required by the Strategic Assessment Provisions of the Environment Protection and Biodiversity Conservation Act 1999.

The most frequently caught byproduct species during the surveys (Figure 57, Table 15) were: several species of cephalopods grouped into two families: Sepiidae (cuttlefish) and Loliginidae (squid), two species of scallop, the mud scallop (Amusium pleuronectes) and the fan scallop (Annachlamys flabellata); two species of bugs, the mud bug (Thenus parindicus) and the sand or reef bug (Thenus australiensis). Records were analysed to describe the spatial distribution, density trends and length structure of these species or group of species.

Figure 57: Proportion of the number of individual, by species, caught during the surveys.
<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Thenus parindicus</em></td>
<td>95.3</td>
</tr>
<tr>
<td>Sepiidae - undifferentiated</td>
<td>94.87</td>
</tr>
<tr>
<td><em>Penaeus esculentus</em></td>
<td>87.01</td>
</tr>
<tr>
<td>Amusium pleuronectes</td>
<td>86.66</td>
</tr>
<tr>
<td><em>Metapenaeus endeavouri</em></td>
<td>85.48</td>
</tr>
<tr>
<td><em>Penaeus semisulcatus</em></td>
<td>72.93</td>
</tr>
<tr>
<td>Loliginidae - undifferentiated</td>
<td>62.44</td>
</tr>
<tr>
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</tr>
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<td><em>Penaeus merguiensis</em></td>
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</tr>
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<td><em>Annachlamys flabellata</em></td>
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<tr>
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</tr>
<tr>
<td><em>Thenus australiensis</em></td>
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</tr>
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<td>Hydrophiidae - undifferentiated</td>
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</tr>
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</tr>
<tr>
<td><em>Penaeus monodon</em></td>
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<td>Order Octopoda - undifferentiated</td>
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<td><em>Anoxypristis cuspidata</em></td>
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</tr>
<tr>
<td>Chelonidae - undifferentiated</td>
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</tr>
<tr>
<td><em>Syngnathoides biaculentus</em></td>
<td>0.21</td>
</tr>
<tr>
<td><em>Pristis microdon</em></td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 15: Percentage of sampling sites (n=516) where each particular species or group of species were caught.

8.2 Data collection and analysis

At every trawling station, the number of individuals from each byproduct species caught was counted. Individual weight and length were measured for all species but cephalopods; for which, only the combined weight from all individuals was recorded. Large catches were sub-sampled; and total numbers of individual caught were subsequently estimated by raising the sub-sample count with the ratio of weight of the total catch to the sub-sample.

The gear used for sampling at each station was a twin trawl. On rare occasions, only catch from one net was processed. Seldom, only total weights or only total numbers in the catch by species were recorded. Missing records were imputed using the following method to convert between mass and numbers:

1. When only total weights by species were recorded from one net, the total number of individuals belonging to that species was calculated using individual mean weights measured from the sample taken with the second net.

2. When only total weights by species were recorded from both nets, total numbers of individuals for that species were calculated using the average individual weight by species in the same region.

Species densities, in number per hectare of swept area, at each trawling station were calculated and plotted to present the spatial distribution of each byproduct species population. Histograms of all survey sites densities showed that the distribution of this variable were skewed as expected from measures of relative abundance of biological organisms (White et al., 1996). Therefore quantiles of density distribution (2.5, 50 and
97.5 percentiles) were used to summarize the data. Individual mean weights per haul were also displayed to identify spatial variation of size in these populations.

Length measurements were collected for all species except cephalopods. Length frequency distributions, combining all regions, were plotted for each survey to provide some insight into their size and age composition.

8.3 Results

8.3.1 General distribution

By-product species were widely distributed throughout the NPF and all recorded species are common in the Gulf of Carpentaria. Two species or species groups were found at over 90% of sites trawled: Sepiidae (cuttlefish) and T. parindicus (mud bug). The mud scallop A. pleuronectes and Loliginidae (squid) were found at >60% of trawl sites. The remaining species were found at <50% of trawl sites. Some such as A. flabellata (fan scallop) and T. australiensis (reef bug) were quite common, being found at 27% and 19% of sites, respectively. Seasnakes were found at about 11% of sites, while sawfish were found at <2% of trawl sites.

