An Integrated Monitoring Program for the Northern Prawn Fishery: Assessing the Design and Developing Techniques to Incorporate Survey Results into Fishery Assessment

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CSIRO

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Australian Government
Fisheries Research and Development Corporation

Australian Government
Australian Fisheries Management Authority

Project FRDC 2004/099

Ye, Y.

An integrated monitoring program for the Northern Prawn Fishery : assessing the design and developing techniques to incorporate survey results into fishery assessment.

Bibliography.
Includes index.
ISBN 1 921061 27 8.

1. Shrimp fisheries - Carpentaria, Gulf of (N.T. and Qld.) - Monitoring. 2. Shrimps - Carpentaria, Gulf of (N.T. and Qld.) - Monitoring. 3. Shrimps - Carpentaria, Gulf of (N.T. and Qld.) - Spawning. I. Ye, Yimin, 1958- . II. CSIRO. Marine and Atmospheric Research. III. Fisheries Research and Development Corporation (Australia). IV. Australian Fisheries Management Authority. (Series : FRDC Project ; no. 2004/099).

333.955580994

Published by CSIRO Marine and Atmospheric Research
FRDC 2004/099

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NON-TECHNICAL SUMMARY

FRDC Project 2004/099
AN INTEGRATED MONITORING PROGRAM FOR THE NORTHERN PRAWN FISHERY: assessing the design and developing techniques to incorporate survey results into fishery assessment

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Project objectives

a. To refine the design and analyses for two trawl surveys in the Gulf of Carpentaria

b. To undertake a survey in August 2004 to provide biomass and spawning indices of the main commercial prawn species in the Gulf of Carpentaria

c. To undertake a survey in January/February 2005 to provide a recruitment index of the main commercial prawn species in the Gulf of Carpentaria

d. To determine the appropriate scale and frequency of future surveys

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

f. To develop methods that can incorporate survey information effectively into stock assessment

Non-technical Summary

An international review of the Northern Prawn Fishery 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 a FRDC-funded monitoring project (FRDC 2003/075) in 2003/04 and this project (FRDC 2004/099) in 2004/05.

Two surveys were undertaken during the 2004/05 financial year.

Sampling frames for the two surveys

For both the January and August surveys, the sampling frames used this year were the same as those used last year. Both surveys adopted the same stratification in which the strata are defined by subregion and water depth (for details see Ye et al. 2004).

Spawning-Index Survey

A Spawning-Index survey was completed in August 2004 in order to produce an index of abundance for much of the old and new fishing grounds in the Mornington, Vanderlins and Groote Eylandt regions. Two hundred and fourteen sites were sampled in 16 strata of 8 subregions. The spawning stock was defined as prawns greater than 26 mm for males and 28 mm for females for the tiger, endeavour, and banana prawns (*P. merguiensis*). The survey was 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, so that both tiger prawn species are found in large enough numbers to survey.

The stratification resulted in a regional Spawner Index Coefficient of Variation (CV) of about 20% which is good given the large area that was covered with the resources available. We have found therefore that a useful relative index of spawning abundance can be produced. On the other hand, the survey is not intended to provide precise within-region indices.

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, if repeated to become a yearly series, can:

- 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.

Using the spawning survey abundance indices, together with commercial catch and effort data, a technique has been developed to estimate annual recruitment, as well as availability and catchability coefficients. The method was first applied to the grooved tiger prawns *(P. semisulcatus)* in the North Groote area and it produced promising preliminary results. However, the model needs further refinement and testing on other species, such as brown tiger prawns *(P. esculentus)* and endeavour prawns.

Recruitment-Index Survey

This was a very large survey; a total of 303 sites were sampled in 11 sub regions and 24 strata in January 2005. It was undertaken with great success given the survey length, number of people involved and the geographic spread of the sites that had to be sampled. A regional Recruitment Index was produced for the five commercial species. Recruitment was defined by the presence of prawns smaller than 30 mm carapace length (CL) for males and 38 mm CL for females of banana prawns *(Penaeus merguiensis)*, brown tiger prawns *(P. esculentus),* blue endeavour prawns *(Metapenaeus endeavouri)*, and red endeavour prawns *(M. ensis)*, respectively. It was defined at a larger size for grooved tiger prawns *(P. semisulcatus)*: < 33 mm for males and < 38 mm for females. CV's ranged from about 11 to 40%, indicating greater variation than for the spawning index.

Generally, past survey data collected in the 1980s had shown a clear relationship between mean catch rates and variance (Dichmont et al. 2002) and this relationship was used in the current survey design to stratify a region and allocate the number of sites within a stratum. The data from the two surveys described here confirm the close relationship between mean catch rate and the variance in the catch.

There were important differences in species composition, distribution and abundance between the regions (fully described in subsequent chapters), and these differences changed between the 2002/03, 2003/04 and 2004/05 surveys.

Many aspects of the survey reflect anecdotal relative distribution of prawn species between the regions supported by historical studies and the industry even though the survey needs to be repeated before these are fully substantiated. We obtained a slightly higher banana prawn *(P. merguiensis)* catch rate in 2005 (2.6 prawns per hectare) than in 2003 (1.4 prawns per hectare) and 2004 (0.6 prawns per hectare).

Estimation of prawn availability and its impact on survey catch rates

A mathematical model was developed to estimate fishing catchability coefficients, prawn availability and recruitment, simultaneously. The model was applied to the northern Groote Eylandt area where scientific surveys were also carried out in 1983-85. As grooved tiger prawns migrate offshore during the winter season, the impact of availability changes on the survey catch rates of grooved tiger prawns is most significant. The study has, therefore, focused on grooved tiger prawns and incorporated both commercial catch/effort and survey data. The model successfully produced estimates for fishing catchability coefficients, prawn availability and annual recruitment. However, there is a high degree of confounding between the three parameters, which may have caused biased estimates. The problems are twofold: firstly, the three parameters are related to each other; secondly, the data used lack contrast, which may be caused by the low number of survey years to date. It is potentially important for future studies to use additional information such as environmental variables to estimate prawn availability separately

Recommendations and Conclusions

1. It is recommended that future surveys keep 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 estimated recruitment and calculated stock sizes. Ideally, both should be obtained from independent sources as little commercial logbook data from past decades can be applied to the recruitment parameter.

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. Although it is unclear at this stage whether the survey needs to be undertaken annually, it is certain that the survey should be done when there are significant changes in the fishing fleet or in seasonal fishing patterns.

5. Since the mid-season closure is currently of 2-3 months duration, little fishery dependent data (logbook data) are available on brown tiger prawns. It would be of value to consider repeating the Spawning Index survey annually to provide distribution and abundance data for the period of the closure.

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 timing of the annual spawning surveys for the NPF monitoring program has changed for a variety of reasons. Due to their inshore migration after June each year, the availability of grooved tiger prawns *(P. semisulcatus)* varies greatly between July and August. Thus, the change in survey timing due to the reviewed starting date of the second fishing season in 2005 has had a large impact on survey catch rates for grooved tiger prawns *(P. semisulcatus)*; and therefore fishing catchability coefficients of the fishing fleet at the beginning of the second fishing season. Using commercial catch and effort data, together with the survey abundance indices, we have presented an integrated method to estimate annual recruitment, availability and catchability coefficients for the grooved tiger prawns *(P. semisulcatus)* in the northern Groote area. The model was designed to account for the variation in survey results due to change in survey timing. The method requires further refinement and testing for other regions and species, although preliminary outcomes are promising.

CHAPTER 1. INTRODUCTION

1.1 Background

For more than a decade the Northern Prawn Fishery assessments have indicated that the tiger prawn resource is overexploited. 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. 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. The clear message of the review was that a survey program is an essential investment for this fishery.

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). The August survey, aimed at estimating a spawning index that could also be used in future fishing power studies, was undertaken in 3 regions of the Gulf of Carpentaria (GOC). 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 project (FRDC 2004/099) aims to continue the recruitment and spawning stock surveys, to finalize the design and to develop techniques that can effectively use the survey data to improve the NPF tiger prawn stock assessment.

1.2 Need

An 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 is used as the sole index of abundance in the NPF assessments.

[1] Dr Deriso from Scripps Institution of Oceanography reviewed the NPF tiger prawn assessment in 2001

The historical survey data used to determine the initial design for this project is more than a decade old and does not cover the full study area. Therefore, the initial surveys will be largely exploratory in nature and very much a trial to see if the proposed design is effective. Also, the survey design includes integrated components such as the assessment of long-term changes in fishing power and the contraction of the fishery over time. Neither component has been undertaken in prawn survey designs (both nationally and internationally) before. These aspects highlight that this project has a large research component; the appropriate survey design is still being developed and methods for incorporating the results of the surveys into future stock assessments need to be developed.

There is a need to provide an updated survey design for the NPF that would work in the long-term to provide indices of abundance for key species and enhance a difficult-to-use commercial catch rate series. Furthermore, the design needs to address target, byproduct and possibly some effects-of-trawling issues to make the best use of the surveys, as they will be a large expense to the industry.

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 a couple of projects including this project, has basically been adopted for future monitoring surveys for the NPF.

The estimates of a recruitment index and a spawning stock index provide extra information to help management decisions. As the time series of the annual indices increases, they will help to refine fishing power estimates for the main commercial prawn species and will be incorporated into assessment models to improve the stock assessment. Based on these more reliable assessments, AFMA can design better management strategies and implement prompt regulations for the long term sustainability of the NPF. In addition, the abundance and spatial distribution information 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.

1.4 Further development

The current program of Prawn Monitoring Surveys in the NPF began in August 2002. The surveys were initiated by NORMAC after an international review of the NPF Tiger Prawn Stock Assessment highlighted uncertainties in the assessment that could be best overcome by carrying out regular prawn monitoring surveys. 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 three years. Stock assessment relies heavily on time series data. Both recruitment and spawning stock surveys should ideally be continued for many years to allow the best use of the survey indices in stock assessment.

1.5 Planned outcomes

The project was planned to produce an integrated monitoring survey design; defining the objectives, scale, frequency and costs of the surveys, after further test and refinement. The implementation of the monitoring program was aimed to produce quantitative descriptions of the spatial distribution and temporal variation of the populations of all commercial prawn and byproduct species. The distribution information and the recruitment and spawning indices derived from the surveys could be incorporated into stock assessment models to reduce uncertainties, to evaluate the impact of fishing, and to better design management strategies and regulations.

The experience and design perspectives of the prawn monitoring surveys can make a significant contribution to the design of long-term monitoring programs for any fisheries that involve multiple regions and multiple species.

1.6 Conclusions and Recommendations

1. It is recommended that future surveys keep 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 estimated recruitment and calculated stock sizes. Ideally, both should be obtained from independent sources as little commercial logbook data from past decades can be applied to the recruitment parameter.

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. Although it is unclear at this stage whether the survey needs to be undertaken annually, it is certain that the survey should be done when there are significant changes in the fishing fleet or in seasonal fishing patterns.

5. Since the mid-season closure is currently of 2-3 months duration, little fishery dependent data (logbook data) are available on brown tiger prawns. It would be of value to consider repeating the Spawning Index survey annually to provide distribution and abundance data for the period of the closure.

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 timing of the annual spawning surveys for the NPF monitoring program has changed for a variety of reasons. Due to their inshore migration after June each year, the availability of grooved tiger prawns *(P. semisulcatus)* varies greatly between July and August. Thus, the change in survey timing due to the reviewed starting date of the second fishing season in 2005 has had a large impact on survey catch rates for grooved tiger prawns *(P. semisulcatus)*; and therefore fishing catchability coefficients of the fishing fleet at the beginning of the second fishing season. Using commercial catch and effort data, together with the survey abundance indices, we have presented an integrated method to estimate annual recruitment, availability and catchability coefficients for the grooved tiger prawns *(P. semisulcatus)* in the northern Groote area. The model was designed to account for the variation in survey results due to change in survey timing. The method requires further refinement and testing for other regions and species, although preliminary outcomes are promising.

8. The NPF monitoring surveys are costly, but they provide valuable fishery-independent data that are useful for overcoming the serious confounding between fishing power and abundance. Consequently, these data improve the stock assessment. However, incorporating the survey abundance indices into the stock assessment is not as straightforward as it looks. It poses a great technical challenge and requires effort to develop innovative methods that can effectively use the information from the survey data to enhance the stock assessment. It seems that the most effective way to allocate the costs and benefits of the project is to separate the research component of the project from the annual monitoring. The former should be funded as a discrete research initiative through the FRDC and the latter can be undertaken as a project funded through AFMA.

1.7 Acknowledgements

This project was funded by the Mac Initiated Research Fund of the Northern Prawn Fisheries Management Advisory Committee, FRDC, 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. 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 Toni Cannard who helped to proof, edit and produce the final report.

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CHAPTER 2. SAMPLING GEAR AND DATA COLLECTED

2.1 Introduction

Our surveys are designed to complete a long-term dataset capable of providing key parameters to support the management of the Northern Prawn Fishery. A major issue for long-term research surveys is to use sampling gear to ensure that the fishing power of the survey vessel can be maintained 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.

There were two events that occurred during the year that had the potential to affect the standardization of the surveys, although we believe at this stage that the results of the surveys are not compromised by these events:

- In the August survey of 2004 (FV Arnhem Pearl and FV Australian Pearl), new nets were used in place of the initial sets of nets used for the surveys. However, the nets were manufactured by the same company and to the same design of the first sets of survey nets.

- In the February survey of 2005, (FV Karumba Pearl and FV Northern Pearl), the FV Northern Pearl one wing of one net separated from the trawl board during one shot. The net was re-attached to the trawl board and the survey continued. The data recorded from the catch from the other net was used in the analysis.

2.2 Trawl gear description

For each survey, two vessels were chartered and, as much as possible, worked in similar areas at the same time. Each vessel used two 12-fathom tiger prawn nets manufactured for CSIRO by GNM Chandlery, Cairns. Net and rigging specifications were as follows:

- 400d/30ply 2” stretched mesh net.
- Codend of 400d/4x16ply black braided 1⅞” 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 about 30 minutes in length, unless trawling was interrupted due to rough bottom or gear problems. Descriptors relating to weather, tides, moonphase and details of problems with gear were also recorded. Vessel trawl speed was maintained at about 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. All squid and cuttlefish were frozen and later transported to CSIRO, Cleveland for identification and further processing. 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 and sawfish. Some selected species of fish were collected for other staff from CSIRO working on aspects of 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).

3.1.1 *Definition of size group for survey indices*

In both surveys, we caught few prawns smaller than 20 mm. We classified prawns into two size groups, representing different age classes. For the spawning survey in August, "adults" were of primary interest, and therefore only catch rates of adult prawns were analysed and presented in this report. For the recruitment survey in January, "sub-adults" were of more interest and their catch rates were examined.

For the August surveys, we analysed prawns with a carapace length of at least 26 mm (males) or 28 mm (females), for the tiger, endeavour and banana prawns. This covers the range of sizes most likely to become spawners or to be caught in the second season of the fishery. These "adult" prawns accounted for almost all of the tiger catch in the August surveys (Figure 1 to Figure 2). The modal size for male grooved tiger prawns (*P. semisulcatus*) in August surveys was about 10 mm less than for females. For brown tiger prawns (*P. esculentus*) the difference in size between males and females was somewhat smaller. For common banana prawns (*P. merguiensis*) it was closer to 5 mm (Figure 3), reflecting the smaller size attained by this species. Almost no banana prawns *(P. merguiensis)* were smaller than the "adult" threshold, probably partly because there were few available to measure due to low catch rates at this time of year. The distribution for blue endeavour prawns *(M. endeavouri)* in August (Figure 4) was similar to that for brown tiger prawns *(P. esculentus)*.

For the January surveys, we were interested in "sub-adult" prawns. For grooved tiger prawns *(P. semisulcatus)*, we defined these to be females with a carapace < 38 mm and males with a carapace < 33 mm. For all other species the female and male thresholds were < 33 mm and < 30 mm respectively. These size thresholds mean that the index includes animals that were spawned between June/July and September/October (the previous year), the major spawning period for the tiger species.

For grooved tiger prawns *(P. semisulcatus)*, "sub-adult" prawns accounted for a high proportion of the catch in the January surveys, the threshold clearly partitioning one major younger cohort from one (males) or two (females) older cohorts (Figure 5). For female brown tiger prawns *(P. esculentus)*, the threshold appears to have selected prawns (Figure 6) from the latter half of the bi-modal spawning season (Dichmont et al. 2001), and successfully eliminated those spawned more than a year ago. However, it should be noted that there is some variation in length frequency distribution from year to year.

For banana prawns *(P. merguiensis)*, very few male prawns were larger than the designated “sub-adult” size range (Figure 7), in marked contrast to the proportion of females above this limit. The features of the length frequency distribution for blue endeavour prawns *(M. endeavouri)* (Figure 8) are similar to those of brown tiger prawns (*P. esculentus)*, but these prawns have either spawned earlier or grown more slowly, as more prawns were in the “sub-adult” size range.

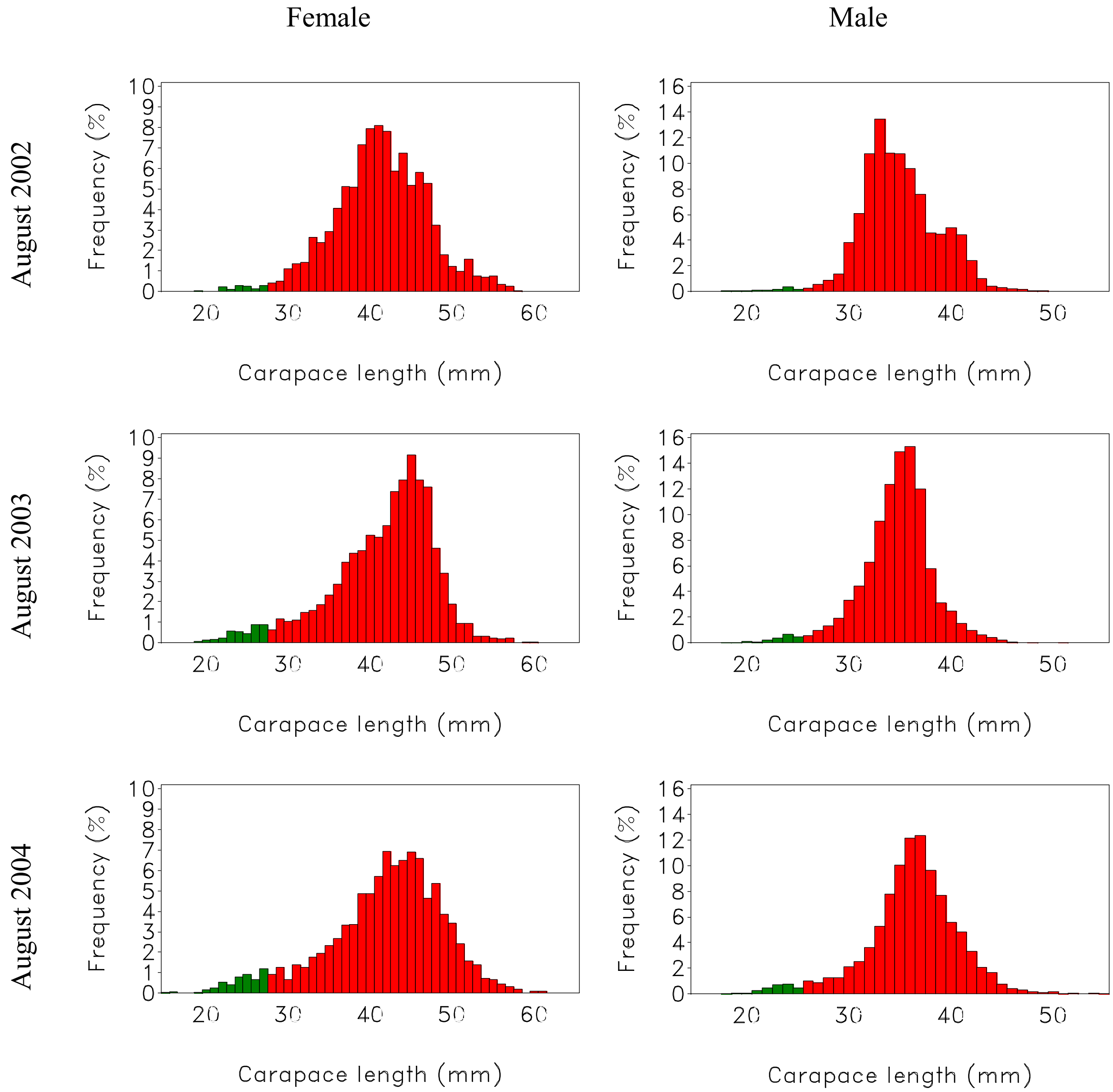

Figure 1: Grooved tiger prawns *(P. semisulcatus)*. Frequency distribution of carapace lengths of male and female prawns from the three spawning surveys, partitioned into “sub-adult” (green) and “adult” (red) prawns. These are pooled data from all samples in all regions in each survey.

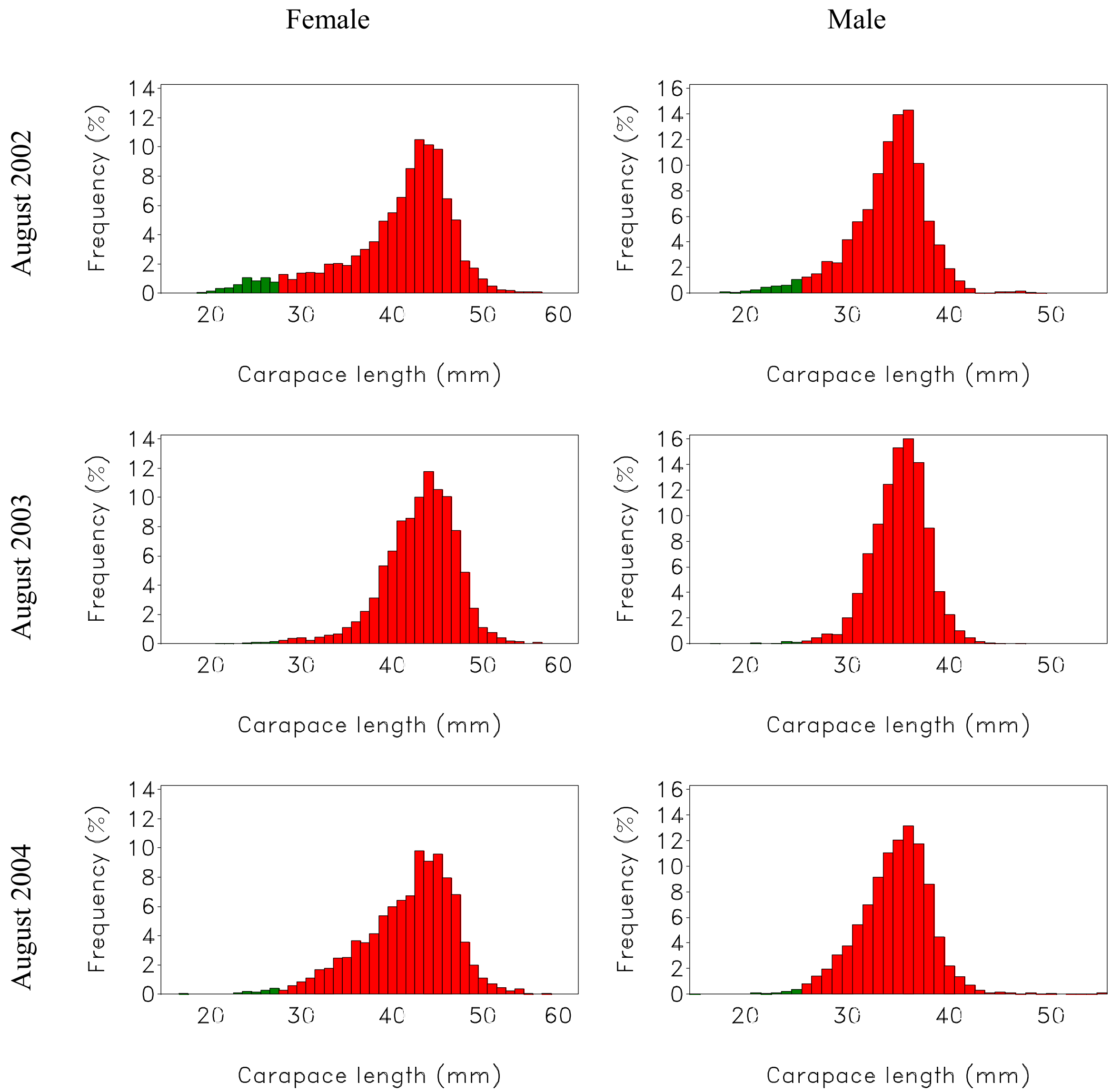

Figure 2: Brown tiger prawns *(P. esculentus)*. Frequency distribution of carapace lengths of male and female prawns from the three spawning surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

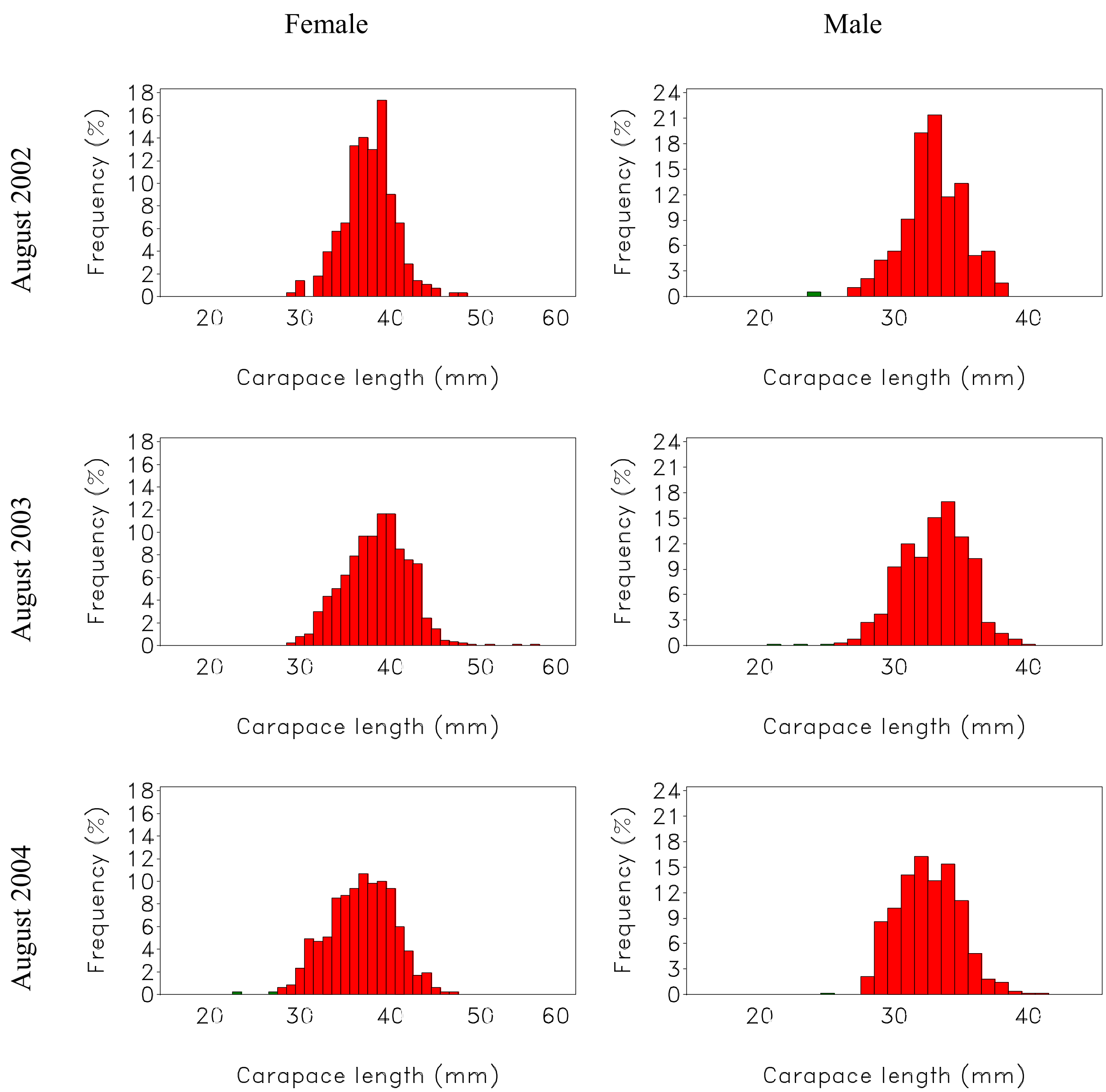

Figure 3: Banana prawns *(P. merguiensis)*. Frequency distribution of carapace lengths of male and female prawns from the three spawning surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

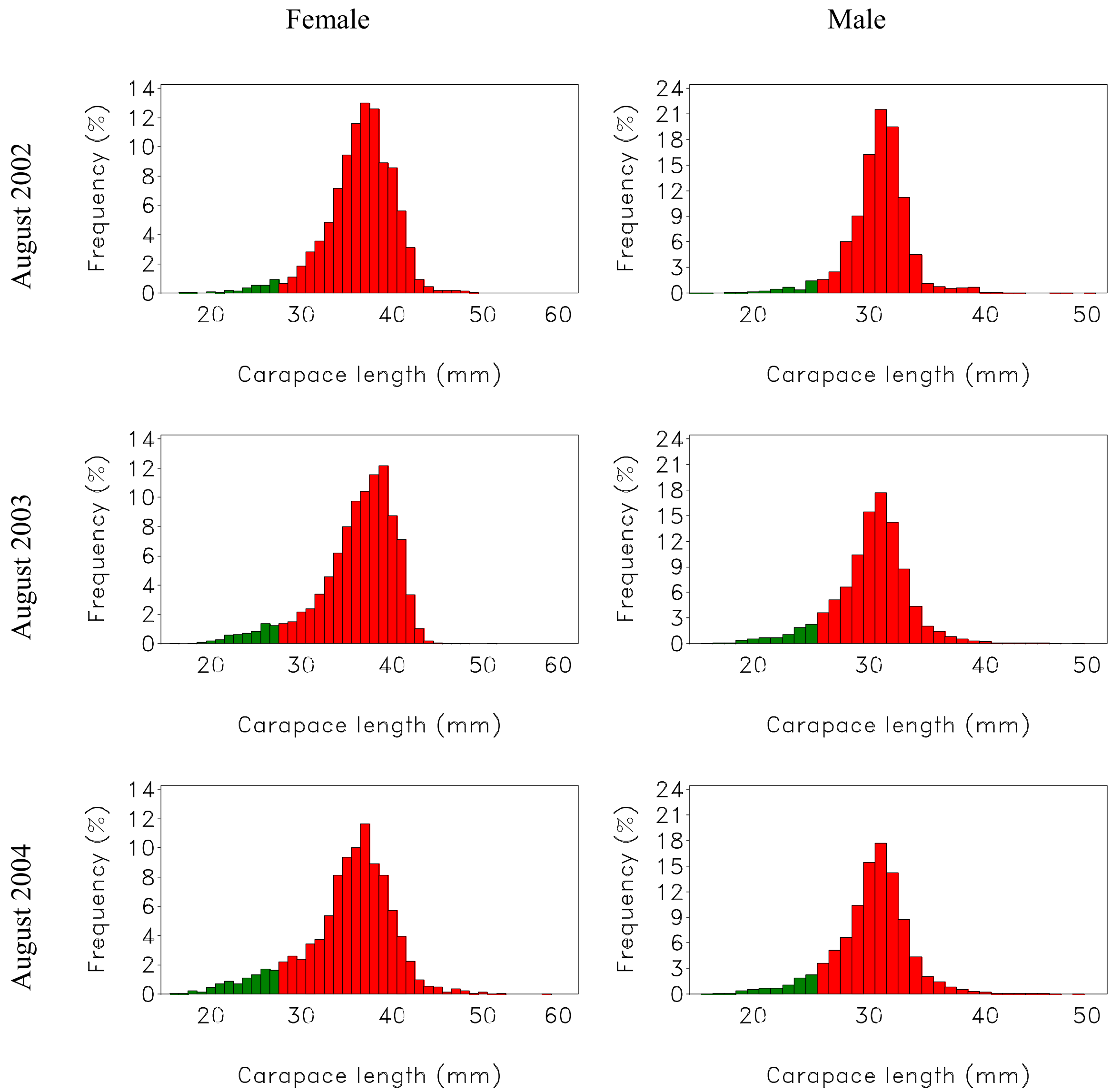

Figure 4: Blue endeavour prawns *(M. endeavouri)*. Frequency distribution of carapace lengths of male and female prawns from the three spawning surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

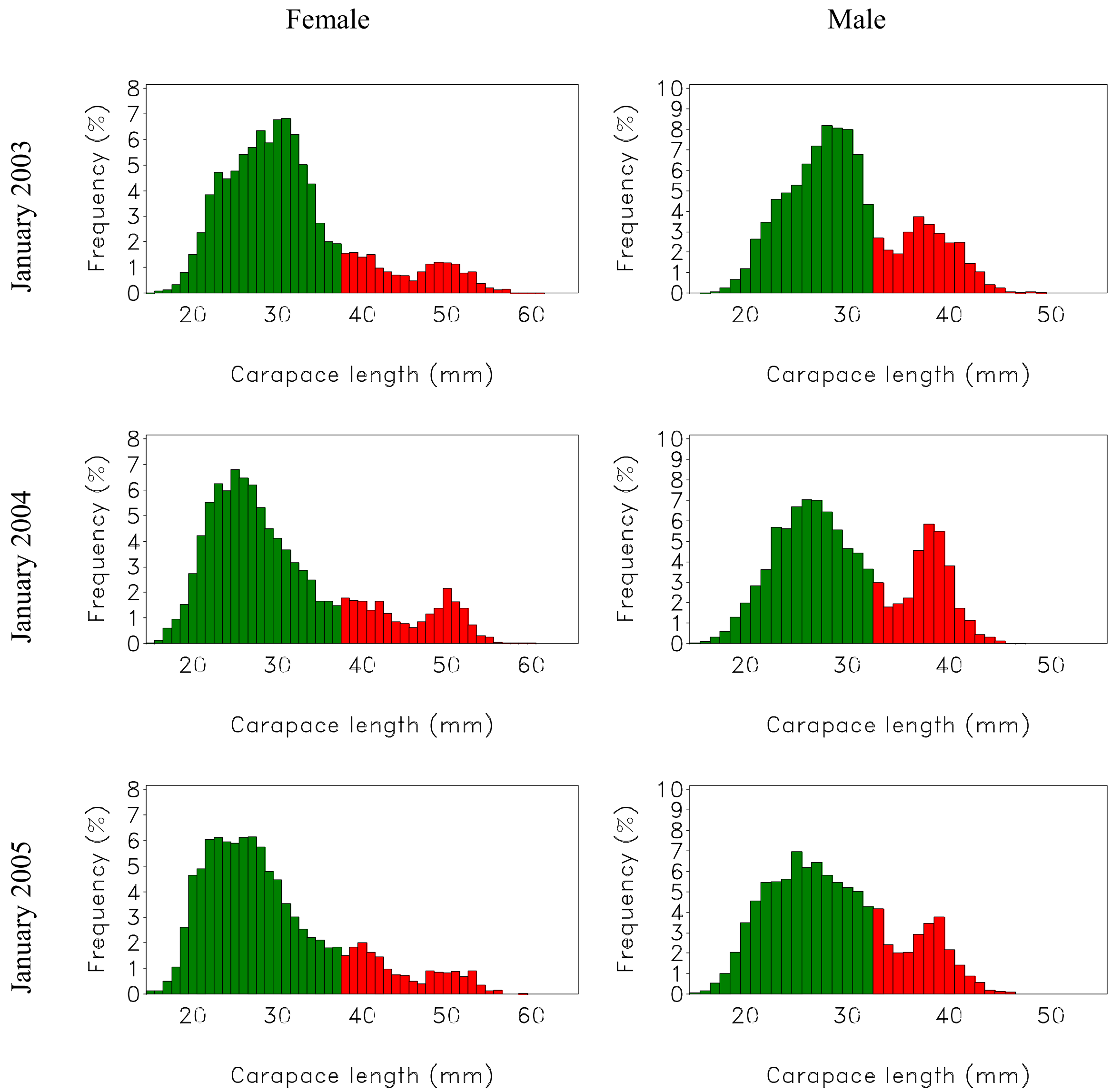

Figure 5: Grooved tiger prawns *(P. semisulcatus)*. Frequency distribution of carapace lengths of male and female prawns from the three recruitment surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

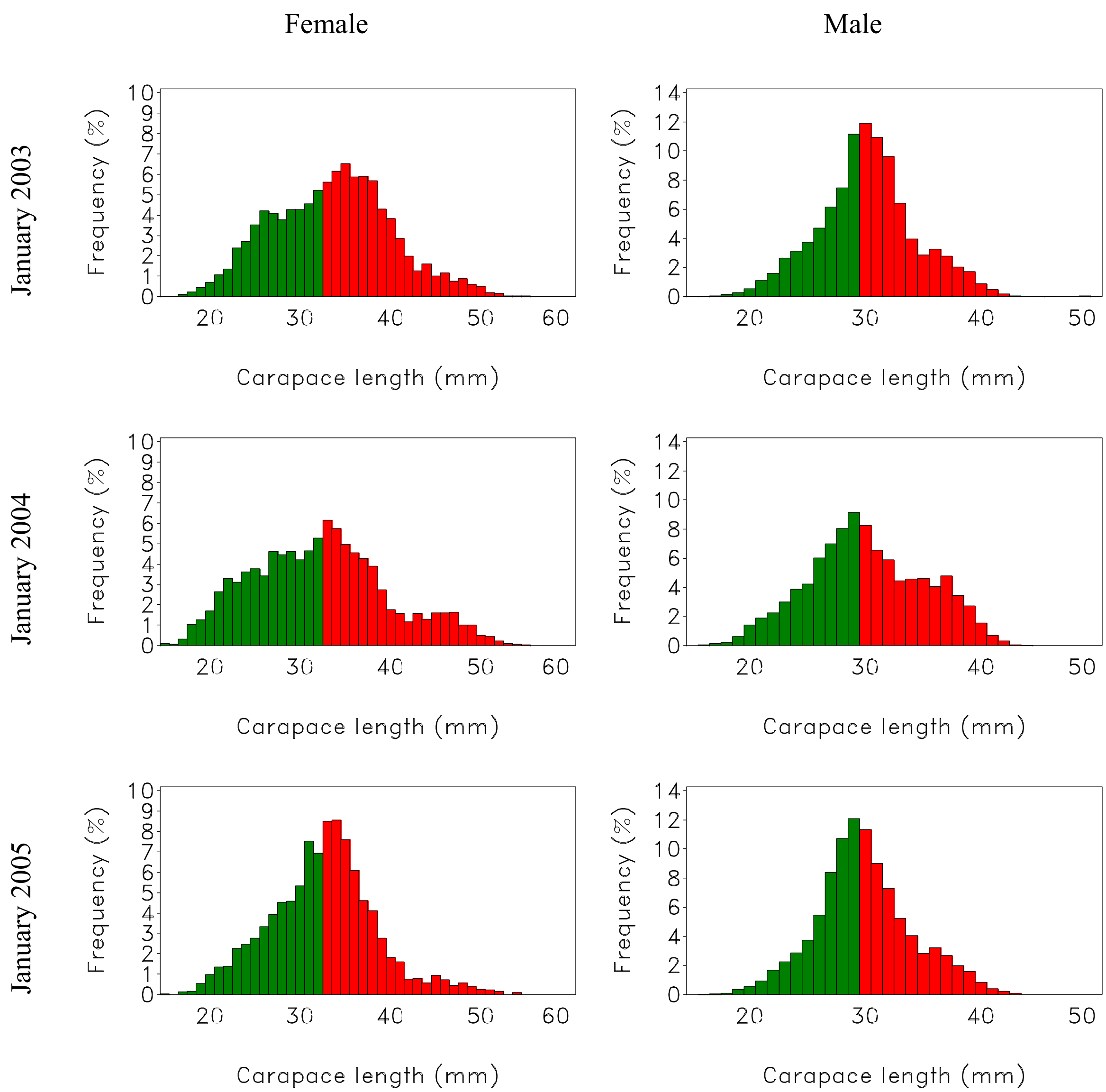

Figure 6: Brown tiger prawns (*P. esculentus*). Frequency distribution of carapace lengths of male and female prawns from the three recruitment surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

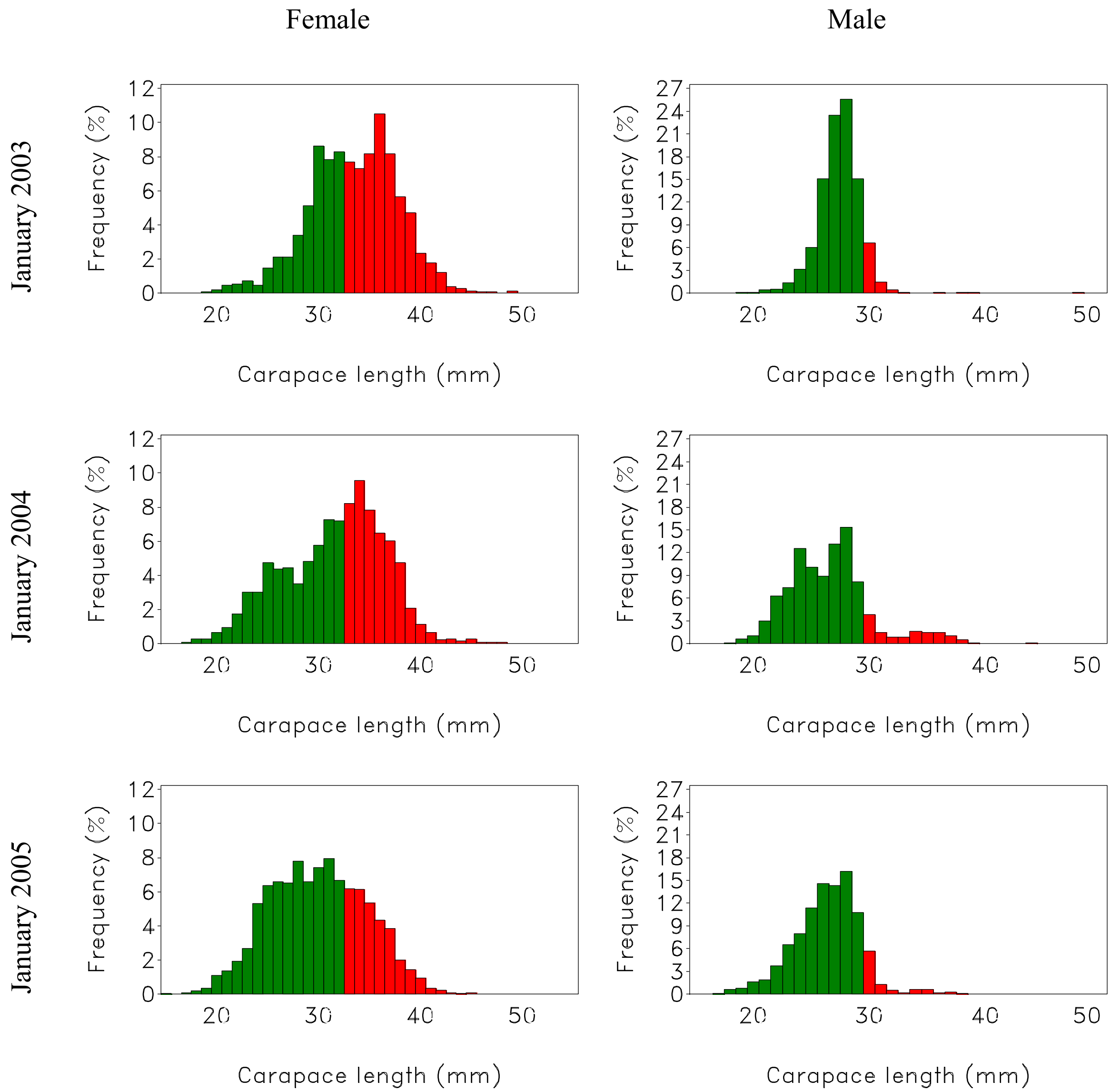

Figure 7: Banana prawns *(P. merguiensis)*. Frequency distribution of carapace lengths of male and female prawns from the three recruitment surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

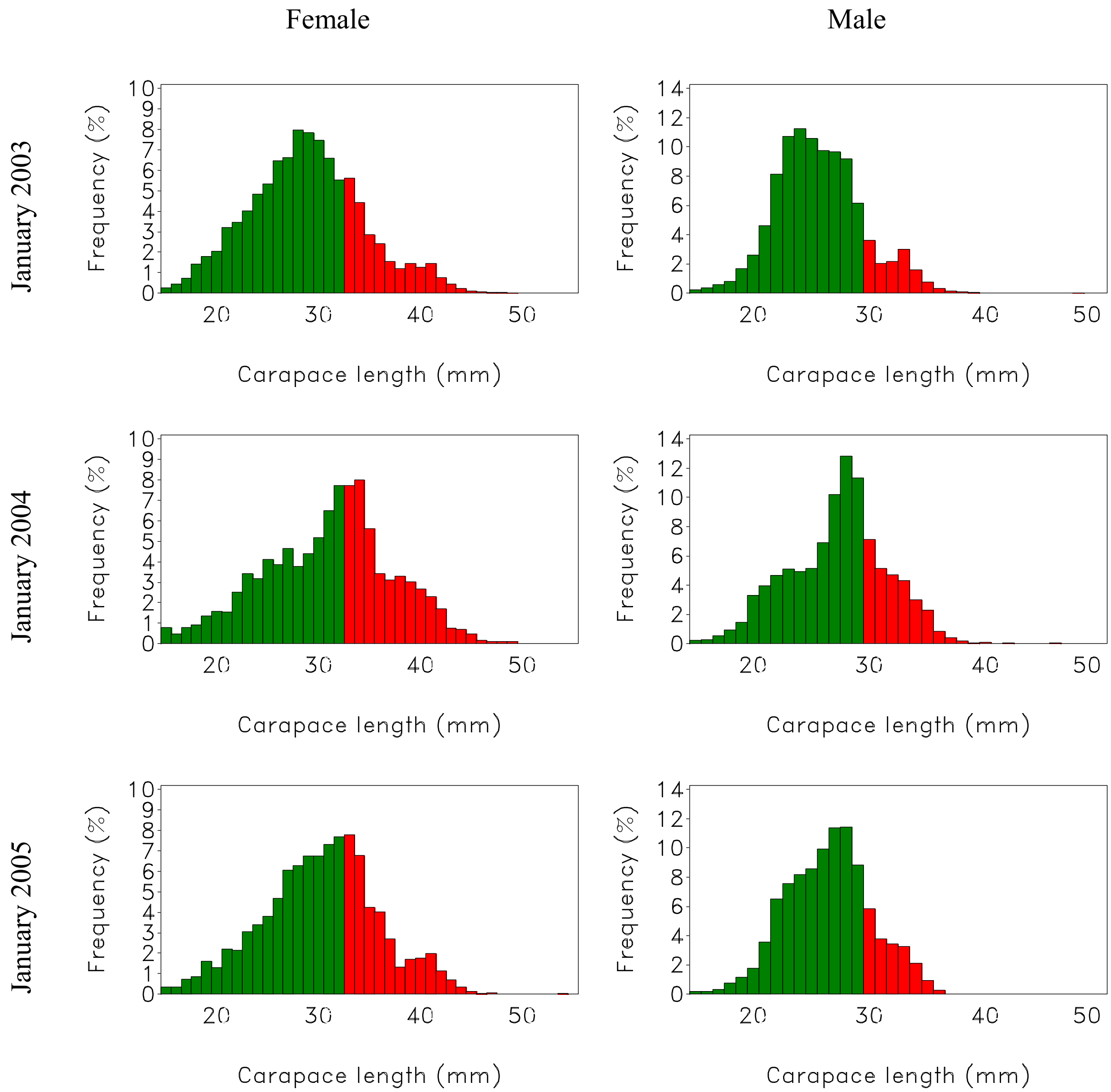

Figure 8: Blue endeavour prawns *(M. endeavouri)*. Frequency distribution of carapace lengths of male and female prawns from the three recruitment surveys, partitioned into "sub-adult" (green) and "adult" (red) prawns. These are pooled data from all samples in all regions in each survey.

3.2 Prawn density

Initially (Dichmont et al. 2004), we analysed the number of prawns caught per hour trawled. However, for comparison with historical survey data it is more meaningful to calculate the number of prawns per hectare 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 surveys.

In the calculation of the number of prawns per hectare, the trawl was assumed to sweep a 30 m wide path and the distance covered by the trawl was estimated from the difference in GPS location at the start and end of the trawl. The exception was for trawl paths that were appreciably bent to avoid difficult terrain. For these trawls, we estimated the swept area from the product of speed and duration.

Most trawls swept an area of 8–10 hectares, with a modal area around 9 hectares (Figure 9). With increasing experience of conducting these surveys, especially now that we have identified and dealt with untrawlable sites, swept area has become more consistent over time: about one-third of trawls were outside the range of 8–10 hectares in August 2002; however it was less than 5 percent in January 2004.

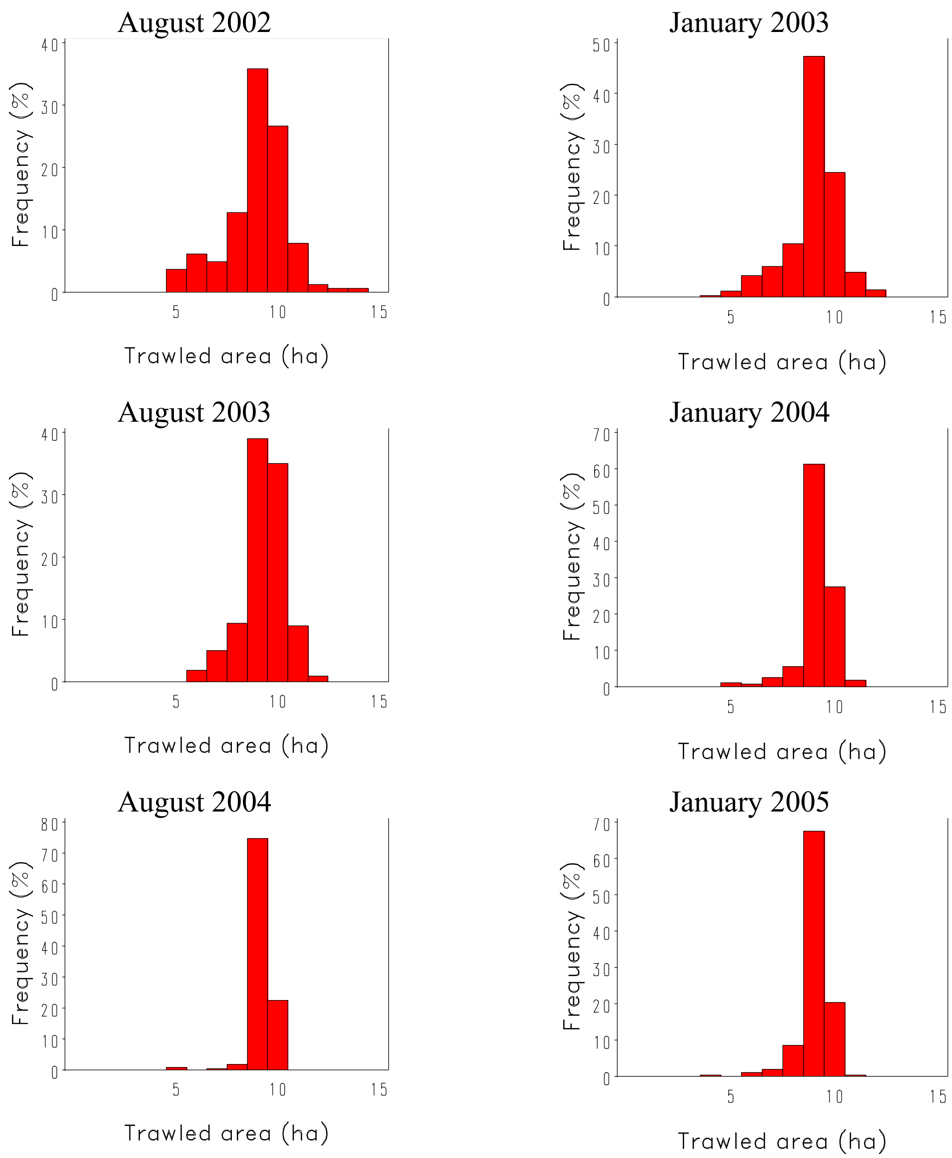

Figure 9: Estimated area swept by trawls (in hectares) during the spawning and recruitment surveys.

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 nm 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 January and August 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 August survey, the strata within each region were originally defined by fishing effort and water depth (Figure 10). However, to facilitate comparison with the January survey and to ensure compatibility with the concurrent project in the Eastern Gulf of Carpentaria, we retrospectively stratified the August survey in a manner similar to the January survey, where the strata are defined by sub-region and water depth (Figure 11). 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 August 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.

[2] Additional offshore sites sampled in January 2003 for a bycatch monitoring project were not included in the calculation of the recruitment index.

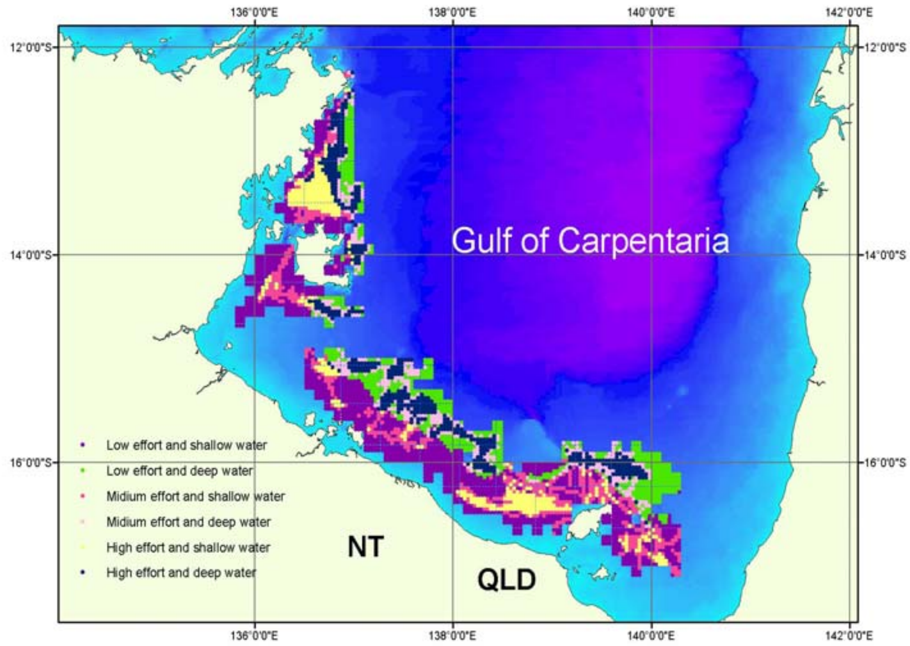

Figure 10: Original stratification based on fishing effort and water depth for the August 2002 spawning index survey.

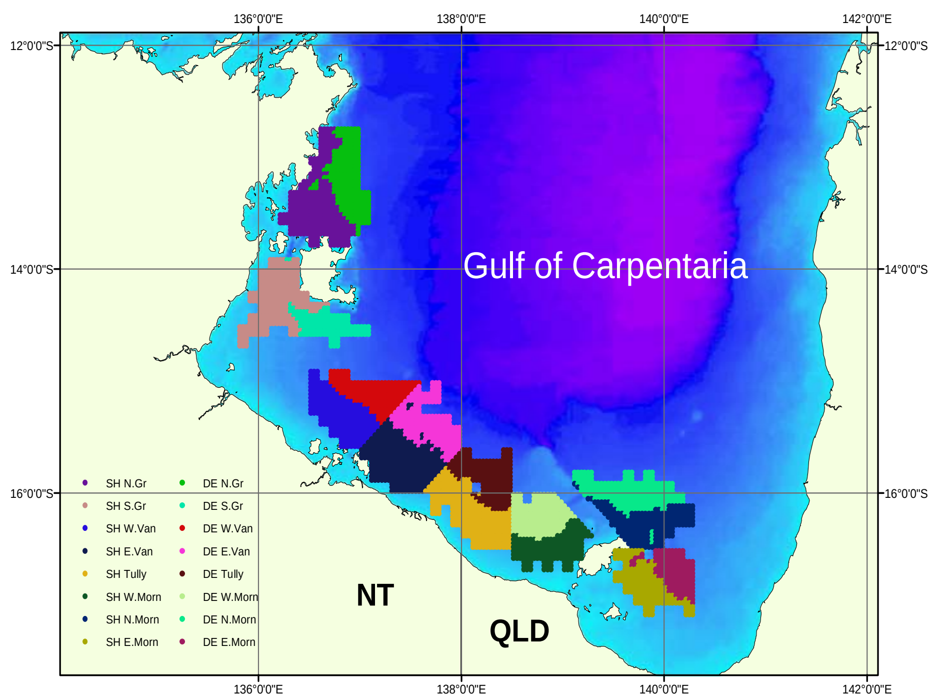

Figure 11: Modified stratification based on January-style sub-region and depth for the August 2003 spawning index survey.

For the January 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 August sampling frame. Even after this change, the east Mornington sub-region included a larger area in the January survey than in the August 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 12.

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.

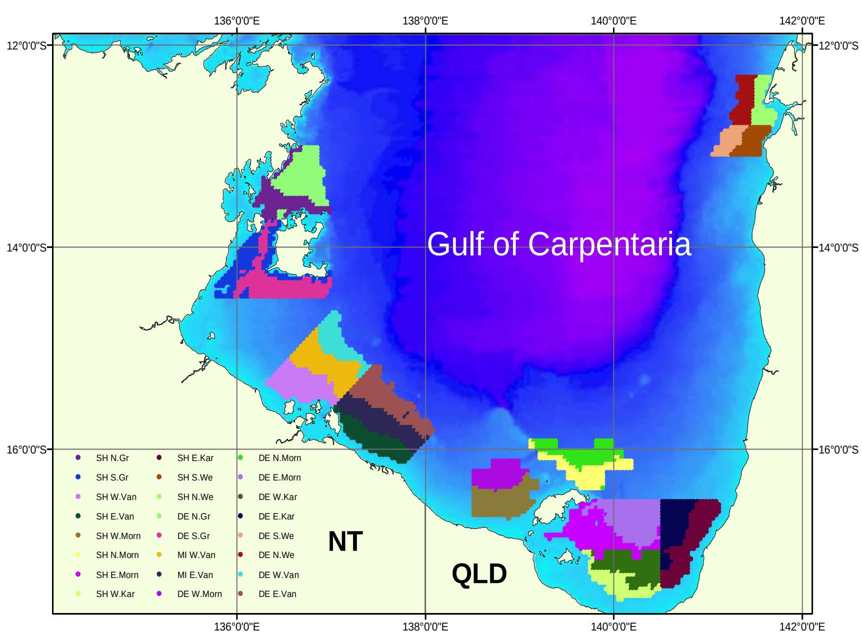

Figure 12: Modified frame for January recruitment index survey, stratified by sub-region and depth.

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 ($\bar{y}_{R,i}$), where each stratum weight ($w_{R,i}$) 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.

$$\hat{\mu}_R = \sum_{i=1}^{N_R} w_{R,i} \bar{y}_{R,i} \quad (1)$$

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.

$$V(\hat{\mu}_R) = \sum_{i=1}^{N_R} w_{R,i}^2 V(\bar{y}_{R,i}) \quad (2)$$

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 areal proportion of each stratum relative to the whole survey.

$$\hat{\mu}_G = \sum_{i=1}^{N_G} w_{G,i} \bar{y}_{G,i} \quad (3)$$

3.5 References

Dichmont, C.M., Die, D., Punt, A.E., Venables, W., Bishop, J, Deng, A. and Dell, Q. 2001. Risk assessment and sustainability indicators for prawn stocks in the northern prawn fishery. FRDC 98/109.

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Ye, Y., Dichmont, C., Vance, D., Burridge, C., Pendrey, R., Van der Velde, T., Bishop, J., Donovan, A., and Deng, A. 2004. Design, implementing and assessing an integrated monitoring program for the NPF: developing an application to stock assessment. FRDC 2003/075.

CHAPTER 4. RECRUITMENT INDEX

4.1 Introduction

The objectives of the Recruitment Index survey were to provide:

a. a final design for future surveys, scoping the spatial scale and temporal regularity of the survey, including the cost of these subsequent surveys.

b. an index of recruitment with coefficients of variation (CV) for tiger, banana and endeavour prawns.

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

d. advice as to the utility of the survey for byproduct biology and abundance.

4.2 Survey design

The survey design mainly addresses the following aspects:

- The timing of the surveys within a year depending on survey objectives,
- The spatial extent of the survey given the resources available, and
- Stratification and site selection.

These points have been extensively discussed in Dichmont et al. (2002) but confirmation of these issues is needed in light of our practical experience.

4.2.1 Timing of the survey

The motivation for the timing of the Recruitment Index survey in January is:

- Banana prawns *(P. merguiensis)* are less aggregated in January (Crocos, Wang and Vance, unpublished data) and therefore can be adequately surveyed with relatively low fishing effort (the main risk here is that our information on the aggregation behaviour comes from surveys in the Weipa region only, and we have assumed the behaviour is similar in all regions).
- Tiger prawn recruitment peaks between December and February (Somers et al. 1987). If banana prawns *(P. merguiensis)* were not being surveyed, then February would probably be a slightly better time to sample tiger prawns.
- Due to the offshore movement of prawns as they mature, it is likely that the resource is more contracted in January than later in the year, and therefore easier to sample.

A cost-effective approach to obtaining a Recruitment Index for both banana and tiger prawns is to conduct the survey in January.

A risk for undertaking the survey so early in the year is that sampling in January may miss the smaller recruitment that occurs to the fishery later in the year or miss the peak of recruitment in years in which recruitment is delayed. However, we attempted to minimize this risk by sampling a large range of depths, from relatively shallow to the deeper edge of the fishery.

In order to sample as close to new moon as possible, all January surveys were undertaken by two vessels. Trawls were carried out on the following nights: 25 January–12 February 2003, 12–28 January 2004 and 3–20 February 2005. Moon phase is known to affect catchability and so it is **recommended that future surveys be undertaken at a similar moon phase and calendar month in each region.**

From the results shown in Section 3.4.2, there is some indication that different regions may have different recruitment as the relative abundance between shallow and deep strata is not consistent across regions. However, we generally trawled depth ranges from about 8 to 45m which is likely to sample most of the prawn distribution. Furthermore, the mean-variance relationship for banana prawns *(P. merguiensis)* is similar to that of tiger prawns. This suggests that the banana prawns *(P. merguiensis)* have yet to school (one of our major reasons for undertaking the survey so early in the year). Indications are that the timing is correct, but more surveys are needed to confirm this.

4.2.2 *Extent of the survey*

The spatial extent of the survey recommended in Dichmont et al. (2002) was based on past logbook and survey data. In January, the prawns are distributed either on the fishing grounds or inshore towards the mangroves and the seagrass beds. The final definition of survey regions (the sampling frame) has been given in Chapter 3. The spatial extent of the January survey was decreased slightly from that proposed in Dichmont et al. (2002). In particular, a section in the south-eastern Vanderlins region was omitted as the available funding could not cover the recommended area with good precision. Further changes in other regions e.g. Mornington were due to having to remove large areas of untrawlable ground from the survey design, based on advice from industry and the experience of the August 2002 survey. For compatibility with the August survey, 18 grid cells in the 'Karumba' region were re-allocated to the 'Mornington' region. Finally, we added extra 5 grid cells to the Weipa region, in shallow waters (< 8m) in the north-eastern part of Albatross Bay. Three of these were sampled from January 2004 onwards in order to capture a potential peak in banana prawn *(P. merguiensis)* catch rates at the near-shore edge of the sampling frame.

4.2.3 *Stratification and site selection*

A critical problem for this survey was to sample enough sites to produce useful indices of abundance given the resources available. This is because a relative index of abundance needs to be able to differentiate between random noise and real changes in abundance over a realistic time scale. This high precision can be gained by obtaining a large number of sample sites and/or by stratification. The former is often limited by financial constraints and therefore stratification is an essential aspect of survey design.

Past studies have shown that brown tiger prawns (*P. esculentus)* tend to be found in higher abundance inshore than offshore for most of the year (Somers et al. 1987). Grooved tiger prawns *(P. semisulcatus)* have been found to be more mobile and even in January and February have been found in higher abundance offshore than inshore in North Groote and Weipa. For both tiger species, there was substantial alongshore difference in density and species composition within each region.

Based on this information, the primary mechanism for stratification was alongshore distance and the secondary was offshore distance divided into roughly shallow and deep regions. Stratification details have been shown in the previous chapter. The depth strata are not consistent from one region to the next, due to the large variation in the offshore distance for a specific depth range that is governed by the different bottom topography. The partitions were chosen so that the strata for a given region would be reasonably similar in spatial extent, but with inshore boundaries on an 8 m depth contour.

A fully stratified random survey was attempted in August 2002. The number of sites per night obtained was well below reasonable levels and an adapted approach was used to select sites for the January survey. At first, an attempt at a computerised design method based on the development of Marine Protected Area Systems using simulated annealing was attempted. However, the optimisation of distance travelled and sampling over the regions resulted in aberrations that seriously compromised coverage. As a concession, sites were chosen from two sets of random sites. Each set consisted of randomly chosen sites with a designed number of sites per stratum. Wherever possible, primary sites were used. Secondary sites were used only when the distance between primary sites was too great to travel between trawls. In these cases, nearby secondary sites were allocated instead of primary sites, so that a reasonable number of sites could be trawled each night. This slightly non-random design often occurs in an *ad hoc* way in the field. Since the number of secondary sites used is low, we feel that the randomness assumed in the analyses is still warranted.

All strata within a given region were intended to be sampled with the same intensity, for two reasons. First of all, the multi-species nature of this survey together with the lack of historical data (for example on the Vanderlins) meant that it was not possible to optimise the allocation of samples in proportion to the anticipated relative means (and hence variances). Secondly, it resulted in a more-or-less uniform distribution of sites over each region that would facilitate the application of spatial statistics (and hence mapping of predicted means with appropriate prediction errors) at a later date. Table 1 shows the number of sites successfully sampled in the three surveys.

From a practical point of view, when field conditions were good and an extra night's sampling was available, this resulted in some strata receiving considerably more effort than others (for example, the northern part of Groote compared with the southern part).

Table 1: Sampling design by region for January in terms of sampling frame size and number of sites successfully sampled.

Region	Location	Depth stratum	Number of 2 nm sites for selection	Number of sites sampled in Jan 2003	Number of sites sampled in Jan 2004	Number of sites sampled in Jan 2005
Groote	North	Shallow (8–25 m)	133	22	22	22
		Deep (25–40 m)	190	19	19	20
	South	Shallow (8–20 m)	164	11	13	14
		Deep (20–40 m)	207	16	16	16
	Total		**694**	**68**	**70**	**72**
Vanderlins	West	Shallow (8–25 m)	169	11	11	12
		Medium (25–35 m)	186	8	10	10
		Deep (35–40 m)	116	11	11	11
	East	Shallow (8–20 m)	132	11	10	10
		Medium (20–30 m)	174	9	8	9
		Deep (30–40 m)	190	11	8	11
	Total		**967**	**61**	**58**	**63**
Mornington	West	Shallow (8–25 m)	167	10	10	10
		Deep (25–33 m)	121	8	9	12
	North	Shallow (14–35 m)	121	10	10	11
		Deep (35–44 m)	139	20	19	20
	East	Shallow (8–20 m)	218	18	23	20
		Deep (20–36 m)	226	9	10	12
	Total		**992**	**75**	**81**	**85**
Karumba	West	Shallow (8–15 m)	102	11	13	14
		Deep (15–24 m)	169	7	7	8
	East	Shallow (8–12 m)	174	11	10	11
		Deep (12–20 m)	147	11	11	11
	Total		**592**	**40**	**41**	**44**
Weipa	South	Shallow (8–30 m)	69	8	8	8
		Deep (30–40 m)	60	6	7	7
	North	Shallow (7–25 m)	70	6	13	13
		Deep (25–40 m)	88	10	12	11
	Total		**287**	**30**	**40**	**39**

4.3 Variability of catch rates

Analysis of historical data (Dichmont et al. 2002) showed that there is a fairly predictable relationship between the mean μ_i for the i'th stratum and its standard deviation σ_i:

$$\sigma_i = e^{\alpha} \mu_i^{\beta} \tag{3}$$

Estimates of parameters α and β from the current recruitment index surveys were obtained by regressing stratum $\log_e$-transformed sample standard deviations on $\log_e$-transformed sample means, weighting by sample size. The intercept for the best-fitting line is an estimate of α, and the slope is an estimate of β. Strata with a mean of zero (and hence a standard deviation of zero) were omitted from this analysis, as these cannot be log-transformed.

The coefficient of variation (C.V.) for a given stratum can be simply derived as follows:

$$CV_i = \frac{\sigma_i}{\mu_i} = e^{\alpha} \mu_i^{\beta - 1} \tag{4}$$

The relationship between the C.V. and the mean changes dramatically as β ranges from, say, 0.5 to 1.2 (Figure 13). If β=1, the C.V. is constant for all mean catch rates, since it does not depend on the mean. If β>1, the C.V. increases with the mean, so high mean catch rates will be associated with a large C.V. If β<1, the C.V. decreases with mean, so a larger C.V. is more likely when the mean catch rate is low. The C.V. decreases most rapidly with increasing mean catch rates when β=0.5, which corresponds to a random distribution of the prawns. Usually β>0.5, and in this case the spatial distribution is said to be clumped. The role played by the coefficient α is to scale the curves up or down. When β=1, α is simply the natural logarithm of the C.V.

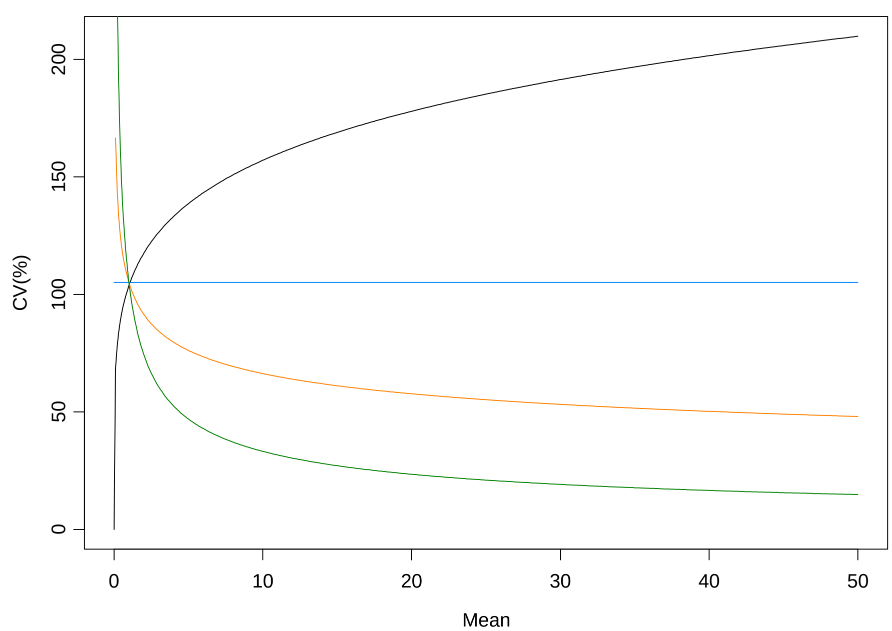

Figure 13: Relationship between the coefficient of variation (C.V.) and mean, with coefficient α=0.05 and various values of β: β=0.5 (green line, indicating a random distribution); β=0.8 (yellow line); β=1.0 (blue line); and β=1.2 (black line).

The relationship in (3) continues to be an effective model to describe the relationship between observed standard deviations and means for strata in the three recruitment surveys, particularly for the two tiger prawn species which have a wide range of mean catch rates over the 22 strata (Figure 14). A separate model was fitted for each species to the data combined over regions and surveys. In fact, the coefficients for brown tiger prawns *(P. esculentus)* and grooved tiger prawns *(P. semisulcatus)* are so similar (Table 2) that a common model could have been fitted to the mean-standard deviation data for the tiger prawns. Likewise, the endeavour prawns have a similar relationship (Table 2 and Figure 15), even though the catch rates of red endeavour prawns *(M. ensis)* are mostly much lower than those of blue endeavour prawns *(M. endeavouri)*.

Table 2: Parameters for relationship between mean and standard deviation per stratum for sub-adults of seven species, based on number of prawns caught per hectare in the January 2003, 2004 and 2005 surveys.

Species	Intercept (α)	S.E. of α	Slope (β)	S.E. of β
Tiger prawns				
P. esculentus	**0.129**	0.048	**0.895**	0.031
P. semisulcatus	**0.212**	0.038	**0.865**	0.015
Endeavour prawns				
M. endeavouri	**–0.056**	0.054	**0.795**	0.036
M. ensis	**0.062**	0.091	**0.780**	0.030
Banana prawns				
P. merguiensis	**0.539**	0.060	**0.876**	0.024
King prawns				
P. latisulcatus	**0.527**	0.089	**0.922**	0.031
P. longistylus	**–0.118**	0.240	**0.708**	0.060

All seven species (Table 2) showed a clumped spatial distribution (β>0.5). Four species (*P. esculentus*, *P. semisulcatus*, *P. merguiensis* and *P. latisulcatus*) had an estimated slope ($\hat{\beta}$) close to 0.9. For blue endeavour prawns *(M. endeavouri)* and red endeavour prawns *(M. ensis)* the slope was shallower (about 0.8). For red spot king prawns *(P. longistylus)* the slope was only 0.7, but with a larger standard error due to its consistently low catch rates in these surveys. For all of these species, higher mean catch rates will usually be associated with a lower C.V. at the stratum level.

Despite the similarity of its estimated slope to those of the tiger prawns, the banana prawn (*P. merguiensis*) catch rates were much more variable than the tiger prawns: its estimated intercept ($\hat{\alpha}$ =0.539) was more than double that of the grooved tiger prawn *(P. semisulcatus)* ($\hat{\alpha}$ =0.212) and the brown tiger prawn (*P. esculentus)* ($\hat{\alpha}$ =0.129). The sample size for banana prawns *(P. merguiensis* in a given stratum would therefore need to be double that of grooved tiger prawns *(P. semisulcatus)* to achieve the same precision for a given mean catch rate.

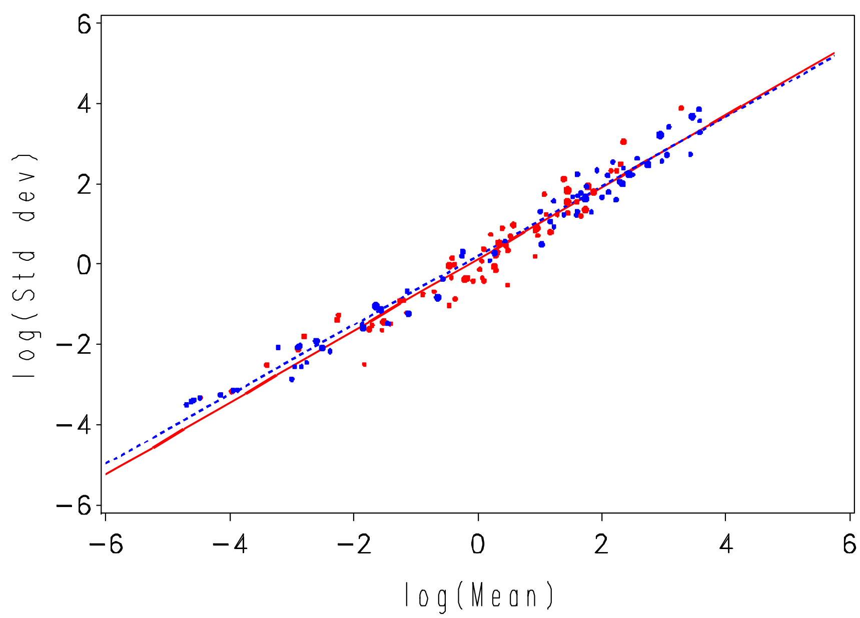

Figure 14: Brown tiger prawns *(Penaeus esculentus)* **(red) and Grooved tiger prawns** *(Penaeus semisulcatus)* **(blue). Relationship between sample mean and sample standard deviation for number of sub-adult prawns caught per hectare in the January 2003, 2004 and 2005 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.**

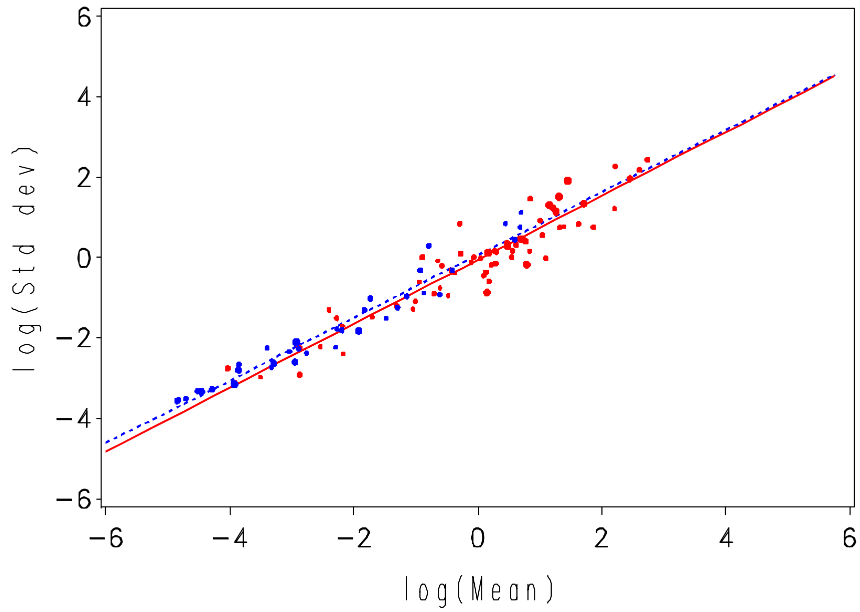

Figure 15: Blue endeavour prawns *(Metapenaeus endeavouri)* **(red) and red endeavour prawns** *(Metapenaeus ensis)* **(blue). Relationship between sample mean and sample standard deviation for number of sub-adult prawns caught per hectare in the January 2003, 2004 and 2005 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.**

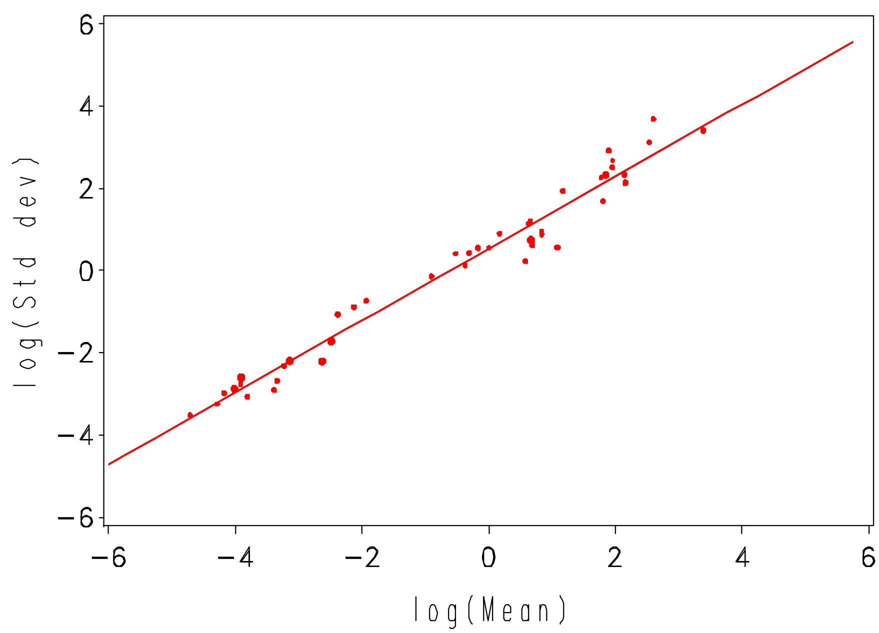

Figure 16: Banana prawns *(Penaeus merguiensis)*. **Relationship between sample mean and sample standard deviation for number of sub-adult prawns caught per hectare in the January 2003, 2004 and 2005 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.**

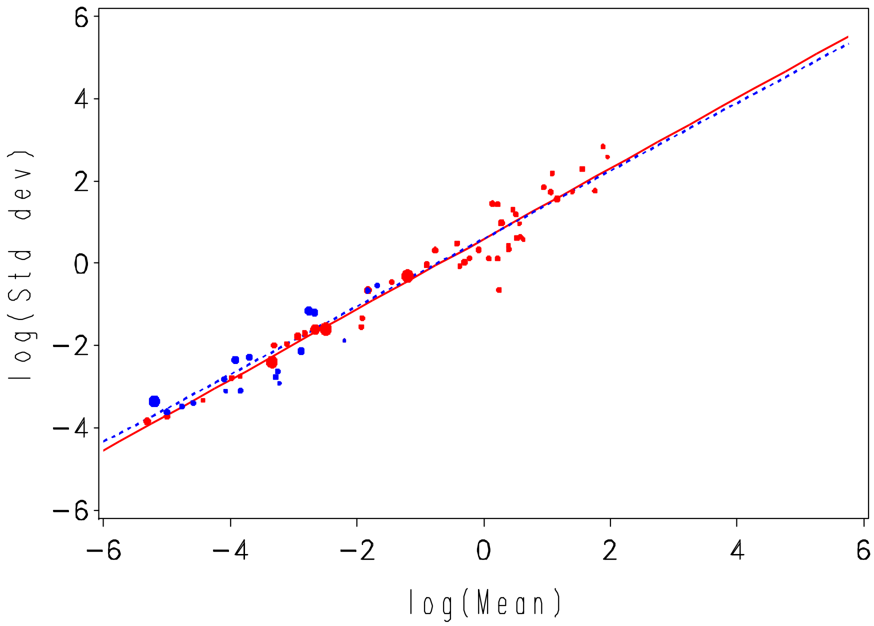

Figure 17: Western king prawn *(Penaeus latisulcatus)* (red) and red spot king prawns *(Penaeus longistylus)* (blue). Relationship between sample mean and sample standard deviation for number of sub-adult prawns caught per hectare in the January 2003, 2004 and 2005 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.

4.4 Recruitment index

4.4.1 Precision of index

The catch rates presented for each species are the number of sub-adult prawns caught per hectare (definitions are given in Section 3.2). For a small number of trawls, the catch from one net was discarded from analysis because of gear problems or the presence of, for example, substantial numbers of jellyfish that suggest the catch would not be representative. Trawls of less than 15 minutes' duration were discarded. Most trawls swept 8–10 hectares, with a peak of around 9 hectares. An index was calculated for each region and species, using the methods described in Section 2.4.

The effectiveness of the stratification for the January surveys can be assessed by analysis of variance on log-transformed catch rates — $\log_{10}$(count/hectare + 0.01). By including data from all three January surveys, we can also assess the year-to-year variation in catch rates, and the extent to which region or stratum-within-region differences vary between years. *F*-ratios are a useful measure of the relative contributions of the stratifying factors (regions, sub-regions and depth strata) to the variation in catch rates.

An example analysis of variance (Table 3) shows the partitioning of variation in log-transformed catch rates of sub-adult grooved tiger prawns *(P. semisulcatus)* into temporal (Survey), spatial (large-scale: Region; medium-scale: Region×Sub-region and Region×Sub-region×Depth), and space-time interactions at three levels (Survey×Region, Survey×Region×Sub-region and Survey×Region×Sub-region×Depth). All F-ratios were highly statistically significant ($p < 0.0001$), partly because of the large number of degrees of freedom for within-stratum variation. Nonetheless, the fact that F-ratios for spatial variation ranged from 9.7 at the lowest level (Region×Sub-region×Depth) to 616.3 at the highest level (Region) demonstrates that the chosen strata have partitioned the variation effectively. There were substantial overall differences between surveys (F-ratio of 19.3 for Survey), but the temporal changes also differed among regions (F-ratio of 9.1 for Survey×Region).

Table 3: Analysis of variance of $\log_{10}$-transformed grooved tiger prawns *(P. semisulcatus)* sub-adult catch rates from January surveys in 2003, 2004 and 2005.

Source	Degrees of freedom	Sum of squares	Mean square	F-ratio
Survey	2	13.7	6.9	19.3
Region	4	874.6	218.6	616.3
Survey × Region	8	25.8	3.2	9.1
Region × Sub-region	6	115.1	19.2	54.1
Survey × Region × Sub-region	12	14.5	1.2	3.4
Region × Sub-region × Depth	13	44.7	3.4	9.7
Survey × Region × Sub-region × Depth	26	21.14	0.8	2.3
Within-stratum	796	282.4	0.4	
Total	867	1390.2		

Interpretation is focussed on the tiger, endeavour and banana prawns *(P. merguiensis)* as these are of commercial interest; but results for king prawn species, western king prawn *(P. latisulcatus)* and red spot king prawn *(P. longistylus)*, have been included for completeness. Since the red spot king prawn (*P. longistylus*) was caught in very low quantities, no further analysis was carried out for this species.

Regional differences in catch rates were the dominant source of variation for the five commercial species, with *F*-ratios for Region ranging from 132 to 616 (Table 4). There were substantial year-to-year differences in overall abundance (*F*-ratios of 19–30 for Survey), but the smaller *F*-ratios for the Survey×Region interaction (6–18) are consistent with broad regional profiles remaining stable over the three-year period. For grooved tiger prawns *(P. semisulcatus)*, differences among sub-regions were more important (*F*-ratio of 54) than depth differences (*F*-ratio of 10). Though the difference was less marked, this was also true for brown tiger prawns *(P. esculentus)*, banana prawns *(P. merguiensis)* and the two king prawn species. For the endeavour prawns, however, sub-region and depth were equally important stratification factors. The low *F*-ratios for the Survey×Region×Sub-region×Depth interaction (2–4 except for king prawns) compared with Region×Sub-region×Depth (7–31) indicate that there was some stability in the patterns of distribution at the medium scale. For *M. ensis*, the within-region stratification accounted for relatively little variation (F-ratios of 3 for Region×Sub-region and 7 for Region×Sub-region×Depth) mainly because this species was found almost exclusively in Weipa and even there the catch rate was low.

Table 4: Results from analysis of variance of $\log_{10}$-transformed sub-adult catch rates from January surveys in 2003, 2004 and 2005 (*F*-ratios for effects relative to within-stratum variance).

Species	*F*-ratios for effects						
	Survey	Region	Survey × Region	Region × Sub-region	Survey × Region × Sub-region	Region × Sub-region × Depth	Survey × Region × Sub-region × Depth
Tiger prawns							
P. esculentus	19	132	8	17	3	10	2
P. semisulcatus	19	616	9	54	3	10	2
Endeavour prawns							
M. endeavouri	42	320	18	16	6	12	2
M. ensis	32	166	9	3	3	7	4
Banana prawns							
P. merguiensis	30	203	6	46	7	31	3
King prawns							
P. latisulcatus	15	26	2	17	2	6	1
P. longistylus	1	11	4	11	3	4	1

Sub-adult brown tiger prawns (*P. esculentus)* catch rates were highest in Groote over the three-year period (8.5 ha^{-1} in 2003, 2.4 ha^{-1} in 2004 and 6.9 ha^{-1} in 2005) (Table 5). Catch rates around Mornington and the Vanderlins (1.6–4.1 ha^{-1}) were mostly 30–70% less than for Groote and always low (<1.0 ha^{-1}) in Karumba and Weipa. The overall catch rate was highest in 2003 (3.9 ha^{-1}) and lowest in 2004 (1.5 ha^{-1}), and increased to 3.1 ha^{-1} in 2005. The behaviour of the regional means over the three surveys echoed that for the overall mean.

Over the three-year period, catch rates of sub-adult grooved tiger prawns *(P. semisulcatus)* in January were consistently highest at Weipa (20.4 ha^{-1} in 2003, 7.2 ha^{-1} in 2004 and 16.1 ha^{-1} in 2005) (Table 5). Catch rates in Groote and the Vanderlins were 15–60% lower than for Weipa, and always low around Mornington (< 1.0 ha^{-1}) and negligible (< 0.1 ha^{-1}) in Karumba. The overall catch rate was highest in 2003 (9.2 ha^{-1}) and much lower in 2004 (3.4 ha^{-1}) with an increase in 2005 (4.5 ha^{-1}). This pattern over the three years was echoed in the regional indices for Groote and Weipa.

Blue endeavour prawns *(Metapenaeus endeavouri)* catch rates were very much higher at Groote and the Vanderlins in 2003 (9.4 and 7.8 ha^{-1}), but in 2004 and 2005 the catch rates in these two regions dropped to values comparable with Mornington (Table 6). Catch rates were consistently low in Weipa and negligible in Karumba. The overall catch rate was highest in 2003 (4.5 ha^{-1}) and lowest in 2004 (1.1 ha^{-1}), with a slight increase to 1.6 ha^{-1} in 2005.

Red endeavour prawns *(Metapenaeus ensis)* were much less abundant everywhere than the other commercial endeavour prawn species (Table 6). Weipa was the only region with consistently non-negligible catch rates (1.1 ha^{-1} in 2003, 1.0 ha^{-1} in 2004 and 0.3 ha^{-1} in 2005). The overall catch rates for this species were an order of magnitude smaller than the other commercial species.

Regional catch rates of sub-adult banana prawns *(P. merguiensis)* were consistently highest in Karumba and Weipa (Table 7), always negligible in Groote and low in the Vanderlins and Mornington. Catch rates of 7.1 ha^{-1} and 10.4 ha^{-1} for Karumba and Weipa in 2005 were considerably higher than the previous catch rates of approx 2 ha^{-1} for this region, and resulted in 2005 having the highest overall catch rate of 2.6 ha^{-1}.

Sub-adult western king prawn *(Penaeus latisulcatus)* had consistently negligible catch rates in Karumba and Weipa and mostly low catch rates in the other three regions (Table 7). All of the overall catch rates were below 1.0 ha^{-1}.

Given the observed relationship between the standard deviation and mean, the coefficient of variation for a region can be expected to decrease as the mean for that region increases. Regions with a mean catch rate below 1.0 ha^{-1} tended to have an appreciably higher C.V. than those regions with a higher mean catch rate. For the tiger prawns *(P. esculentus)*, blue endeavour prawns *(M. endeavouri)* and banana prawns *(P. merguiensis)*, this is also a reasonable threshold for identifying regions where a species can be harvested in commercial quantities. In assessing the C.V. obtained from these surveys, we therefore focus on those regional indices of at least 1.0 ha^{-1}.

Indices for the two tiger species and blue endeavour prawns *(M. endeavouri)* had the best precision in the Vanderlins (C.V. of 9–17%). In fact, indices in Groote were almost as good, except for brown tiger prawns *(P. esculentus)* in 2003 where the C.V. was 42% due to one trawl with an exceptionally high catch in south Groote. Likewise, for the two predominant species in Mornington (brown tigers and blue endeavours), the C.V. ranged from 11 to 21%. For grooved tiger prawns *(P. semisulcatus)* in Weipa, the C.V. ranged from 11 to 25%.

Taking into account the regions where each species is most prevalent, blue endeavour prawns *(M. endeavouri)* had the best precision (C.V. of 9–21% in Groote, Vanderlins and Mornington; Table 6) followed by grooved tiger prawns *(P. semisulcatus)* (C.V. of 11–23% in Groote, Vanderlins and Weipa; Table 5) and brown tiger prawns *(P. esculentus)* (C.V. of 11–42% in Groote, Vanderlins and Mornington; Table 5). Precision was generally poor banana prawns *(P. merguiensis),* with few indices having a C.V. of less than 30% even in Karumba and Weipa (Table 7). Given the previous comments about the variability of this species, it would be necessary to double the sample size in Karumba and the shallow (inshore) strata at Weipa in order to achieve precision comparable to that of the other commercial species.

The precision of the global indices over the three years was excellent for blue endeavour prawns *(M. endeavouri)* (C.V. of 6–8%; Table 6) and grooved tiger prawns *(P. semisulcatus)* (C.V. of 6–11%; Table 5). It was generally good for brown tiger prawns *(P. esculentus)* (C.V. of 9–19%; Table 5) and modest for banana prawns *(P. merguiensis)* (C.V. of 23–29%; Table 7).

Table 5: Mean number of sub-adult tiger prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with standard error (S.E.) and coefficient of variation (C.V.). Regions with highest abundance have shaded background.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Brown tiger prawns ***(P. esculentus)***							
2003	**Mean**	**8.5**	**3.4**	**4.1**	**0.8**	**0.3**	**3.9**
	S.E.	3.5	0.6	0.9	0.2	< 0.1	0.8
	C.V.	42	17	21	24	24	19
2004	**Mean**	**2.4**	**1.6**	**1.9**	**0.2**	**0.2**	**1.5**
	S.E.	0.3	0.3	0.3	0.1	< 0.1	0.1
	C.V.	14	16	17	36	23	9
2005	**Mean**	**6.9**	**2.1**	**3.9**	**0.5**	**0.2**	**3.1**
	S.E.	1.8	0.2	0.4	0.1	< 0.1	0.4
	C.V.	26	12	11	29	25	12
Grooved tiger prawns ***(P. semisulcatus)***							
2003	**Mean**	**14.4**	**17.1**	**0.1**	**< 0.1**	**20.4**	**9.2**
	S.E.	2.7	2.8	< 0.1	< 0.1	4.8	1.0
	C.V.	19	16	17	40	23	11
2004	**Mean**	**4.2**	**6.7**	**0.7**	**< 0.1**	**7.2**	**3.4**
	S.E.	0.5	1.1	0.3	< 0.1	1.3	0.3
	C.V.	12	16	38	42	18	10
2005	**Mean**	**7.0**	**5.6**	**0.8**	**< 0.1**	**16.1**	**4.5**
	S.E.	0.8	0.6	0.1	< 0.1	1.8	0.3
	C.V.	12	11	18	31	11	6

Table 6: Mean number of sub-adult endeavour prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with standard error (S.E.) and coefficient of variation (C.V.). Regions with highest abundance have shaded background.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Blue endeavour prawns *(M. endeavouri)*							
2003	**Mean**	**9.4**	**7.8**	**1.6**	**< 0.1**	**0.4**	**4.5**
	S.E.	1.0	0.7	0.2	< 0.1	0.1	0.3
	C.V.	11	9	14	36	23	6
2004	**Mean**	**1.7**	**1.6**	**0.9**	**< 0.1**	**0.2**	**1.1**
	S.E.	0.2	0.2	0.2	< 0.1	< 0.1	0.1
	C.V.	10	10	21	34	35	7
2005	**Mean**	**2.1**	**1.3**	**2.7**	**< 0.1**	**0.8**	**1.6**
	S.E.	0.3	0.1	0.4	< 0.1	0.1	0.1
	C.V.	15	9	13	45	14	8
Red endeavour prawns *(M. ensis)*							
2003	**Mean**	**< 0.1**	**0.3**	**0**	**0**	**1.1**	**0.2**
	S.E.	< 0.1	< 0.1	0	0	0.4	0.1
	C.V.	19	32	–	–	34	22
2004	**Mean**	**< 0.1**	**0.1**	**0**	**0**	**1.0**	**0.1**
	S.E.	< 0.1	< 0.1	0	0	0.2	< 0.1
	C.V.	31	45	–	–	21	19
2005	**Mean**	**< 0.1**	**0**	**0**	**0**	**0.3**	**< 0.1**
	S.E.	< 0.1	0	0	0	< 0.1	< 0.1
	C.V.	49	–	–	–	20	19

Table 7: Mean number of sub-adult banana prawns*(P. merguiensis)* and king prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with standard error (S.E.) and coefficient of variation (C.V.). Regions with highest abundance have shaded background.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Banana prawns *P. merguiensis*							
2003	**Mean**	**< 0.1**	**1.5**	**1.7**	**2.1**	**1.9**	**1.4**
	S.E.	< 0.1	0.8	0.6	0.4	1.5	0.3
	C.V.	30	58	34	20	78	23
2004	**Mean**	**0**	**0.1**	**< 0.1**	**2.5**	**2.3**	**0.6**
	S.E.	0	< 0.1	< 0.1	1.1	0.7	0.2
	C.V.	–	61	35	42	31	29
2005	**Mean**	**< 0.1**	**0.3**	**1.8**	**7.1**	**10.4**	**2.6**
	S.E.	< 0.1	0.1	0.7	3.1	2.8	0.6
	C.V.	86	53	37	43	27	23
Western king prawns *(Penaeus latisulcatus)*							
2003	**Mean**	**2.8**	**0.3**	**1.0**	**0.1**	**< 0.1**	**0.9**
	S.E.	1.8	< 0.1	0.6	< 0.1	< 0.1	0.4
	C.V.	65	24	63	49	24	43
2004	**Mean**	**< 0.1**	**0.6**	**0.3**	**0**	**< 0.1**	**0.3**
	S.E.	< 0.1	0.5	0.1	0	< 0.1	0.2
	C.V.	34	87	39	–	56	57
2005	**Mean**	**0.1**	**0.1**	**0.4**	**< 0.1**	**< 0.1**	**0.2**
	S.E.	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1
	C.V.	45	73	21	46	37	21

4.4.2 *Results by stratum*

The results for the individual sites are presented in a later Chapter. The results presented here (Figure 18–Figure 23) are mean catch rates by stratum. These plots highlight where the highest catches occurred. They also show whether a stratum has a high mean catch due to a few productive sites or consistently high catch rates over most sites in that stratum. If it is the former, then the standard error for that stratum will be higher than for similar means in other strata, resulting in a higher coefficient of variation (C.V.) for that stratum.

For example, in the January 2003 survey, standard errors of ± 8–15 prawns per hectare were obtained for four grooved tiger prawns *(P. semisulcatus)* strata (Figure 19) where the mean was 30–40 prawns per hectare. Thus, the means for the shallow strata in the eastern Vanderlins and north Weipa were estimated less precisely than for the deep stratum in north Groote and the shallow stratum in the western Vanderlins.

4.4.2.1 *Brown tiger prawns*

Over the three years, three regions consistently produced higher catch rates of brown tiger prawns (*P. esculentus*): Groote, the Vanderlins and Mornington. Catch rates were below 2 individuals ha^{-1} in all strata in Karumba and Weipa in all three surveys (Figure 18).

In Groote, catch rates of sub-adult brown tiger prawns (*P. esculentus*) were generally highest in the south Groote sub-region, and usually more abundant in the shallow stratum; consistent with historical survey data for that area (Somers et al. 1987). In the Vanderlins, the eastern sub-region was slightly more productive than the western sub-region, but there was no consistent trend across depth strata over the three years. Catch rates were consistently lower north of Mornington than in the eastern and western sub-regions. This is consistent with an absence of nursery seagrass habitat on the northern side of Mornington Island: suitable nursery habitat is known to exist on the southern side and on the mainland south-east of Mornington (Coles and Lee Long 1985). Again, there was no consistent trend across the depth strata.

4.4.2.2 *Grooved tiger prawns*

Three regions consistently produced higher catch rates of grooved tiger prawns (*P. semisulcatus*) over the three years: Weipa, Groote and the Vanderlins. Catch rates were almost all below 1 ha^{-1} in all strata in Mornington and Karumba in the three surveys (Figure 19).