8.3.2 Scallops

Two scallop species were recorded during the surveys: mud scallop (Amusium pleuronectes) and fan scallop (Annachlamys flabellata). A. pleuronectes was caught at 87% of all sites sampled while A. flabellata was present in 27% of them (Table 15). Both species were present in all five regions of the Gulf of Carpentaria.

8.3.2.1 Mud scallop (Amusium pleuronectes)

In 2011, mud scallops were widely distributed in the survey area (Figure 58 and Figure 59). Mean densities ranged from 5.1± 0.7 individuals ha⁻¹ to 79.9±15.3 individuals ha⁻¹ at Karumba and Weipa, respectively. They were found at high densities in Groote and Mornington as well. The densities of mud scallops varied with depth and they were sparse or absent from Karumba and Weipa inshore sites.

Overall, densities in summer were higher than winter (for example at Groote Island, (69.3± 9.8 individuals ha⁻¹ in summer to 27.5±6.3 individuals ha⁻¹ in winter; and at Mornington 24.1± 6.9 individuals ha⁻¹ in summer to 12.7±3.6 individuals ha⁻¹ in winter) (Figure 60). There is no evidence of a decline in median densities through time, although they fluctuate significantly over the regions (Figure 60). No pattern of scallop density with depth common to all regions could be identified. In general, high densities lay between 10 and 40 meters of depth, but in some regions they were common at 40-50 m depth (Figure 61).

The distribution of the mud scallop shell length were unimodal (Figure 63) with lengths ranging between approx. 25 mm to 80 mm. Mud scallops were smaller in summer than in winter. Large scallops were caught at Groote in winter and Karumba in summer.
Figure 58 Spatial distribution of mud scallop (*Amusium pleuronectes*) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 59 Spatial distribution of mud scallop (*Amusium pleuronectes*) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 60 Time series of mud scallop (*Amusium pleuronectes*) densities by season and region.

Figure 61 Mud scallop (*Amusium pleuronectes*) densities at depth by season and region.
Figure 62 Time series of mud scallop (*Amusium pleuronectes*) individual mean weight per haul by season and region.
Figure 63 Mud scallop (*Amusium pleuronectes*) length frequency distributions.
Figure 64 Spatial distribution of fan scallop (*Annachlamys flabellata*) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 65 Spatial distribution of fan scallop (*Annachlamys flabellata*) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 66 Time series of fan scallop (*Annachlamys flabellata*) densities by season and region.

Figure 67 Fan scallop (*Annachlamys flabellata*) densities at depth by season and region.
Figure 68 Time series of fan scallop (*Annachlamy flabellata*) individual mean weight per haul by season and region.

Figure 69 Fan scallop (*Annachlamy flabellata*) mean weight at depth by season and region.
8.3.2.2 Fan scallop (*Annachlamys flabellata*)

This species was present at approximately one third of the site sampled (Table 15). It was present in all regions of the Gulf (Figure 64 and Figure 65), often at very low densities, ranging from $0.22\pm0.02$ to $8.88\pm1.16$ individuals ha$^{-1}$. Largest densities were found north of Mornington Island and in the vicinity of the Sir Edward Pellew Islands (Vanderlins) in summer (Figure 64 and Figure 65). Densities were higher in summer ($4.15\pm1.5$ ind ha$^{-1}$) than in winter ($1.13\pm0.53$ ind ha$^{-1}$).

No trend in the time series of densities was evident (Figure 66). Densities appeared to be larger between 20 to 40 m depth (Figure 67).

Individual mean weight per haul of *A. flabellata* ranged from $11.66\pm0.91$ g at Weipa to $23.93\pm8.09$ g at Groote in summer (Figure 64 and Figure 65). Median weights were larger in winter than in summer (Figure 68). No clear pattern of weight at depth could be indentified: in the majority of cases, it appeared constant (Figure 69).