Catch rates were consistently higher in north Groote than in south Groote, and always highest in the deep stratum in north Groote. At Weipa, catch rates were consistently higher in shallow water and there was no consistent difference between north and south, as might be expected for a region with less than half the area of the Groote region. In the Vanderlins, 2003 was the only year with a pronounced trend across depth strata, and there was no consistent difference in catch rates between the eastern and western sub-regions.

4.4.2.3 *Endeavour prawns*

The profile for blue endeavour prawns (*M. endeavouri*) was very similar to the brown tiger prawns (*P. esculentus*), with highest catch rates in Groote, the Vanderlins and Mornington and negligible catch rates in Karumba and Weipa (Figure 20).

In the Groote region, blue endeavour prawns *(M. endeavouri)* showed no consistent inshore-offshore or north-south trends. On the other hand, in the Vanderlins the catch rates were generally higher in the east than the west and highest in the shallow stratum.

Catch rates of the red endeavour prawn (*M. ensis*) were consistently high in Weipa and negligible elsewhere (Figure 21).

4.4.2.4 ***Banana prawns***

For sub-adult banana prawns (*P. merguiensis*), catch rates were consistently the highest in Weipa and Karumba (Figure 22). The shallow stratum in north Weipa consistently produced the highest mean catches, though with a large standard error in 2003. While there were a couple of high catch rates in the Vanderlins and Mornington regions in 2003, the Karumba region was more consistently productive over the three years. Catch rates in Groote were consistently negligible.

4.4.2.5 ***King prawns***

Sub-adult western king prawns (*P. latisulcatus*) were rarely caught in meaningful quantities (Figure 23), exceeding 1 ha^{-1} in only three instances (shallow north Groote and east Mornington in 2003, and shallow west Vanderlins in 2004). Catch rates of red spot king prawns (*P. longistylus*) were even lower than this.

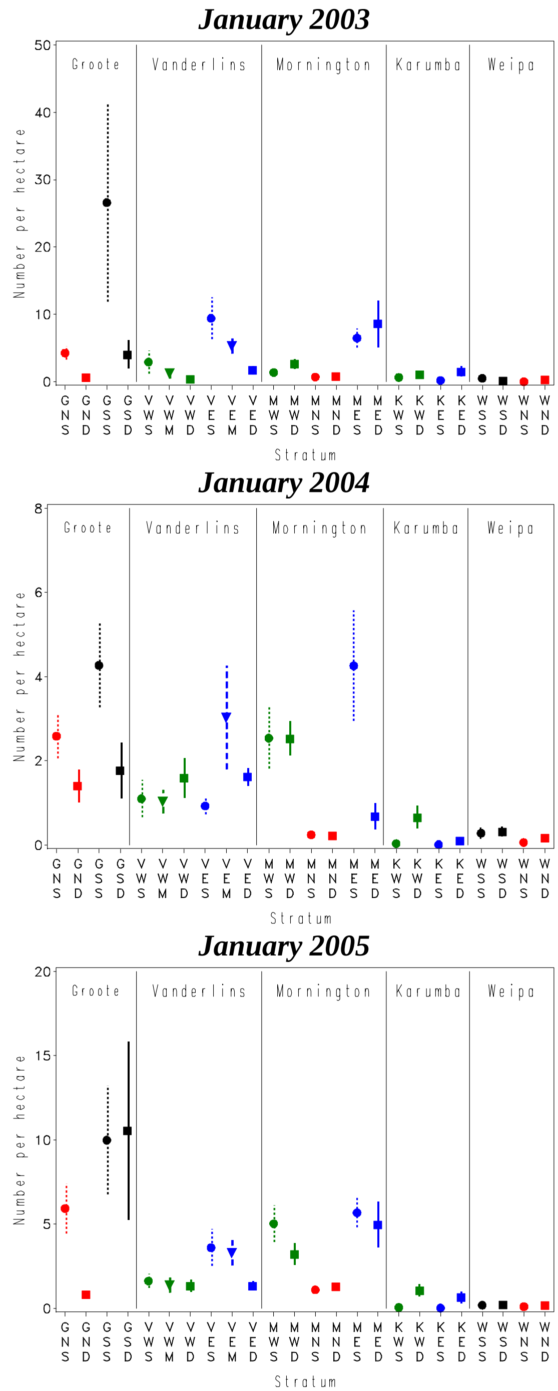

Figure 18: Brown tiger prawns *(Penaeus esculentus)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

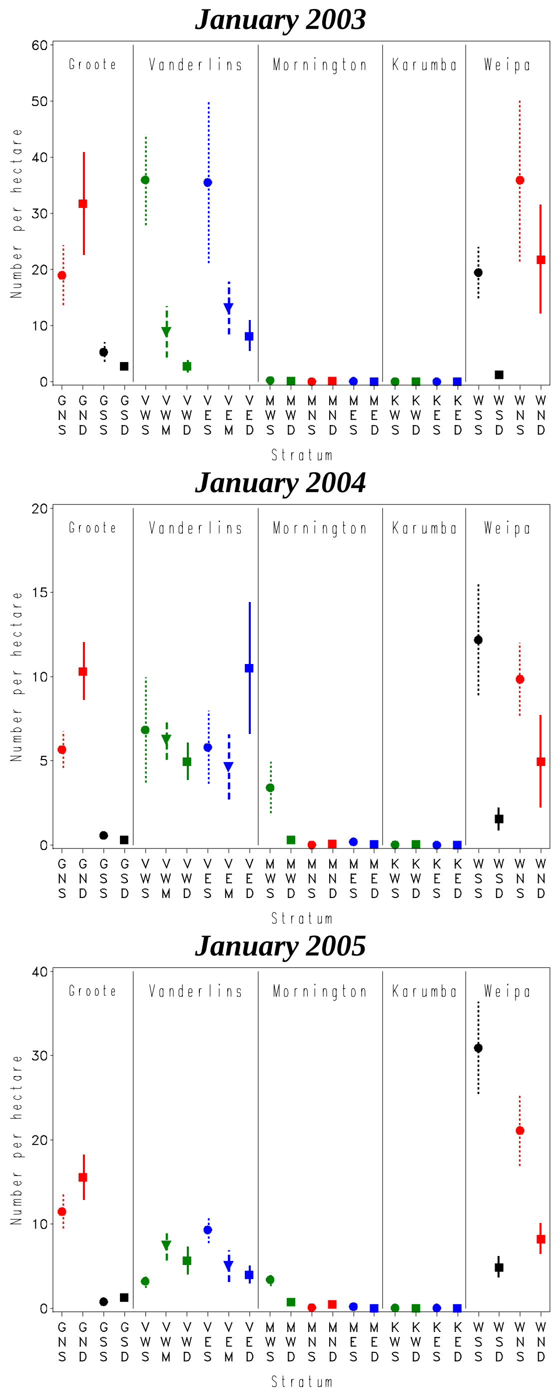

Figure 19: Grooved tiger prawns *(Penaeus semisulcatus)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

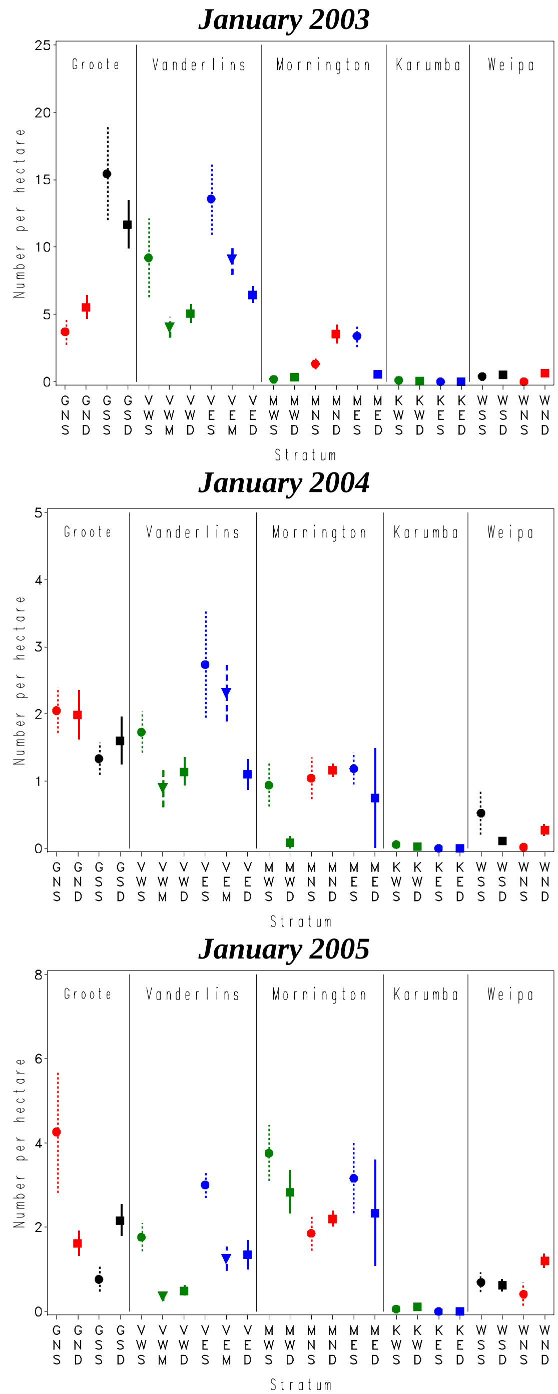

Figure 20: Blue endeavour *prawns (Metapenaeus endeavouri)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

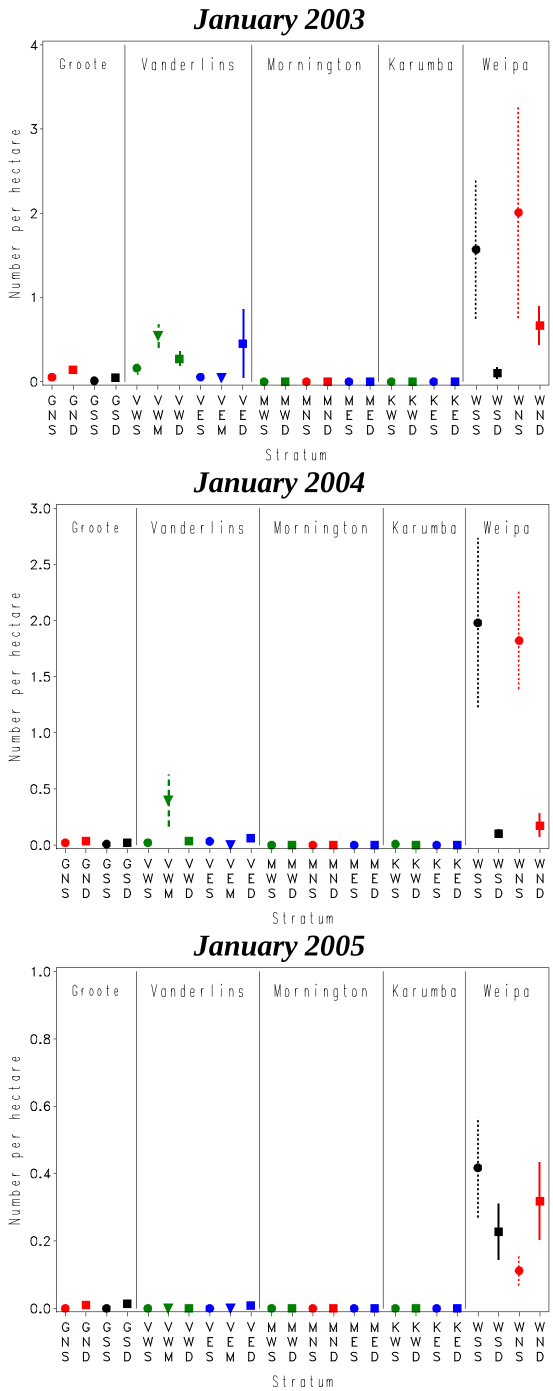

Figure 21: Red endeavour prawns *(M. ensis)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

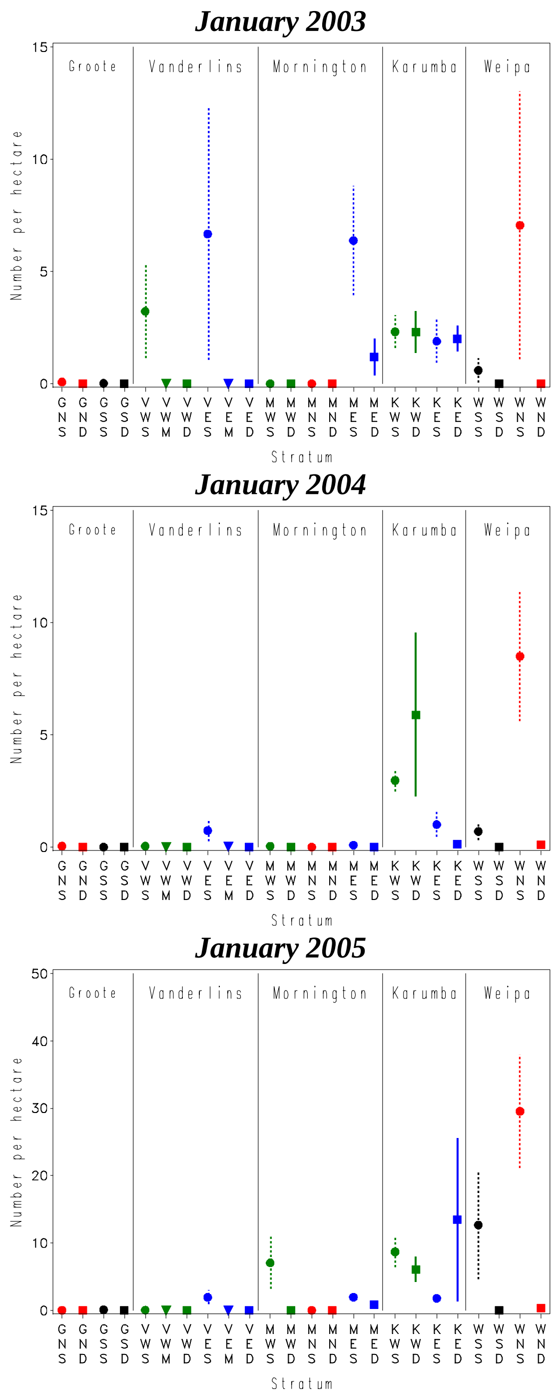

Figure 22: Banana prawns *(Penaeus merguiensis)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

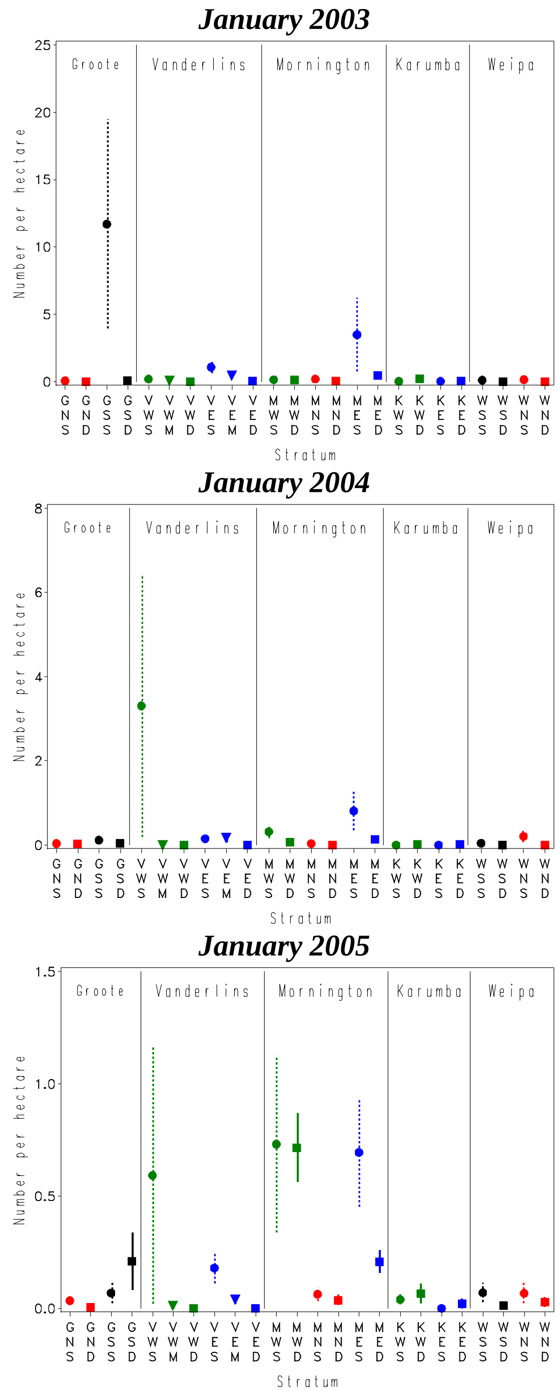

Figure 23: Western king prawn *(Penaeus latisulcatus)*. Mean number of sub-adult prawns per hectare (with standard errors) in each stratum for the January 2003, 2004 and 2005 surveys. Label on horizontal axis indicates region {G=Groote, K=Karumba, M=Mornington, V=Vanderlins, W=Weipa}, sub-region {N (red)=north, S (black)=south, E (blue)=east, W (green)=west} and depth {D (solid line)=deep, M (dashed line)=medium, S (dotted line)=shallow}. Note the different scales on each figure.

4.5 Discussion

The Recruitment Surveys conducted in January 2003, 2004 and 2005 have been the first surveys ever to provide a simultaneous Gulf-wide fishery-independent assessment of the stocks of all commercial prawn species. This has filled regional gaps for which no previous survey data were available (Vanderlins and Mornington). It has also enabled the regional distribution of individual species to be assessed more comprehensively than before, and highlighted substantial differences between sub-regions for some species. For example, catch rates of grooved tiger prawns *(P. semisulcatus)* were much higher in north Groote than in south Groote, while the reverse was true for brown tiger prawns (*P. esculentus*). Sub-adult prawns were sometimes more abundant in shallow water, sometimes in deep. This may indicate either that distance from shore is a more important driver or that the peak in recruitment happens at different times in different regions.

The global recruitment indices of both tiger prawn species and blue endeavour prawns *(M. endeavouri)* were highest in 2003 and lowest in 2004. For brown tiger prawns (*P. esculentus*), the mean for 2005 was similar to 2003 but for the other two species there was little increase between 2004 and 2005. Catch rates for banana prawns *(P. merguiensis)* were lower than for the other three species, but in fact 2005 produced the highest global catch rate for this species for the three years of surveys. However, this trend should be interpreted with some caution as the survey excludes two statistical areas that produced much of the commercial catch in recent years (Mitchell and part of Bold). The catch rates for red endeavour prawns *(M. ensis)* were so low everywhere except the shallow waters of the Weipa region (where mean catch rates of ~2 ha^{-1} were observed) that it is probably misleading to interpret the apparent decrease in the global index.

4.6 Conclusions

1. Analysis of variance on log-transformed catch rates for each species demonstrated the effectiveness of the stratification for the January survey (Table 4). Region differences were a dominant component of variation, and there were also appreciable differences among strata within regions, as captured by the terms Region×Sub-region and Region×Sub-region×Depth. Even though abundance differed between the surveys, the Region×Sub-region×Depth interaction accounted for considerably more than the (statistically significant) Survey×Region×Sub-region×Depth interaction. This suggests that the stratification employed in the current survey design has successfully captured relatively persistent patterns in the distribution of each prawn species and is therefore likely to be of long-term value in enhancing the precision of recruitment indices.

2. The results provide a quantitative description of the spatial distribution and temporal variation of all commercial species. The description is consistent with qualitative information available prior to the surveys:

- The species profile varied from region to region. For example, the catch consisted of both brown and grooved tiger prawns and blue endeavour prawns *(M. endeavouri)* in the Groote region but almost entirely of banana prawns *(P. merguiensis)* with a few brown tiger prawns *(P. esculentus)* in the Karumba region. In Weipa, grooved tiger prawns *(P. semisulcatus)* were the dominant species, with banana prawns *(P. merguiensis)* also abundant and red endeavour prawns *(M. ensis)* much less abundant. This was the only region with non-negligible densities of red endeavour prawns.
- Within some regions, there was further partitioning among species. For example, grooved tiger prawns *(P. semisulcatus)* were more abundant in north Groote while brown tiger prawns (*P. esculentus*) were more abundant in south Groote. The inshore south Weipa region had consistently higher catch rates than the other three strata.
- There was marked variation over the three years; some of it was consistent over regions. For example, brown tiger prawns (*P. esculentus*) had lower catch rates in every region in the 2004 survey compared with the 2003 and 2005 surveys.
- The variation increased with the mean and this relationship was consistent over regions.
- The slope of the relationship between mean and standard deviation ranged from 0.8 to 0.9 for commercial species, including banana prawns *(P. merguiensis)*; showing that all of these species exhibit some level of non-randomness in their spatial distribution.
- However, banana prawns *(P. merguiensis)* had consistently higher variability than the other commercial species and would benefit from more intensive sampling in strategic areas such as Karumba and the shallow stratum in Weipa.

3. For most species there was no consistent depth preference across regions for sub-adults at this time of year. This result is different to the Spawning Index survey. We can therefore conclude that the recruitment timing is different between regions but also distance from the nursery grounds may be a better stratification variable than depth.

4. The global recruitment index was highest in 2003 for both tiger prawns, and lowest in 2004.

5. The global recruitment index for banana prawns *(P. merguiensis)* was very low both in 2003 and 2004, increasing slightly in 2005 due to a marked increase in the Karumba and Weipa regions. However, it should be noted that two other regions not included in these surveys produced most of the banana prawn *(P. merguiensis)* catch in these years.

6. Based on points 2 and 3 above, no single area seems to be able to represent another. This means that surveys of all areas need to be continued so that a Recruitment Index can be obtained for the two tiger, the endeavour and the banana prawn species.

4.7 References

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Somers, I.F., Crocos, P.J. and Hill, B.J. 1987. Distribution and abundance of the tiger prawns *Penaeus esculentus* and *P. semisulcatus* in the north-western Gulf of Carpentaria, Australia. Aust. J. Mar. Freshw. Res. 38: 63-78.

CHAPTER 5. SPAWNING SURVEY

5.1 Introduction

The objectives of this survey were to provide:

a. an index of spawning abundance with coefficient of variation (CV) for tiger and endeavour prawns,

b. a distribution of abundance over the old and present fishing grounds at a time when prawns are expected to be most abundant on the fishing grounds,

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

d. a catch rate distribution map made available to industry on the AFMA web site.

5.2 Survey design

The timing of the survey and spatial extent of the survey was discussed extensively in Dichmont et al. (2002) and the issues are summarised below. The Spawning survey would provide a relative index of spawning abundance of tiger prawns and address the issue of the spatial contraction of the fishery. It has also been shown that this survey is useful as input to the spatial model developed by the fishing power project[3].

5.2.1 *Extent and timing of the survey*

In Dichmont et al. (2002), detailed analyses were carried out on the distribution of tiger prawn fishing effort in the first six weeks of the second season, with a view to defining suitable regions for the August survey and the extent of each region. Because most of the commercial effort in the Gulf of Carpentaria at this time is focused around three areas, Groote, the Vanderlins and Mornington Island, only these areas were surveyed.

The catchability of tiger prawns decreases markedly during the cooler winter months. This is especially true for grooved tiger prawns (*P. semisulcatus*) that migrate offshore beyond the fishing grounds. Because of this difference in availability between grooved and brown tiger prawns, brown tiger prawns (*P. esculentus*) tend to get fished earlier in the season than grooved tiger prawns *(P. semisulcatus)* (Figure 24) and, in recent years, their numbers decline dramatically by September. The survey therefore has to optimise its timing between fishing too early (at times when catchability is low) and too late (when few brown tiger prawns remain). To minimise costs, a survey in August was to be undertaken, just prior to the start of the second season on 1 September and centred on the new moon. Trawls were carried out on the nights of 16–26 August 2002, 31 July to 14 August 2003, and 20 July to 4 August 2004.

[3] A new approach to fishing power and its application in the NPF. ARF and FRRF fund.

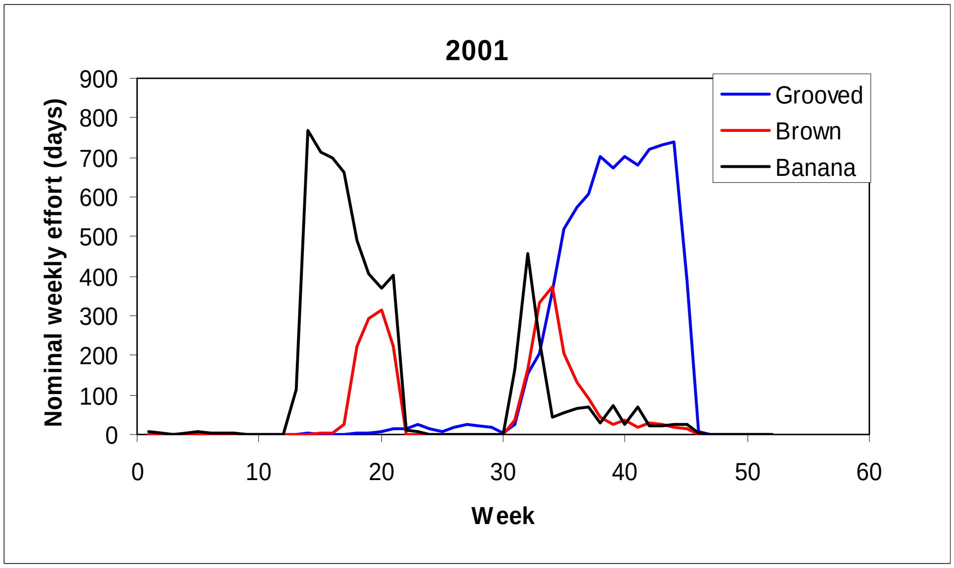

Figure 24: Weekly effort pattern targeted at banana prawns *(P. merguiensis)*, and grooved tiger prawns *(P. semisulcatus)* and brown tiger prawns *(P. esculentus)* for the year 2001.

5.2.2 *Stratification and site selection*

The survey design proposed in Dichmont et al. (2002; 2004) was used with very few changes. The overall area was based on 6 nm grid scale logbook data for 1980-2000 for the 6-week period August to mid-September. This means that, within limits, a region that was fished at some time during the history of the fishery would be included within the survey.

In Dichmont et al. (2004), the first stratification criterion was based on depth. Two depth strata were used at the 30 m depth contour for each region (i.e. > 30 m, < 30 m). Within each depth stratum, a second criterion, fishing effort, was applied (we assume that, generally, the fishery tends to fish in higher density areas). Vessel Monitoring System (VMS) data at 2 nm scale for the year 2000 was used to divide the area into low, medium and high effort grids. An additional stratum within the shallow area is needed as some previously fished areas fall within permanent closures.

Since the survey is a stratified random survey, the intention was that only the primary sampling sites should be used, and secondary sites should be used when a primary site falls within untrawlable ground (Figure 25). The *in situ* reality was that the number of primary sites was too many for a nights trawling, given the large distances to be travelled between sites, and the August 2002 survey was unable to trawl the expected number of sites. Survey redesign after the first few nights was required, and some secondary sites were trawled if the travel distance to the next primary site was too far. This did not happen often enough for the randomness of the survey to be compromised.

For subsequent surveys in August, we adopted the January 2003 sampling scheme for the Mornington region for compatibility with another project, having demonstrated that the distribution of sample sites was compatible with the existing effort/depth design. We retrospectively partitioned the Groote and Vanderlins regions into sub-regions and depth strata similar to the January 2003 survey design. In the process, we augmented the sampling sites in the shallow waters in the eastern Vanderlins, as this area had previously been under-sampled due to the time constraints described earlier. Table 8 shows the number of sites successfully sampled in the three surveys, using January-style strata to allocate sampling effort.

Table 8: Sampling design for August by region in terms of modified sampling frame size and number of sites successfully sampled.

Region	Location	Depth stratum	Number of 2 nm sites for selection	Number of sites sampled in Aug 2002	Number of sites sampled in Aug 2003	Number of sites sampled in Aug 2004
Groote	North	Shallow (8–30 m)	327	17	16	15
		Deep (30–51 m)	225	19	23	25
	South	Shallow (8–25 m)	288	10	12	14
		Deep (25–50 m)	135	9	9	10
	Total		**975**	**55**	**60**	**64**
Vanderlins	West	Shallow (8-30 m)	233	12	12	13
		Deep (30-51 m)	181	11	14	14
	East	Shallow (8-35 m)	308	4	14	15
		Deep (35-56 m)	220	12	13	13
	Tully	Shallow (8-30 m)	283	6	9	9
		Deep (30-48 m)	197	9	11	11
	Total		**1422**	**54**	**73**	**75**
Mornington	West	Shallow (8–25 m)	186	10	10	11
		Deep (25–33 m)	180	8	12	11
	North	Shallow (8–35 m)	216	4	11	10
		Deep (35–44 m)	236	15	21	20
	East	Shallow (8–20 m)	185	14	16	16
		Deep (20–36 m)	139	5	7	7
	Total		**1142**	**56**	**77**	**75**

NPF survey sampling sites (2nm grid) in Groote

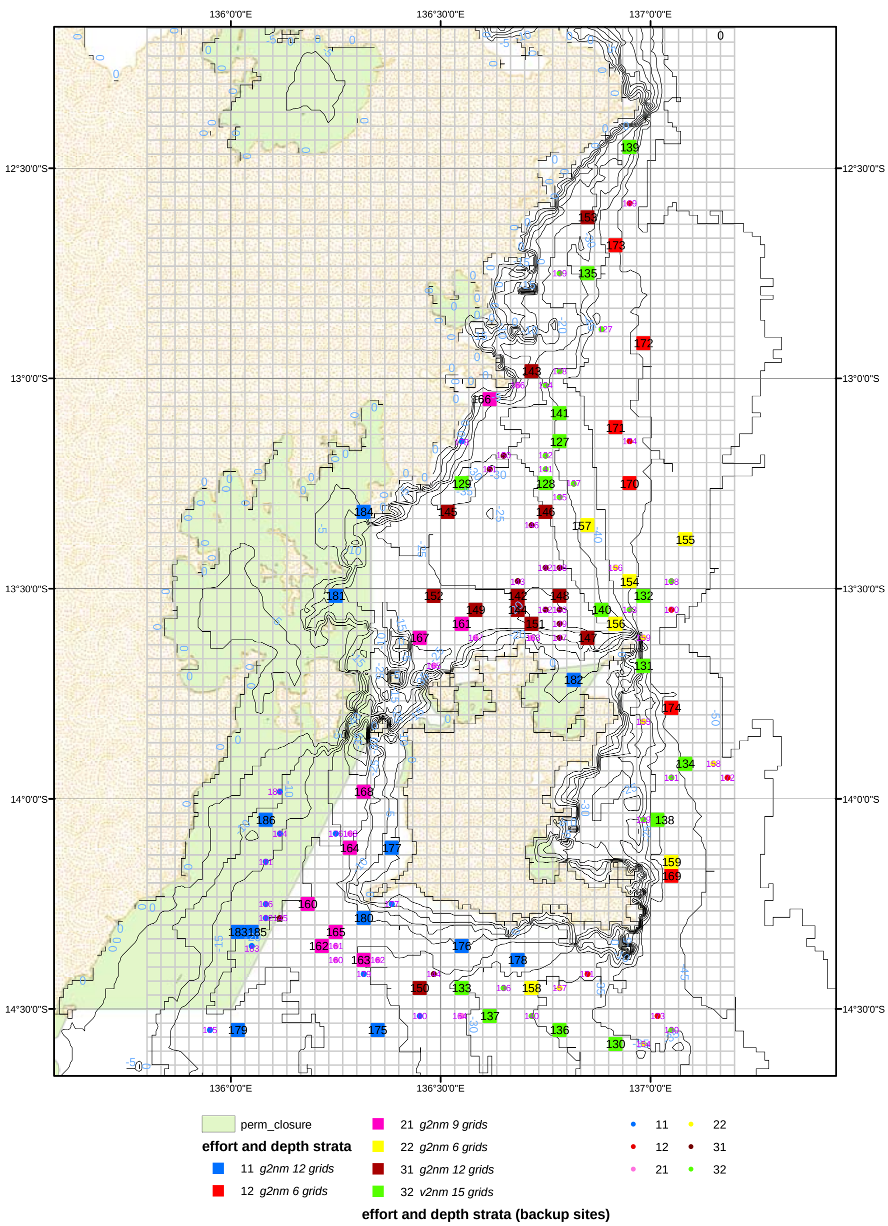

Figure 25: Location of 2-nm sampling grids for Groote Eylandt. The primary sampling grids are completely colour-filled according to their depth and effort stratum. Secondary (backup) sampling grids are denoted by a coloured dot within the grid.

5.3 Variability of catch rates

The number of sites chosen for the survey was based on relationships between stratum means and standard deviations obtained in past surveys – some from over 20 years ago.

$$\sigma_i = e^{\alpha} \mu_i^{\beta} \tag{3}$$

This form of power-law relationship is still valid: as the mean catch rate of a stratum increases, so does the standard deviation in a fairly predictable fashion. Until we have enough survey data to roughly predict the stratum means and allocate the number of samples accordingly, we can only maintain some form of conservatism in the number of sites. The analyses were initially carried out for each region separately, but results were very similar for each region and survey so they have been combined.

Table 9: Parameters for relationship between mean and standard deviation per stratum for adults of seven species, based on number of prawns caught per hectare in the August 2002, 2003 and 2004 surveys.

Species	Intercept (α)	S.E. of α	Slope (β)	S.E. of β
Tiger prawns				
P. esculentus	**0.310**	0.068	**0.805**	0.039
P. semisulcatus	**0.315**	0.052	**0.827**	0.024
Endeavour prawns				
M. endeavouri	**0.083**	0.074	**0.841**	0.047
M. ensis	**0.352**	0.107	**0.834**	0.040
Banana prawns				
P. merguiensis	**0.700**	0.092	**0.907**	0.042
King prawns				
P. latisulcatus	**0.609**	0.070	**0.855**	0.033
P. longistylus	**0.949**	0.376	**0.936**	0.106

For adults of the two tiger species in August, the relationship between the mean and standard deviation was almost identical over the wide range in mean catch rates (Figure 26). The slopes ($\hat{\beta} \approx 0.8$; Table 9) were lower than for sub-adults in January ($\hat{\beta} \approx 0.9$; Table 2), suggesting that tiger prawns are slightly less spatially aggregated in August than January. For the endeavour species, the slopes for adults in August ($\hat{\beta} \approx 0.8$; Table 9) were similar to those for sub-adults in January. The standard deviation for red endeavour prawns *(M. ensis)* appeared to increase more sharply with mean catch rates than it did for blue endeavour prawns *(M. endeavouri)* (Figure 27), but this is probably an artefact of extrapolation due to the absence of medium to high mean catch rates for red endeavour prawns *(M. ensis)*.

The slope for adult banana prawns *(P. merguiensis)* in the August surveys ($\hat{\beta}$ =0.907; Table 9) was very similar to that for sub-adults in the January surveys ($\hat{\beta}$ =0.876; Table 2), but the standard deviation was considerably higher in August than in January ($\hat{\alpha}$ =0.700 compared with $\hat{\alpha}$ =0.539). However, the relationship is less well-defined in the August survey because it lacks data from the two best areas for catching banana prawns *(P. merguiensis)* (Weipa and Karumba) and because banana prawn stocks are considerably depleted by August due to targeted fishing in April and May.

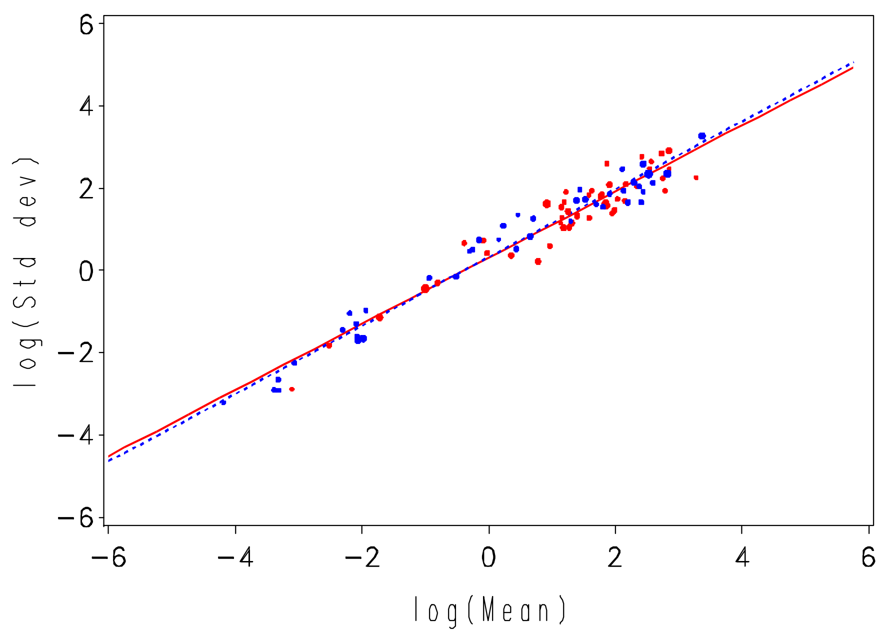

Figure 26: Brown tiger prawns *(Penaeus esculentus)* **(red) and grooved tiger prawns** *(Penaeus semisulcatus)* **(blue). Relationship between sample mean and sample standard deviation for number of adult prawns caught per hectare in the August 2002, 2003 and 2004 surveys. The mean and standard deviation have been log$_e$-transformed. Symbol size is proportional to stratum sample size.**

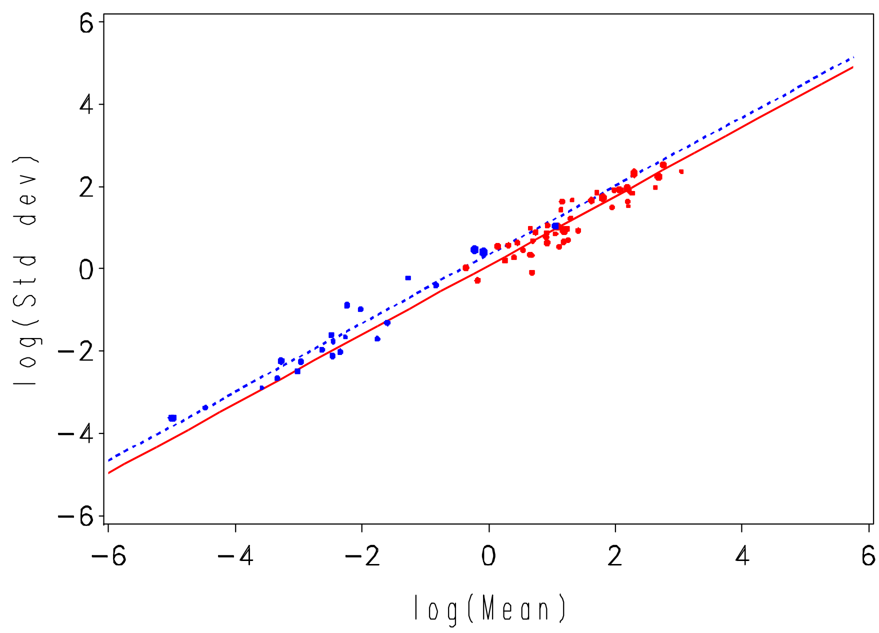

Figure 27: Blue endeavour prawns *(Metapenaeus endeavouri)* **(red) and red endeavour prawns** *(Metapenaeus ensis)* **(blue). Relationship between sample mean and sample standard deviation for number of adult prawns caught per hectare in the August 2002, 2003 and 2004 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.**

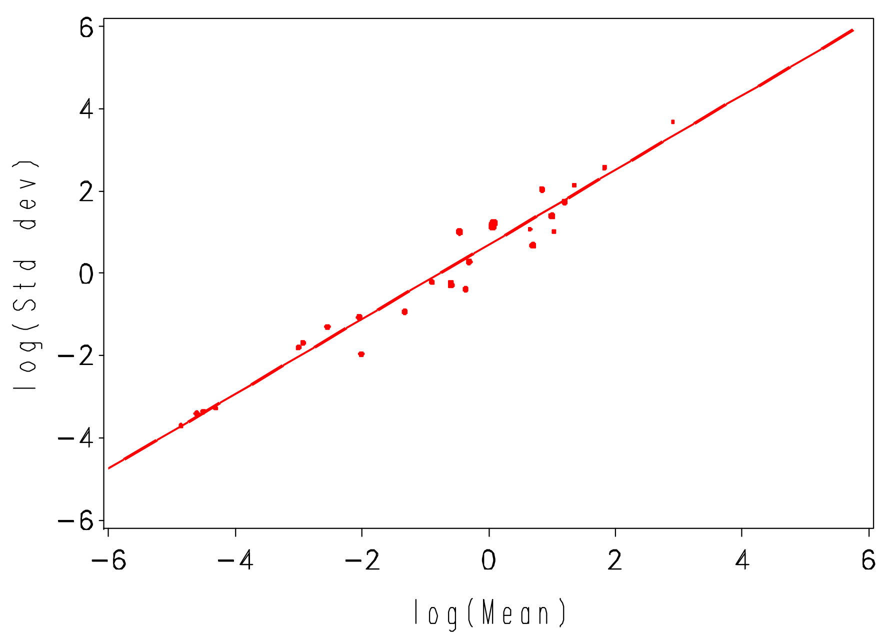

Figure 28: Banana prawns *(Penaeus merguiensis).* **Relationship between sample mean and sample standard deviation for number of adult prawns caught per hectare in the August 2002, 2003 and 2004 surveys. The mean and standard deviation have been $\log_e$-transformed. Symbol size is proportional to stratum sample size.**

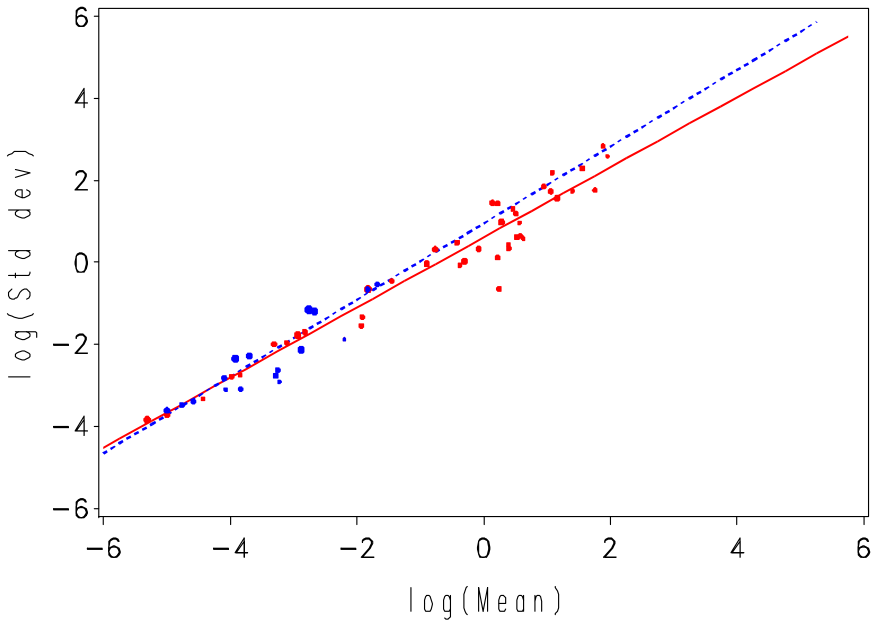

Figure 29: Western king prawn *(Penaeus latisulcatus)* (red) and red spot king prawns *(Penaeus longistylus)* (blue). Relationship between sample mean and sample standard deviation for number of adult prawns caught per hectare in the August 2002, 2003 and 2004 surveys. The mean and standard deviation have been log_e-transformed. Symbol size is proportional to stratum sample size.

5.4 Spawning index

5.4.1 *Precision of index*

The catch rates presented for each species are the number of adult prawns caught per hectare (definitions are given in Section 2.3). For a small number of trawls, the catch from one net was discarded from analysis because of gear problems or the presence of, for example, substantial numbers of jellyfish that suggest the catch would not be representative. Trawls of less than 15 minutes' duration were discarded. Most trawls swept 8–10 hectares, with a peak of around 9 hectares. An index was calculated for each region and species, using the methods described in Section 2.4.

We carried out analysis of variance on log-transformed catch rates for each species — $\log_{10}$(count/hectare + 0.01). This enabled the effectiveness of the modified stratification for the August surveys to be assessed.

An example analysis of variance (Table 10) shows the partitioning of variation in log-transformed catch rates of adult grooved tiger prawns *(P. semisulcatus)* into temporal (Survey), large-scale spatial (Region), medium-scale (Region×Sub-region and Region×Sub-region×Depth), and space-time interactions (Survey×Region, Survey×Region×Sub-region and Survey×Region×Sub-region×Depth). Spatial variation (Region, Region×Sub-region and Region×Sub-region×Depth) was the dominant component of variation, similar to the January surveys (Table 3). However, unlike the January surveys, there was little consistent change across the regions over the three years (the variance between Surveys was less than within-stratum variation) and the large-scale space-time interaction was not much larger than within-stratum variation (Survey×Region was not statistically significant). The medium-scale space-time interactions (Survey×Region×Sub-region and Survey×Region×Sub-region×Depth) were also not much larger than the within-stratum variation. At this time of year, there was stronger differentiation in abundance by depth than between sub-regions (*F*-ratio of 49.4 for Region×Sub-region×Depth compared with 28.2 for Region×Sub-region) than was the case in the January surveys.

Table 10: Analysis of variance of log_{10}-transformed grooved tiger prawns *(P. semisulcatus)* adult catch rates from August surveys in 2002, 2003 and 2004.

Source	Degrees of freedom	Sum of squares	Mean square	*F*-ratio
Survey	2	0.4	0.2	0.3
Region	2	395.4	197.7	330.9
Survey × Region	4	3.5	0.9	1.5
Region × Sub-region	5	84.1	16.8	28.2
Survey × Region × Sub-region	10	17.2	1.7	2.9
Region × Sub-region × Depth	8	236.1	29.5	49.4
Survey × Region × Sub-region × Depth	16	11.4	0.7	1.2
Within-stratum	541	323.3	0.6	
Total	588	1076.5		

Table 11: Results from analysis of variance of log_{10}-transformed adult catch rates from August surveys in 2002, 2003 and 2004 (*F*-ratios for effects, together with residual variance).

Species	*F*-ratios for effects						
	Survey	Region	Survey × Region	Region × Sub-region	Survey × Region × Sub-region	Region × Sub-region × Depth	Survey × Region × Sub-region × Depth
Tiger prawns							
P. esculentus	4	45	2	16	1	21	3
P. semisulcatus	0	331	1	28	3	49	1
Endeavour prawns							
M. endeavouri	3	15	1	41	2	4	3
M. ensis	1	63	3	14	2	25	1
Banana prawns							
P. merguiensis	3	4	2	70	1	16	2
King prawns							
P. latisulcatus	0	72	2	16	1	21	3
P. longistylus	4	4	1	3	3	1	1

In the August surveys, regions were the dominant source of variation for brown tiger prawns *(P. esculentus)*, grooved tiger prawns *(P. semisulcatus)*, red endeavour prawns *(M. ensis)* and western king prawn *(P. latisulcatus)* (*F*-ratios for Region ranging from 45 to 331; Table 11). Peak catch rates of banana prawns *(P. merguiensis)* were found in different regions over the three years, as well as being low, resulting in its low *F*-ratio for Region. Presumably, banana prawn *(P. merguiensis)* stocks are much depleted by August due to the intensity of fishing effort during April and May. Catch rates of red spot king prawns *(P. longistylus)* were the lowest of all species, therefore leaving little scope for large *F*-ratios in this relatively complex model structure.

In contrast to regional variation, changes in catch rates over the three surveys were a small component of variation (*F*-ratios for Survey ranging from <1 to 4; Table 11). The regional profile was comparatively stable over the three years (the highest *F*-ratio for the Survey×Region interaction was 3, for red endeavour prawns *(M. ensis)* which has low catch rates). Strata within regions (Region×Sub-region×Depth) accounted for substantial variation (*F*-ratios of 19–42, excluding red spot king prawns *(P. longistylus)*). The within-region profile captured by the strata also appeared to be quite stable over the three years, given that *F*-ratios for Survey×Region×Sub-region and Survey×Region×Sub-region×Depth ranged from only 1 to 3. In contrast to the January surveys, depth stratification accounted for more variation in tiger prawn catch rates than sub-regions in August, as shown by the larger *F*-ratios for Region×Sub-region×Depth than Region×Sub-region. For banana prawns *(P. merguiensis)*, sub-regions were more important than depth at this time of year.

Table 12: Mean number of adult tiger prawns caught per hectare per region for the August surveys in 2002, 2003 and 2004, with standard error (S.E.) and coefficient of variation (C.V.).

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Brown tiger prawns ***(P. esculentus)***					
2002	**Mean**	**10.0**	**7.7**	**7.6**	**8.3**
	S.E.	1.9	1.1	1.0	0.7
	C.V.	19	14	13	9
2003	**Mean**	**5.9**	**6.7**	**6.6**	**6.5**
	S.E.	1.1	0.7	0.7	0.5
	C.V.	19	10	10	7
2004	**Mean**	**7.8**	**3.1**	**5.7**	**5.2**
	S.E.	1.6	0.4	0.8	0.5
	C.V.	21	12	14	10
Grooved tiger prawns ***(P. semisulcatus)***					
2002	**Mean**	**12.2**	**3.4**	**0.5**	**4.9**
	S.E.	1.8	0.6	0.2	0.6
	C.V.	15	17	28	11
2003	**Mean**	**6.4**	**4.6**	**< 0.1**	**3.6**
	S.E.	0.8	0.6	< 0.1	0.3
	C.V.	12	13	31	9
2004	**Mean**	**6.1**	**4.4**	**0.1**	**3.5**
	S.E.	0.8	0.6	< 0.1	0.3
	C.V.	13	13	37	9

Table 13: Mean number of adult endeavour prawns caught per hectare per region for the August surveys in 2002, 2003 and 2004, with standard error (S.E.) and coefficient of variation (C.V.).

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Blue endeavour prawns *(Metapenaeus endeavouri)*					
2002	**Mean**	**9.5**	**7.1**	**7.0**	**7.7**
	S.E.	1.3	1.2	0.9	0.7
	C.V.	13	16	13	8
2003	**Mean**	**4.8**	**3.1**	**5.9**	**4.5**
	S.E.	0.6	0.3	0.6	0.3
	C.V.	13	9	10	6
2004	**Mean**	**7.6**	**2.4**	**4.6**	**4.5**
	S.E.	1.1	0.2	0.5	0.4
	C.V.	14	10	12	8
Red endeavour prawns *(M. ensis)*					
2002	**Mean**	**0.7**	**0.2**	**0**	**0.2**
	S.E.	0.2	< 0.1	0	< 0.1
	C.V.	22	39	–	19
2003	**Mean**	**0.2**	**< 0.1**	**0**	**< 0.1**
	S.E.	< 0.1	< 0.1	0	< 0.1
	C.V.		21	–	28
2004	**Mean**	**0.2**	**< 0.1**	**0**	**0.1**
	S.E.	< 0.1	< 0.1	0	< 0.1
	C.V.	30	46	–	25

Table 14: Mean number of adult banana prawns *(P. merguiensis)* and king prawns caught per hectare per region for the August surveys in 2002, 2003 and 2004, with standard error (S.E.) and coefficient of variation (C.V.).

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Banana prawns *(P. merguiensis)*					
2002	**Mean**	**0.3**	**0.4**	**2.4**	**1.0**
	S.E.	0.2	0.2	2.2	0.7
	C.V.	47	61	92	70
2003	**Mean**	**0.5**	**2.0**	**0.9**	**1.2**
	S.E.	0.2	0.9	0.4	0.4
	C.V.	37	47	47	33
2004	**Mean**	**1.0**	**0.2**	**0.8**	**0.6**
	S.E.	0.7	< 0.1	0.2	0.2
	C.V.	67	33	26	33
Western king prawn (*P. latisulcatus*)					
2002	**Mean**	**1.3**	**2.4**	**2.5**	**2.1**
	S.E.	0.9	1.5	1.0	0.7
	C.V.	66	62	40	34
2003	**Mean**	**0.5**	**1.8**	**1.1**	**1.2**
	S.E.	0.4	0.4	0.2	0.2
	C.V.	73	21	24	18
2004	**Mean**	**0.5**	**0.6**	**1.8**	**1.0**
	S.E.	0.4	0.5	0.1	0.2
	C.V.	36	32	23	19

Over the three years, mean catch rates for grooved tiger prawns *(P. semisulcatus)* exhibited a pronounced and stable regional pattern: highest in Groote (6.1–12.2 ha^{-1}; Table 12), moderate in the Vanderlins (3.4–4.6 ha^{-1}) and negligible in the Mornington region (<0.1–0.5 ha^{-1}). Averaging over regions, the global index for grooved tiger prawns *(P. semisulcatus)* was highest in 2002 (4.9 ± 0.6 ha^{-1}) then levelling out over the following two years (~3.6 ± 0.3 ha^{-1}).

Catch rates of adult brown tiger prawns *(P. esculentus)* were more similar across regions (Table 12), though the highest catch rates were in Groote in 2002 and 2004 (10.0 ha^{-1} and 7.8 ha^{-1} respectively). Catch rates in the Vanderlins and Mornington in 2002 and 2003 were almost identical (~7.7 ha^{-1} in 2002 and ~6.7 ha^{-1} in 2003). The global index for brown tiger prawns *(P. esculentus)* declined from 8.3 ha^{-1} (± 0.7 ha^{-1}) in 2002 to 5.2 ha^{-1} (± 0.5 ha^{-1}) in 2004.

Similar to brown tiger prawns *(P. esculentus)*, the highest mean catch rates of blue endeavour prawns *(M. endeavouri)* were found in the Groote region in 2002 and 2004 (9.5 ha^{-1} and 7.6 ha^{-1} respectively; Table 13). Unlike brown tiger prawns *(P. esculentus)*, however, the Vanderlins mean catch rates of blue endeavour prawns *(M. endeavouri)* were only half those of the Mornington region in 2003 and 2004. The global index for this species followed the pattern for grooved tiger prawns *(P. semisulcatus)*: highest in 2002 (7.7 ± 0.7 ha^{-1}) then levelling out over the following two years (4.5 ± ~0.3 ha^{-1}).

The catch rates of red endeavour prawns *(M. ensis)* were low everywhere (Table 13), though the Groote region consistently produced the highest catch rates (0.2–0.7 ha^{-1}). The Mornington region produced no catch at all.

Catch rates of banana prawns *(P. merguiensis)* were much lower than the tigers and blue endeavour prawns *(M. endeavouri)* (Table 14) with a maximum of 2.4 ha^{-1} in the Mornington region in 2002. With such low catch rates, the precision of the indices was poor and even the C.V. for the global index ranged from 33% to 70%. The global index was similar in 2002 and 2003 (1.0 ± 0.7 ha^{-1} and 1.2 ± 0.4 ha^{-1} respectively) and dropped to 0.6 ± 0.2 ha^{-1} in 2004.

Mean catch rates of western king prawns *(P. latisulcatus)* in the August surveys were generally better than those of banana prawns *(P. merguiensis)* (Table 14), the highest being ~2.5 ha^{-1} (Mornington and Vanderlins regions in 2002). The global index declined from 2.1 ± 0.7 ha^{-1} in 2002 to 1.2 ± 0.2 ha^{-1} in 2003 and stayed at this level in 2004.

Given the observed relationship between the standard deviation and mean, the coefficient of variation for a region can be expected to decrease as the mean for that region increases. Regions with a mean catch rate below 1.0 ha^{-1} tended to have an appreciably higher C.V. than those regions with a higher mean catch rate. For the tiger prawns, blue endeavours and banana prawns, this is also a reasonable threshold for identifying regions where a species can be harvested in commercial quantities. In assessing the C.V. obtained from these surveys, we therefore focus on those regional indices of at least 1.0 ha^{-1}.

The precision of the catch estimates was best overall for blue endeavour prawns *(M. endeavouri)*; the C.V. was similar across regions and ranged from 9% to 16%. For the two tiger prawn species, the C.V. was comparable to that for blue endeavour prawns *(M. endeavouri)* in two out of three regions (Table 12). For grooved tiger prawns *(P. semisulcatus)*, the C.V. was much higher in the Mornington region, but this is no surprise as the catch rates there were negligible. However, the C.V. was consistently high for brown tiger prawns *(P. esculentus)* in the Groote region. The high C.V. suggests that more sampling is required in the shallow waters of the south Groote sub-region in particular, where catches of this species tend to be highest. Precision was consistently poor for banana prawns *(P. merguiensis)* at regional level (Table 14), the lowest C.V. being 26% and only two-thirds of regional means having a C.V. of less than 50%. However, catch rates were low for this species, which in any case tends to be heavily depleted by fishing earlier in the year.

The precision of the global indices over the three years was excellent for blue endeavour prawns *(M. endeavouri)* (C.V. of 6–8%; Table 13). Precision was good for brown tiger prawns *(P. esculentus)* (C.V. of 7–10%; Table 12) and grooved tiger prawns *(P. semisulcatus)* (C.V. of 9–11%; Table 12). It was poor for banana prawns *(P. merguiensis)* (C.V. of 33–70%; Table 14).

5.5 Results by region and stratum

The results for the individual sites are presented in Chapter 7. We present here the mean catch rate by stratum for the five main commercial prawn species (Figure 30–Figure 35). These plots highlight where the highest catches occurred, together with their standard errors. A high standard error is usually an indication that catch rates were highly variable across trawls within that stratum. For example, banana prawns *(P. merguiensis)* in east Mornington (Figure 34) have large standard errors in both years for this reason, and this may be caused by a few highly productive sites, as opposed to consistently high catch rates in the stratum.

5.5.1 Brown tiger prawns

Catch rates of adult brown tiger prawns (*P. esculentus*) were broadly similar across the three regions in all three August surveys, though there was a mixture of high and low catches among strata within regions (Figure 30). In Groote and the Vanderlins, catches tended to be higher in the shallow part of each sub-region; whereas it was frequently higher in the deep parts of Mornington sub-regions, particularly east Mornington which consistently produced the highest catch rate. In the Vanderlins, catch rates increased in an easterly direction with a peak in the Tully sub-region. In 2003 and 2004, south Groote had higher catches than north Groote but the catch rates were similar in 2002.

5.5.2 Grooved tiger prawns

For all three surveys, adult grooved tiger prawns (*P. semisulcatus*) were caught mainly in the Vanderlins and Groote, with very few caught in the Mornington region (Figure 31). The deeper stratum in north Groote generally produced the highest catch rates. In all sub-regions, this species was consistently caught in greater numbers in the deeper stratum.

5.5.3 Endeavour prawns

Adult blue endeavour prawns *(M. endeavouri)* prawns (Figure 32) were not consistently more abundant in any region compared with the others, being found in reasonable amounts in all three regions. In the Vanderlins, catch rates increased in an easterly direction in all years, and in Mornington the highest catch rates were generally in the northern sub-region.

Mean catch rates for Red endeavour prawns *(M. ensis)* were consistently the highest in deeper waters of north Groote (Figure 33), though at 0.8–2.9 ha^{-1} the catch rates were very low compared with other species. Elsewhere, catch rates ranged from zero (Mornington) to very low (south Groote and the Vanderlins).

5.5.4 Banana prawns

Strata with relatively high catch rates of adult banana prawns (*P. merguiensis*) had large standard errors (Figure 34), demonstrating that one or two hotspots have dominated the mean. These were in the deep part of east Mornington in all three surveys, and the shallow waters in the Tully sub-region of the Vanderlins in 2003.

5.5.5 *King prawns*

Like the banana prawns (*P. merguiensis*), higher catch rates of adult western king prawns (*P. latisulcatus*) were also associated with large standard errors (Figure 35), indicating the effect of sporadic hotspots. Catch rates of red spot king prawns (*P. longistylus*) have not been presented here as they were so low.

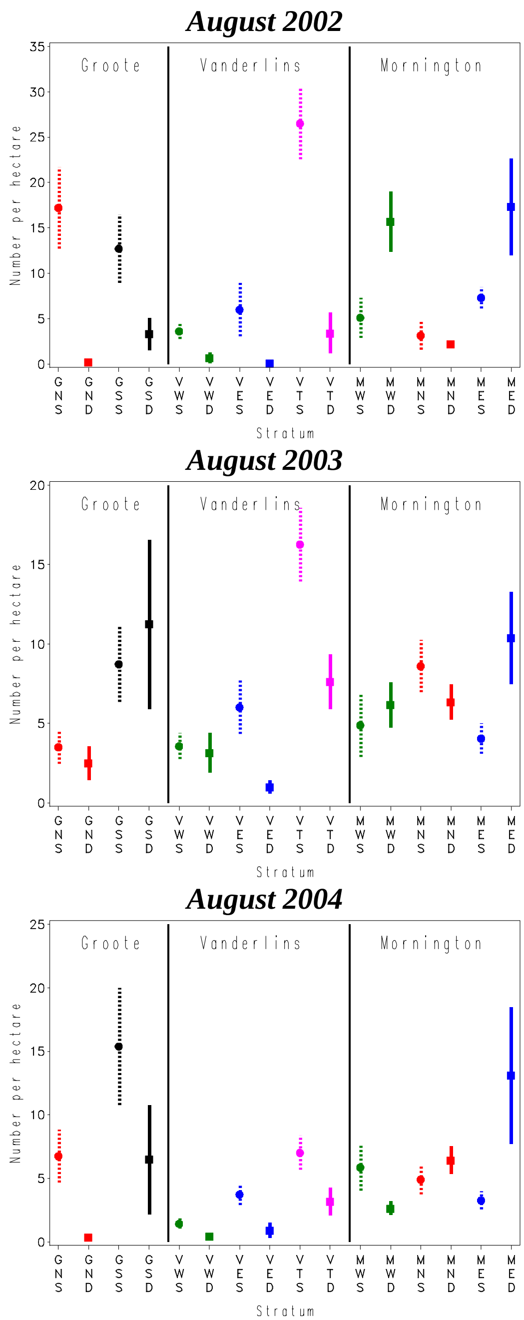

Figure 30: Brown tiger prawns *(Penaeus esculentus)*. **Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.**

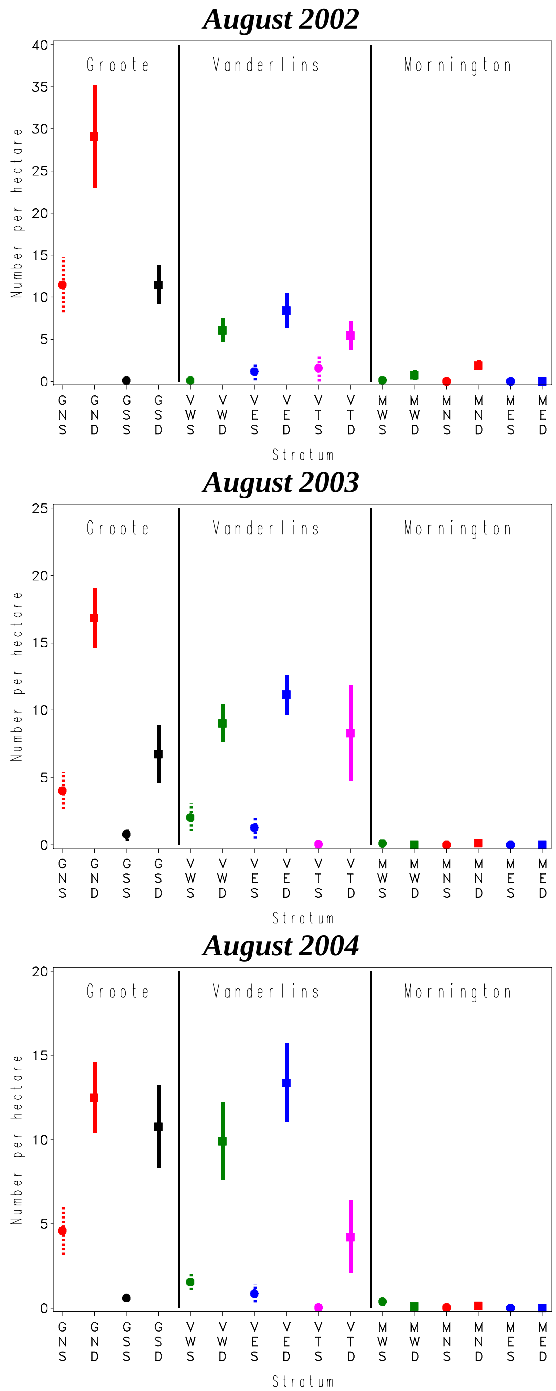

Figure 31: Grooved tiger prawns *(Penaeus semisulcatus)*. Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.

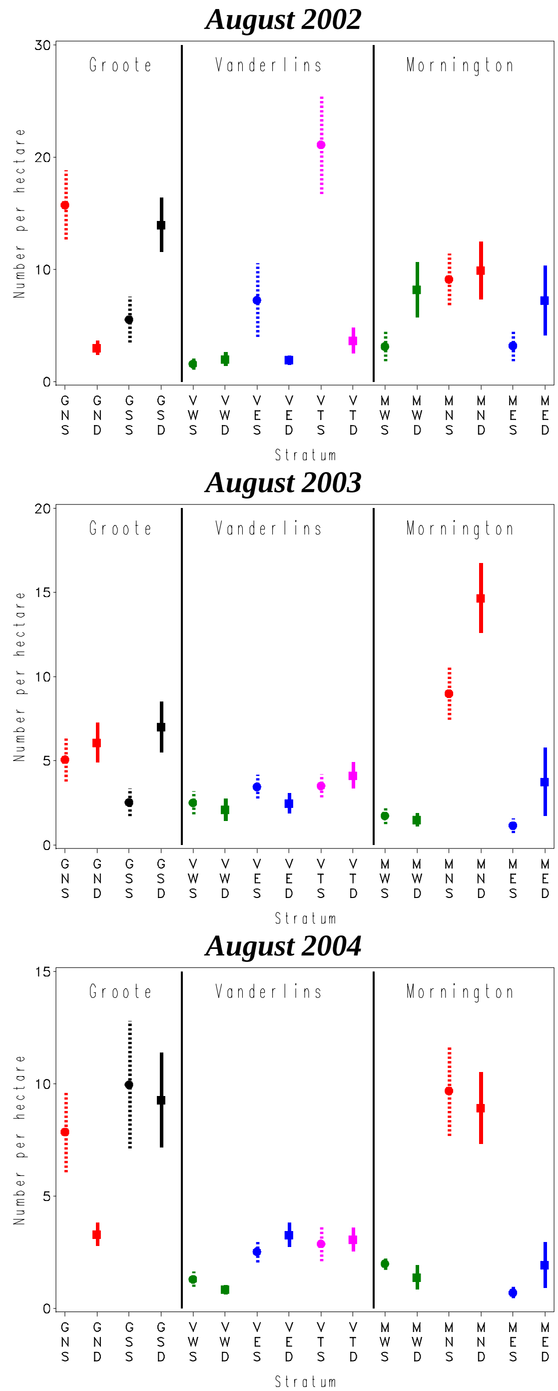

Figure 32: Blue endeavour prawns *(Metapenaeus endeavouri)*. **Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.**

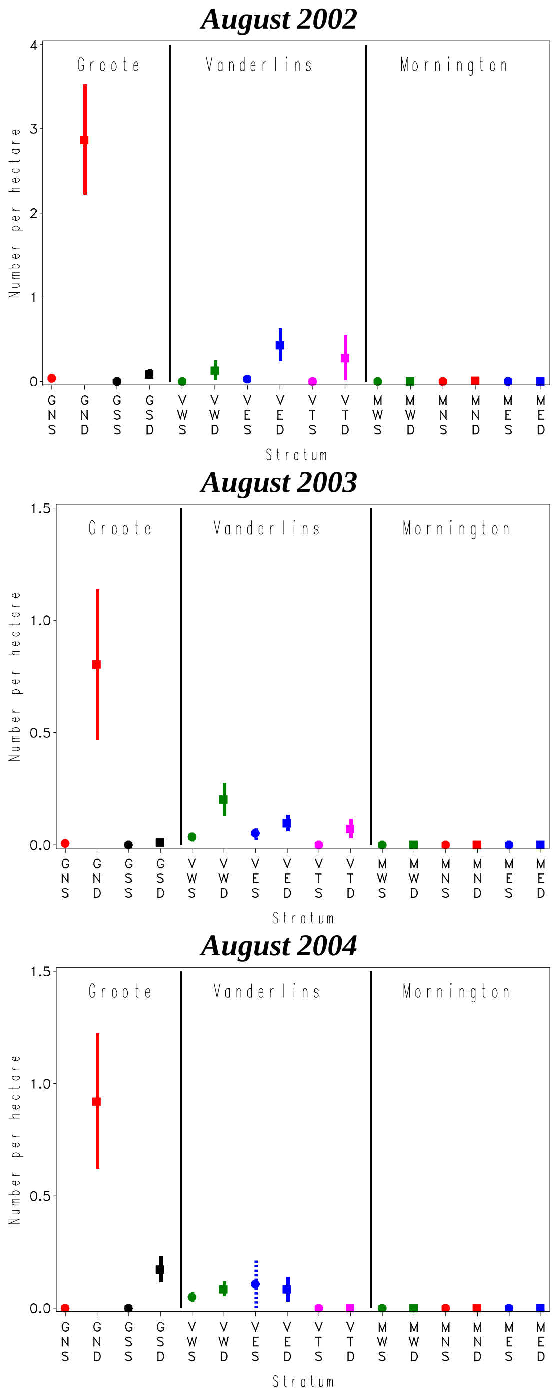

Figure 33: Red endeavour prawns (*Metapenaeus* ensis). Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.

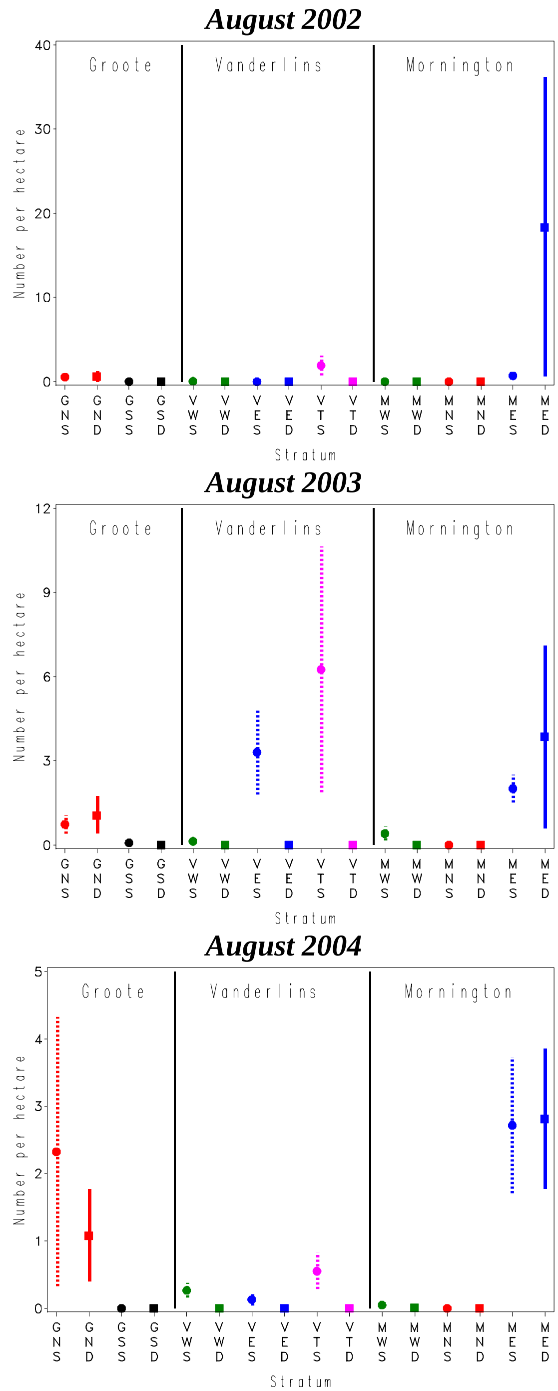

Figure 34: ***Penaeus merguiensis*. Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.**

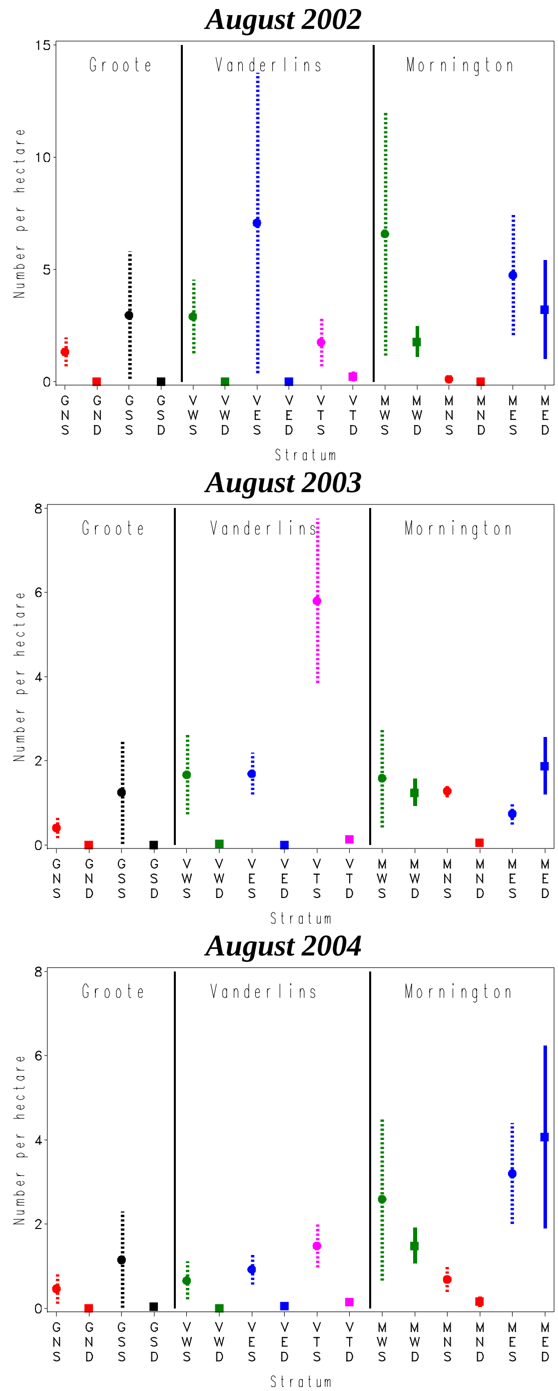

Figure 35: Western king prawns *(Penaeus latisulcatus)*. Mean number of adult prawns per hectare (with standard errors) in each stratum for the August 2002, 2003 and 2004 surveys. Label on horizontal axis indicates region {G=Groote, M=Mornington, V=Vanderlins}, sub-region {N=north, E=east, S=south, T=Tully, W=West – various colours}, and depth {D (solid line)=deep, S (dotted line)=shallow}. Note the different scales on each figure.

5.6 Discussion

The spawning surveys in August cover three key regions: Groote, Vanderlins, and Mornington. These areas produced 71.5% of the annual catch of tiger prawns in the NPF in 2002 (Perdrau and Garvey 2003).

The analysis of variance on log-transformed catch rates shows that, with the modified stratification for August, differences among regions were a dominant source of variation and the second largest contribution to variability was the Sub-region × Depth interaction, nested in Region. This demonstrates the effectiveness of the modified stratification using sub-region and depth. However, for different species there are local peaks in abundance that do not necessarily fall inside the pre-determined stratum boundaries. A model-based index would capture these patterns and has the potential to produce a more precise index.

The level of variation in catch rates found within each region in the recent survey was mostly within the limits expected from analyses of past survey data. For regions where the mean catch rate is low, comparisons between strata are probably not statistically significant. However, in regions where the mean catch rate is high, it is likely that useful comparisons will be able to be made between years in the future; particularly for those species and regions that are regarded as being very important for the fishery; e.g. brown tiger prawns *(P. esculentus)* at Mornington, grooved tiger prawns *(P. semisulcatus)* at Groote.

The pattern of catches for tiger prawns agrees with the regional pattern of commercial catches seen in the fishery in recent years – adult grooved tiger prawns *(P. semisulcatus)* were most abundant north of Groote. Adult brown tiger prawns were caught in similar numbers across the three regions, whereas historically these would have been highest around Mornington Island.

The combined tiger prawn catch was highest at Groote, particularly north of Groote, and this pattern was also reflected in the catch rates in the commercial fishing seasons that began just after the completion of these surveys. This gives us some confidence that the trends in catches seen in the survey reflected real patterns of abundance on the fishing grounds.

The three surveys now carried out in the Vanderlins region have substantially enhanced our knowledge of the distribution of prawn species in this area. Considering there was no historical data on which to gauge likely levels of variability, we have obtained good C.V.s for this region.

There are distinct differences between regions in the mix of species, with grooved tiger prawns *(P. semisulcatus)* noticeably absent from the Mornington region, but this region being important for brown tiger prawns *(P. esculentus)* and blue endeavour prawns *(M. endeavouri)*. The best region for red endeavour prawns *(M. ensis)* was Groote, while this was generally the worst region for banana prawns (*P. merguiensis*). Therefore, further surveys in August need to continue sampling these three regions to provide an accurate estimate of the spawning abundance in the Gulf of Carpentaria.

Global mean catch rates for the two tiger prawn species were highest in 2002. For brown tiger prawns *(P. esculentus)*, the global index has declined over the three years while for grooved tiger prawns *(P. semisulcatus)* it dropped in 2003 and remained the same in 2004.

5.7 Conclusions

1. The analysis of variance demonstrates the effectiveness of the modified sub-region and depth stratification in the reduction of variation and in the production of relatively low coefficients of variation for tiger prawns (10–28% for means of at least 1.0 ha^{-1}).

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 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.

3. The distribution patterns of blue endeavour prawns *(M. endeavouri)* were similar to those of brown tiger prawns *(P. esculentus)*, while the patterns of red endeavour prawns *(M. ensis)* were similar to grooved tiger prawns *(P. semisulcatus)* (although the *M. ensis* densities were very low).

4. The mean-variance relationships obtained were, in general, similar to those derived from past surveys. While the slopes of the mean-variance relationships for the tiger prawn spawning-indices were lower than for the January recruitment index survey, the intercept for all species was higher in August. For a given mean catch rate, the standard deviation therefore would tend to be higher in August than in January.

5. We were able to produce good indices of abundance at regional levels, and the C.V. for the global index was very low for both tiger prawns and blue endeavour prawns *(M. endeavouri)* (6–11%).

6. Preliminary work using these results in another study (the fishing power project) has shown that this survey (as part of an ongoing series) will be useful for evaluating both the fishing power series over time, and spatial changes of the fishery relative to the resource.

7. As a result of the good precision obtained, the survey will be very useful as an index of Spawning abundance as part of an ongoing series.

5.8 References

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CHAPTER 6. MODEL-BASED ESTIMATES OF ABUNDANCE INDICES

6.1 Introduction

The project "Designing, implementing and assessing an integrated monitoring program for the Northern Prawn Fishery" has performed surveys at twice a year since August 2002. The *spawning surveys* are intended to assess the stocks of adult prawns at the time of year at which they are known to spawn, around August / September. Spawning surveys have been undertaken in 2002, 2003 and 2004. The *recruitment surveys* are intended to assess the stocks of juvenile or sub-adult prawns after they have moved offshore from their inshore nursery habitats, around January / February. The recruitment surveys were taken in 2003, 2004 and 2005.

Work to date has focused on creating design-based abundance indices for each species, using a stratified random design. The design of the stratification used ecological knowledge about the habitat and movements of the eight species of prawns targeted by the surveys. Thus, separate stratifications were used for the spawning and recruitment surveys. For each stratification, the fishery was stratified into regions and each region was divided further into two or three along-shore sub-regions. The sub-regions then were stratified into two or three depth classes. The number of sites chosen within each stratum was based on a mean-variance relationship observed in historical surveys, and it has been kept roughly constant for each of the surveys.

Abundance indices and standard errors were then calculated of each of five regions, by taking a weighted sum of the means of the strata in each region. The weights used were simply the proportion of the region represented by the strata. Because they can provide reliable inferences using a small number of samples, design-based approaches to estimating abundance are often used when it is difficult or expensive to obtain samples.

The design-based approach to abundance estimation assumes a homogeneous response (in this case the count of the size class of interest) within strata. Inferences about population quantities are made by treating the response as non-random and assuming that all randomness is induced by the design (Chen et al., 2004). In contrast, a model-based approach assumes that the response is generated by an underlying stochastic process with known structure (that is, a model or probability distribution), apart from a fixed number of parameters. The randomness associated with the selection of samples is ignored, apart from assuming that they are independent and identically distributed.

Counts tend to be both skewed and heteroskedastic, so the standard errors for design-based abundance indices do not accurately capture the precision of abundance estimates. The use of a model-based approach can provide more precise estimates. In addition by the appropriate choice of model, it can ensure that confidence intervals around the estimates reflect the heteroskedasticity and non-negativity of the count data.

This report uses a modelling approach to produce regional and overall abundance indices and confidence intervals for the northern prawn fishery (NPF). The abundances are modelled using the designed strata as predictors, and thus use exactly the same inputs as the design-based analyses and similarly produce a single estimate of abundance for each strata. The only difference is that counts are modelled using an appropriate distribution and as a result, the associated error or uncertainty can be estimated with more confidence.

The abundance indices for each strata are calculated by finding the mean predicted abundance for each species, and the confidence intervals around the means are found using Bayesian bootstrapping.

6.2 Model-based methodology

Generalised linear models (GLMs) are used extensively in fisheries research – as evidenced by the 2004 special issue *Models in fisheries research – GLMs, GAMs and GLMMs* in Fisheries Research, prefaced by Xiao et al. (2004). Their use for such is described in Venables and Dichmont (2004). Section 6.2.1 briefly summarises the use of GLMs for modelling count data, Section 6.2.2 describes the form of models implemented in this study, and Section 6.2.3 outlines the use of Bayesian bootstrapping for producing confidence intervals.

6.2.1 Linear and generalised linear models

Linear models describe a response variable y as a weighted sum of p predictor variables $x_1,...,x_p$ plus some normally distributed error $\varepsilon \sim N(0,\sigma^2)$. That is

$$y = \sum_{j=1}^{p} x_j \beta_j + \varepsilon = \eta + \varepsilon$$

where

$$\eta = \sum_{j=1}^{p} x_j \beta_j \ .$$

This can be rewritten as

$$y \sim N(\eta, \sigma^2)$$

showing that for a linear model, the response is assumed to follow a normal distribution.

Generalised linear models (McCullagh and Nelder, 1989) extend linear models from requiring a normally distributed response to allow the response variable to take any exponentially distribution. The family of exponential distributions includes both discrete (binomial, Poisson and negative binomial) and continuous (normal, Gamma and inverse normal) distributions.

Transformations of the response variable are incorporated by the specification an appropriate *link* function l between the response mean $E\left[y\right]=\mu$ and the weighted sum η, such that

$$E\left[y\right]=\mu=l^{-1}\left(\eta\right),\qquad \eta=l\left(\mu\right).$$

A GLM can then be written as

$$l\left(y\right)=\sum_{j=1}^{p}x_j\beta_j+\varepsilon=\eta+\varepsilon\ .$$

The goodness of fit of a GLM is measured in terms of the residual deviance rather than the residual error.

There are two probability distributions suitable for modelling counts: the Poisson distribution and the negative binomial distribution.

The Poisson distribution is fully specified by its mean and has probability distribution function given by

$$P\left(Y=y\right)=\frac{e^{-\mu}\mu^{y}}{y!}\ .$$

The variance of a Poisson variable is equal to its mean: $\mathrm{var}\left[y\right]=\mu=E\left[y\right]$. The appropriate link function for a Poisson distribution is the log-link function $\eta=\log\left(\mu\right)$.

The negative binomial distribution is used to model counts when the variance is not equal to the mean. It has an additional shape parameter θ and probability distribution function given by

$$P\left(Y=y\right)=\frac{\Gamma\left(y+\theta\right)}{y!\Gamma\left(\theta\right)}\frac{\theta^{\theta}\mu^{y}}{\left(\mu+\theta\right)^{\theta+y}}$$

with $E\left[y\right]=\mu$ and $var[\,y\,]=\mu(1+\mu/\theta)$. As in the case of Poisson variables, it is fitted in a GLM using the log link function.

An offset is a term added to a linear predictor that has a coefficient set to be equal to one. An offset can be used within a GLM to standardise counts. For example, to model count per unit of effort (CPUE) using a Poisson or negative binomial model, an offset of $\log\left(\text{unit of effort}\right)$ is added to the predictor. The log transformation must be specified because of the use of log-link function.

6.2.2 *The implemented models*

For each species, a GLM model is used to predict the response given the predictors. Because the prawn counts indicate over-dispersion (that is, the variance increases with the counts)*, the negative binomial distribution is used.

The general form of the models used is specified as follows:

$$l\left(y\right)=\eta=\text{year}\times\text{strata}+\text{offset}\left[\log\left(\text{area trawled}\right)\right]$$

* Shown in the Chapters “Recruitment Surveys” and “Spawning Surveys”.

where *y* is the recorded count of the size class of interest (adults or subadults) and the offset term enables the prediction of count per hectare.

Thus, the linear predictor consists of a weighted sum

$$\eta = \sum_{j=1}^{p} \beta_j x_j$$

where the predictors x_j correspond to the different combinations of year and strata, and the model effectively fits separate negative binomial distributions with a common dispersion parameter θ to the counts within each stratum. Like the design-based abundance indices, the model assumes that the abundances within strata are homogeneous and it predicts a common mean abundance for each site within a stratum.

6.2.3 *Bayesian bootstrapping for improved accuracy assessment*

The bootstrap is a general tool for assessing the accuracy of a statistical model (Hastie, et al., 2001). The basic idea is to randomly draw samples with replacement from the data, until the set of samples is the same size as the original data set. This is done a large number of times. The model is then fitted to each bootstrap sample. Using the models, the predicted mean abundances for each of the strata are calculated. Because each model will give slightly different results, this gives a distribution for each of the strata means; and the standard 90% confidence interval for the true means can be found by taking the 5th and 95th percentiles of the bootstrap distribution (Efron and Tibshirani, 1993).

The Bayesian bootstrap is analogous to the bootstrap (Rubin, 1981). Instead of sampling with replacement, each Bayesian bootstrap (BB) replication generates a posterior probability for each x_i, where values of X that are not observed in the sample data have zero posterior probability, just as they have zero probability under the sample density. The posterior probability for each of the x_i is centred at $1/n\ \left\{0, \frac{1}{n}, \frac{2}{n}, ..., 1\right\}$, where *n* is the size of the data set, but has variability. Each Bayesian bootstrap replication is generated by drawing $(n-1)$ uniform $(0,1)$ random variates $u_1, u_2, ..., u_{n-1}$, ordering them and calculating the gaps $g_i = u_i - u_{i-1}$ for $i = 1, ..., n-1$ where $u_0 = 0$, and $u_n = 1$. Then, $g = (g_1, ..., g_n)^T$ is the vector of probability to attach to the data values $x_1, ..., x_n$ in the BB replication. Considering all BB replications gives the BB distribution of the distribution of X, and thus of any parameter of this distribution (Rubin, 1981).

For example, for the mean of X, in each BB replication we calculate the mean of X as if g_i were the probability that $X = x_i$. That is, we calculate $\sum_1^n g_i x_i$. The distribution of the values of $\sum_1^n g_i x_i$ over all BB replications is the BB distribution of the mean of X.

In this study, confidence intervals around the stratum mean abundances were found using a version of the Bayesian bootstrap where the samples used are simply re-weighted versions of the data, with the weights are randomly drawn from the set.

In Chapters 4 and 5, the estimates of mean density in each region were presented together with standard errors (SE). The symmetric confidence intervals of those estimates can be calculated based on the Normal sampling distribution of the sample mean. In contrast, the assumption of a negative binomial density will provide the same estimates for the mean density for each region, but the BB confidence intervals will be asymmetric - the 5% and 95% endpoints do not have the same distance from the sample mean. As catch rates usually have a skewed distribution, the traditional standard errors, although reasonably robust, are affected by the lack of Normality in the sampling distribution of the sample mean, especially the skewness. Therefore, the BB confidence intervals should provide more accurate confidence intervals.

6.3 Abundance indices & confidence intervals – recruitment surveys

The estimates of regional mean recruitment indices together with confidence intervals for tiger prawns are presented in Table 15; banana prawns (*P. merguiensis*) and king prawns in Table 16; and endeavour prawns in Table 17. As expected, the estimates of the means are the same as those presented in Tables 5-7 in Chapter 4. The 90% confidence intervals estimated using the Bayesian bootstrap exhibit skewed distributions for the mean catch rates. For example, the 5th percentile of the bootstrap distribution is 3.69 units away from the mean brown tiger prawns *(P. esculentus)* catch rate in Groote, 2003, but the 95th percentile is 6.55 units away (Table 15). In contrast with the traditional standard errors, the Bayesian bootstrap confidence intervals are shifted in the direction of the skewness.

Brown tiger prawns *(P. esculentus)* were most abundant in Groote. Its catch rate reached 8.46 prawns per hectare in 2003 and 6.87 prawns per hectare in 2005 (Table 15). Vanderlins and Mornington also had moderate catch rates ranging from 1.57 to 4.13 prawns per hectare in 2003-2005. In contrast, Karumba and Weipa had quite low catch rates from 0.17 to 0.84 prawns per hectare during the 3 year survey period.

Grooved tiger prawns *(P. semisulcatus)* had a spatial distribution slightly different from brown tiger prawns *(P. esculentus)*. The areas where grooved tiger prawns *(P. semisulcatus)* were most abundant were Weipa, Groote and Vanderlins. The catch rate varied from 5.64 to 20.37 prawns per hectare in 2003-2005 (Table 15). Although Mornington had a good catch of brown tiger prawns *(P. esculentus)*, the catch rate of grooved tiger prawns *(P. semisulcatus)* was very low, only from 0.11 to 0.81 prawns per hectare. Karumba had a catch rate even lower than Mornington, only 0.02-0.03 grooved tiger prawns *(P. semisulcatus)* per hectare (Table 15).

Banana prawns (*P. merguiensis*) were abundant in Weipa and Karumba, from 1.87 to 10.87 prawns per hectare in 2003-2005 (Table 16). They were least abundant at Groote, with only 0.01-0.03 prawns per hectare. Their abundances at Vanderlins and Mornington were in between those at Karumba and Groote. It may be concluded that banana prawns (*P. merguiensis*) are mainly distributed along the east coast of the Gulf.

King prawns exhibited very low catch rates across the survey areas, most areas having a catch rate of < 1 prawn per hectare, except Groote in 2003 (Table 16). Over all of the regions, there was no distinguishable spatial distribution pattern.

Of the two endeavour prawn species, blue endeavour prawns *(M. endeavouri)* was more abundant than red endeavour prawns *(M. ensis)*. During the three yearly recruitment surveys, blue endeavour prawns *(M. endeavouri)* showed the highest catch rates in Groote (from 1.73 prawns per hectare, Table 17), slightly lower catch rates in Vanderlins, and the lowest in Karumba and Weipa, only 0.02-0.76 prawns per hectare. Red endeavour prawns *(M. ensis)* was the least abundant commercial prawn species in the Gulf, only 1 prawn per hectare was found in Weipa, 0-0.27 prawns per hectare in Groote and Vanderlins, and none were caught in Mornington and Karumba.

Table 15: Mean number of sub-adult tiger prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Brown tiger prawns *(P. esculentus)*							
2003	**Mean**	**8.46**	**3.36**	**4.13**	**0.84**	**0.25**	**3.90**
	5%	4.77	2.61	2.95	0.60	0.17	3.03
	95%	15.01	4.34	5.52	1.18	0.34	5.21
2004	**Mean**	**2.42**	**1.57**	**1.89**	**0.22**	**0.20**	**1.49**
	5%	1.92	1.25	1.47	0.12	0.14	1.30
	95%	2.97	2.01	2.42	0.35	0.27	1.70
2005	**Mean**	**6.87**	**2.06**	**3.94**	**0.48**	**0.17**	**3.11**
	5%	4.58	1.74	3.33	0.29	0.11	2.61
	95%	9.79	2.42	4.61	0.72	0.24	3.7
Grooved tiger prawns *(P. semisulcatus)*							
2003	**Mean**	**14.42**	**17.11**	**0.11**	**0.02**	**20.37**	**9.21**
	5%	10.97	13.26	0.09	0.01	14.23	7.76
	95%	19.65	21.29	0.14	0.04	28.31	10.68
2004	**Mean**	**4.15**	**6.69**	**0.58**	**0.02**	**7.19**	**3.42**
	5%	3.36	5.25	0.37	0.01	5.46	2.95
	95%	4.98	8.42	1.12	0.04	9.23	3.94
2005	**Mean**	**7.04**	**5.64**	**0.81**	**0.03**	**16.15**	**4.47**
	5%	5.85	4.76	0.62	0.02	13.62	4.06
	95%	8.54	6.56	1.04	0.04	18.72	4.89

Table 16: Mean number of sub-adult banana *(P. merguiensis)* and king prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Banana prawns *(P. merguiensis*)							
2003	**Mean**	**0.02**	**1.48**	**1.67**	**2.11**	**1.87**	**1.38**
	5%	0.01	0.49	0.89	1.55	0.46	0.96
	95%	0.03	2.94	2.72	2.81	4.33	1.92
2004	**Mean**	**0.01**	**0.11**	**0.03**	**2.52**	**2.28**	**0.65**
	5%	0.00	0.04	0.02	1.46	1.41	0.44
	95%	0.02	0.23	0.05	4.28	3.57	0.94
2005	**Mean**	**0.03**	**0.27**	**1.81**	**7.11**	**10.38**	**2.62**
	5%	0.00	0.12	1.00	3.84	6.72	1.91
	95%	0.06	0.53	2.93	12.47	15.01	3.62
Western king prawns *(Penaeus latisulcatus)*							
2003	**Mean**	**2.80**	**0.28**	**0.95**	**0.10**	**0.07**	**0.92**
	5%	0.54	0.19	0.33	0.05	0.05	0.39
	95%	5.68	0.39	2.22	0.18	0.09	1.59
2004	**Mean**	**0.06**	**0.63**	**0.27**	**0.01**	**0.06**	**0.27**
	5%	0.03	0.11	0.15	0.00	0.02	0.12
	95%	0.10	1.67	0.46	0.02	0.13	0.55
2005	**Mean**	**0.09**	**0.14**	**0.42**	**0.03**	**0.05**	**0.18**
	5%	0.04	0.04	0.31	0.01	0.02	0.13
	95%	0.16	0.31	0.58	0.06	0.07	0.24

Table 17: Mean number of sub-adult endeavour prawns caught per hectare per region for the January surveys in 2003, 2004 and 2005, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region					
		Groote	Vanderlins	Mornington	Karumba	Weipa	All
Blue endeavour prawns *(M. endeavouri)*							
2003	**Mean**	**9.36**	**7.75**	**1.60**	**0.05**	**0.41**	**4.45**
	5%	7.88	6.81	1.27	0.02	0.28	4.04
	95%	11.03	8.89	1.96	0.07	0.55	4.89
2004	**Mean**	**1.73**	**1.62**	**0.90**	**0.02**	**0.24**	**1.06**
	5%	1.48	1.38	0.67	0.01	0.13	0.96
	95%	2.02	1.86	1.23	0.03	0.37	1.18
2005	**Mean**	**2.09**	**1.34**	**2.74**	**0.04**	**0.76**	**1.61**
	5%	1.68	1.17	2.24	0.02	0.61	1.44
	95%	2.64	1.51	3.35	0.07	0.92	1.81
Red endeavour prawns *(M. ensis)*							
2003	**Mean**	**0.07**	**0.27**	**0**	**0**	**1.09**	**0.18**
	5%	0.05	0.17	0	0	0.61	0.12
	95%	0.09	0.42	0	0	1.64	0.23
2004	**Mean**	**0.02**	**0.10**	**0**	**0**	**1.00**	**0.11**
	5%	0.01	0.05	0	0	0.71	0.08
	95%	0.03	0.18	0	0	1.34	0.15
2005	**Mean**	**0**	**0**	**0**	**0**	**0.27**	**0.02**
	5%	0	0	0	0	0.2	0.02
	95%	0.01	0.01	0	0	0.36	0.03

6.3.1 *Annual changes by region*

Besides the regional variation in prawn abundance, temporal change in abundance always attracts great interest in fisheries. Figures 1-6 show changes in the regional and gulf-wide sub-adult abundances for the recruitment surveys in 2003-2005.

Brown tiger prawns *(P. esculentus)* had higher catch rates in 2003 and 2005 than in 2004 in four survey regions, Groote, Vanderlins, Mornington and Karumba (Figure 36). Only Weipa exhibited a different trend, decreasing from 2003 to 2005. But it should be noted that the catch rate in Weipa was very low compared with other regions. The global mean catch rate was highest in 2003, followed by 2005, and the lowest in 2004.

Grooved tiger prawns *(P. semisulcatus)* had a temporal trend similar to brown tiger prawns *(P. esculentus)* in global abundance indices (Figure 37). But, there was a large variation in temporal trend between regions. Among the three areas where grooved tiger prawns *(P. semisulcatus)* were abundant, Groote and Weipa showed a v-shape pattern, in contrast with the pattern seen in Vanderlins.

Banana prawns (*P. merguiensis*) were most abundant in Karumba and Weipa. In these two regions, the catch rates were the highest in 2005, but low in 2003 and 2004 (Figure 38). Other regions showed different patterns. The global abundance index was the highest in 2005, followed by 2003, then 2004.

For king prawns, the global abundance index had a decreasing trend from 2003 to 2005 (Figure 39). No consistent patterns could be found among the regions. Overall, the abundance of king prawns was very low.

Blue endeavour prawns *(M. endeavouri)* had the highest global catch rate in 2003, which was mainly caused by the high catch rates in Groote and Vanderlins in that year (Figure 40). It dropped to the lowest rate in 2004 and recovered slightly in 2005. All regions had quite variable catch rates over the three years.

Red endeavour prawns *(M. ensis)* were captured only in three of the five survey regions, Groote, Vanderlins and Weipa. A consistent decline in abundance from 2003 to 2005 was observed in all of the three regions (Figure 41).