*Annachlamys flabellata*’s shell length ranged approximately from 25 mm to 60 mm in summer (Figure 70). Few shells less than 35 mm were present in winter. Length distributions were uni-modal. Smaller sized recruits were much more frequent in summer. The mode of each distribution was around 40 mm in summer and 45-50 mm in winter. This shift suggests that summer surveys captured new recruits.
8.3.3 Bugs

Among three species of bugs recorded in the surveys, mud bugs (*Thenus parindicus*) and reef bugs (*Thenus australiensis*) were the most abundant (Table 15). The third species, *Thenus* sp., had only a few records and its distribution is not presented here.

8.3.3.1 Mud bugs (*Thenus parindicus*)

Mud bugs were the most frequently caught species: they were present at 95% of the sampling sites (Table 15). Their densities ranged between 0.16±0.04 to 15.48±0.77 individuals ha\(^{-1}\) (Figure 71 and Figure 72). Largest densities were found in Karumba; 10.02±1.39 individuals ha\(^{-1}\) (Figure 73). The lowest densities of 2.49±0.27 and 3.01±0.34 individuals ha\(^{-1}\) were recorded in Groote and Vanderlins, respectively. Densities appeared to have declined around Mornington in the past decade (Figure 73). They seem to have increased in Weipa. Mud bug density tended to decrease with depth in all regions except Weipa where the trend was less clear (Figure 74).

Mean weights per haul were higher in winter than summer (for example 102.47±2.93 compared to 94.11±2.84 grams at Groote and 78.47±2.36 compared to 75.38±2.65 grams at Vanderlins respectively) (Figure 75). Often in summer, median weight increased with depth: a less clear pattern seen in winter. Large individuals were often found north of Groote (Figure 71 and Figure 72).

Depth did not appear to influence mean weights in winter (Figure 75). But larger individuals were caught deeper in summer in Mornington and Vanderlins regions.

Reef bugs carapace length (CL) ranged between 20 and 70 mm. The length frequency distributions appeared to be bimodal in summer with a mode around 30 mm and a second one around 55 mm (Figure 76). The first mode disappeared in winter, which suggests that mud bugs recruit annually in spring or summer.

8.3.3.2 Reef bug (*Thenus australiensis*)

Reef bugs (*Thenus australiensis*) are less common than the mud bugs in the Gulf of Carpentaria. They were present in 19% of all the survey samples (Table 15). Densities varied between 0.15±0.01 and 0.82±0.17 individuals ha\(^{-1}\) (Figure 77 and Figure 78). Reef bug’s largest densities were recorded in Weipa and were almost absent from Karumba. Densities increased with depth at Weipa, or did not vary with it in other regions (Figure 79). There was no trend in abundance over time.

Mean weight per haul ranged from 25.5±2.17 grams in shallow waters at Weipa to 162.0±22.67 grams in shallow waters at Vanderlins. The reef bug’s size range was larger in winter than in summer (Figure 80). In general, median weight tended to increase with depth (Figure 81). Smaller individuals were generally found throughout the whole depth range sampled.

Reef bugs carapace length (CL) ranged between 20 and 80+ mm. (Figure 82). Length frequency distributions (LFD) showed that smaller individuals were more frequent in summer than in winter which suggests recruitment occurred at the beginning of each year. Large individuals in the 70-80 mm CL range were found throughout the study area in summer and winter. The number of length measurements collected for reef bug was small compared to mud bugs; therefore it is difficult to precisely describe the modes of the LFD. However, there was a mode in size around 30-40 mm CL in summer, with a few large individuals up to 70 – 80 mm CL. Large individuals are mainly caught in winter.
Figure 71 Spatial distribution of mud bug (*Thenus parindicus*) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 72 Spatial distribution of mud bug (*Thenus parindicus*) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 73 Time series of mud bug (*Thenus parindicus*) densities by season and region.

![Figure 73](image)

Figure 74 Mud bug (*Thenus parindicus*) density variation at depth by season and region.