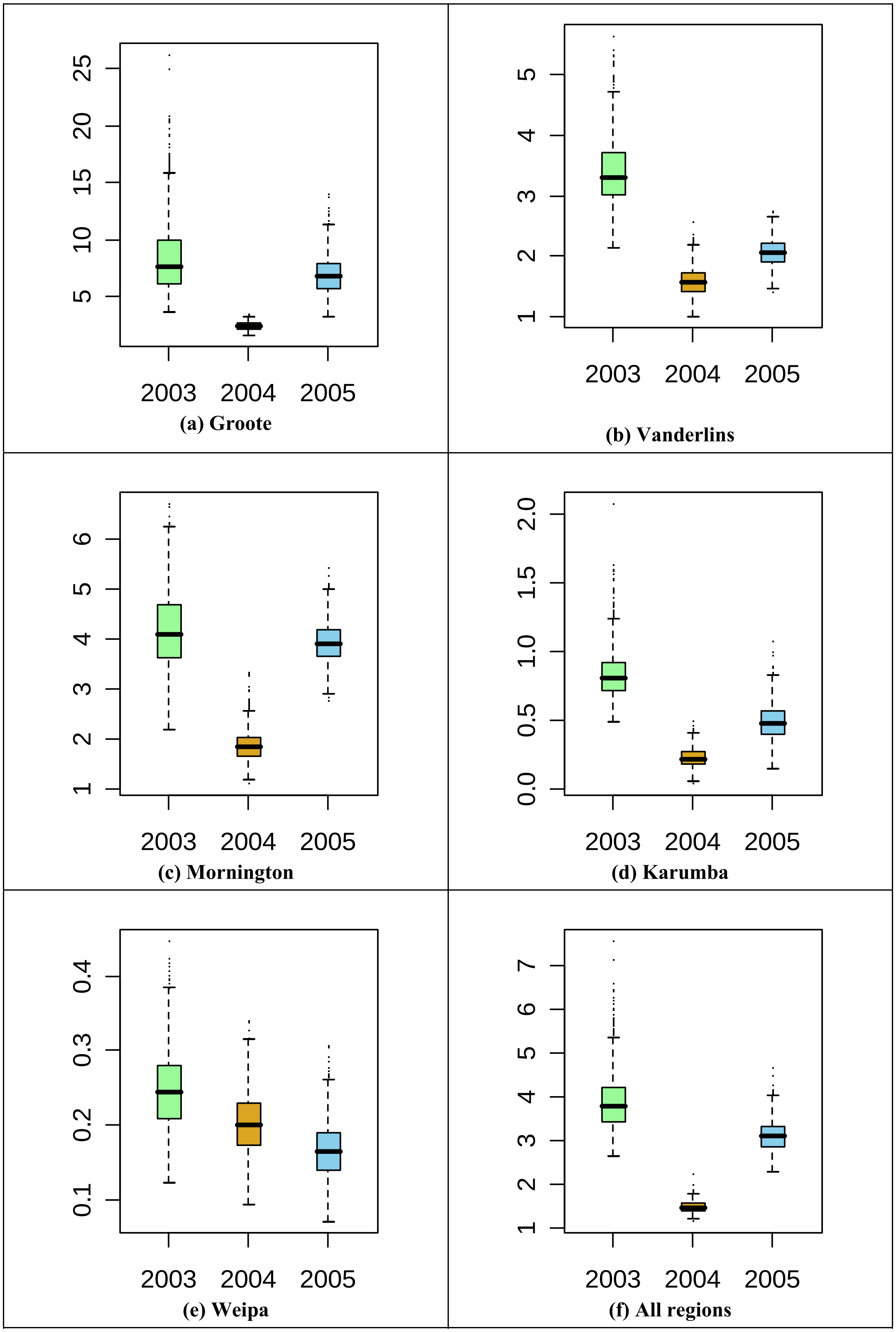


Figure 36: Brown tiger prawns *(P. esculentus)*. **Mean number of sub-adult prawns per hectare in each year for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure.**

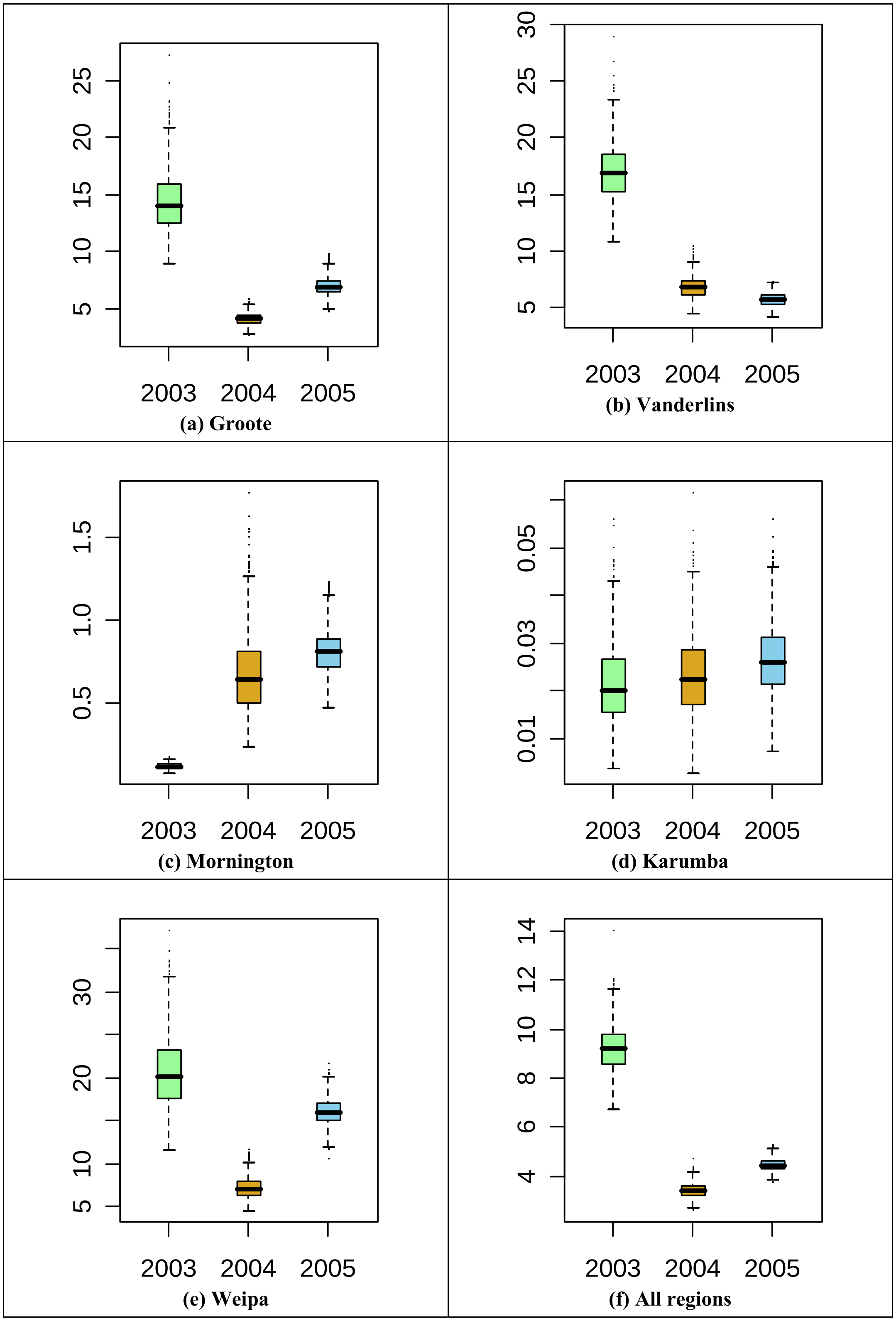


Figure 37: Grooved tiger prawns *(P. semisulcatus).* **Mean number of sub-adult prawns per hectare in each region for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure.**

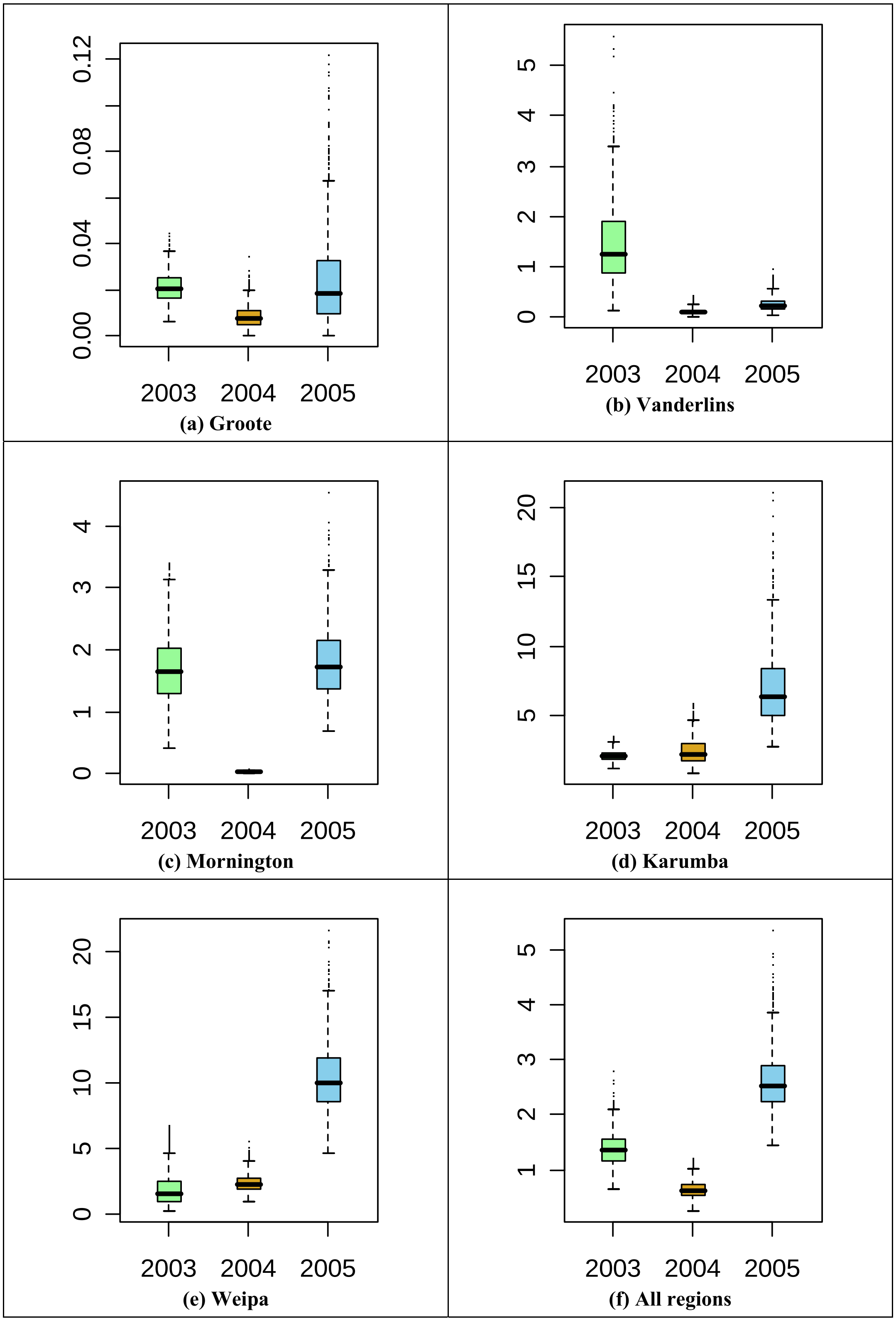


Figure 38: Banana prawns *(P. merguiensis).* **Mean number of sub-adult prawns per hectare in each region for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure.**

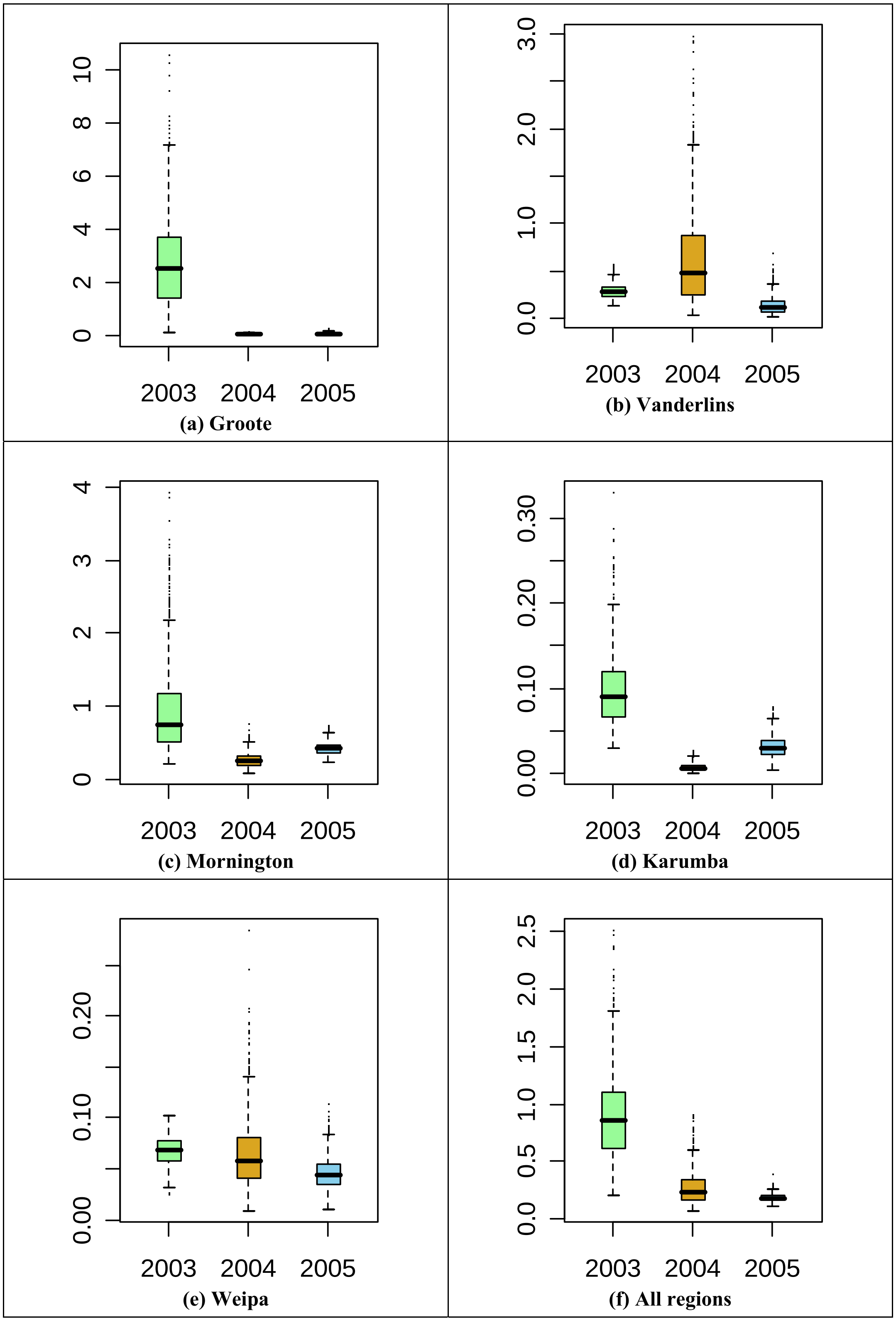


Figure 39: Western king prawns *(Penaeus latisulcatus)*. Mean number of sub-adult prawns per hectare in each region for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure.

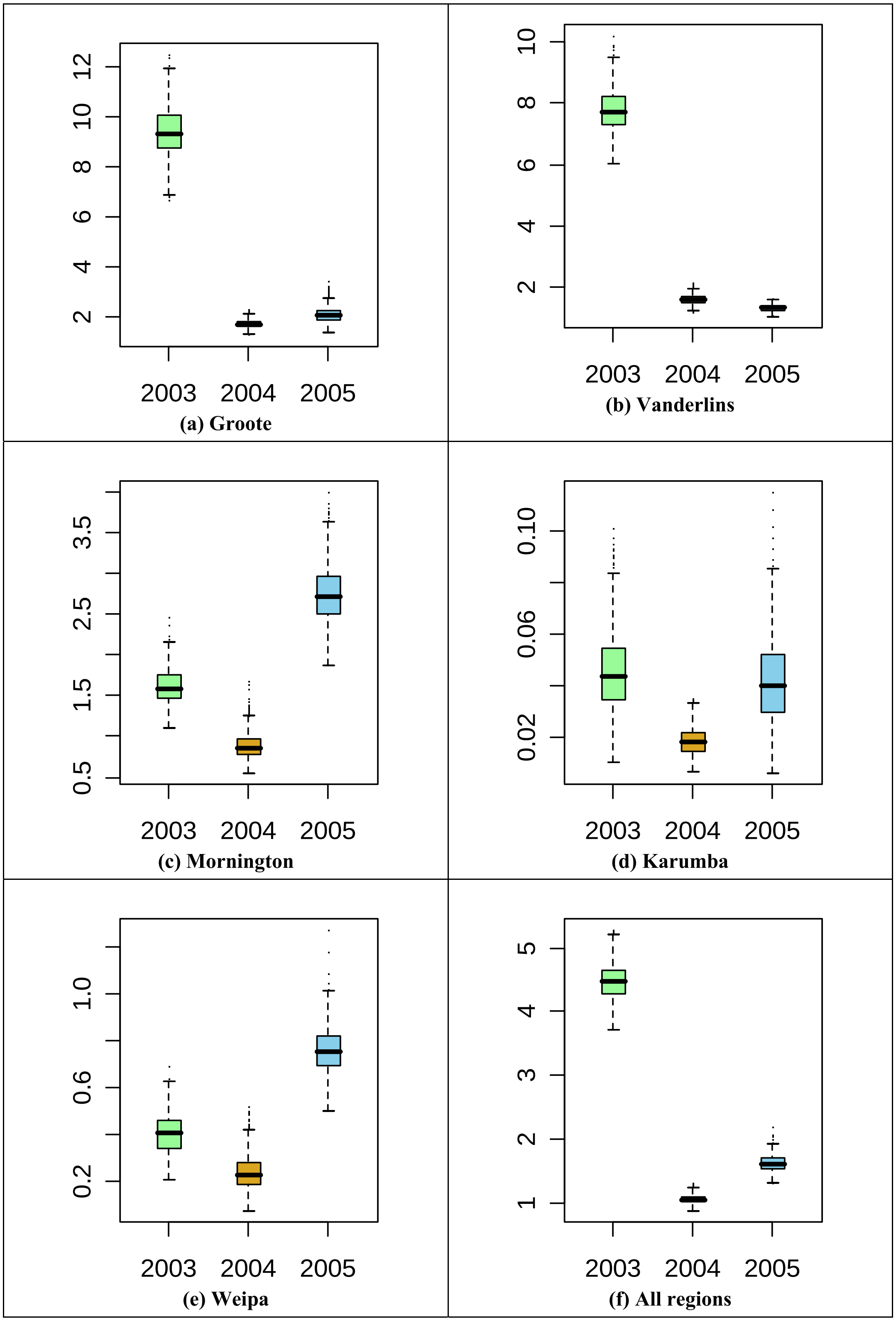


Figure 40: Blue endeavour prawns *(M. endeavouri)*. Mean number of sub-adult prawns per hectare in each region for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure.

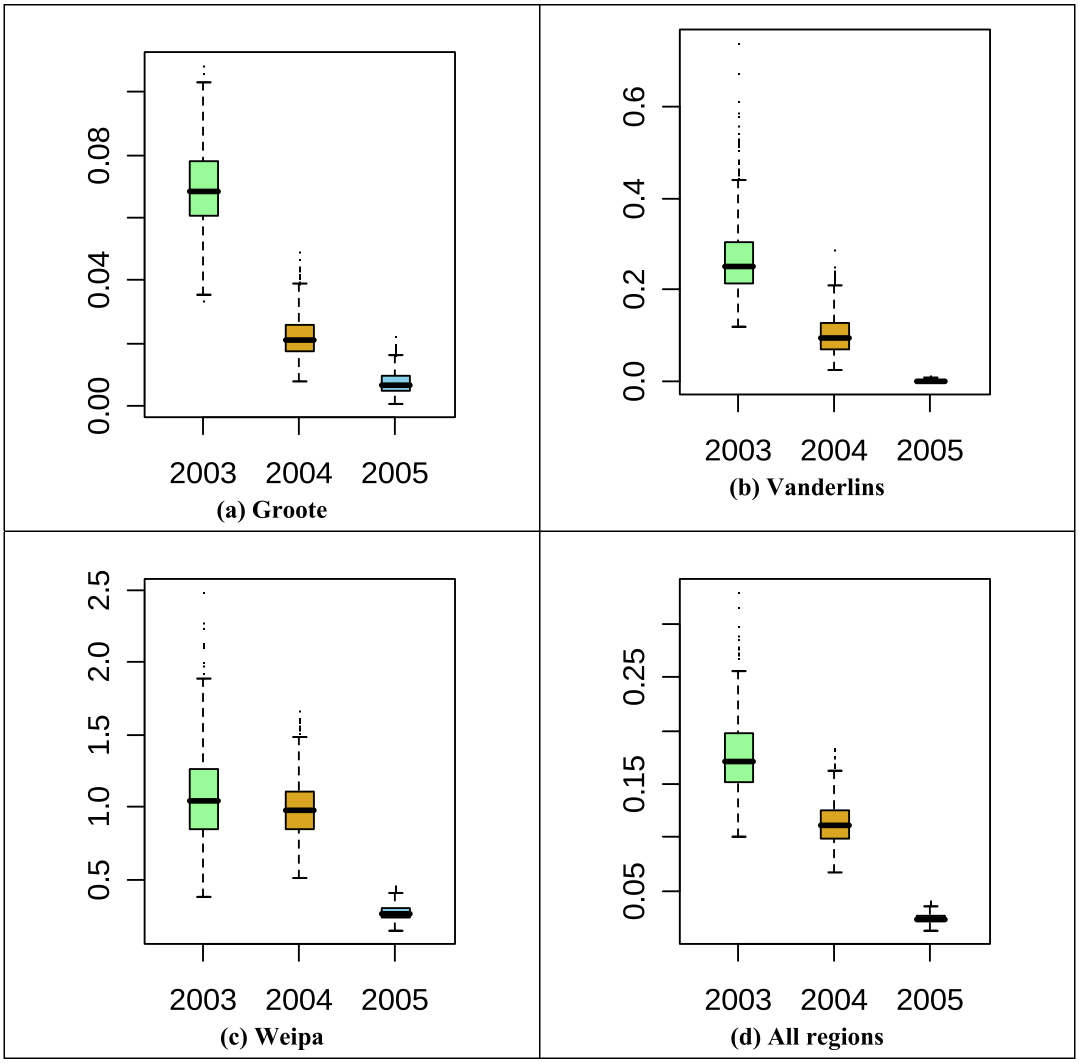


Figure 41: Red endeavour prawns *(M. ensis)*. **Mean number of sub-adult prawns per hectare in each region for the January 2003, 2004 and 2005 surveys. Note the different scales on each figure. Since their abundances were zero, the Mornington and Karumba regions have not been shown.**

6.3.2 *Regional differences*

Regional differences in prawn abundance are better depicted in Figure 42. Brown tiger prawns *(Penaeus esculentus)* were mainly distributed in the west coast of the Gulf, from Groote to Mornington. In contrast, grooved tiger prawns *(P. semisulcatus)* were abundant in Groote, Vanderlins and Weipa. Although, Groote and Vanderlins were the common areas for tiger prawns, the two species appeared to alternate; when one species was abundant in one region, the other was less abundant (and *vice versa*). The phenomenon existed in other regions as well.

Banana prawns (*P. merguiensis*) had high catch rates in Weipa and Karumba, along the east coast of the Gulf of Carpentaria. They were less abundant in Mornington, Vanderlins and Groote (the western and south-western coasts). King prawns were most abundant in Groote, and rare in all of the other four regions.

Blue endeavour prawns *(M. endeavouri)* had higher catch rates in Groote, Vanderlins and Mornington, than in Karumba and Weipa, although the variation within a region was very large. In contrast, red endeavour prawns *(M. ensis)* were relatively abundant in Weipa, but had very low catch rates in Groote and Vanderlins and no catch in Mornington and Karumba.

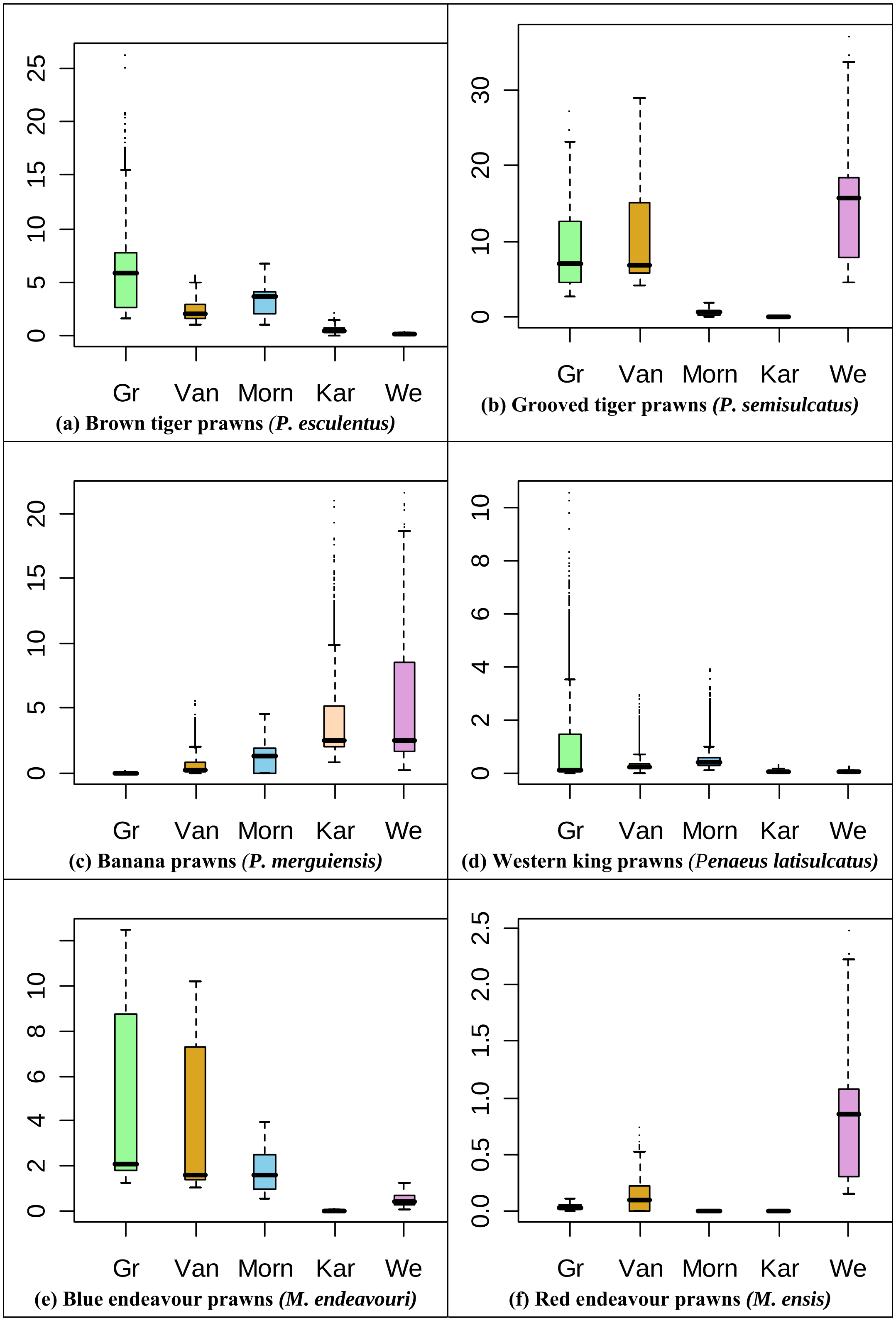


Figure 42: Mean number of sub-adult prawns per hectare in each region for the recruitment surveys. Note the different scales on each figure.

6.4 Abundance indices and confidence intervals – spawning surveys

The Bayesian bootstrap estimates for the spawning abundance indices of the commercial prawn species are presented in Tables 18-20, based on the data collected during the August surveys in 2002-2004. The estimates of the means are the same as those presented in Chapter 5. However, the confidence intervals should be more accurate as the Bayesian bootstrap percentile intervals shift in the direction of the skewness.

The spawning abundance survey covered only three regions Groote, Vanderlins and Mornington. The catch rates of brown tiger prawns *(P. esculentus)* were quite similar among the three regions, ranging from 3.08 to 10.03 prawns per hectare during the three surveys. The between-year variation in global index was even less, from 5.24 to 8.34 prawns per hectare (Table 18).

The spatial distribution of grooved tiger prawns *(P. semisulcatus)* seems limited to Groote and Vanderlins, with quite low catch rates in Mornington (0.05 to 0.54 prawns per hectare, Table 18). The distribution is consistent with that seen in the recruitment survey in February (Table 15). Its between-year variation was not large, from 3.48 to 4.91 prawns per hectare.

Banana prawns (*P. merguiensis*) had very low catch rates in all the three survey regions, and the global index varied from 0.60 prawns per hectare in 2004 to 1.06 prawns per hectare in 2003 (Table 19). There are two reasons for this. One is that the west coast of the Gulf is not a typical banana prawn (*P. merguiensis*) habitat, as found from the recruitment survey (Table 16). The other reason is that after the banana prawn (*P. merguiensis*) season in the first half of each year, the banana population has been depleted to a low level.

King prawns catch rates ranged from 0.5 to 2.54 prawns per hectare during the three annual surveys (Table 19). Although these catch rates are not high compared with tiger prawns, they are higher than the catch rates of the recruitment survey (which were < 1 prawn per hectare, except for Groote in 2003 (Table 16)). The high abundances in August suggest a strong recruitment between February and July for king prawns.

Blue endeavour prawns *(M. endeavouri)* had quite high catch rates – from 2.37 to 9.54 prawns per hectare (Table 20), which are very close to the catch rates of tiger prawns (Table 18). The between year variation in abundance was also low, from 4.47 to 7.73 prawns per hectare. In contrast, red endeavour prawns *(M. ensis)* had negligible catches in Groote and Vanderlins, 0.05-0.89 prawns per hectare, and no catch in Mornington. These results are consistent with the recruitment survey (Table 17).

Table 18: Mean number of adult tiger prawns per hectare per region for the August surveys in 2002, 2003 and 2004, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Brown tiger prawns *(P. esculentus)*					
2002	**Mean**	**10.03**	**7.73**	**7.64**	**8.34**
	5%	7.43	6.37	6.33	7.33
	95%	13.1	9.26	9.15	9.39
2003	**Mean**	**5.89**	**6.74**	**6.63**	**6.47**
	5%	4.44	5.73	5.66	5.80
	95%	7.58	7.84	7.67	7.17
2004	**Mean**	**7.79**	**3.08**	**5.75**	**5.24**
	5%	5.45	2.53	4.70	4.45
	95%	10.54	3.65	6.94	6.13
Grooved tiger prawns *(P. semisulcatus)*					
2002	**Mean**	**12.19**	**3.43**	**0.54**	**4.91**
	5%	9.59	2.63	0.33	4.1
	95%	15.23	4.33	0.78	5.8
2003	**Mean**	**6.40**	**4.64**	**0.05**	**3.64**
	5%	5.2	3.76	0.03	3.15
	95%	7.6	5.62	0.08	4.14
2004	**Mean**	**6.10**	**4.37**	**0.12**	**3.48**
	5%	4.97	3.51	0.07	3.02
	95%	7.32	5.27	0.19	3.95

Table 19: Mean number of adult banana *(P. merguiensis)* and king prawns caught per hectare per region for the August surveys in 2002, 2003 and 2004, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Banana prawns *(P. merguiensis)*					
2002	**Mean**	**0.39**	**0.39**	**2.35**	**1.01**
	5%	0.16	0.15	0.32	0.31
	95%	0.63	0.81	5.87	2.13
2003	**Mean**	**0.52**	**1.99**	**0.86**	**1.06**
	5%	0.27	0.93	0.46	0.75
	95%	0.88	3.62	1.59	1.92
2004	**Mean**	**1.03**	**0.18**	**0.79**	**0.60**
	5%	0.31	0.11	0.51	0.38
	95%	2.3	0.29	1.12	0.97
Western king prawns *(Penaeus latisulcatus)*					
2002	**Mean**	**1.32**	**2.39**	**2.54**	**2.15**
	5%	0.42	0.86	1.34	1.27
	95%	2.77	4.71	4.15	3.26
2003	**Mean**	**0.51**	**1.82**	**1.06**	**1.21**
	5%	0.14	1.24	0.79	0.93
	95%	1.2	2.46	1.44	1.56
2004	**Mean**	**0.50**	**0.63**	**1.83**	**0.99**
	5%	0.12	0.43	1.23	0.74
	95%	1.13	0.87	2.59	1.28

Table 20: Mean number of endeavour prawns caught per hectare per region for the August surveys in 2002, 2003 and 2004, with lower (5%) and upper (95%) confidence intervals.

Year	Statistic	Region			
		Groote	Vanderlins	Mornington	All
Blue endeavour prawns *(M. endeavouri)*					
2002	**Mean**	**9.54**	**7.09**	**6.98**	**7.73**
	5%	7.78	5.71	5.70	6.89
	95%	11.44	8.79	8.19	8.68
2003	**Mean**	**4.83**	**3.08**	**5.89**	**4.47**
	5%	3.93	2.65	5.10	4.05
	95%	5.86	3.54	6.87	4.92
2004	**Mean**	**7.62**	**2.37**	**4.57**	**4.52**
	5%	6.04	2.05	3.81	4.02
	95%	9.25	2.71	5.35	5.07
Red endeavour prawns *(M. ensis)*					
2002	**Mean**	**0.69**	**0.13**	**0**	**0.24**
	5%	0.47	0.07	0	0.18
	95%	0.93	0.21	0	0.32
2003	**Mean**	**0.19**	**0.07**	**0**	**0.08**
	5%	0.09	0.05	0	0.05
	95%	0.35	0.09	0	0.12
2004	**Mean**	**0.24**	**0.05**	**0**	**0.09**
	5%	0.14	0.03	0	0.06
	95%	0.36	0.10	0	0.13

6.4.1 *Annual changes by region*

For quick interpretation using visual impact, the changes in the regional and gulf-wide adult prawn abundances are presented in Figures 43-48. The percentiles help show the variation, skewness of distribution, and confidence of the mean catch rate estimates.

The temporal variation in brown tiger prawn *(P. esculentus)* catch rates differed with region, decreasing from 2002 to 2005 in Vanderlins and Mornington; but with an apparent recovery in 2005 in the Groote region (Figure 43). The largest variation occurred in Vanderlins.

For grooved tiger prawns *(P. semisulcatus)*, the between-year variation is not consistent (Figure 44). The overall abundance index over the three survey regions had the highest value in 2002, but dropped by about 30% in 2003 and 2004.

Banana prawns (*P. merguiensis*) exhibited a high catch rate in only one year in each region. Groote had a high catch rate in 2004, Vanderlins in 2003 and Mornington in 2002. It seems that the high catch area moved towards the north from 2002 to 2004.

King prawns had low catch rates in general; the highest was only about 2 prawns per hectare (Figure 46). As for other species, the temporal variation assumed different patterns in different regions. The global abundance index showed a clear trend of decline from 2002 to 2004.

The two endeavour species seemed to have a similar temporal pattern in 2002-2004 in Groote and Vanderlins (Figures 12-13). Overall, they had a high catch rate in 2002, lower in 2003 and 2004.

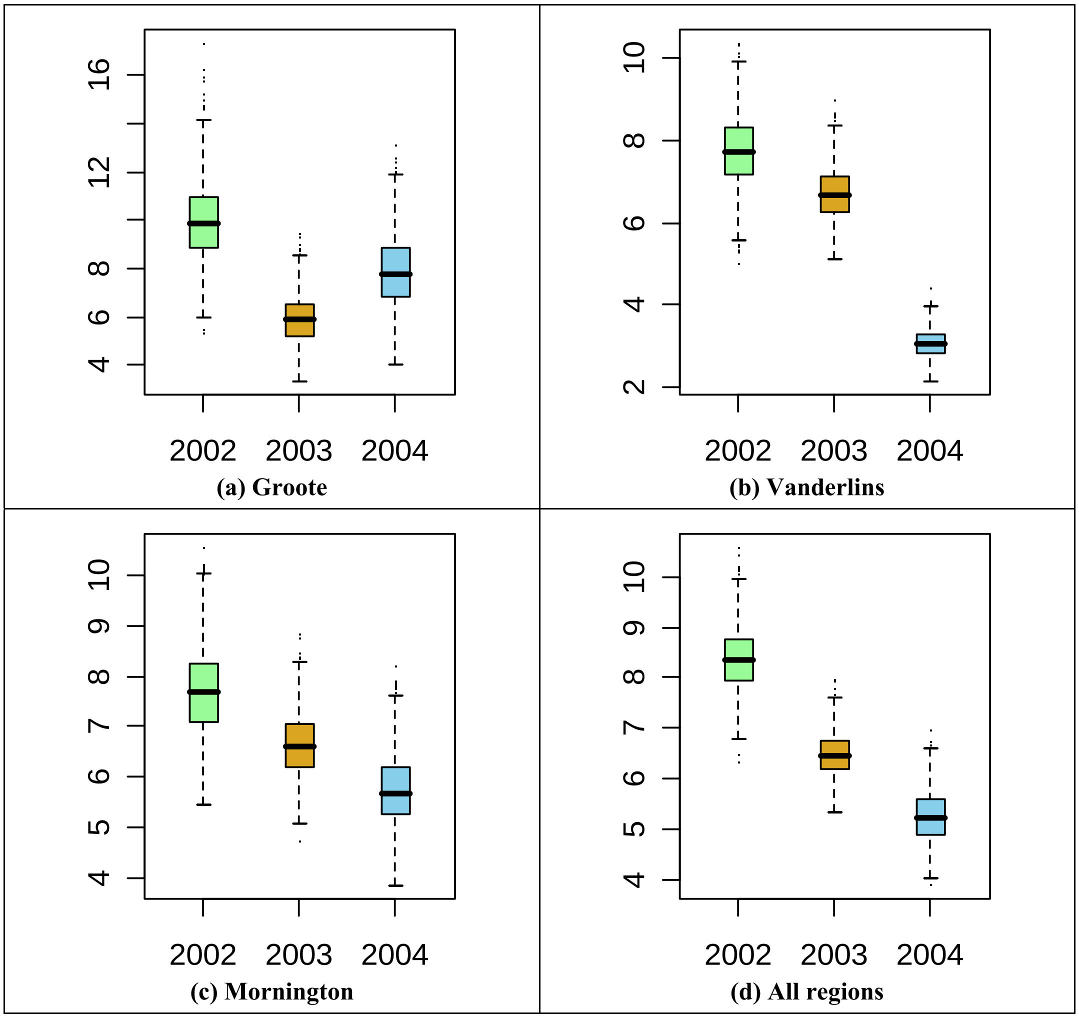


Figure 43: Brown tiger prawns *(P. esculentus)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure.

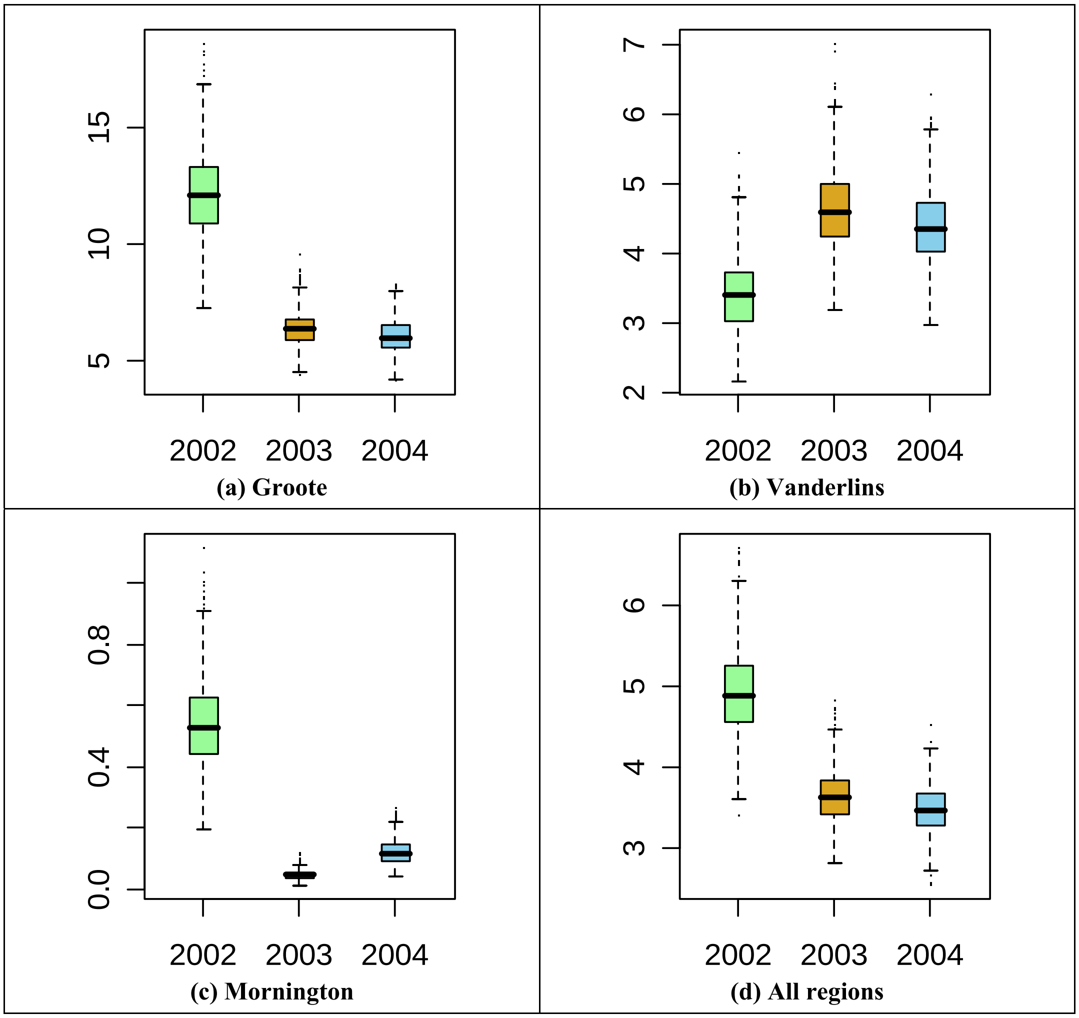


Figure 44: Grooved tiger prawns *(P. semisulcatus)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure.

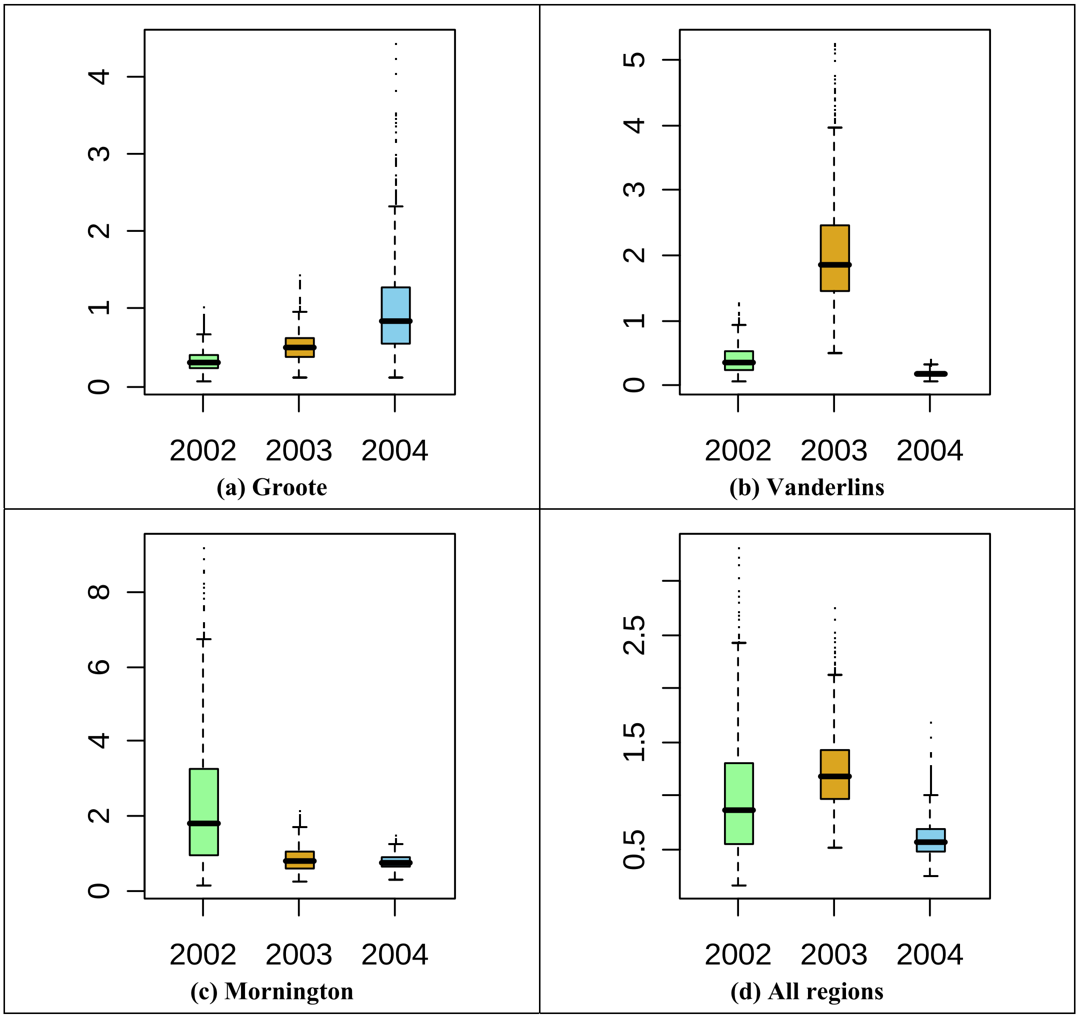


Figure 45: Banana prawns *(P. merguiensis)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure.

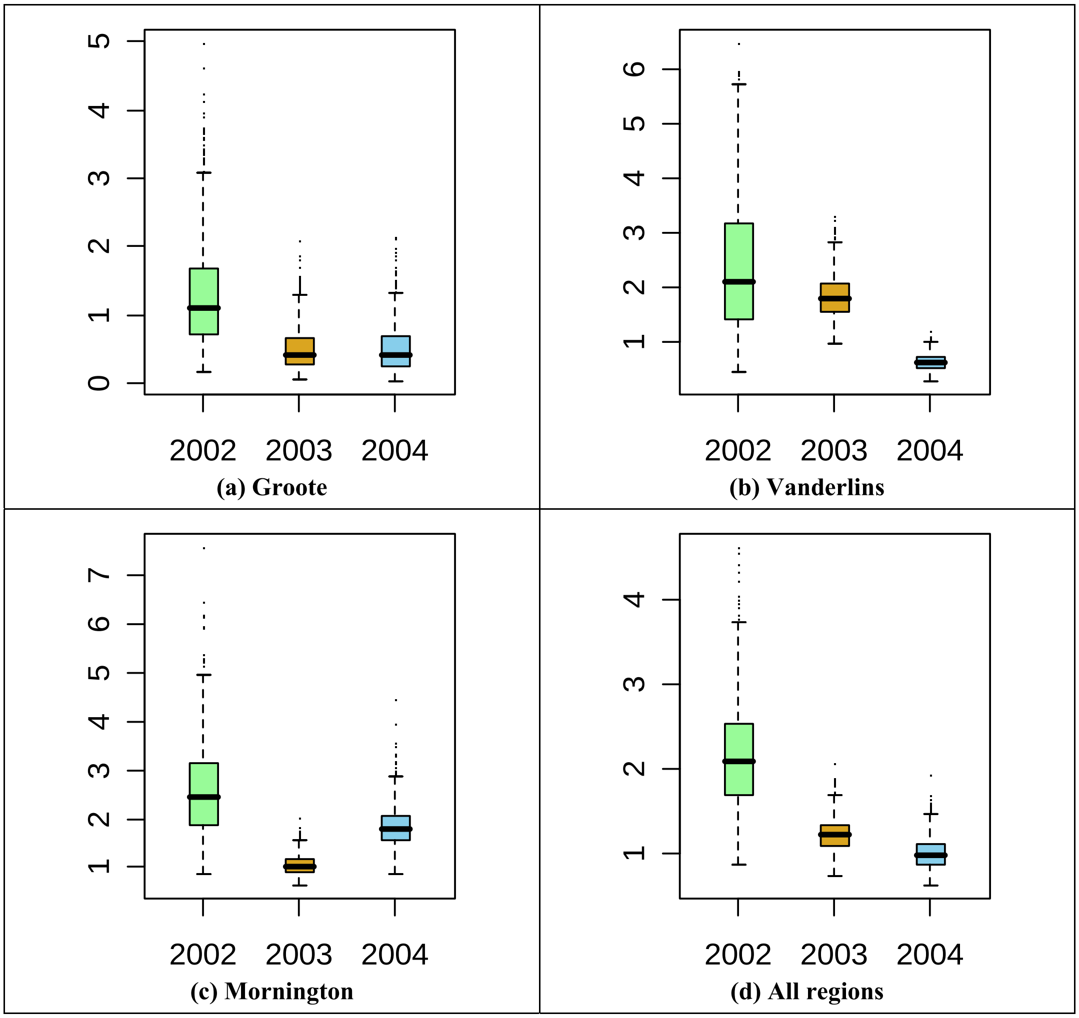


Figure 46: Western king prawn *(P. latisulcatus)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure.

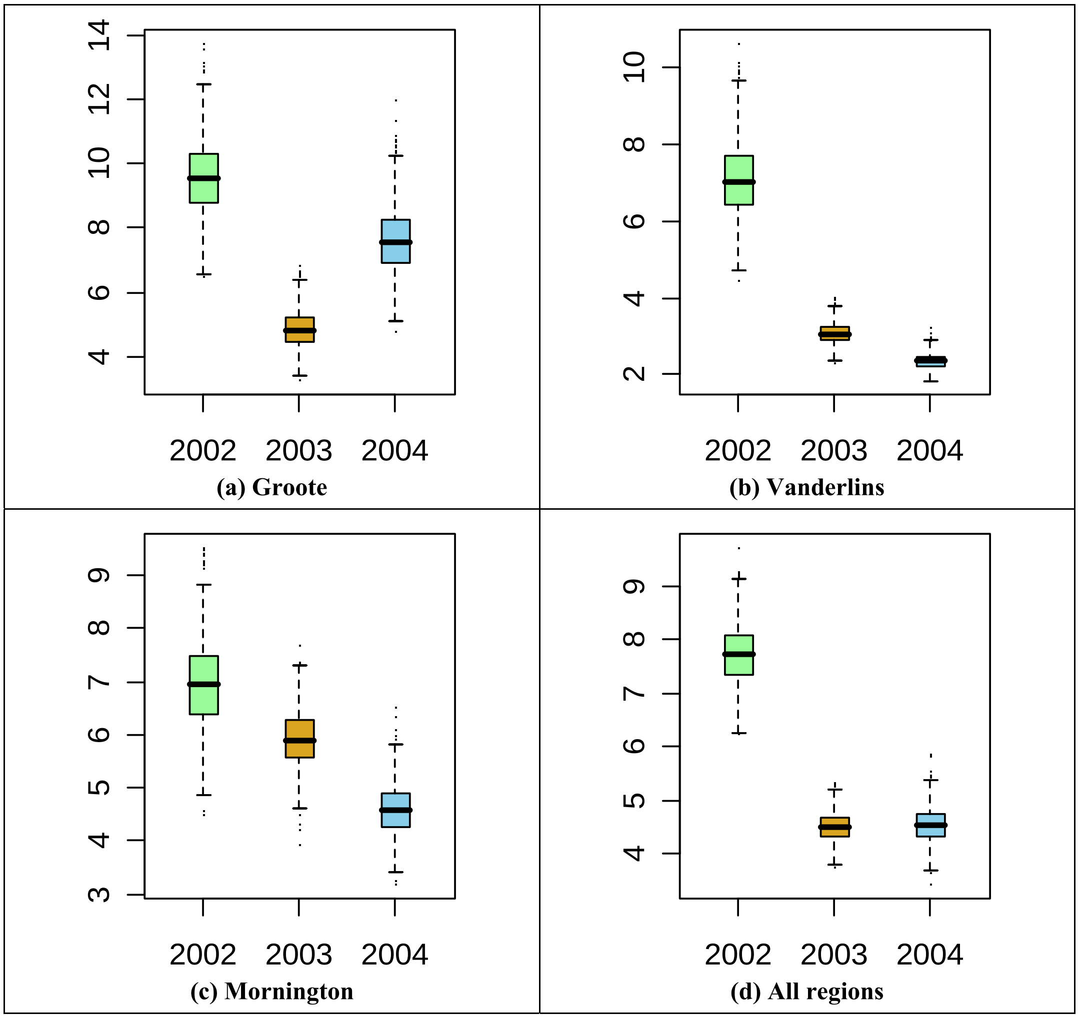


Figure 47: Blue endeavour prawns *(M. endeavouri)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure.

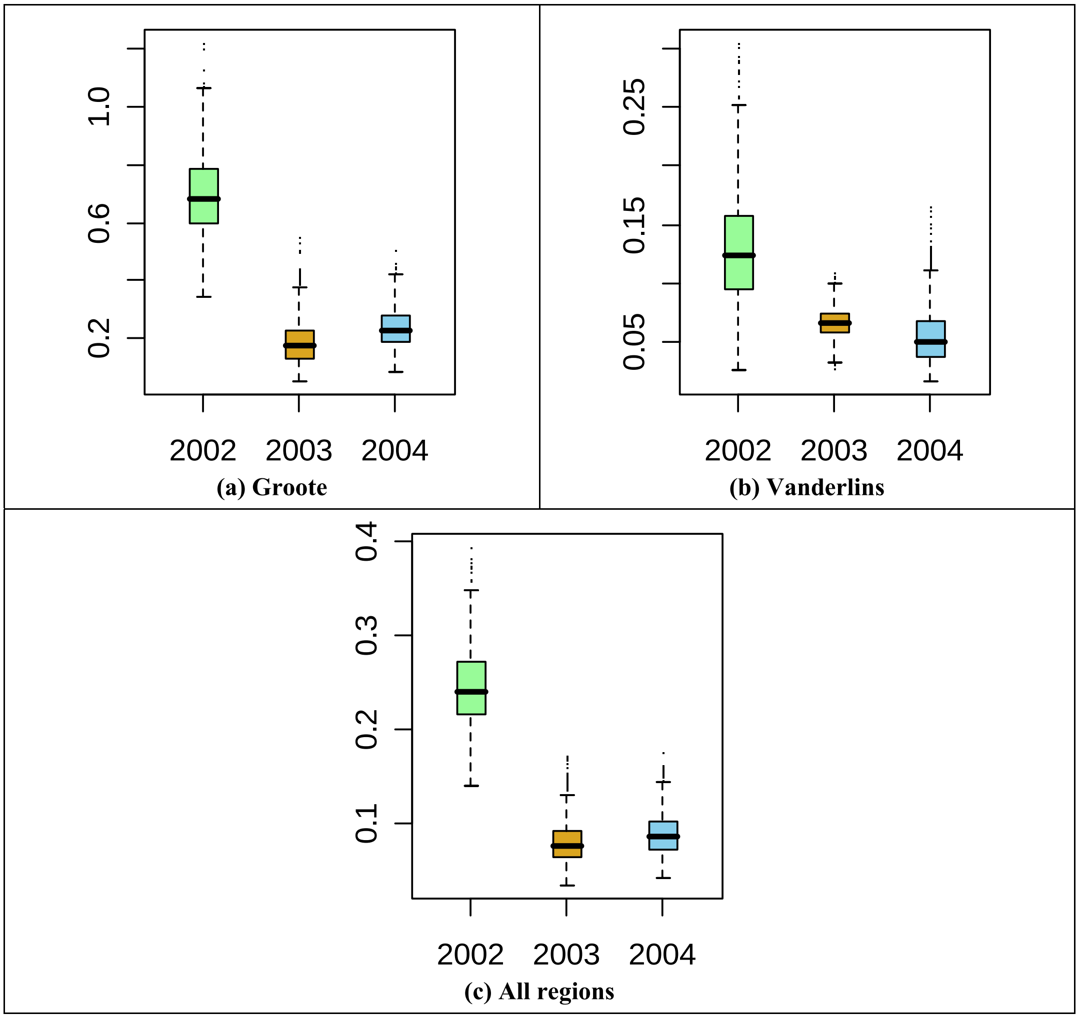
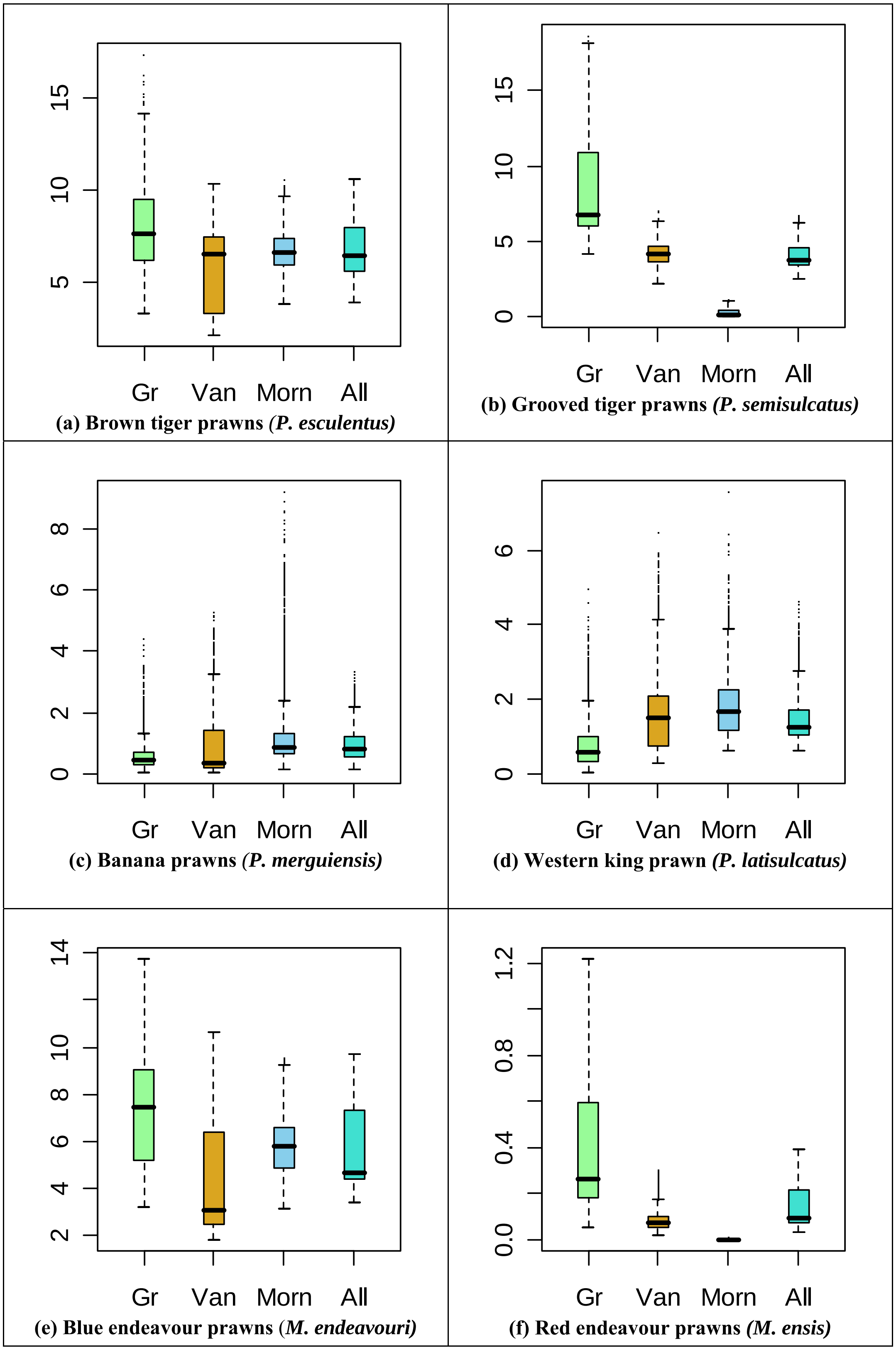


Figure 48: Red endeavour prawns *(M. ensis)*. Mean number of adult prawns per hectare in each region for the August 2002, 2003 and 2004 surveys. Note the different scales on each figure. Since the abundances were zero, the Mornington region has not been shown.

6.4.2 *Regional differences*

Regional differences in spawning prawn abundance for the major commercial species are shown in Figure 49. Brown tiger prawns *(Penaeus esculentus)*, banana prawns *(P. merguiensis)*, and blue endeavour prawns *(M. endeavouri)* (left column in Figure 49) exhibited low variation in abundance between the three regions (Groote, Vanderlins and Mornington) in contrast with other three species, grooved tiger prawns *(P. semisulcatus)*, western king prawn *(P. latisulcatus)* and red endeavour prawns *(M. ensis)* (right column of Figure 49). However, it should be noted that the pattern seen in Figure 49 may not apply to the whole Gulf of Carpentaria and that it may change over time.



(a) Brown tiger prawns *(P. esculentus)*

(b) Grooved tiger prawns *(P. semisulcatus)*

(c) Banana prawns *(P. merguiensis)*

(d) Western king prawn *(P. latisulcatus)*

(e) Blue endeavour prawns (*M. endeavouri)*

(f) Red endeavour prawns *(M. ensis)*

Figure 49: Mean number of adult prawns per hectare in each region for the spawning surveys. Note the different scales on each figure.

6.5 Discussion

The use of a model-based approach for estimating abundance indices combined with Bayesian bootstrapping has provided an improved assessment of the accuracy of the estimated indices. Because they model the counts, instead of depending on the randomness of the design, model-based approaches can also be used when samples have not been collected in a rigorously randomised manner.

In addition, whilst a randomised design should be set up so as to incorporate spatial variation at the design stage, this is not always possible prior to collecting the data. A model-based approach can be used to acknowledge that there always is an underlying spatial pattern to abundances. It can be incorporated directly into the models by using covariates that vary spatially and are known to be related to abundances, for example: depth, sediment type and nearness to nursery habitats. Modelling against spatial covariates can be used to make spatially varying predictions of abundance. Therefore, they may provide both better estimates of abundances and a means to reduce the amount of surveys required; and/or they may help to update the design so as to better reflect the spatial variation in abundance.

6.6 References

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CHAPTER 7. PRAWN SIZE COMPOSITION, MATURITY AND PARASITES

7.1 Introduction

It is important when analysing the prawn catch data from these surveys and, ultimately, 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 (January), we need to know that our survey has adequately sampled the smaller, new recruits to the fishery, whereas for the August 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 we 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 callipers 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 August 2004 and January 2005, 26,490 prawns and 37,082 prawns (respectively) were measured.

The size range of prawns measured in both surveys was large (Table 21, Table 22). For example, in August 2004, the smallest grooved tiger prawns *(Penaeus semisulcatus)* measured was 10.3 mm Carapace Length (CL) and the largest was 67.0 mm CL. For all species the mean size of all prawns measured was larger in August than in 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). However, the smallest prawns of some species measured were less in August than in January, suggesting late recruitment for some individuals of grooved tiger prawns *(P. semisulcatus)* and blue endeavour prawns *(M. endeavouri)* in 2004. For most species, the smallest prawns were caught in January, as was the case in 2003.

Table 21: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in August 2003 and August 2004.

	August 2003				August 2004			
Species	Number measured	Mean	Min	Max	Number measured	Mean	Min	Max
Penaeus esculentus	9373	38.7	17.4	56.8	7436	37.8	15.7	58.2
Penaeus semisulcatus	6939	38.4	18.7	60.4	7343	38.0	10.3	67.0
Metapenaeus endeavouri	8367	33.6	16.6	51.4	8113	32.7	10.4	57.1
Metapenaeus ensis	253	33.2	20.9	49.5	380	33.4	16.7	54.2
Penaeus merguiensis	1493	36.6	21.5	56.4	1354	35.3	23.3	47.4
Penaeus latisulcatus	1876	37.8	18.6	58.1	1818	35.5	20.6	57.2
Penaeus longistylus	13	38.7	24.1	53.2	40	35.7	21.2	57.5
Penaeus monodon	10	55.9	38.6	66.0	6	47.9	40.1	57.4

Apart from black tiger prawns *(P. monodon)*, the sizes of prawns caught in August 2004 were not substantially different from those caught in August 2003 (Table 21). The mean size of black tiger prawns *(P. monodon)* was 8 mm smaller in 2004, than in 2003. For most species, the mean size was slightly smaller in 2004, than in 2003. Similarly, there was no strong overall trend in the size of prawns caught between January 2003 and 2004.

The size composition of prawns caught for each species is slightly different for each region but the predominant patterns can be clearly seen at North Groote Eylandt. In January 2003, the majority of prawns in the population were small; derived from spawning occurring in the last half of the previous year (Figure 50a and Figure 50b). The shallow water samples (< 30 m) had a larger proportion of smaller prawns in two cohorts than the offshore samples (deep > 30 m). The subsequent growth of the prawns present in the population in January can clearly be seen from the survey samples in August 2003 (Figure 50c and Figure 50d). However, the arrows indicating growth of the cohorts need to be treated with caution as there would have been migration of prawns between shallow and deep water sites. As in the previous year, some of the larger prawns from the population in August 2003 can still be seen in January 2004; together with a large proportion of new recruits from the 2003 spring/summer spawning (Figure 50e and Figure 50f). As in 2003, the contribution of the January 2004 recruits to the fishery stock can be seen from the survey results for August 2004; the prawns have grown from about 25-35 mm CL to about 35-45 mm CL (Figure 50g and Figure 50h).

The size of the large female grooved tiger prawns *(Penaeus semisulcatus)* at North Groote varies annually. The mode in the deep water sites was 42 mm CL in 2004, compared with a mode of 45 mm CL in 2003 and of 40 mm CL in 2002.

Table 22: The number measured and the mean, minimum and maximum sizes of all commercial prawn species measured during the two surveys in January 2004 and January 2005.

	January 2004				January 2005			
Species	Number measured	Mean	Min	Max	Number measured	Mean	Min	Max
Penaeus esculentus	7225	31.5	15.6	55.3	11141	31.6	14.5	54.6
Penaeus semisulcatus	10366	30.8	14.4	60.4	12138	29.6	14.2	59.7
Metapenaeus endeavouri	4457	29.7	12.3	49.8	5968	28.8	13.1	54.1
Metapenaeus ensis	1256	32.6	15.9	49.7	704	37.4	16.7	51.8
Penaeus merguiensis	2393	29.9	17.3	48.7	5164	28.8	14.7	45.3
Penaeus latisulcatus	1045	32.4	18.4	55.8	1788	34.7	19.1	54.5
Penaeus longistylus	115	34.2	18.4	54.2	61	36.3	17.0	55.0
Penaeus monodon	5	41.5	31.6	58.4	118	36.6	22.0	56.1

The pattern size and growth for brown tiger prawns *(Penaeus esculentus)* at North Groote was similar to grooved tiger prawns *(P. semisulcatus)* although there was a smaller proportion of very small recruits in January in both years (Figure 51). The larger brown tiger prawns *(P. esculentus)* recruits may be determined by the larger size that they leave their seagrass nursery habitats (Kenyon et al. 2004). The January recruits grow and contribute to the cohort of large prawns in August each year. The size frequency distributions were very similar for the two years of surveys, although in January 2004 there was a suggestion of two cohorts in the population compared to only one cohort in January 2003. However, in August the abundance of prawns in the shallow (< 30 m) and deep (> 30 m) habitats were reversed in 2004, relative to 2003. In 2003, most prawns were caught in the deep survey trawls (although good numbers were also caught shallow) (Figure 51c and Figure 51d); in 2004 most prawns were caught in the shallow survey trawls (Figure 51g and Figure 51h). In 2004, only 71 brown tiger prawns *(P. esculentus)* were caught in the deep habitats at North Groote, similar to the small numbers and the erratic size composition seen at the deep sites in August 2002. Of the two tiger prawns, brown tiger prawns *(P. esculentus)* are found at a lower abundance in offshore waters at Groote.

Penaeus semisulcatus - North Groote

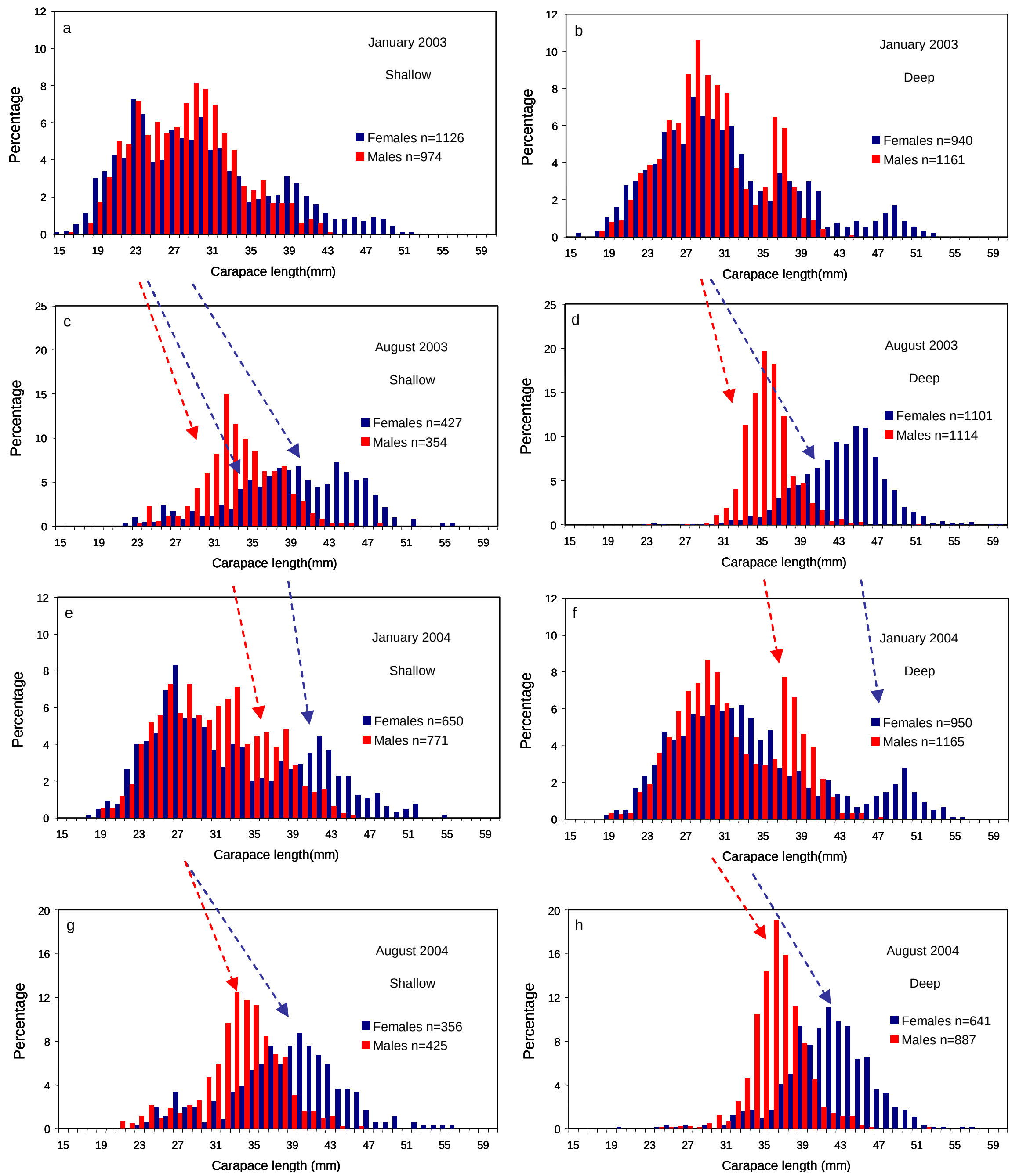

Figure 50: Percentage length frequency distribution of grooved tiger prawns *(Penaeus semisulcatus)* at shallow and deep sites at North Groote in January 2003, August 2003, January 2004 and August 2004. Note the different scales for each six-monthly set of data.

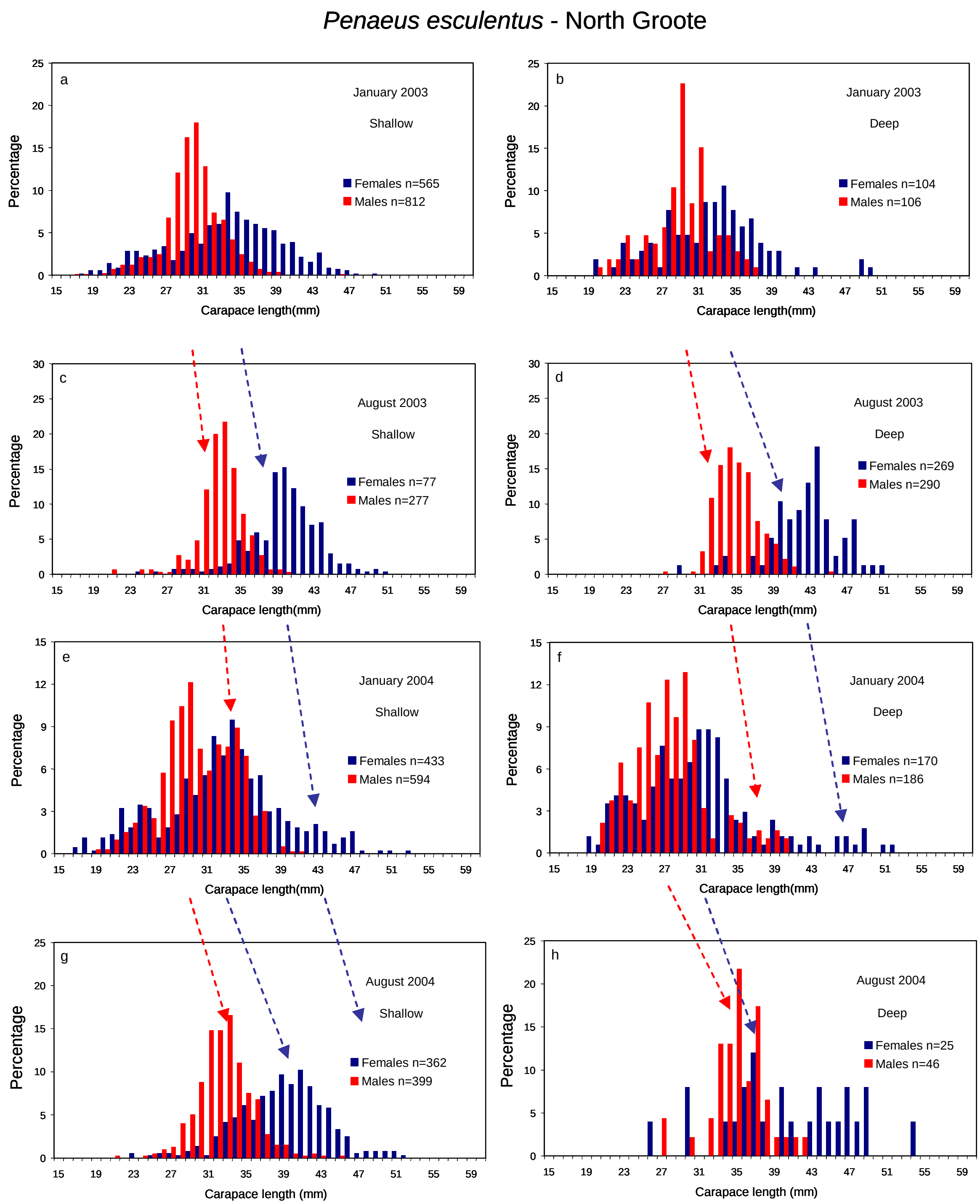

Figure 51: Percentage length frequency distribution of brown tiger prawns *(Penaeus esculentus)* at shallow and deep sites at North Groote in January 2003, August 2003, January 2004 and August 2004. Note the different scales for each six-monthly set of data.

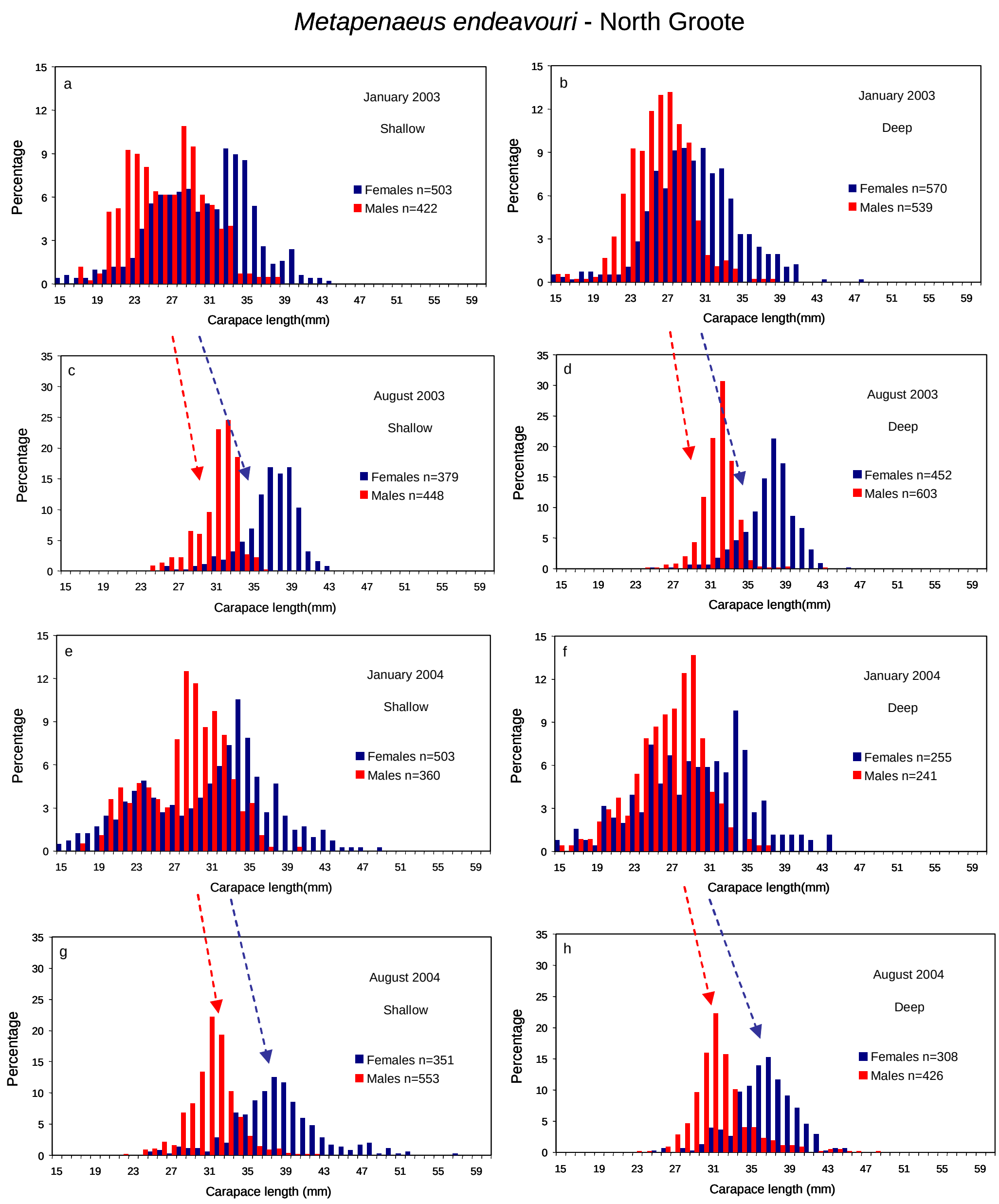

Figure 52: Percentage length frequency distribution of blue endeavour prawns *(Metapenaeus endeavouri)* at shallow and deep sites at North Groote in January 2003, August 2003, January 2004 and August 2004. Note the different scales for August and January.

In general at North Groote Eylandt, the size frequency distributions for blue endeavour prawns *(M. endeavouri)* were similar to the two tiger species (Figure 52). Like the tiger prawns, blue endeavour prawns *(M. endeavouri)* recruits to the fishing grounds in summer, following a spring/early summer spawning during the previous year. In both January 2003 and 2004 there were two cohorts of recruits at the shallow water sites, although there was only one cohort at the deep water sites. This pattern suggests that two major peaks of recruitment have occurred to the fishing grounds from inshore nursery grounds, but that only the first cohort of recruits had migrated as far as the deep water sites. In both August 2003 and 2004, the growth of the January recruits is evident by the presence of significantly larger adult prawns and no recruits in the survey catch.

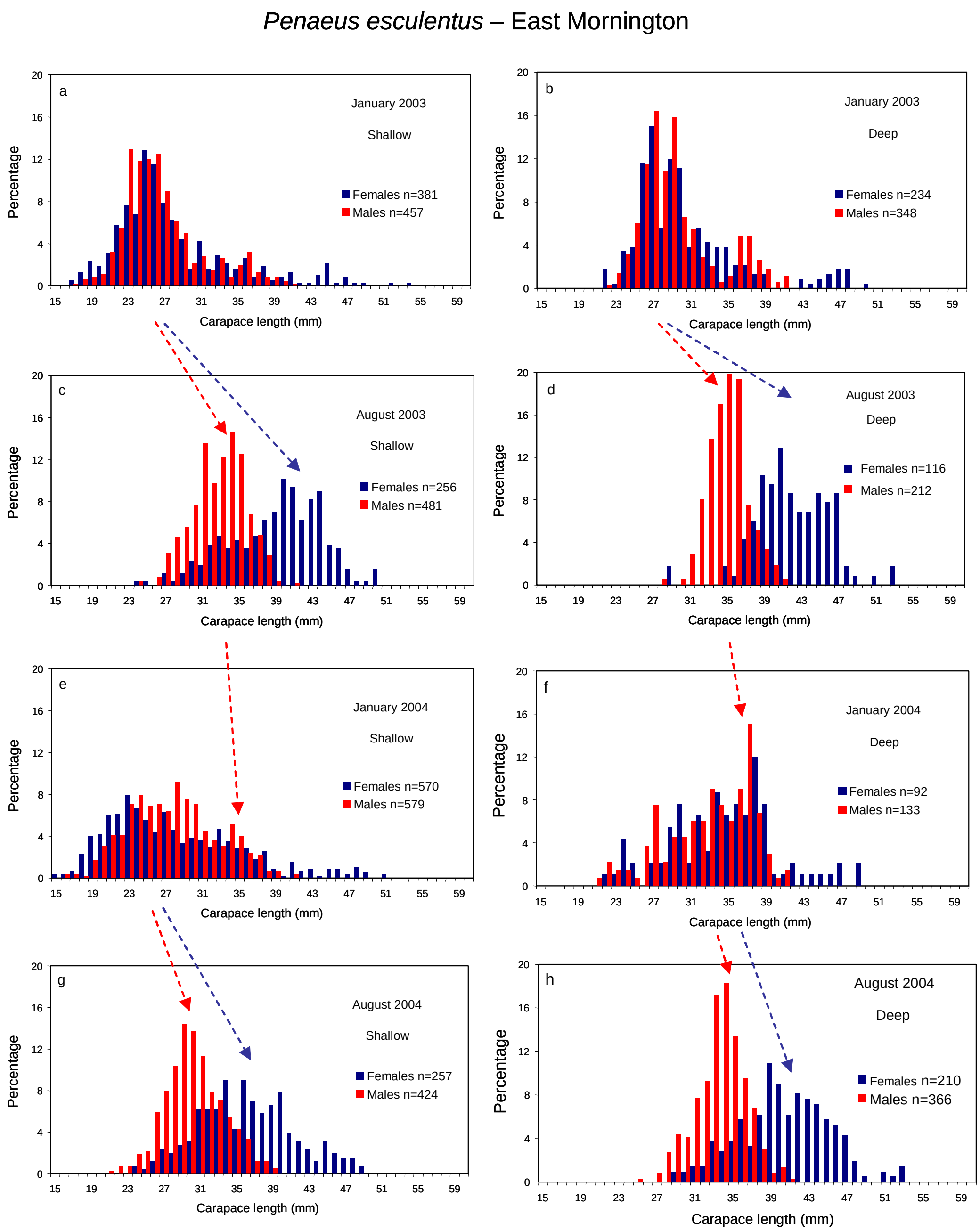

Figure 53: Percentage length frequency distribution of brown tiger prawns *(Penaeus esculentus)* over all shallow and deep sites at East Mornington Island in January 2003, August 2003, January 2004 and August 2004.

The size composition of prawns in the brown tiger prawns *(P. esculentus)* populations around Mornington Island were of some interest. In January, there were some new recruits and some larger prawns from the previous year in all areas, particularly north and west Mornington. At East Mornington, there was a much higher proportion of larger prawns in the population in January 2004 compared to 2003, particularly at the deep water sites (Figure 53). Many of these larger prawns are probably survivors from the fishery in 2003. By August each year, the January recruits had grown and contributed to the fishery stocks, both in the shallow and the deep strata.

The pattern of size distributions of brown tiger prawns *(Penaeus esculentus)* at West Mornington in January was similar for 2003 and 2004 (Figure 54). There was a small cohort of large prawns in shallow and deep water that would have been recruits from the previous year. At west Mornington in both 2003 and 2004, the contribution of the January recruits to the fishery stock in August is clear; the size distribution of the stock is larger due to growth of individual prawns from January to August and the females and males separate as females grow larger.

In 2003, the North Mornington sites had the smallest proportion of new recruits and also had a high proportion of large prawns from the previous year's stock. In 2004, this pattern was even more accentuated, with only a very small proportion of new recruits at the shallow and deep sites (Figure 55). By August of both years, good numbers of large prawns were evident from the recruitment to the fishery early in each year, both in the shallow and the deep strata.

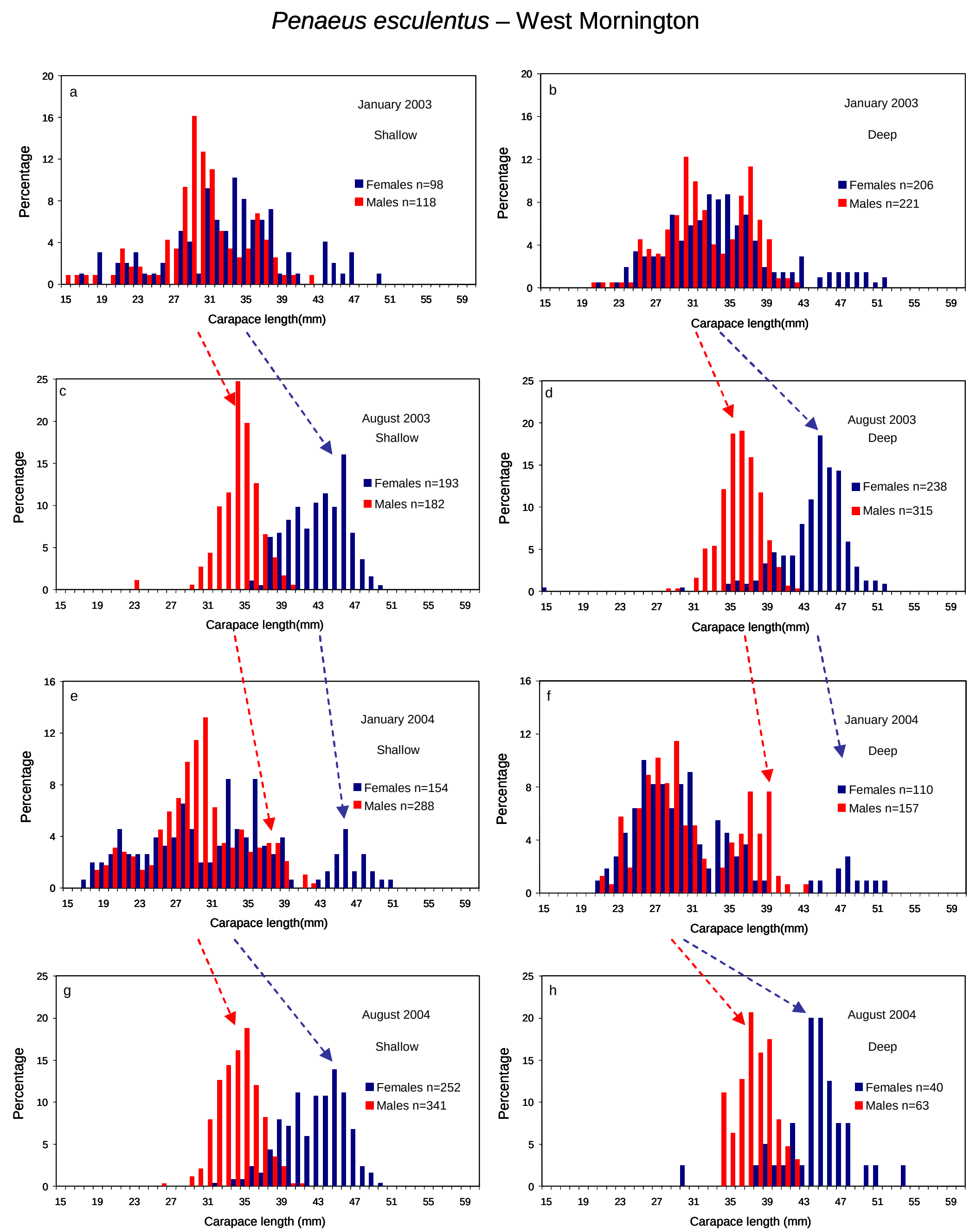

Figure 54: Percentage length frequency distribution of brown tiger prawns *(Penaeus esculentus)* over all shallow and deep sites at West Mornington Island in January 2003, August 2003, January 2004 and August 2004. Note the different scales for each six-monthly set of figures.

Penaeus esculentus – North Mornington

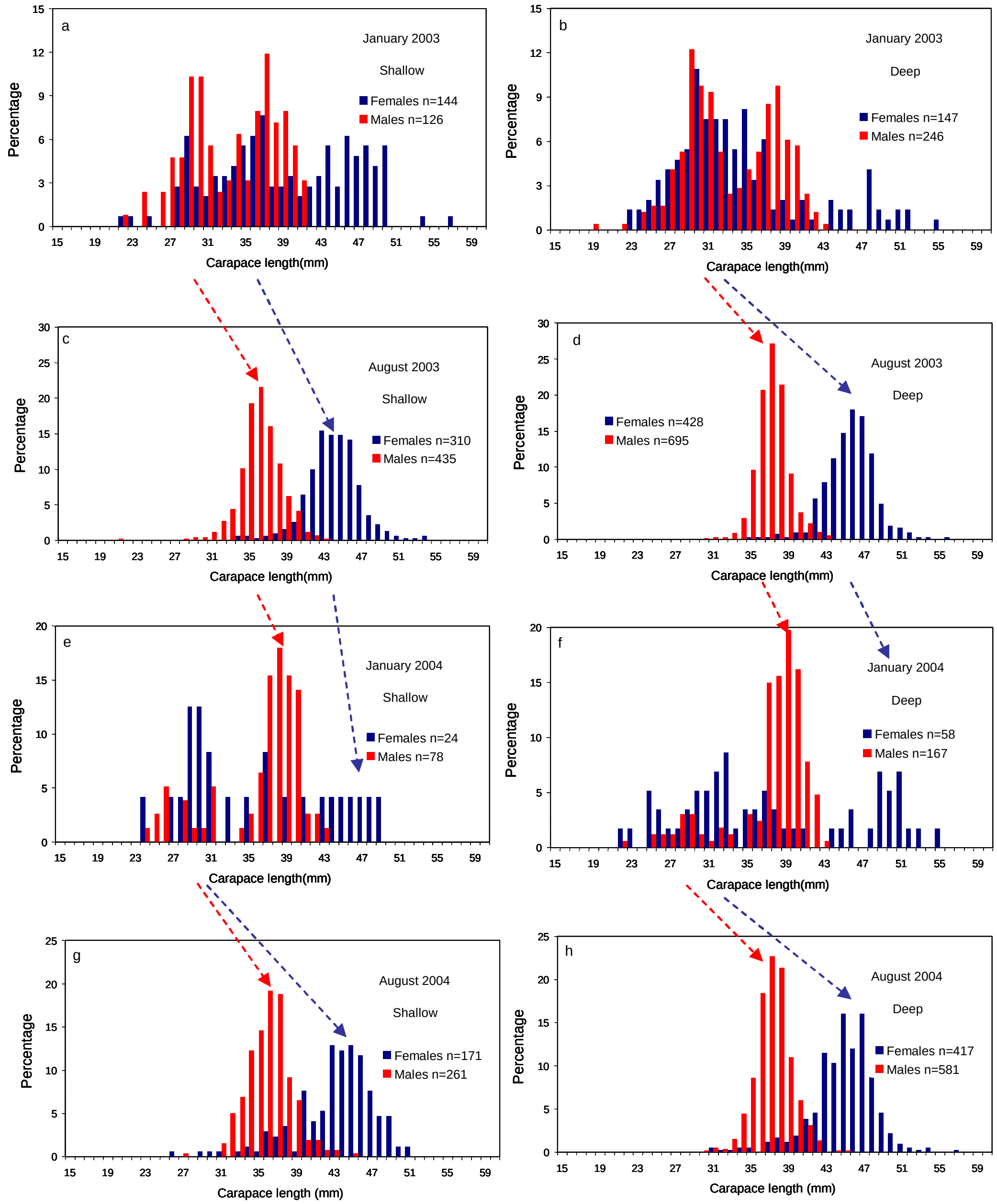

Figure 55: Percentage length frequency distribution of brown tiger prawns *(Penaeus esculentus)* over all shallow and deep sites at North Mornington Island in January 2003, August 2003, January 2004 and August 2004. Note the different scales for each six-monthly set of figures.

7.3.2 *Prawn maturity*

A large proportion of the females measured in August 2002, 2003 and 2004 had visible ovaries (ripe) indicating that they were in reproductive condition (Table 23). Over the three years, when more than 50 females of brown tiger prawns *(P. esculentus)* were caught in a region, more than 60% (from 62.3 to 92.2%) of the females had visible ovaries. For grooved tiger prawns *(P. semisulcatus)*, mostly more than 40% of the females were ripe, apart from south Groote in 2002. There was a higher proportion of ripe female grooved tiger prawns *(P. semisulcatus)* in the deeper water sites. The proportion of ripe blue endeavour prawns *(M. endeavouri)* was usually around 70% and always greater than 40% except for east Mornington. At east Mornington, only 10-20% of females were ripe in 2003 and 2004. There was not much difference between shallow and deep water sites among region or year.

Table 23: The percentage of females measured with visible ovaries at each group of sites in August 2002, August 2003 and August 2004. Percentages were only included if at least 50 females were measured.

	Brown tiger prawns *Penaeus esculentus*						**Grooved tiger prawns** *Penaeus semisulcatus*						**Blue endeavour prawns** *Metapenaeus endeavouri*					
	Shallow			Deep			Shallow			Deep			Shallow			Deep		
	02	***03***	***04***	***02***	***03***	***04***	***02***	***03***	***04***	***02***	***03***	***04***	***02***	***03***	***04***	***02***	***03***	***04***
North Groote	62	77	78		64		48	53	41	68	75	53	74	79	84	62	75	61
South Groote	71	86	85				21	66	41	52	80	41	75	76	83	58	74	62
W. Vanderlins	67	78	77		86			50	38	56	71	69	79	73	82	42	71	
Vanderlins		82	88							67	69	65		82	78	56	71	46
E. Vanderlins	87	77	84		89	91				75	86	70	75	70	68	52	70	62
W. Mornington	79	92	83		89								62	74	28		67	
N. Mornington		75	82	91	89	91				80	80			73	71	71	73	72
E. Mornington	79	79	65		75	67							54	29	12		21	16

In January 2003, January 2003 and January 2005, the proportion of ripe females was generally less than it was in August for most species, particularly for grooved tiger prawns *(P. semisulcatus)* (Table 24). The lower proportion of ripe females in the population is consistent with the higher numbers of young recruits in the populations in January compared to August. The differences in the proportions of spawners between brown tiger prawns *(P. esculentus)* and grooved tiger prawns *(P. semisulcatus)* are also consistent with the results of the CSIRO study at Groote Eylandt in 1983 to 1985, where brown tiger prawns *(P. esculentus)* was shown to mature at a smaller size and have a less seasonal pattern of spawning (Crocos 1987). There was no consistent pattern across regions from 2003 to 2005.

Table 24: 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 January 2004 and January 2005. Percentages were only included if at least 50 females were measured

	Brown tiger prawns *Penaeus esculentus*						**Grooved tiger prawns** *Penaeus semisulcatus*					
	Shallow			Deep			Shallow			Deep		
	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
North Groote	46.7	53.6	66.7	41.3	30.6	22.9	13.1	21.4	19.1	18.5	28.0	15.7
South Groote	24.4	53.2	46.8	45.7	40.6	55.1	2.8		0.0	26.6	42.9	18.2
West Vanderlins	51.4	19.3	51.3	58.9	25.8	43.9	2.6	15.1	19.5	36.6	26.8	18.2
East Vanderlins	35.0	44.3	55.1	25.6	37.8	42.7	1.5	4.5	11.7	21.5	16.9	26.6
West Mornington	45.9	49.4	25.7	51.0	23.6	17.8		13.8	23.6			15.2
North Mornington	68.8		40.3	21.8	39.7	14.7				68.0	54.8	68.3
East Mornington	14.2	16.7	25.8	20.9	34.8	47.0						
West Karumba												
East Karumba												
South Weipa								3.4	3.0			27.9
North Weipa							2.2	1.6	0.1	10.5	13.8	12.3

Table 25: 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 January 2004 and January 2005. Percentages were only included if at least 50 females were measured

	Blue endeavour prawns *Metapenaeus endeavouri*						**Banana prawns** *Penaeus merguiensis*					
	Shallow			Deep			Shallow			Deep		
	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
North Groote	43.7	53.6	59.2	45.4	45.1	69.6						
South Groote	35.5	41.4	53.7	60.3	66.2	59.6						
West Vanderlins	63.5	12.6	63.1	18.3	69.4	66.7	47.7					
East Vanderlins	45.9	19.7	61.6	22.0	56.8	54.4	30.8	8.1	50.0			
West Mornington			47.5			22.4			32.4			
North Mornington	58.8	29.0	26.6	34.5	13.7	23.4						
East Mornington	65.2	30.3	37.3			56.6	48.4		52.2			73.2
West Karumba							19.3	49.8	17.6	30.9	30.9	32.5
East Karumba							14.8	77.3	62.6	31.3	31.3	49.1
North Weipa						34.3	33.6	51.1	19.9			50.0

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). As found in previous surveys, three prawn species commonly were found with bopyrid parasites (grooved tiger prawns *(P. semisulcatus),* banana prawns *(P. merguiensis)* and red endeavour prawns *(M. ensis*) (Table 26). However, in August 2004, some species not commonly found with bopyrid parasites were recorded: brown tiger prawns *(P. esculentus)* (Vanderlins, shallow-0.2%, deep-1.8% (3 individuals infested in total); Mornington, shallow-0.2%); blue endeavour prawns *(M. endeavouri)* (North Groote, shallow-0.1% (1 individual infested)). The percentages of prawns with parasites were mostly quite low. As in 2002/2003, the highest proportion of prawns infected with parasites was grooved tiger prawns *(P. semisulcatus)* in the shallow waters of North Groote. However, the highest percentage infected in August 2004 was 12.0% – less than the 21% and 14% recorded in January and August 2003.

Table 26: The percentage of prawns measured with bopyrid parasites at the shallow and deep sites in August 2003 and 2004

	Penaeus semisulcatus				*Metapenaeus ensis*				*Penaeus merguiensis*			
	Shallow		Deep		Shallow		Deep		Shallow		Deep	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
January												
North Groote	21.4	12.9	7.6	5.0								
South Groote	2.1	1.4		0.9			1.4	1.4				
West Vanderlins		0.2						0.6				
East Vanderlins			0.1		12.5							
West Mornington												
North Mornington												
East Mornington												
West Karumba									0.7	0.2	0.4	
East Karumba									1.5		0.2	
North Weipa	1.3	1.8		0.5								
South Weipa	1.1	0.9										
August												
North Groote	14.0	12.0	3.1	7.9								
South Groote	5.1	3.0	0.3	0.2								
West Vanderlins		0.3	0.1									
East Vanderlins			0.1									
West Mornington												
North Mornington												
East Mornington										0.6		0.5

7.4 Conclusions

1. The January survey has once again clearly been successful in sampling smaller prawns recruiting to the fishery.
2. The August survey has also been successful in sampling mature and spawning prawns in the fishery.
3. Although January is a time of recruitment of new prawns to the fishing grounds, there are still some older prawns present in the populations.
4. For tiger and endeavour prawns, a clear relationship between January recruits and the subsequent August fishery population exists in many regions for both 2003 and 2004.
5. A long term series of the two surveys would provide a good link between stock and subsequent recruitment.
6. There were some differences in size frequency distributions between surveys in the two years suggesting that there was some difference in the timing of recruitment to the fishery between years.