![Figure 74](image)
Figure 75 Mud bug (*Thenus parindicus*) mean weight at depth by season and region.
Figure 76 Mud bug (*Thenus parindicus*) carapace length frequency distribution by survey.
Figure 77 Spatial distribution of reef bug (*Thenus australiensis*) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 78 Spatial distribution of reef bug (*Thenus australiensis*) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
### Figure 79 Reef bug (*Thenus australiensis*) density at depth by season and region.

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</tbody>
</table>

### Figure 80 Reef bug (*Thenus australiensis*) mean weight time series by season and region.

<table>
<thead>
<tr>
<th>Region</th>
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<td>Weipa</td>
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</tbody>
</table>

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Northern Prawn Fishing Monitoring
Figure 81 Reef bug (*Thenus australiensis*) mean weight at depth by season and region.
8.3.4 Cephalopods

Cephalopods caught during the NPF survey were not identified at the species level due to time constraints. Instead, they were grouped into two families: Sepiidae (cuttlefish) and Loliginidae (squid). Dunning et al. (1994) recorded five taxa of loliginid squids and seven of cuttlefishes from scientific surveys carried in the Gulf of Carpentaria between 1990 and 1991.

8.3.4.1 Cuttlefish (Sepiidae)

The Sepiidae family includes numerous species (more than 100) that live in tropical, subtropical and temperate waters in all oceans and seas except the coasts of the Americas (Adam and Rees 1966). Sepiids are benthic or benthopelagic, and are incidentally caught in prawn fishing.

Sepiidae were caught at 95% of all sites visited during the 2011 surveys (Table 15). They were distributed across the entire study area (Figure 83 and Figure 84) with densities ranging between 0.38±0.01 and 4.01±0.19 individuals ha⁻¹; while the upper and lower densities were found in the shallow and deep waters at Weipa. Cuttlefishes were more abundant in summer than winter (Figure 85). To 2010, their densities increased in recent year in several regions of the Gulf of Carpentaria, yet declined in 2011. In general in 2011, cuttlefish density increased with depth (Figure 86).
The mean weight of cuttlefish catch per trawl is much the same in summer and winter, and between region; it varies between 50 and 67 grams. For example, cuttlefish catches at Mornington were 61.25±2.89 grams in summer and 56.02±3.54 grams in winter. Each region contained a mixture of small and large individuals (Figure 83 and Figure 84). Median weights of cuttlefishes were similar at all depths but their variances tended to decrease with increasing depth (Figure 87).
Figure 83 Spatial distribution of cuttlefish (*Sepiidae*) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 84 Spatial distribution of cuttlefish (Sepiidae) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 85 Time series of cuttlefish (*Sepiidae*) densities by season and region.

Figure 86 Cuttlefish (*Sepiidae*) density at depth by season and region.
Squid (Loliginidae)

Squid are benthic or benthopelagic organisms, incidentally caught during prawn fishing. Occasionally, their spawning aggregations are targeted by prawn fishers. They were caught in 62% of the samples collected across the Gulf of Carpentaria (Table 15). Densities varied between $0.33\pm0.01$ and $1.38\pm0.19$ individuals ha$^{-1}$. Squid abundances were lower at Groote and higher at Karumba and Mornington (Figure 88 and Figure 89). Higher densities were often recorded during winter (Figure 90). Squid were often more abundant in shallow water, except in winter at Weipa (Figure 91).

The mean weight of squid catch per trawl is much the same in summer and winter; it varies between 33 and 50 grams in summer and 26 and 56 grams in winter. There is more variation between regions that season. For example, squid catches at Mornington were $50.48\pm3.9$ grams in summer and $56.69\pm3.31$ grams in winter; while squid catches at Groote were $41.36\pm9.34$ grams in summer and $26.9\pm4.02$ grams in winter. Squid were not clearly segregated in space by size: samples from all regions contained a mixture of small and large individual mean size by haul (Figure 88 and Figure 89). No clear pattern of mean weight variation at depth is evident (Figure 92).
Figure 88 Spatial distribution of squid (Loliginidae) from winter 2009 and summer 2010 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 89 Spatial distribution of squid (*Loliginidae*) from summer 2011 and winter 2011 surveys. Top: catch rate (no/ha); bottom: individual mean weight (g).
Figure 90 Time series of squid (*Loliginidae*) densities by season and region.