7.5 References

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CHAPTER 8. BYPRODUCT SPECIES

8.1 Introduction

The NPF monitoring project conducted two surveys in the 2004/05 year; one in July to survey prawn spawning stock abundance and the other in February to survey recruitment to the fishery. The surveys were designed mainly to obtain reliable indices of abundance of prawn species. However, byproduct species caught during the surveys were also recorded and the resulting data were examined to investigate the utility of the surveys for collecting useful data on these species. The modern tendency to follow ecosystem-based fisheries management in both research and management strategy, and the Strategic Assessment Provisions of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), also require data collection for all key species related to prawn fishing. Given the advantages of a fishery-based survey platform covering large areas, both on the fishing ground and on inshore areas, the data on byproduct species collected during the surveys will provide valuable information about their spatial distributions, densities and catch rates.

A total of 7 byproduct species and/or species groups were recorded during the two surveys, including 2 species of scallop, *Annachlamys flabellata* and *Amusium pleuronectes*, 3 species of bugs, *Thenus indicus*, *Thenus orientalis*, and *Thenus* spp., 1 family of cuttlefish, *Sepiidae* and 1 family of squid, *Loliginidae*. A few species of byproduct fish (e.g. *Diagramma labiosum*, *Epinephelus* and *Cephalopholis* spp., *Plectropomus* and *Variola* spp.) were caught during the surveys, but the numbers recorded were very low and were excluded from the analysis of spatial distribution and catch rates.

8.2 Processing of the survey data

To describe the spatial distribution and abundance of a species, catch rate as number/hour or catch rate as weight/hr is the index most often used in fisheries. Although the survey staff attempted to record as much information for byproduct species as possible, it was not possible to have all catches of byproduct species counted, measured in length and weighed separately for each net at each site. When a large volume of byproduct species was caught in one shot, total weight was measured and a sub-sample was taken for counting. Sometimes only the catch from one net was processed fully. On other occasions, only total catch weight was recorded or only total numbers of catch for each species were counted. For those sampling sites and trawl nets that did not have data to calculate their total catch rates in number or weight, imputation was carried out as follows:

1. When a sub-sample of a species was taken, the mean individual weight of the sample was first calculated. Then, the total number of individuals of that species for the sampled net was calculated from the total catch weight and the mean individual weight of the sub-sample.

2. When total catch weight for a species was recorded from only one net, the total number or total weight of the other net was calculated based on the assumption that the two nets at the same site had the same mean individual weight for the species.
3. When only total weight of catch of a species was recorded for a site, the total number of individuals for that species was imputed by using the average individual weight of the species in the same region.
4. All catch rates were standardized to number per hectare of swept area.

The spatial distribution of catch rates was depicted by location on a map. For clear visualisation, those sites with zero catch were not shown. Catch rates were divided into 5 grades, each grade consisting of about 20% of the non-zero catch to avoid visual distortion. The catch rates shown on the maps were average catches of the two nets towed at each site and expressed as "number per hectare of net swept area" (the unit is different from the "number per net-hour trawling at 3.2 knots" used in Dichmont et al. (2004)). The same treatment applies to plots depicting the distribution of mean individual weights.

For some abundant byproduct species, we also produced a table of detailed statistics. We post-stratified the survey areas into 5 strata by depth (<15m, 15-25m, 25-35m, 35-45m and >45m). The stratification used in the survey was designed particularly to sample the prawn species and therefore may not be an ideal design for sampling the byproduct species. The catch rates were first calculated at each site (the sampling unit in the survey). Mean catch rates and standard errors in each stratum and in each region were then estimated based on basic post-stratification theory (Kish 1995). Post-stratification is an example of improving the estimator by the proper utilization of ancillary sources of information. It is an "adjustment" or "correction" of the mean. The variance of the mean is usually larger than a proportionate sample because of its disproportionate sample size. However, when the sample size in each stratum is moderately large, the variance of the post-stratified survey data can approach that of the original proportionate sample of the same size.

As byproduct species were not the target species of the survey, some species were not caught at many sampling sites. In our figures, we present only those species which have a fairly good spatial coverage, although they may still have a certain proportion of zero-catch records. The resulting statistics are calculated using the data of all sampled sites, whether they are zeros or non-zeros. The mean catch rate of a region is a weighted estimate over all depth strata. Similarly, the mean catch rate of a depth stratum is a weighted estimate over all regions of the same depth. The regional estimate gives information about the variation in density over large scale areas. The stratum estimate captures the distribution of a species along depth.

We also present the length frequency distributions of the byproduct species, which can give information about their size and age composition. The length frequency distributions were simply pooled over all measurements taken during the survey (i.e. from all regions and all strata). No standardization was possible because length frequency data were not collected from all the sites. When the collection of length frequency data was significantly unbalanced in spatial distribution (e.g. only from areas of abundant juveniles), the measured length distribution would not represent the total population. This distortion may lead to biased conclusions regarding recruitment, individual growth and age composition. Consequently, caution should be exercised when interpreting the length frequency distribution graphs in this chapter.

8.3 Results - Scallops

Two scallop species were recorded during the two surveys: mud scallop (*Amusium pleuronectes*) and fan scallop (*Annachlamys flabellata*). In general, the survey data shows that *A. pleuronectes* has a wider distribution and has higher catch rates than *A. flabellata.*

8.3.1 *Mud scallop*

The mud scallop (*A. pleuronectes*) has not been subject to extensive study, but its general life cycle is assumed to be the same as the saucer scallop (Dredge and Williams 2002). Saucer scallops are winter-spring spawners that have a short (2-3 weeks) pelagic larval phase. The scallops settle on the ocean floor, perhaps undergoing a transitional byssal phase. They appear to be effectively sedentary from this time on and settle in aggregations or beds. They spawn in their first winter of life, at an age of 9-12 months, and thereafter each winter.

8.3.1.1 ***Spatial distribution***

A. pleuronectes was widely distributed in the survey area (Figure 56). In July 2004, Mornington had the highest catch rates, with most sites having >26 scallops per hectare. In contrast, the adjacent area, Karumba, had the lowest density, almost all sites having <2 scallops per hectare. North Groote also has a low density, particularly in deep waters.

The February 2005 survey showed a slightly different spatial distribution (Figure 57). Mornington, which had the highest densities in the July 2004 survey, had catch rates clearly lower than Vanderlins and Groote. Karumba still had the lowest densities with most sites having <2 scallops per hectare. Overall, the densities in February 2005 were much higher than in July 2004.

In July 2004, Groote and Karumba (where the lowest catch rates were found) had mud scallops of the largest size (Figure 60). The mud scallops in Vanderlins and Mornington were consistently small, with most sites having scallops less than 16 g. The February 2005 survey showed a size distribution different from that found in July 2004 (Figure 59). North Groote and Karumba were the areas where large scallops were caught at most of its sites, particularly those in shallow waters. There is a clear trend in Groote and Vanderlins – smaller scallops distributed in shallow waters, but larger ones in deep waters. In general, mud scallops have a smaller size in February than in July. (It should be noted that the size grades used in Figures 60 and 61 are not the same.)

The spatial distributions of mean catch rates and individual sizes of mud scallops seen in the 2004/05 surveys are similar to those found in the 2003/04 surveys (for details see Ye et al. 2004).

8.3.1.2 *Catch rates*

The monitoring surveys were designed to obtain reliable abundance indices for key prawn species. Byproduct species were not the target species of the surveys. The area covered by the monitoring surveys may have very low or even zero density for some byproduct species. Although the byproduct species presented in this chapter had a relatively wide spatial coverage, some sample sites had zero catches. The spatial distributions in Figure 56 to Figure 59 show only the sites that have non-zero catches. However, in the calculation of area mean catch rates and stratum mean catch rates in Table 27 and Table 28, all sites sampled, including those with zero catch rates were used; i.e. the mean catch rates represent the overall density in the area or stratum. Please note that the July surveys differed from the February surveys in spatial coverage. The July surveys included only Groote, Mornington and Vanderlins, but the February surveys sampled also Weipa and extra sites at Karumba.

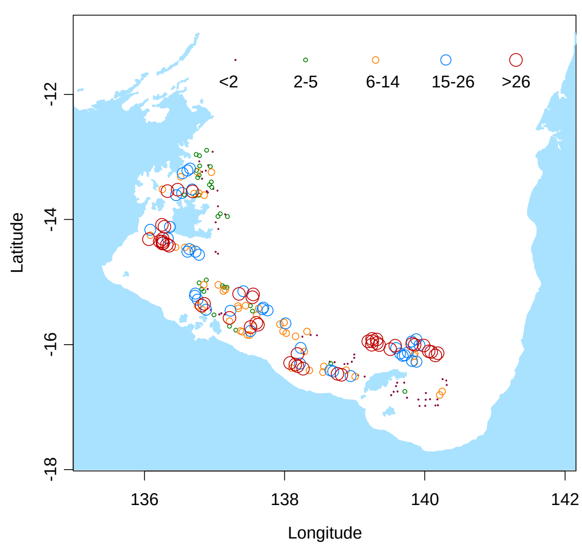

Figure 56: Spatial distribution of mud scallops (*Amusium pleuronectes*) (no/ha) in July 2004.

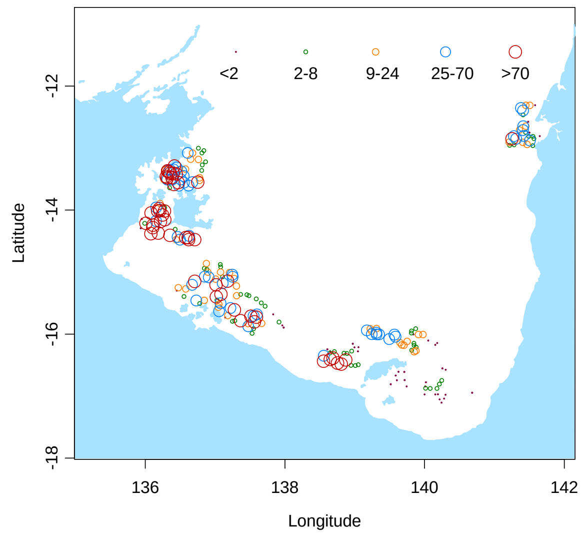

Figure 57: Spatial distribution of mud scallops (*Amusium pleuronectes*) (no/ha) in February 2005.

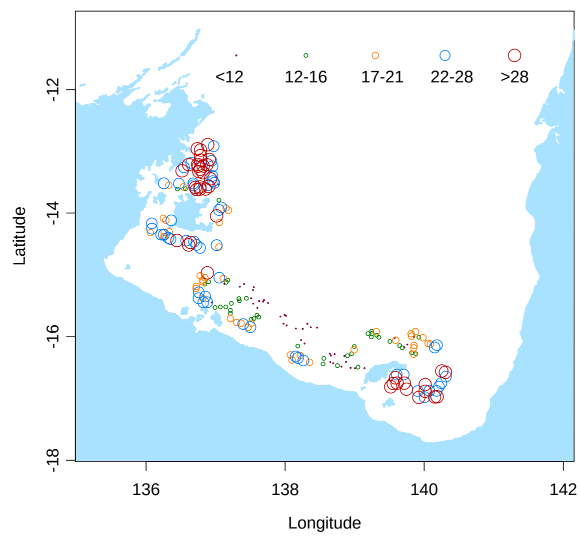

Figure 58: Distribution of average individual weight (g) of mud scallops (*Amusium pleuronectes*) in the survey of July 2004.

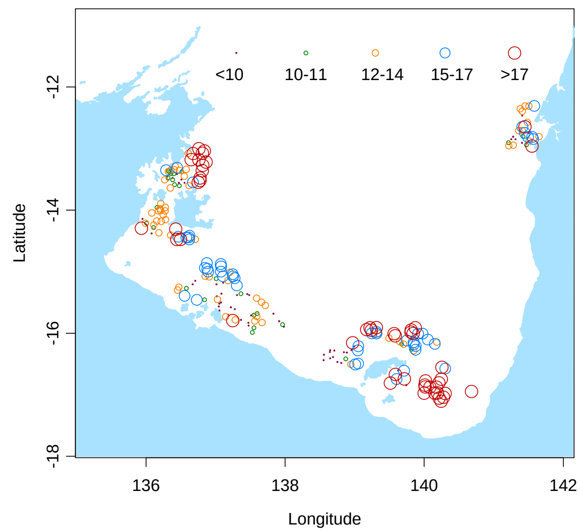

Figure 59: Distribution of average individual weight (g) of mud scallops (*Amusium pleuronectes*) in the survey of February 2005

The July surveys show that mud scallops are usually distributed between 15 m and 45 m (Table 27 and Figure 60). Stable catch rates were recorded over the range of water depths surveyed. This distribution is similar to the distributions seen in the 2002/03 and 2003/04 surveys. Both shallow (<15 m) and deep (>45 m) waters had lower catch rates. As the peak catch rates appeared in different depth strata in different years, we may conclude that there is some shift in spatial distribution from year to year.

Abundance of mud scallops in 2004 differed from 2002 and 2003 (Table 27). Among areas, the catch rate in Groote increased markedly (18.1 scallops/ha) in 2004 in comparison with the 2002 and 2003 surveys (13.5 scallops/ha and 7.6 scallops/ha respectively), but that catch in Mornington decreased (15.5 scallops/ha) from last two years (27.0 scallops/ha and 20.4 scallops/ha, respectively). Vanderlins had catch rate of 15 scallops/ha, in between the last two years' catch rates (Table 27).

The February 2005 survey showed a distribution with depth similar to those seen in the last two surveys (Table 28 and Figure 61). The average catch rates are relatively low in waters shallower than 15 m. Similar to the July surveys, the peak catch rate varies over depth with year. In 2005, the highest catch rate occurred in 15-25 m, in contrast with the high catch rate in 25-35 m in 2003 and 2004.

Among the areas, Karumba always has the lowest catch rates. In 2005, it dropped further down to 0.04 scallops/ha in 2004 from the rate of about 0.3 scallops/ha in 2003 and 2004. Vanderlins and Groote are the two areas of abundant mud scallops. In 2005, the mean catch rate in Groote increased to 81.1 scallops/ha, overtaking Vanderlins and becoming the highest catch rate, in contrast with what was seen over the last two surveys (Table 28). The catch rate in Mornington was quite stable and remained 15-22 scallops/ha in 2003-2005. Weipa exhibited a large variation in catch rate, 22.5 scallops/ha in 2005 in comparison with 53.8 scallops/ha in 2003 and 7.3 scallops/ha in 2004.

The mean weight of individual scallops had a much smaller variation, both among areas and among depth strata (Table 29, Figure 62-Figure 63). The lowest mean weight was seen in waters deeper than 45 m in July. However, it must be kept in mind that this might be caused by a small sample size as indicated by the larger standard error. In the February surveys, scallop size remained almost stable among depth strata, except the stratum shallower than 15 m that had an extremely large size in 2005, more than double the size in 2003 and 2004 (Table 30). A details check shows that there were only very few records in that depth stratum in 2005.

The size differences among regions are similar to those among depth strata (Table 29-Table 30). The highest mean weight recorded in the July 2004 survey was in Groote (26.5 g), and the lowest size was only 15.0 g at the Vanderlins (Table 29). Differences of similar scales were also found in the February surveys. Vanderlins had the lowest weight of 11.6 g, and Karumba the largest weight of 52.7 g in 2005 (Table 30). The very large scallops seen in Karumba had few records. The spatial pattern seem remained similar over the last three years.

Overall, the mean weight in summer is lower than that in July (Table 29-Table 30). But, the difference was minor on average (Figure 62-Figure 63).

Table 27: Mean catch rates (no/ha; standard errors in brackets) of *Amusium pleuronectes* in each depth stratum of the different regions for the July surveys in 2002, 2003 and 2004

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	<15		15-25		25-35		35-45		>45			
Groote	2002	0.1		28.1	6.3	12.9	1.9	4.4	1.1	7.9		13.5	2.1
	2003	8.9	2.6	14.0	3.4	3.8	1.0	2.0	0.4	0.7	0.1	7.6	1.2
	2004	**17.6**	**7.23**	**32.4**	**7.06**	**13.8**	**2.63**	**2.89**	**0.82**	**1.49**	**0.3**	**18.1**	**2.74**
Vanderlins	2002	10.3	6.7	49.8	10.5	23.9	6.2	10.1	1.7			29.5	6.6
	2003	6.8		6.1	2.0	9.1	1.6	8.1	1.8			7.8	0.9
	2004	**5.52**	**0.93**	**19**	**3.29**	**12.2**	**4.59**	**12.4**	**3.28**	**17.9**	**4.2**	**14**	**1.95**
Morningtor	2002	0.9	0.4	57.9	19.3	28.3	10.6	16.6	7.8			27.0	3.9
	2003	1.0	0.4	14.5	4.6	29.5	4.5	32.7	5.3			20.4	2.3
	2004	**1**	**0.43**	**11.5**	**4.77**	**10.8**	**2.71**	**39.9**	**5.18**			**15.5**	**1.93**
Mean	2002	2.9	1.6	45.6	7.4	23.0	4.6	11.0	2.7	7.9			
	2003	3.2	0.6	9.6	1.6	16.6	1.7	16.6	1.8	0.7	0.1		
	2004	**8.62**	**2.85**	**20.8**	**2.89**	**12.1**	**2.22**	**19.5**	**2.24**	**13.9**	**3.16**		

Table 28: Mean catch rates (no/ha; standard errors in brackets) of *Amusium pleuronectes* in each depth stratum of the different regions for the February surveys in 2003, 2004 and 2005

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	<15		15-25		25-35		35-45			
Groote	2003	21.45	9.78	20.37	2.98	9.85	2.18	1.93	0.42	15.58	2.21
	2004	51.97	27.58	56.19	8.11	25.46	5.36	3.96	1.18	41.07	6.11
	2005	**52.01**	**33.19**	**138.54**	**22.96**	**42.61**	**10.80**	**4.16**	**1.25**	**81.08**	**11.63**
Vanderlins	2003	0.15	0.12	5.97	1.92	80.07	16.47	29.57	6.13	38.65	6.30
	2004	0.32	0.12	41.77	15.48	120.20	29.10	83.53	33.24	76.61	14.04
	2005	**9.31**	**3.46**	**55.47**	**14.81**	**23.56**	**6.14**	**10.98**	**3.20**	**28.01**	**4.78**
Morningtor	2003	0.32	0.18	1.34	0.52	37.96	5.30	20.84	4.15	15.01	1.69
	2004	2.71	2.33	44.67	16.47	7.65	2.36	14.63	2.49	21.75	6.21
	2005	**0.35**	**0.18**	**26.38**	**10.36**	**5.62**	**1.18**	**25.43**	**5.43**	**15.41**	**3.95**
Karumba	2003	0.12	0.05	0.64	0.32					0.32	0.13
	2004	0.13	0.04	0.55	0.27					0.29	0.11
	2005	**0.00**	**0.00**	**0.09**	**0.05**					**0.04**	**0.02**
Weipa	2003	4.48	2.60	20.50	7.62	73.10	24.40	86.67	29.50	53.84	11.67
	2004	0.13	0.06	4.26	1.95	7.21	1.72	13.72	3.20	7.32	1.18
	2005	**0.10**	**0.10**	**11.28**	**6.30**	**17.13**	**3.43**	**48.86**	**11.62**	**22.51**	**3.90**
Mean	2003	3.64	1.47	7.75	0.91	50.65	6.73	33.14	5.60		
	2004	8.53	4.17	36.37	6.25	53.80	10.92	43.44	14.57		
	2005	**9.11**	**5.01**	**53.62**	**6.91**	**21.70**	**3.35**	**20.33**	**2.79**		

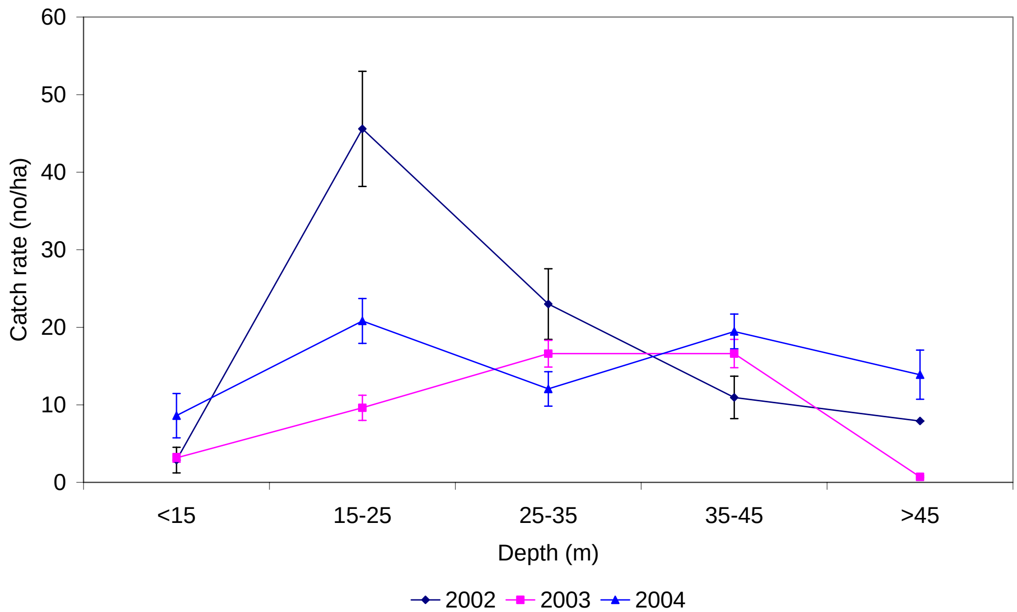

Figure 60: Mean catch rates (no/ha) of mud scallops (*Amusium pleuronectes*) in different depths (the bars indicate 1 standard error) in the July surveys.

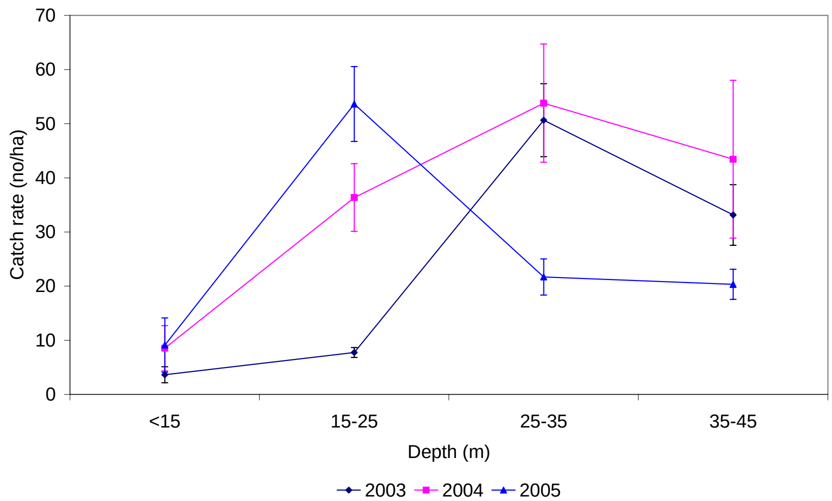

Figure 61: Mean catch rates (no/ha) of mud scallops (*Amusium pleuronectes*) in different depths (the bars indicate 1 standard error) in the February surveys.

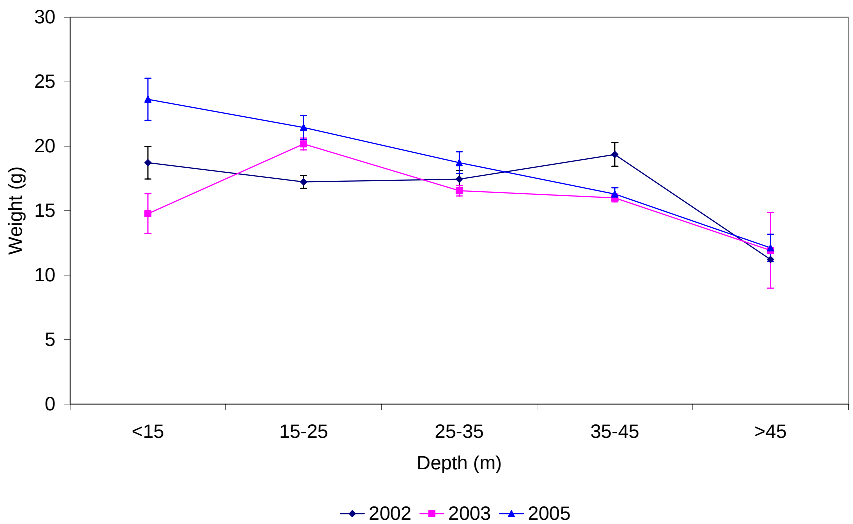

Figure 62: Mean weight (g) of mud scallops (*Amusium pleuronectes*) in different depths (the bars indicate 1 standard error) for the July surveys.

8.3.1.3 *Length Distribution*

The shell length distribution of mud scallops caught in July 2004 ranged from 30 mm to 80 mm with a mode around 55 mm (Figure 64). The distribution is slightly skewed, which may indicate a mode around 40 mm for a second cohort. This possibility is supported by the length distribution obtained in February 2005 (Figure 65), which is a unimodal distribution; presumably, the new generation of scallops in February are not large enough to be caught by our survey nets. If scallops spawn in winter/spring in the Gulf of Carpentaria, by July the youngest cohort should be about 1 year old. In February, this cohort's average size should be about 40 mm. In comparison with saucer scallops (*A. japonicum balloti*), which can reach 90 mm in 6-15 months (Dredge and Williams 2002), it seems that the mud scallop in the Gulf of Carpentaria has a slower growth rate and also a smaller maximum size.

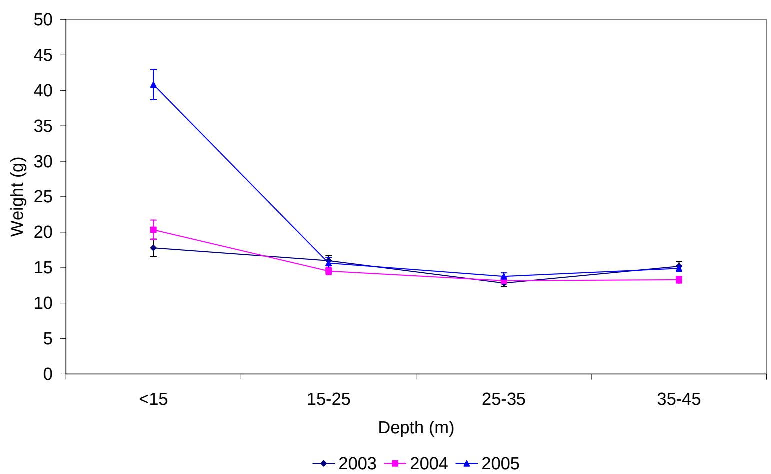

Figure 63: Mean weight (g) of mud scallops (*Amusium pleuronectes*) in different depths (the bars indicate 1 standard error) for the February surveys.

Table 29: Mean weight (g) (standard errors in brackets) of *Amusium pleuronectes* in each depth stratum of the different regions for the July surveys in 2002, 2003 and 2004.

Region	Depth	Mean <15	SE	Mean 15-25	SE	Mean 25-35	SE	Mean 35-45	SE	Mean >45	SE	Mean	SE
Groote	2002	16.29		17.17	0.86	22.22	1.16	24.31	2.94	11.22		19.05	0.68
	2003	18.95	5.74	22.25	1.21	25.98	1.40	26.98	0.88	11.93	2.93	22.91	1.29
	2005	**24.58**	**3.12**	**24.73**	**1.79**	**30.14**	**1.32**	**28.21**	**1.50**	**20.19**	**2.92**	**26.53**	**0.95**
Vanderlins	2002	24.98	5.02	17.59	0.93	16.65	1.39	15.18	0.96			17.28	0.39
	2003	10.32		12.36	0.66	14.58	0.62	11.60	0.43			12.83	0.32
	2005	**16.97**	**1.27**	**18.39**	**0.68**	**15.71**	**1.70**	**11.16**	**0.70**	**9.49**	**1.03**	**14.97**	**0.64**
Mornington	2002	17.14	0.85	16.85	0.67	15.37	0.48	21.26	1.32			17.36	0.79
	2003	19.92	1.62	17.11	1.10	13.75	0.54	14.55	0.51			16.03	0.48
	2005	**27.11**	**2.85**	**21.94**	**2.25**	**15.02**	**1.04**	**14.60**	**0.46**			**18.74**	**0.85**
Mean	2002	18.72	1.26	17.23	0.49	17.45	0.66	19.36	0.91	11.22			
	2003	14.77	1.54	20.18	0.46	16.55	0.41	15.99	0.30	11.93	2.93		
	2005	**23.64**	**1.63**	**21.46**	**0.92**	**18.72**	**0.85**	**16.30**	**0.48**	**12.12**	**1.06**		

Table 30: Mean weight (g) (standard errors in brackets) of *Amusium pleuronectes* in each depth stratum of the different regions for the February surveys in 2003, 2004 and 2005.

Region	Depth	Mean <15	SE	Mean 15-25	SE	Mean 25-35	SE	Mean 35-45	SE	Mean	SE
Groote	2003	14.03	2.19	14.25	0.63	17.28	1.64	29.56	4.76	16.56	0.82
	2004	11.45	0.57	13.41	0.46	18.82	1.62	24.29	2.26	15.75	0.58
	2005	**23.85**	**13.07**	**12.30**	**0.47**	**17.20**	**1.25**	**21.29**	**0.62**	**16.68**	**2.33**
Vanderlins	2003	9.00	1.00	1.15	0.87	9.87	0.67	10.57	0.68	10.58	0.39
	2004	17.21	3.12	12.75	0.62	12.79	0.73	11.27	0.80	12.88	0.49
	2005	**13.86**	**1.64**	**9.08**	**0.46**	**11.73**	**0.68**	**13.27**	**0.79**	**11.58**	**0.38**
Morningtor	2003	20.91	4.32	15.54	0.94	12.89	0.31	17.02	0.62	15.91	0.85
	2004	22.00	3.39	15.36	1.58	9.80	0.54	13.65	0.61	14.61	0.86
	2005	**20.08**	**3.58**	**15.39**	**1.62**	**14.12**	**1.05**	**17.34**	**0.68**	**16.12**	**0.93**
Karumba	2003	19.98	1.51	23.97	3.40					21.53	1.61
	2004	23.78	2.35	16.68	0.73					21.03	1.45
	2005	**68.00**		**28.67**	**3.18**					**52.72**	**1.23**
Weipa	2003	18.44	5.13	14.19	1.06	13.68	1.08	13.74	1.22	14.59	1.00
	2004	17.67	4.33	14.51	1.56	12.27	1.11	9.90	0.41	12.96	0.87
	2005	**12.00**		**13.64**	**1.43**	**12.47**	**0.84**	**10.45**	**0.39**	**12.06**	**0.43**
Mean	2003	17.79	1.23	15.98	0.73	12.82	0.46	15.18	0.70		
	2004	20.34	1.36	14.52	0.53	13.17	0.49	13.29	0.48		
	2005	**40.83**	**2.12**	**15.65**	**0.78**	**13.76**	**0.50**	**14.91**	**0.41**		

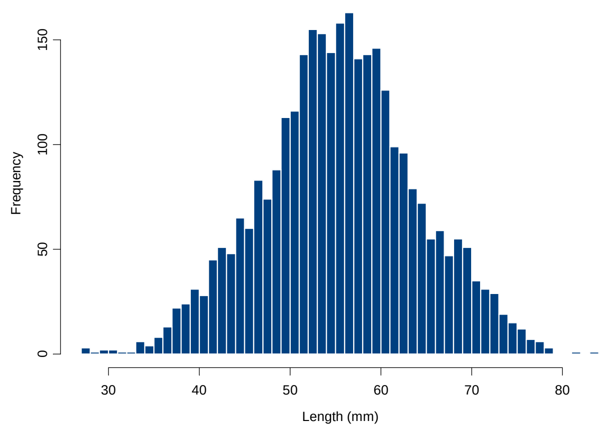

Figure 64: Length distribution of the mud scallops (*Amusium pleuronectes*) caught in July 2004 survey.

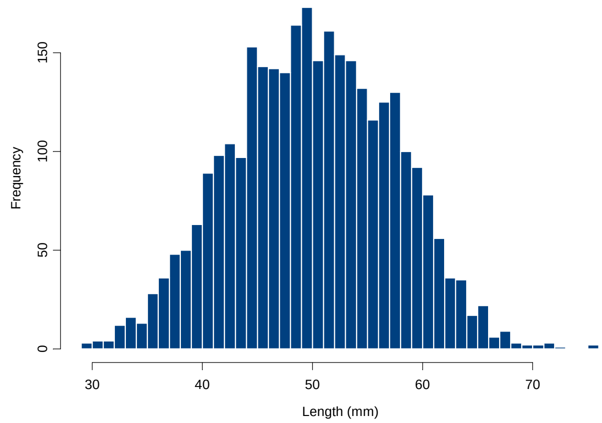

Figure 65: Length distribution of the mud scallops (*Amusium pleuronectes*) caught in February 2005 survey.

8.3.2 *Fan scallop*

Fan scallop *(A. flabellate*) were recorded in both the July 2004 and February 2005 surveys. Their distribution is sparse in the Gulf of Carpentaria. *A. flabellata* were caught at only a few sites in July 2004, and the highest catch rate was around 0.8 scallops per hectare. Mornington had the highest density (Figure 66). More *A. flabellata* were caught in the February 2005 survey (Figure 67). The maximum catch rate increased to 2.7 scallops per hectare. However, the increase in density and spatial expansion was only seen in Vanderlins and Mornington. Weipa was only surveyed in February 2005. Although no comparison is possible to investigate seasonal changes, Weipa had catches of *A. flabellata* at one site (Figure 67).

The mean individual weight of *A. flabellata* in July 2004 ranged from less than 15 g to more than 29 g (Figure 68). In February 2005, the mean weight was lower and less variable, the maximum size being >18 g (Figure 69). The smaller size (Figure 69) and higher catch rate (Figure 66) in February 2005 probably indicate new recruitment.

The shell length of *A. flabellata* collected in July 2004 ranged from 25 mm to 60 mm, but the data are not sufficient to represent a full distribution of length frequency due to the low number of scallop size measurements (Figure 70). Therefore, it is impossible to judge cohort lengths with precision. The data from February 2005 show a smoother length frequency distribution with a single mode at ~ 40 mm (Figure 71). The shift in the mode for shell size in July suggests that the February survey captured new recruits and that they will grow into the size-class defined by the mode at ~55 mm in July.

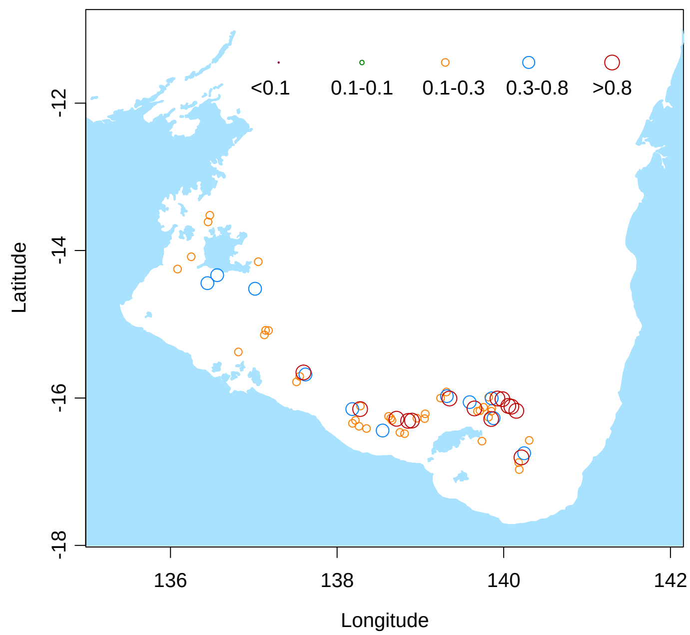

Figure 66: Spatial distribution of scallops *Annachlamys flabellata* (no/ha) in the survey of July 2004.

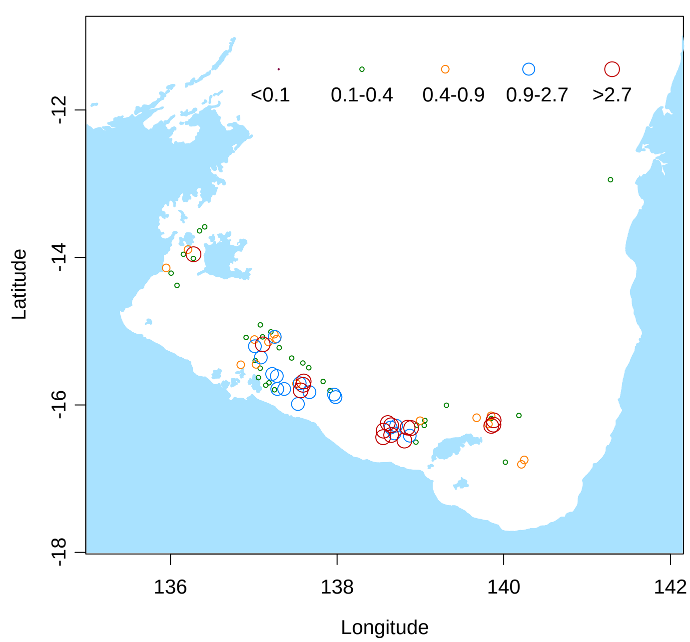

Figure 67: Spatial distribution of scallops *Annachlamys flabellate* (no/ha) in the survey of February 2005.

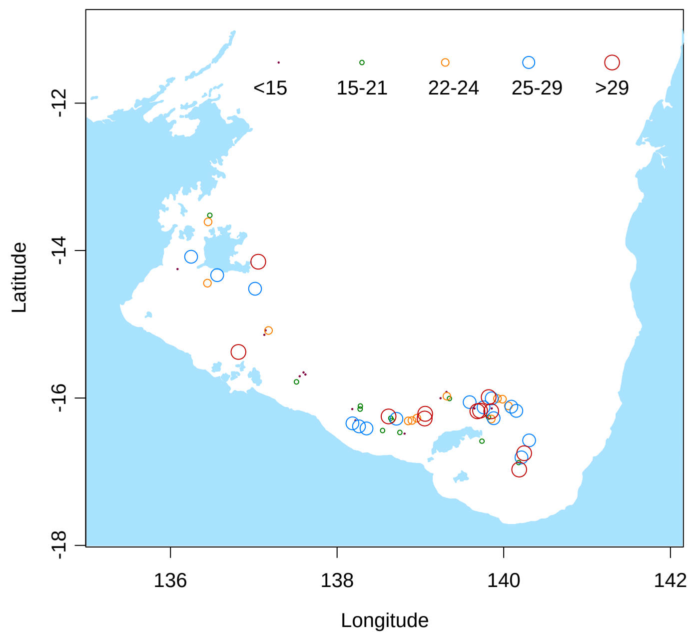

Figure 68: Distribution of average individual weight (g) of scallops *Annachlamys flabellata* in the survey of July 2004.

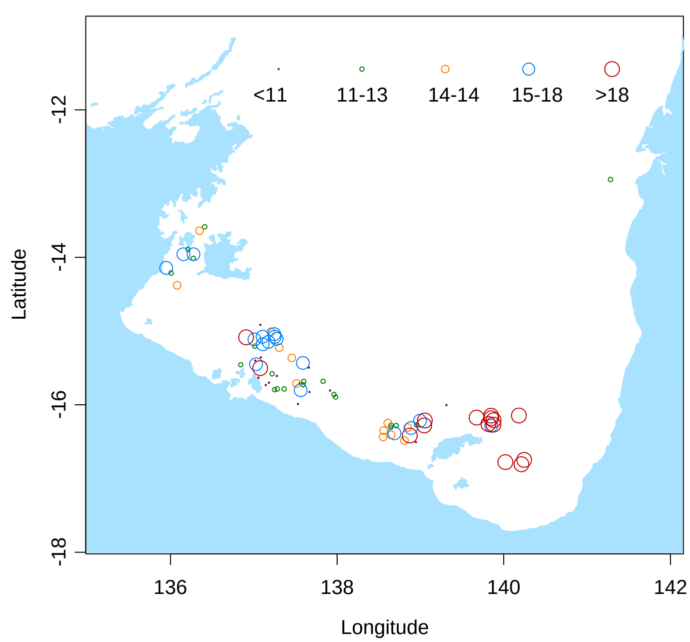

Figure 69: Distribution of average individual weight (g) of scallops *Annachlamys flabellata* in the survey of February 2005.

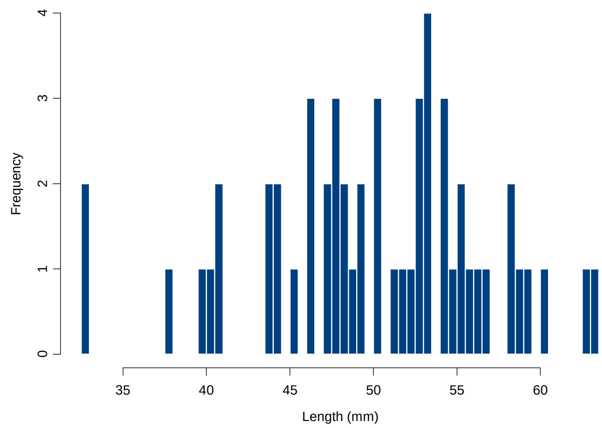

Figure 70: Length distribution of the scallops *Annachlamys flabellata* caught in July 2004.

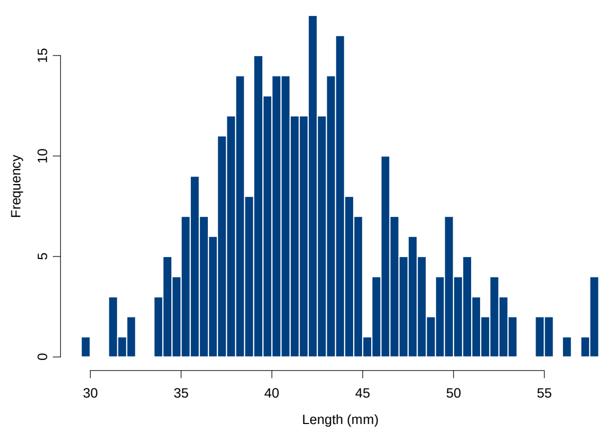

Figure 71: Length distribution of the scallops *Annachlamys flabellata* caught in February 2005 survey.

8.4 Results - Bugs

Among the three bug species that were recorded in the two surveys, mud bugs (*Thenus indicus*) and reef bugs (*Thenus orientalis*) were the most abundant. *Thenus* spp. had only a few records and its distribution is not presented here in detail.

8.4.1 *Mud bugs*

Studies on the Queensland coast suggest that mud bugs (*Thenus indicus*) typically occur on muddy substrates in waters shallower than 25 m north of 23°S (Courtney and Williams, 2002). On the Queensland east coast, about 90 t of mud bugs are landed each year, on average, as byproduct of tiger and endeavour prawn harvests (Courtney and Williams, 2002).

8.4.1.1 ***Spatial distribution***

Mud bugs were widely distributed in the survey area. Their maximum catch rate was more than 2.7 bugs per hectare in the July 2004 survey (Figure 72). Groote had very low catch rates, while Mornington and Karumba had the highest. However, in general, the density of mud bugs was very low.

The catch rates in February 2005 were higher than those in July 2004 (Figure 73). Spatial distribution remained almost same in February as it was in July, and as it has been over the last three years (Ye et al. 2004).

The spatial distribution of individual weights from the July 2004 survey was even, and no clear difference among regions can be identified (Figure 74). Individual lower to upper size classes were <77 g and >113 g.

The size distribution from the survey in February 2005 shows a trend that smaller bugs were more common in the shallow waters in Vanderlins and west Mornington (Figure 75). However, larger bugs dominated the catch in Weipa, Mornington and northern Groote. Overall, their individual size in February was smaller than in July, ranging from <57 g to >104 g.

8.4.1.2 ***Catch rates***

The average catch rates of mud bugs in the different strata ranged from under 2 bugs per hectare at depths of 15-25 m in Vanderlins to 52 bugs per hectare in waters deeper than 45 m in Vanderlins in July 2004 (Table 31). The catch rates are higher and more variable than the last two surveys. In contrast with a decreasing catch trend from inshore to offshore seen in last two years, the catch rates exhibited a marked increase from the 15 m depth to deeper habitats offshore (Figure 76). However, the large catches in depths greater than 45 m are accompanied by a significant standard error, indicating that the high catch was dominated by a few very large records.

The average catch rates of mud bugs in February 2005 also demonstrated a sharp increase in the strata deeper than 25 m (Figure 77); a pattern that contrasted with the last two years' surveys. The large standard errors together with the high mean catch rates indicate a patchy distribution.

Mud bugs are widely distributed in the Gulf of Carpentaria (Figure 72 and Figure 73). They can be caught in depths up to at least 50 m, which is in clear contrast to that the pattern reported in Courtney and Williams (2002) that mud bugs occur in waters shallower than 25 m in the east coast of Queensland.

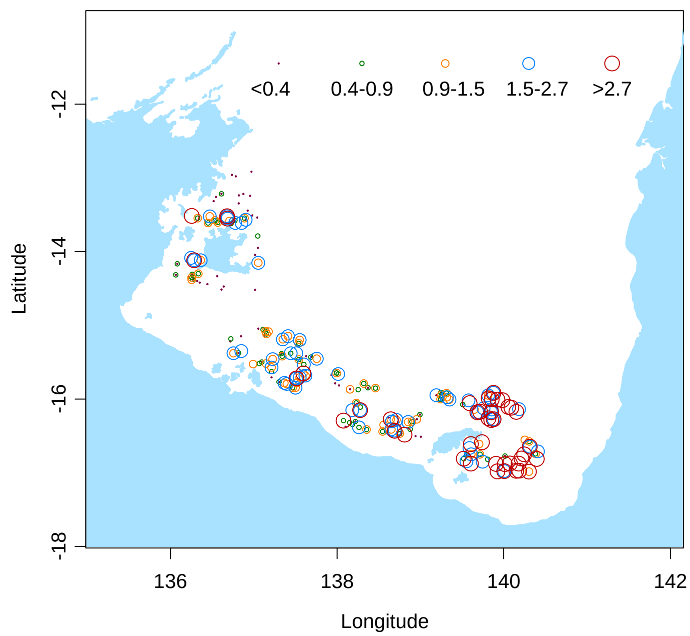

Figure 72: Spatial distribution of mud bugs (*Thenus indicus*) (no/ha) in the survey of July 2004.

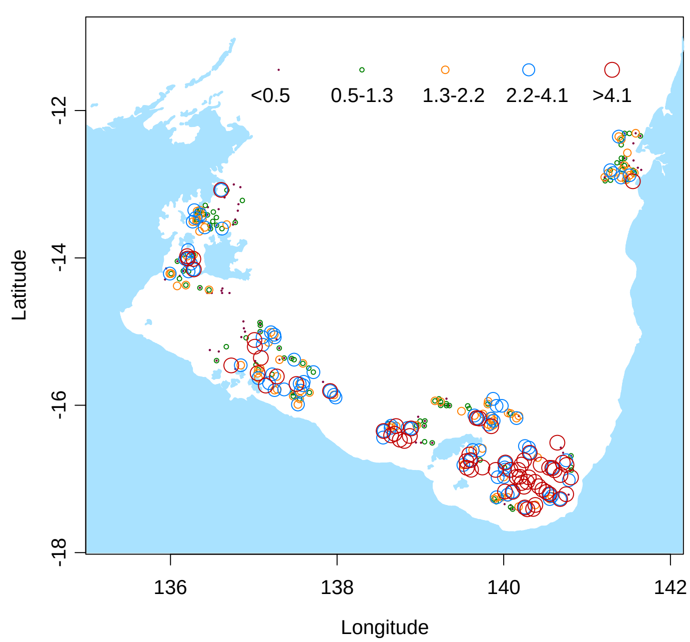

Figure 73: Spatial distribution of mud bugs (*Thenus indicus*) (no/ha) in the survey of February 2005.

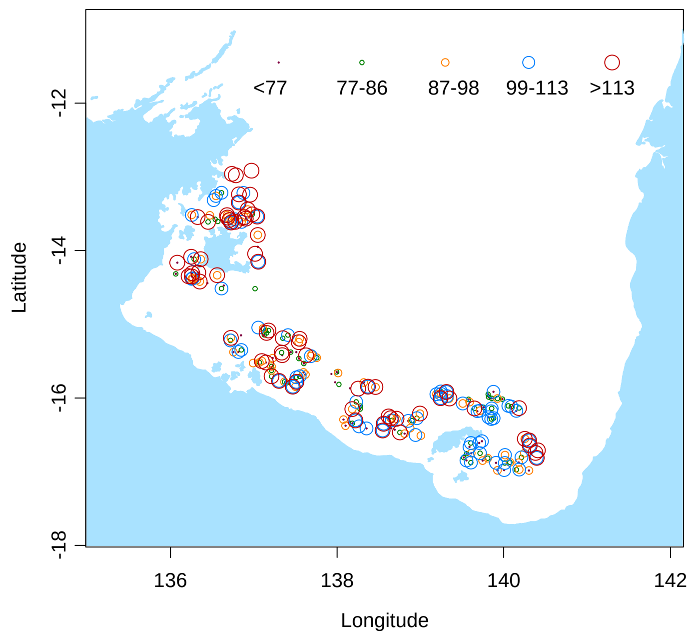

Figure 74: Distribution of average individual weight (g) of the mud bugs (*T. indicus*) caught in the survey of July 2004.