**Loliginidae - undifferentiated**

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<thead>
<tr>
<th>Year</th>
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</tr>
</thead>
<tbody>
<tr>
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<td>Karumba</td>
</tr>
<tr>
<td>Summer</td>
<td>Summer</td>
</tr>
</tbody>
</table>

Figure 91 Squid (*Loliginidae*) density at depth by season and region.

**Loliginidae - undifferentiated**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Number per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>20-30</td>
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<tr>
<td>Groote</td>
<td>Karumba</td>
</tr>
<tr>
<td>Summer</td>
<td>Summer</td>
</tr>
</tbody>
</table>
Figure 92 Squid (*Loliginidae*) mean weight at depth by season and region.


8.4 Discussion

Several byproduct species are incidentally caught by fishermen when targeting prawns in the Gulf of Carpentaria (Wilson et al., 2009). The data from three groups of byproduct species (scallops, bugs and cephalopods) were presented in this section. Each data set contains one or a group of species that are commonly found across the entire Gulf of Carpentaria. Some are found at 60-90% of sites (e.g. Amusium pleuronectes, Thenus parindicus, Loliginidae, Sepiidae). Other species have spatial distributions which are more patchy (e.g. Annachlamys flabellata and Thenus australiensis).

The mud scallop (A. pleuronectes), the mud bug (T. parindicus), the brown tiger prawn (P. esculentus) and the blue endeavour prawn (M. endeavouri) often were present together in survey samples from the same site. These three species were very common in the survey area and were caught at more than 85% of all sampling sites. This association might result from their ability to adapt to the diversity of habitats found in the Gulf of Carpentaria. Milton et al. (2010) concluded that mud scallop did not appear to have a distinct sediment preference. And highest catches were made on either sand or mud substrates.

Some species were not commonly found together, for example reef bug (Thenus australiensis) which were present at offshore sites and squid (Loliginidae) which were caught at sites close to the coast. Such a situation could result from each species having specific habitat requirements, for example a requirement for a particular substrate or depth that are mutually exclusive and well separated in space at the scale of a trawl survey track. The survey data provide some evidence that Loliginidae were found preferentially in shallow water while reef bugs were more abundant in deeper water. Milton et al. (2010) reported that squids, especially smaller species, were more abundant in the shallower inshore areas of the Gulf where the substrate was predominately mud. On the other hand, reef bug (T. australiensis) showed a distinct preference for deep offshore water, greater than about 35—40 m deep and sites 60 or more nautical miles away from the coast (Milton et al., 2010).
References

Adam, W. and W.J. Rees, 1966, A review of the cephalopod family Sepiidae, British Museum (Natural History).


APPENDIX A: PLOTS OF CATCH RATES FOR THE JANUARY/FEBRUARY 2011 RECRUITMENT SURVEY

The following figures provide catch rates (numbers per hour-trawled and weight (kg) per hour trawled) and size distribution (count per lb) of prawns by species for each site:
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Brown tiger prawn catch rate (no/hr) at each site trawled during survey.

Brown Tiger Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria
Brown tiger prawn catch rate (kg/hr) at each site trawled during survey.

Brown Tiger Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Brown tiger prawn size count at each site trawled during survey.

Brown Tiger Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Grooved tiger prawn catch rate (no/hr) at each site trawled during survey.

Grooved Tiger Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

NT
Qld

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Grooved Tiger Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Grooved tiger prawn size count at each site trawled during survey.

Grooved Tiger Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Northern Prawn Fishing Monitoring

CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Blue endeavour prawn catch rate (no/hr) at each site trawled during survey.

Blue Endeavour Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Blue endeavour prawn catch rate (kg/hr) at each site trawled during survey.

Blue Endeavour Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Blue endeavour prawn size count at each site trawled during survey.

Blue Endeavour Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Australian Government
Australian Fisheries Management Authority

Red endeavour prawn catch rate (no/hr) at each site trawled during survey.

Red Endeavour Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Qld
NT
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Red endeavour prawn catch rate (kg/hr) at each site trawled during survey.

Red Endeavour Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Red endeavour prawn size count at each site trawled during survey.

**Red Endeavour Prawn Size Count (no/lb)**
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

**Gulf of Carpentaria**

**NT**

**Qld**
Total common banana prawn catch rate (no/hr) at each site trawled during survey.

Common Banana Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011 Preliminary Results

Australian Government
Australian Fisheries Management Authority

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – February 2011
Preliminary Results

Total common banana prawn catch rate (kg/hr)
at each site trawled during survey.

Common Banana Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Common banana prawn size count at each site trawled during survey.

Common Banana Prawn Size Count (no/lb)

- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

NT Qld
Western king prawn catch rate (no/hr) at each site trawled during survey.

Western King Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Western king prawn catch rate (kg/hr) at each site trawled during survey.

Western King Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

NT

Qld
Western king prawn size count at each site trawled during survey.

Western King Prawn Size Count (no/lb)
- 30+  
- 20 - 30  
- 15 - 20  
- 10 - 15  
- under 10  

Gulf of Carpentaria

NT  
Qld  

Northern Prawn Fishing Monitoring
APPENDIX B: PLOTS OF CATCH RATES FOR THE JULY 2011 SPAWNING SURVEY

The following figures provide catch rates (numbers per hour-trawled and weight (kg) per hour trawled) and size distribution (count per lb) of prawns by species for each site:
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Brown tiger prawn catch rate (no/hr) at each site trawled during survey.

- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

NT  Qld
Brown tiger prawn catch rate (kg/hr) at each site trawled during survey.

Brown Tiger Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

NT

Qld
Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Grooved tiger prawn catch rate (no/hr) at each site trawled during survey.

Grooved Tiger Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Grooved tiger prawn catch rate (kg/hr) at each site trawled during survey.

Grooved Tiger Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Grooved tiger prawn size count at each site trawled during survey.

Grooved Tiger Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research

NPF Monitoring Survey – July 2011
Preliminary Results

Blue endeavour prawn catch rate (no/hr) at each site trawled during survey.

Blue Endeavour Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Blue endeavour prawn catch rate (kg/hr) at each site trawled during survey.

Blue Endeavour Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Blue endeavour prawn size count at each site trawled during survey.

Blue Endeavour Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
Red endeavour prawn catch rate (no/hr) at each site trawled during survey.

Red Endeavour Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Red endeavour prawn catch rate (kg/hr) at each site trawled during survey.

Red Endeavour Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Qld

NT

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Red endeavour prawn size count at each site trawled during survey.

Red Endeavour Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

NT
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CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Total common banana prawn catch rate (no/hr)
at each site trawled during survey.

Common Banana Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

Northern Prawn Fishing Monitoring
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Total common banana prawn catch rate (kg/hr)
at each site trawled during survey.

Common Banana Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

Total common banana prawn catch rate (kg/hr)
at each site trawled during survey.

Common Banana Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria
Common banana prawn size count at each site trawled during survey.

Common Banana Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10
Western king prawn catch rate (no/hr) at each site trawled during survey.

Western King Prawn Catch (no/hr)
- 0
- 1 - 200
- 201 - 500
- 501 - 1000
- 1000+

Gulf of Carpentaria

NT

Qld

Northern Prawn Fishing Monitoring
Western king prawn catch rate (kg/hr) at each site trawled during survey.

Western King Prawn Catch (kg/hr)
- 0 - 3
- 3 - 7
- 7 - 15
- 15 - 30
- 30+

Gulf of Carpentaria

NT

Qld
CSIRO Marine & Atmospheric Research
NPF Monitoring Survey – July 2011
Preliminary Results

Western king prawn size count at each site trawled during survey.

Western King Prawn Size Count (no/lb)
- 30+
- 20 - 30
- 15 - 20
- 10 - 15
- under 10

Gulf of Carpentaria

Northern Prawn Fishing Monitoring