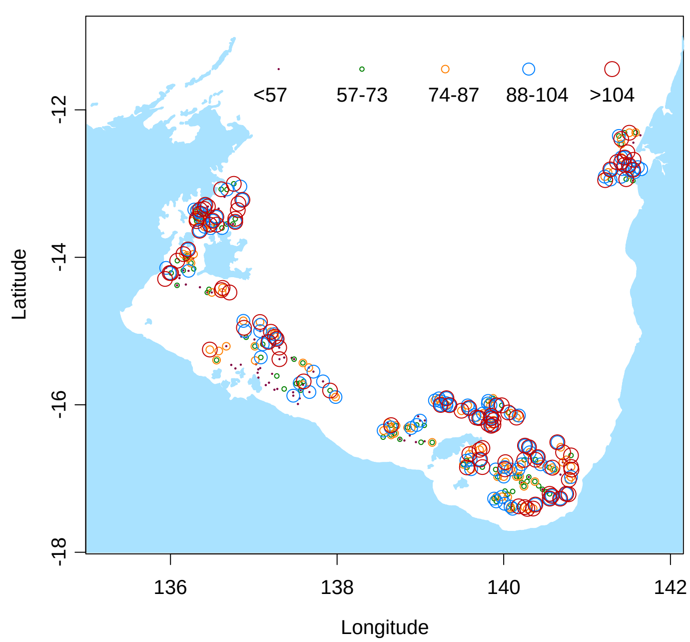

Figure 75: Distribution of average individual weight (g) of mud bugs (*T. indicus*) caught in the survey of February 2005.

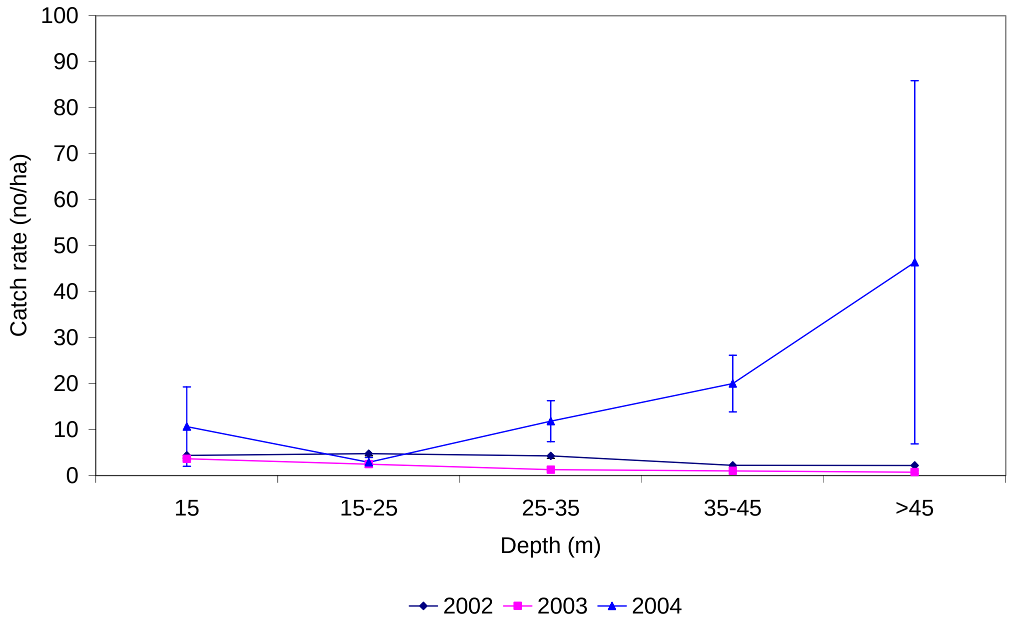

Figure 76: Mean catch rates of mud bugs (*Thenus indicus*) in different depths (the bars indicate 1 standard error) for the July surveys.

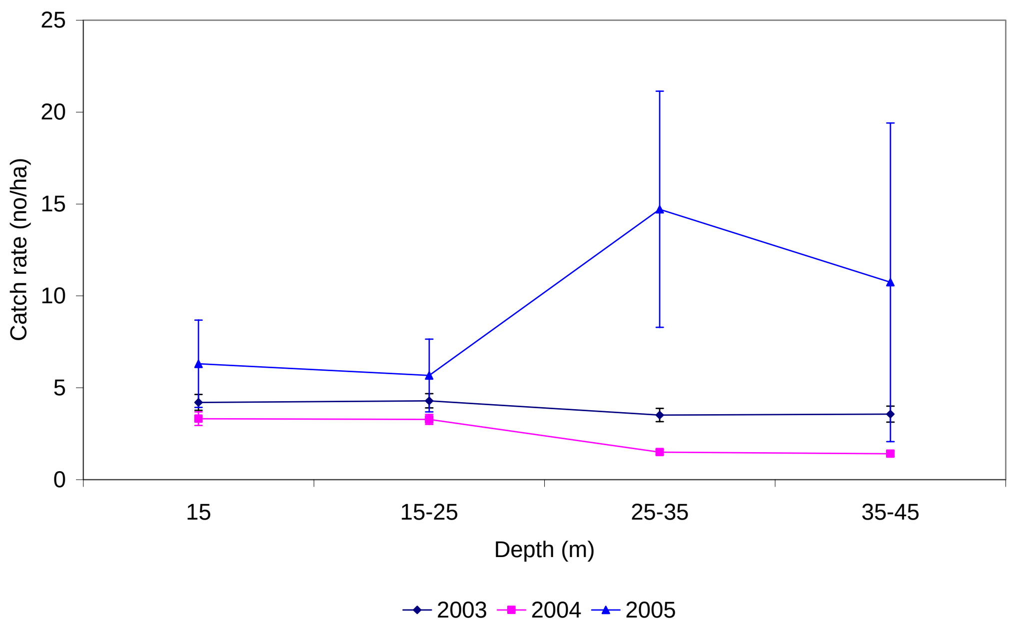

Figure 77: Mean catch rates of mud bugs (*Thenus indicus*) in different depths (the bars indicate 1 standard error) for the February surveys.

Table 31: Mean catch rates (no/ha; standard errors in brackets) of *Thenus indicus* in each depth stratum of the different regions for the July surveys in 2002, 2003 and 2004.

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	15		15-25		25-35		35-45		>45			
Groote	2002	2.85		4.06	0.63	1.26	0.31	0.57	0.24	2.22		2.39	0.22
	2003	3.66	0.63	1.71	0.20	0.72	0.10	0.28	0.06	0.75	0.30	1.56	0.15
	2004	**2.39**	**1.06**	**4.58**	**3.37**	**37.77**	**17.16**	**25.82**	**14.40**	**26.99**	**26.84**	**17.64**	**5.39**
Mornington	2002	4.23	1.47	5.89	0.84	7.84	1.42	2.65	0.88			5.66	0.63
	2003	3.01	0.47	4.50	0.56	2.05	0.13	1.34	0.17			2.84	0.19
	2004	**2.89**	**1.02**	**3.57**	**0.83**	**2.00**	**0.28**	**2.55**	**0.46**			**2.68**	**0.31**
Vanderlins	2002	7.18	1.51	4.44	0.92	2.90	0.40	2.82	0.51			3.74	0.36
	2003	1.40	0.00	1.36	0.12	1.02	0.11	1.08	0.11			1.17	0.06
	2004	**35.61**	**35.39**	**0.95**	**0.14**	**6.18**	**5.45**	**30.65**	**12.20**	**52.71**	**51.65**	**16.94**	**6.55**
Mean	2002	4.40	0.64	4.78	0.47	4.28	0.53	2.24	0.37	2.22			
	2003	3.66	0.29	2.50	0.20	1.29	0.07	1.03	0.07	0.75	0.30		
	2004	**10.66**	**8.63**	**2.89**	**1.07**	**11.83**	**4.45**	**20.03**	**6.16**	**46.39**	**39.48**		

Table 32: Mean catch rates (no/ha; standard errors in brackets) of *Thenus indicus* in each depth stratum of the different regions for the February surveys in 2003, 2004 and 2005.

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	15		15-25		25-35		35-45			
Groote	2003	2.27	0.96	2.08	0.19	1.72	0.27	0.23	0.02	1.83	0.20
	2004	1.24	0.52	1.13	0.10	0.61	0.13	0.21	0.07	0.90	0.11
	2005	**0.50**	**0.20**	**1.61**	**0.21**	**37.42**	**19.40**	**71.54**	**71.15**	**19.01**	**8.86**
Karumba	2003	5.36	0.64	6.76	0.90					5.90	0.52
	2004	3.68	0.61	9.26	1.21					5.85	0.59
	2005	**8.07**	**4.45**	**8.01**	**1.57**					**8.04**	**2.77**
Mornington	2003	4.20	0.46	5.32	1.04	3.52	0.40	2.75	0.32	4.20	0.41
	2004	6.19	1.12	3.43	0.44	2.38	0.32	1.65	0.16	3.34	0.27
	2005	**4.20**	**0.85**	**10.73**	**6.56**	**2.14**	**0.26**	**1.06**	**0.17**	**5.58**	**2.45**
Vanderlins	2003	3.50	2.15	3.82	0.70	4.81	0.90	5.97	0.97	4.67	0.50
	2004	1.08	0.32	0.94	0.40	1.46	0.25	1.82	0.29	1.36	0.16
	2005	**13.35**	**10.40**	**1.86**	**0.31**	**14.82**	**12.81**	**1.39**	**0.29**	**7.81**	**4.87**
Weipa	2003	1.95	0.82	1.59	0.44	2.62	0.49	0.99	0.33	1.79	0.25
	2004	0.15	0.05	0.85	0.19	0.90	0.24	0.83	0.19	0.74	0.10
	2005	**0.20**	**0.10**	**2.56**	**0.88**	**1.06**	**0.14**	**6.92**	**5.52**	**3.02**	**1.66**
Mean	2003	4.21	0.43	4.29	0.39	3.52	0.36	3.57	0.44		
	2004	3.32	0.37	3.28	0.27	1.50	0.14	1.41	0.14		
	2005	**6.30**	**2.37**	**5.67**	**1.98**	**14.71**	**6.42**	**10.74**	**8.67**		

The mean weight of mud bugs in different strata ranged from 55-108 g in July 2004 (Table 33), and this range widened to 56-124 g in February 2005 (Table 34). The mean size of mud bugs did not vary greatly with depth in July 2004. The decreasing trend in size toward offshore strata is in apparent contrast with the almost constant size over depth in both 2002 and 2003 (Figure 78); however, the estimates of deep waters had large standard errors. The mean size of mud bugs varied very little with depth in February 2005.

Table 33: Mean weight (g) (standard errors in brackets) of *Thenus indicus* in each depth stratum of the different regions for the July surveys in 2002, 2003 and 2004.

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	15		15-25		25-35		35-45		>45			
Groote	2002	107.14		99.84	4.34	93.74	4.17	115.22	15.25	95.52		102.07	3.10
	2003	94.04	5.46	93.14	5.34	97.79	3.72	104.26	6.88	96.41	13.77	96.59	2.57
	2004	**107.51**	**10.25**	**96.48**	**5.50**	**71.39**	**19.19**	**90.90**	**20.20**	**88.17**	**28.54**	**90.65**	**6.82**
Mornington	2002	91.99	2.11	84.55	3.47	87.98	3.78	97.80	5.82			89.73	2.07
	2003	91.67	3.50	92.13	2.76	92.24	2.58	101.28	5.79			93.75	1.69
	2004	**86.30**	**1.61**	**98.00**	**3.30**	**95.25**	**1.94**	**92.80**	**4.34**			**94.06**	**1.46**
Vanderlins	2002	78.44	4.48	90.02	2.80	92.52	3.39	90.00	4.16			89.86	1.84
	2003	80.71	17.86	85.74	3.00	80.96	3.69	95.51	3.88			85.75	2.51
	2004	**42.25**	**37.25**	**92.54**	**2.62**	**70.88**	**9.70**	**78.17**	**8.79**	**55.59**	**25.53**	**74.25**	**5.55**
Mean	2002	94.65	1.33	91.36	2.01	91.18	2.16	98.51	4.42	95.52			
	2003	91.09	2.89	93.14	2.72	89.84	1.91	100.84	2.73	96.41	13.77		
	2004	**83.91**	**9.93**	**95.46**	**2.20**	**79.64**	**5.95**	**86.09**	**6.16**	**63.60**	**20.48**		

Table 34: Mean weight (g) (standard errors in brackets) of *Thenus indicus* in each depth stratum of the different regions for the February surveys in 2003, 2004 and 2005

Region		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Depth	15		15-25		25-35		35-45			
Groote	2003	70.73	9.79	78.76	3.28	67.08	3.10	75.56	9.73	73.42	2.55
	2004	108.22	5.93	92.32	2.42	90.10	4.50	107.71	7.72	95.84	2.12
	2005	**124.33**	**34.25**	**76.98**	**3.92**	**56.85**	**10.48**	**83.13**	**39.09**	**79.61**	**7.88**
Karumba	2003	49.83	2.79	52.47	13.47					50.86	5.45
	2004	89.06	3.90	74.09	6.59					83.24	3.46
	2005	84.35	4.10	75.12	4.87					80.76	3.12
Mornington	2003	49.93	3.26	56.27	2.71	83.99	2.19	94.20	3.47	69.03	1.41
	2004	68.06	4.81	81.55	4.08	87.89	3.08	75.83	4.92	80.24	2.07
	2005	**79.22**	**5.06**	**77.84**	**4.03**	**87.21**	**3.48**	**93.85**	**3.87**	**83.24**	**2.10**
Vanderlins	2003	63.04	13.08	59.48	5.26	66.03	3.77	72.57	4.17	65.43	2.64
	2004	80.56	10.42	85.68	5.51	68.13	4.12	70.75	5.30	75.02	2.72
	2005	**36.73**	**7.59**	**54.12**	**5.06**	**75.98**	**6.11**	**78.97**	**10.31**	**66.37**	**3.71**
Weipa	2003	88.40	25.37	96.13	6.61	86.19	6.97	105.58	9.03	94.65	5.59
	2004	73.25	22.48	91.18	6.17	110.78	4.98	114.43	5.42	101.22	4.51
	2005	**78.82**	**26.12**	**86.92**	**11.72**	**102.67**	**6.67**	**77.43**	**19.01**	**87.58**	**7.86**
Mean	2003	56.93	2.99	63.72	2.95	73.67	1.81	84.29	2.79		
	2004	85.41	2.86	84.13	2.17	83.07	2.09	83.79	2.96		
	2005	**82.88**	**5.84**	**72.39**	**2.16**	**77.60**	**3.48**	**83.33**	**7.32**		

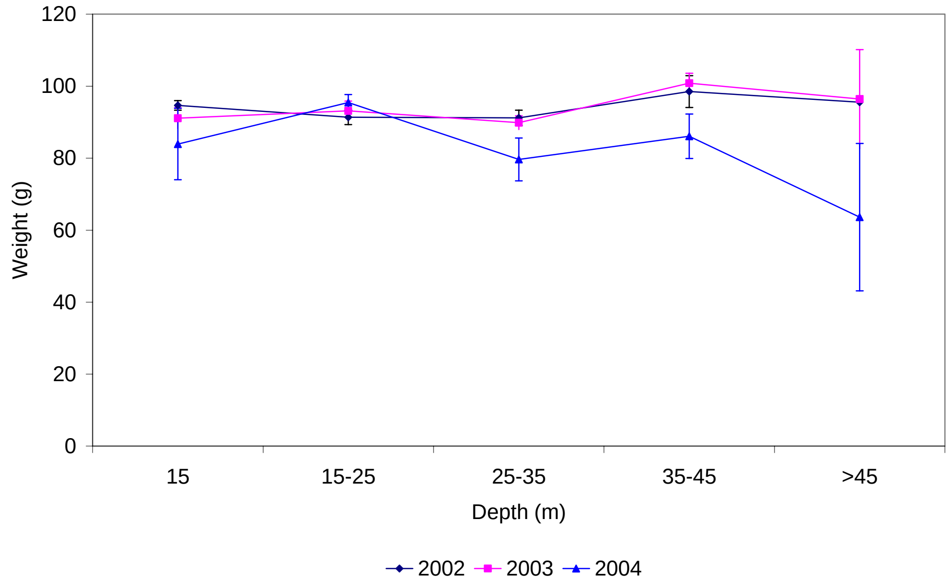

Figure 78: Mean weight (g) of mud bugs (*Thenus indicus*) in different depths (the bars indicate 1 standard error) for the July surveys.

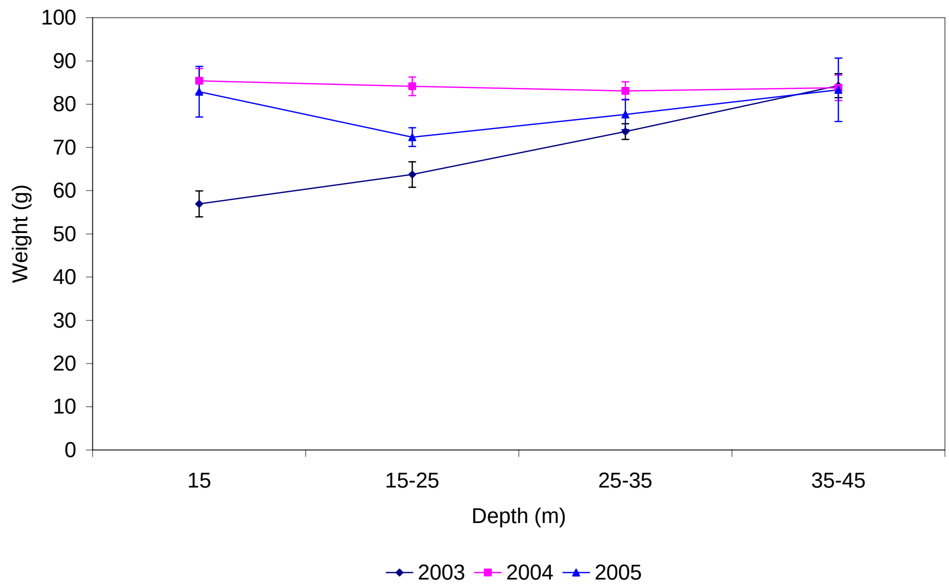

Figure 79: Mean weight (g) of mud bugs (*Thenus indicus*) in different depths (the bars indicate 1 standard error) for the February surveys.

8.4.1.3 *Length distribution*

The length frequency distribution of mud bugs from the July 2004 survey exhibits only one large mode at around 55 mm (Figure 80). Very few are smaller than 40 mm. Mud bugs caught in February 2005 clearly had two modes: one around 35 mm and one around 55 mm, representing two cohorts (Figure 81). The two cohorts in February suggest annual recruitment of small bugs in the spring/early summer prior to February surveys. As well, the distribution suggests that mud bugs seem unlikely to live longer than 3 years. However, potential bias is likely, due to the way all the length distribution data are pooled without considering their locations and net selectivity.

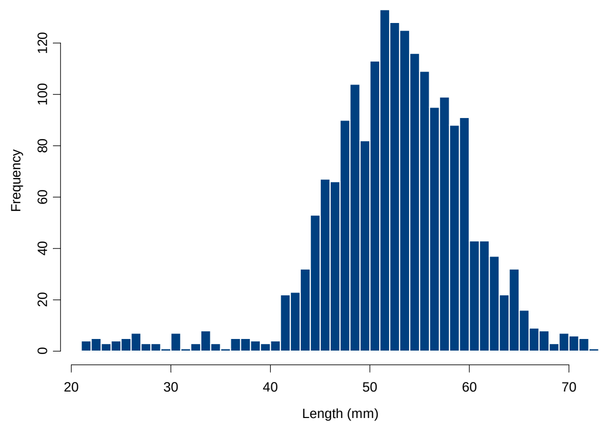

Figure 80: Length frequency distribution of mud bugs (*Thenus indicus*) in July 2004.

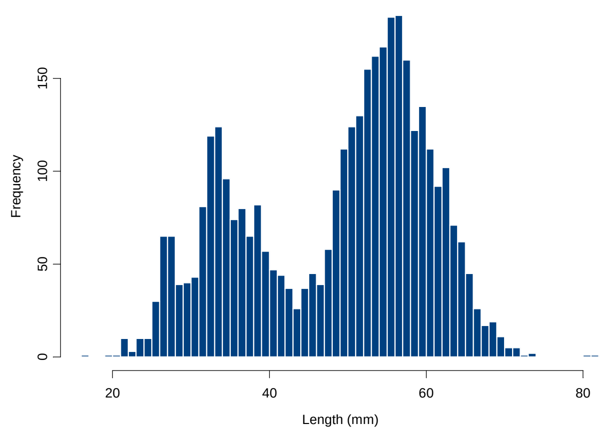

Figure 81: Length frequency distribution of mud bugs (*Thenus indicus*) in February 2005.

8.4.2 *Reef bugs*

On Australia's east coast, reef bugs (*Thenus orientalis*) occur in water depths of 25-60 m, in areas with sandy substrates, and are rarely found south of 26°S (Courtney and Williams, 2002). Spawning activity for reef bugs occurs throughout the year, but peaks in the spring and early summer months. Females carry a relatively small number of eggs (thousands to tens of thousands) on the pleopods (swimming legs) before spawning. The eggs hatch and undergo a series of complex larval metamorphoses of less than a month, before settling out as juveniles. Growth of juveniles appears to be fairly rapid, reaching 60 mm carapace width and recruiting into the Queensland fishery at 1-2 years of age. The annual mortality rate is estimated to be about 75% and longevity appears to be approximately 5-6 years (Courtney and Williams, 2002). On the Queensland east coast, about 340 t of reef bugs are landed each year as byproduct of prawn fishing (Courtney and Williams, 2002).

8.4.2.1 ***Spatial distribution***

In the area covered by the Gulf of Carpentaria prawn trawl fishery, reef bugs are less abundant than mud bugs; they are found at lower densities and their distribution is limited relative to the distribution of mud bugs. Reef bugs are only found in Vanderlins, Mornington and Weipa. However, they are larger than mud bugs (Figure 86 and Figure 87).

In July 2004, reef bugs were caught at only a few sites, mainly in Vanderlins and Mornington (Figure 82). Some catch rates were >0.5 bugs per hectare. Abundance was also low in February 2005; most sites had abundances below 0.5 bugs per hectare (Figure 83). Weipa and Vanderlins had the highest densities of reef bugs in February 2005.

The distributions of the average individual weight of reef bugs are presented in Figure 84 and Figure 85. There seems no clear spatial trend with size. Individual weights ranged mainly from 81 g to 186 g in July 2004 and from 23 g to 136 g in February 2005. The clear difference in mean size between July and February suggests recruitment in early months of each year.

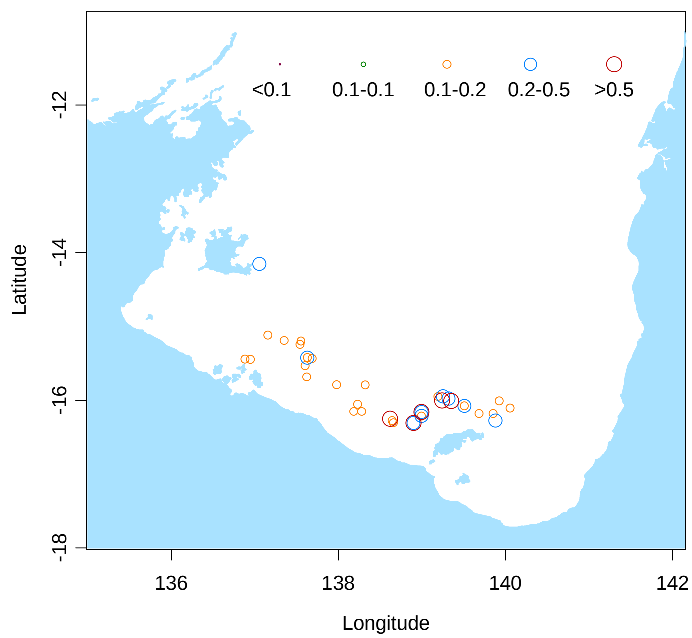

Figure 82: Spatial distribution of reef bugs (*Thenus orientalis*) (no/ha) in July 2002.

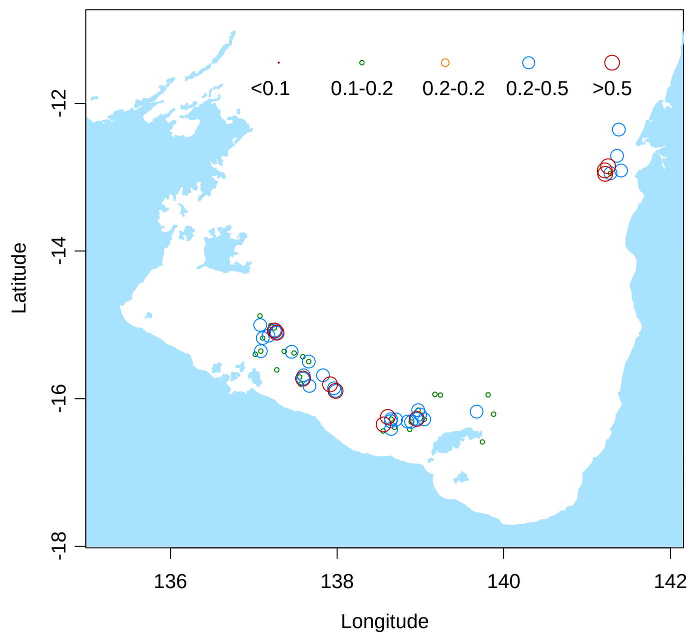

Figure 83: Spatial distribution of reef bugs (*Thenus orientalis*) (no/ha) in February 2005.

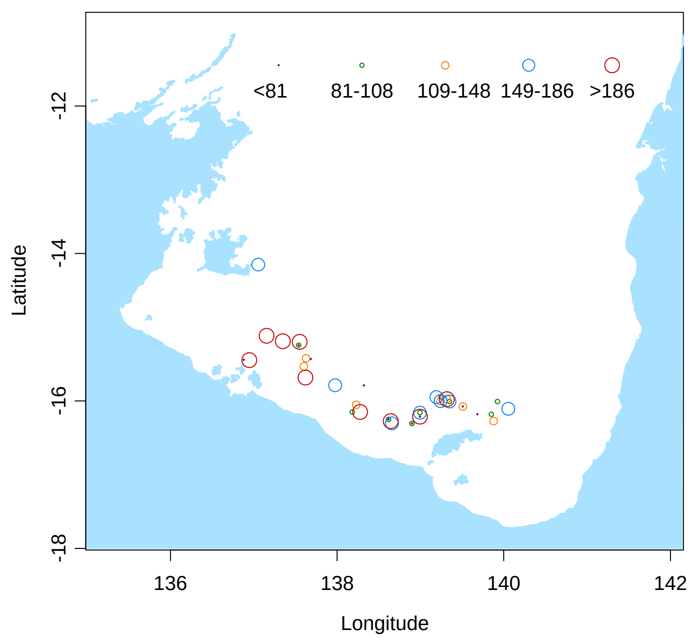

Figure 84: Distribution of average individual weight (g) of the reef bugs (*Thenus orientalis*) caught in the survey of July 2004.

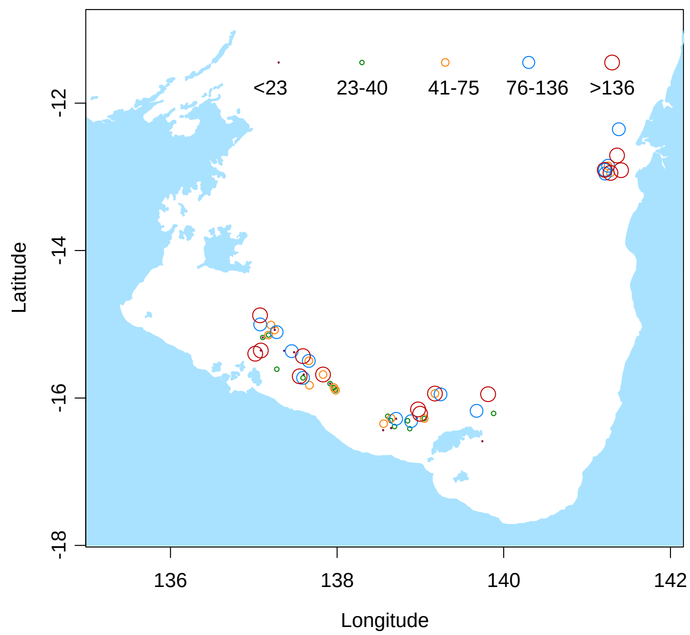

Figure 85: Distribution of average individual weight (g) of the reef bugs (*Thenus orientalis*) caught in the survey of February 2005.

8.4.2.2 *Length Distribution*

Size of reef bugs ranged from 25 mm to 85 mm CL in July 2004. There was only one mode around 60 mm (Figure 86). Length frequency distribution of the reef bugs caught in February 2005 exhibited two modes. One appeared around 30 mm CL and the other located at about 70 mm CL (Figure 87). In general, the number of length measurements is too low and no valuable information can be extracted from the length distributions. The lifespan of reef bugs seems unlikely to exceed 4 years as seen from the length distribution. However, this conclusion needs to be investigated further, as the reef bugs in Queensland east coast are believed to have a maximum longevity of 5-6 years (Courtney and Williams 2002).

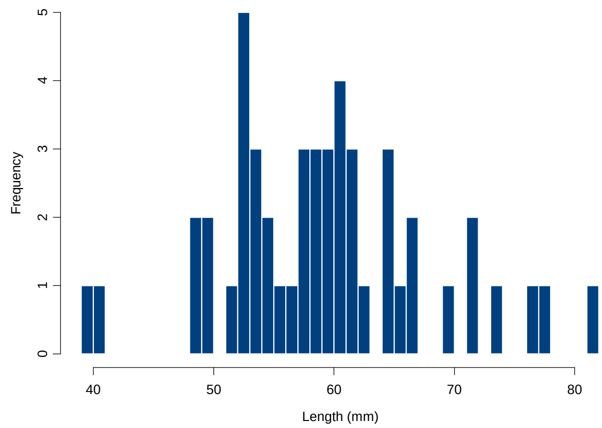

Figure 86: Length frequency distribution of reef bugs (*Thenus orientalis*) in July 2004.

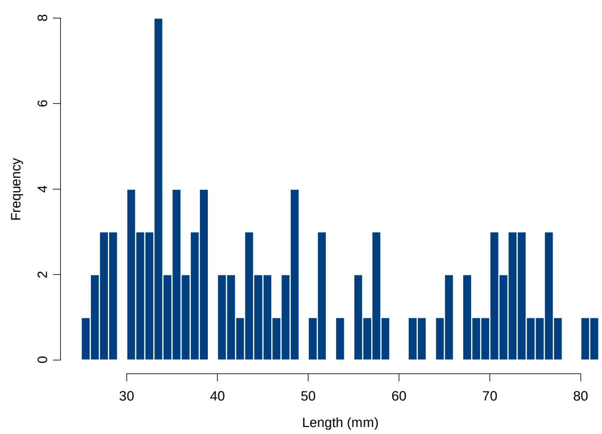

Figure 87: Length frequency distribution of reef bugs (*Thenus orientalis*) in February 2005.

8.5 Results - Cuttlefish

The family *Sepiidae* 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). The *sepiids* are benthic or benthopelagic, and are incidentally caught in prawn fishing. Our surveys did not record them by species, and they were identified to family level only.

8.5.1 *Spatial Distribution*

Sepiidae were frequently caught during the two prawn surveys. In July 2004, the maximum catch rate was more than 1.6 cuttlefish per hectare (Figure 88) in July 2004. High catch rates were recorded in the deeper waters of Groote and Mornington, but also in Karumba (Figure 88). Among the regions, Vanderlins had the lowest catch rates. Catch rates in February 2005 generally were higher than those from July 2004 (Figure 89), though some regions had lower catches; e.g. in east Mornington catches were lower in February than in July. In contrast, increased catch rates were records in other areas.

The individual weight of *Sepiidae* caught during the July 2004 survey ranged mainly from 45 g to 90 g (Figure 90). The February 2005 survey had a slightly lower upper boundary of 78 g (Figure 91). Shallow waters had greater abundances of small cuttlefish; a trend which was clearer in February than in July.

8.5.2 *Size Frequency Distribution*

No size frequency data was recorded for *Sepiidae*.

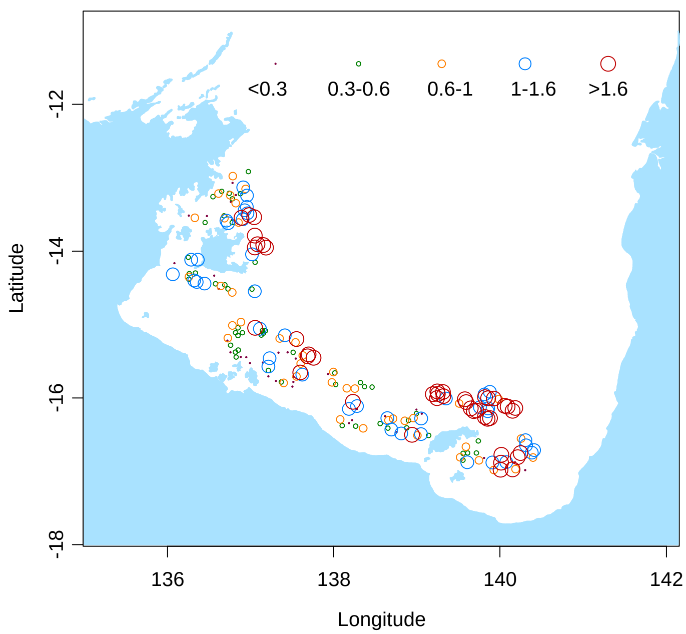

Figure 88: Spatial distribution of cuttlefish (*Sepiidae*) (no/ha) in the survey of July 2004.

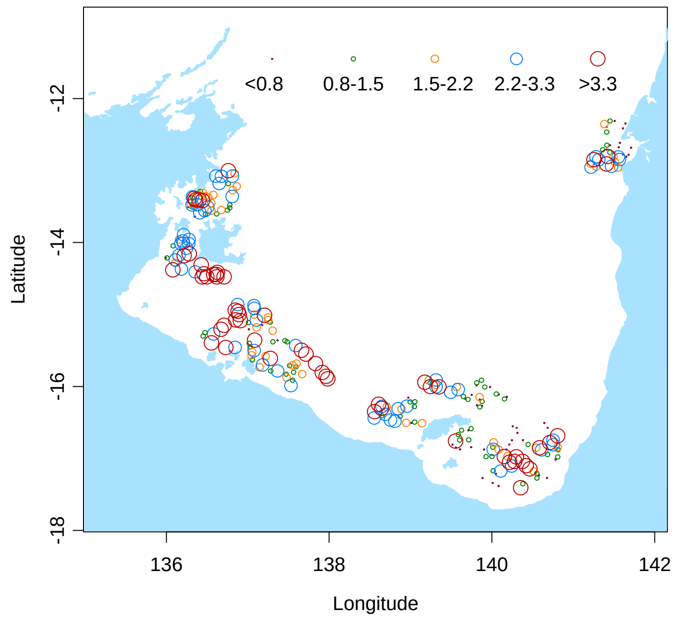

Figure 89: Spatial distribution of cuttlefish (*Sepiidae*) (no/ha) in the survey of February 2005.

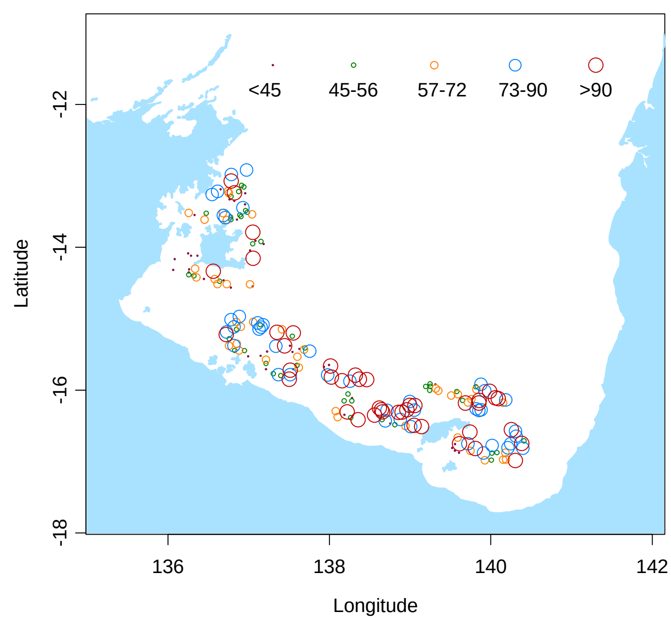

Figure 90: Distribution of average individual weight (g) of the cuttlefish (*Sepiidae*) caught in the survey of July 2004.

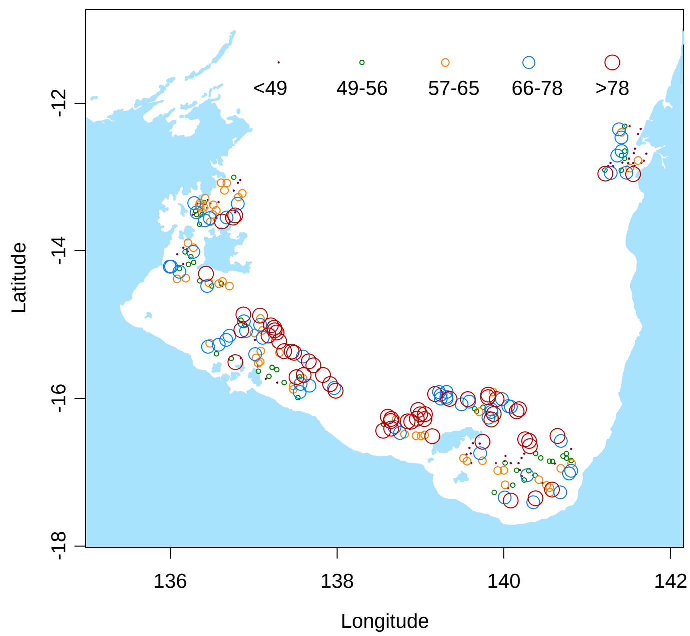

Figure 91: Distribution of average individual weight (g) of the cuttlefish (*Sepiidae*) caught in the survey of February 2005.

8.6 Results - Squid

Squid (*Loliginidae*) are widely distributed in the Gulf of Carpentaria. Like cuttlefish, they were undifferentiated by species during the surveys. Squid are benthic or benthopelagic and are incidentally caught during prawn fishing.

In July 2004, they were caught in all regions that were surveyed. The maximum catch rate recorded was about 1.3 squid per hectare (Figure 92). The most abundant areas were Karumba and west Mornington.

The spatial distribution of the squid in February 2005 did not change very much (Figure 93). Weipa was also surveyed in February and few squid were caught there (at only two sites (Figure 95)). In general, the catch rates in February were lower than those in July, with some catch rates of >0.5 squid per hectare (almost half the maximum value seen in July). No clear spatial distribution pattern can be identified.

The mean individual weight of squid in July 2004 ranged mainly from 25 g to 93 g (Figure 94). Clearly, north Groote had the smallest squid that were caught. The size of squid in the other areas was not able to be differentiated. In February, Karumba stood out from other areas, having high catch rates of small squid (weight range of 16-74 g), thus indicating recruitment in February.

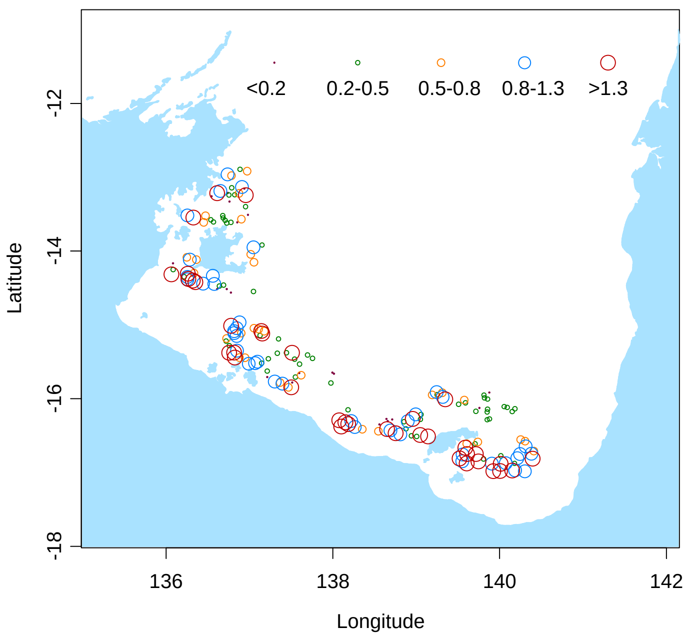

Figure 92: Spatial distribution of squids (*Loliginidae*) (no/ha) in the survey of July 2004.

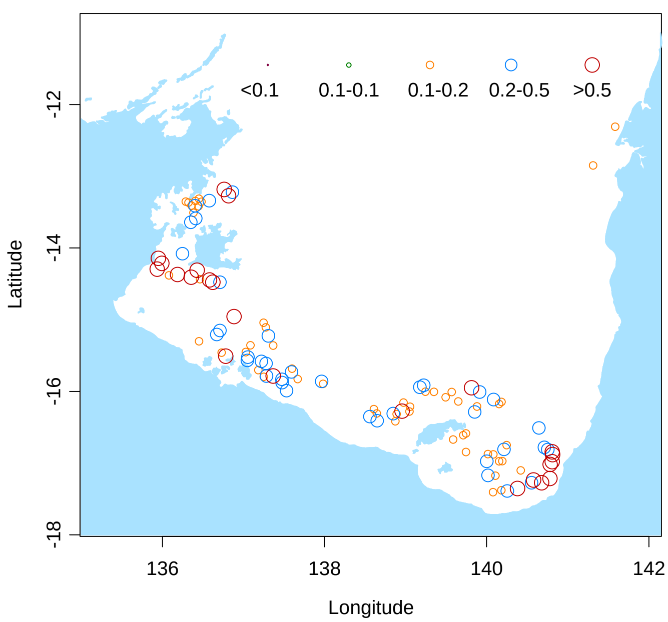

Figure 93 Spatial distribution of squids (*Loliginidae*) (no/ha) in the survey of February 2005.

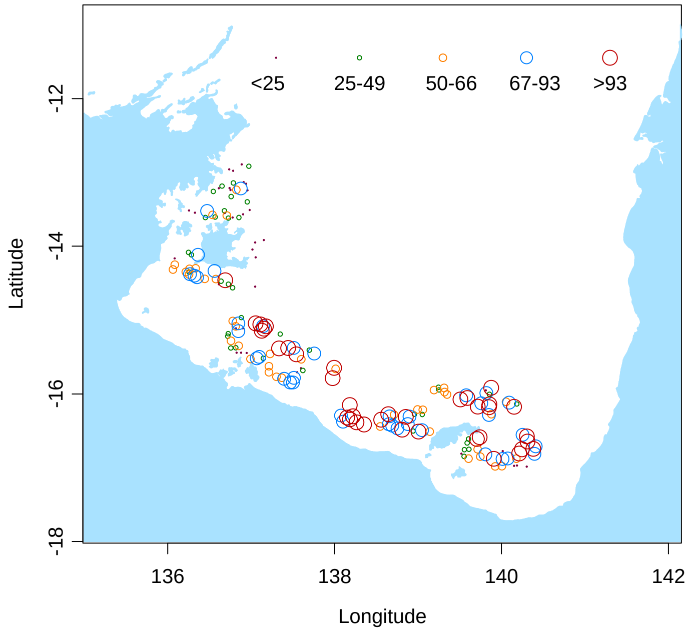

Figure 94: Distribution of average individual weight (g) of the squid (*Loliginidae*) caught in the survey of July 2004.

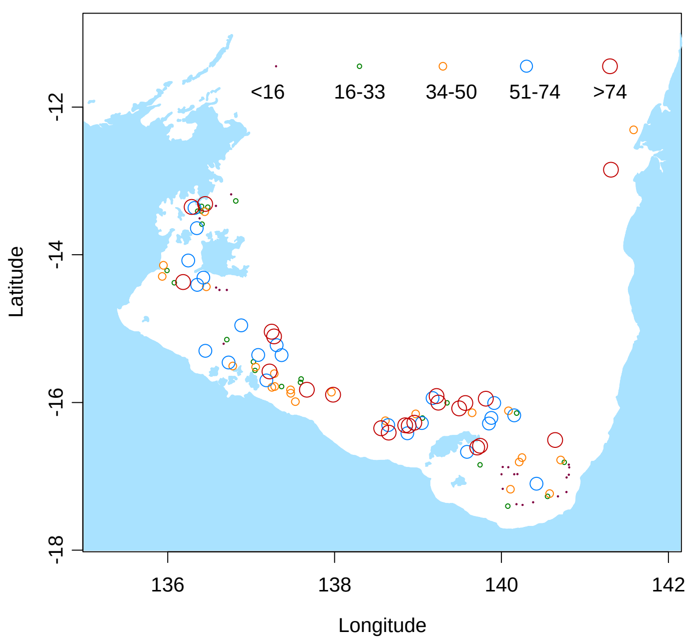

Figure 95: Distribution of average individual weight (g) of the squid (*Loliginidae*) caught in the survey of February 2005.

8.7 Conclusion

The most abundant byproduct species caught during the two prawn surveys were mud scallops (*A. pleuronectes*), mud bugs (*T. indicus*), cuttlefish (*Sepiidae*) and squid (*Loliginidae*). The surveys provide valuable information about their spatial distributions, their density and size. Some results from the two surveys contrast with the existing knowledge about the species that was recorded in other places, e.g. the tropical east-coast of Queensland. For example, elsewhere in the tropics mud bugs (*T. indicus*) are believed to occur in shallow waters less than 25 m depth. Our surveys show mud bugs have a fairly high catch rate even in waters as deep as 50 m. Also, reef bugs (*T. orientalis*) are reported to have longevity of approximate 5-6 years. However, the length frequency distribution from these two surveys cannot fully support this claim. As these byproduct species have not been subject to extensive study, particularly in the Gulf of Carpentaria, further investigation is required.

The spatial distribution of some byproduct species exhibited interesting patterns. For example, mud scallop has a high density in Mornington (15.4 scallops/ha), but a very low density in Karumba (0.04 scallops/ha) (Figure 56 and Figure 57; Table 28). Yet Mornington and Karumba are adjacent regions. It is believed that the distribution of marine animals is often related to sediments. Should the relevant data be available, a correlation analysis may shed more light on the complicated mechanism that determines the spatial distribution for each species in two areas as close as Mornington and Karumba.

8.8 References

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CHAPTER 9. SURVEY CATCH RATES AND VARIATION OF PRAWN AVAILABILITY

9.1 Introduction

Tiger prawns are migratory species. Both species migrate from inshore nursery habitats to offshore adult habitats. By late autumn/ early winter each year, most of the adult grooved tiger prawns *(P. semisulcatus)* that recruited the previous summer are located further offshore in depths >40 m; and after July, they move to shallower waters (<40m) (Crocos and van der Velde 1995). The ecological reasons for this offshore migration are complex and not fully understood. However, it is believed that changes in temperature could be a major trigger, particularly in the determination of time to migrate. Whatever factors trigger the prawn migration, they tend to vary from year to year, and so does the migration. Brown tiger prawns do not make this offshore/onshore migration. In general, they move from shallow to deeper waters and may move up to 70 km from inshore areas adjacent to nursery habitats to their offshore habitats (Somers and Kirkwood, 1984).

To sample the adult spawning stock, the NPF monitoring project has been conducting surveys just before the second prawn season. Due to changes in regulation, as well as managerial and environment-cued scheduling issues, the timing of the pre-season survey has changed substantially; 16-27 August in 2002, 31 July-15 August in 2003 and 20 July-4 August in 2004. Grooved tiger prawns *(P. semisulcatus)* usually start their inshore migration in July and probably have returned to the fishing grounds by the end of September each year (Somers et al. 1987, Somers and Wang 1997). Thus, the availability of grooved tiger prawns *(P. semisulcatus)* (in particular) to the fishery and/or to the survey is not constant, but increases from July to October. As a result, catch rates of the surveys conducted during different time periods are not fully comparable between years. Of course, even if the surveys were fixed at a specific time each year, the potential variation in the timing of migration renders the between-year comparison of catch rates problematic. As this variation is not fully understood, it is probably defendable to assume that this kind of natural variation is random and that over a number of years the resultant noise in the data will cancel out. In contrast, the changes in the timing of the pre-season survey are more complicated as they are large and not random. If availability cannot be taken into account, the suitability of the survey catch rates to represent prawn density will be significantly undermined.

9.2 Prawn migration and availability

The climate in the Gulf of Carpentaria is characterized by distinct wet and dry seasons, with heavy rainfall during the summer from December to March. Mean surface-water temperatures also vary seasonally, with a peak of 30 to 32^{0}C in December and January, a low of 23 to 26^{0}C in July and August (Figure 96). The temperature data were exacted from the NOAA satellite sensor data in the northern Groote area, and 1983-84 and 2002-2004 were selected because these years have scientific survey data in the region.

Somers and Kirkwood (1991) found that grooved tiger prawns *(P. semisulcatus)* dispersed to deeper waters in the winter months from June and August, and so commercial fishery caught less then. Catch per unit effort data from their data show that in the spring months (September to November), tiger prawns appeared to re-aggregate in shallow waters and to become the focus of the commercial fishery. By using April and September survey indices in 1984, Somers and Kirkwood (1991) calculate a natural rate of decline in the population (0.03/week), and the catch rates from intervening months were compared with those predicted from an exponential decay model to define the seasonal adjustment for this species' availability (Figure 97). Although the method used in Somers and Kirkwood (1991) involves a great approximation as fishing was carried out throughout the year in 1984, the estimates of availability over month do make a significant contribution to the refinement of abundance indices and thus, the stock assessment.

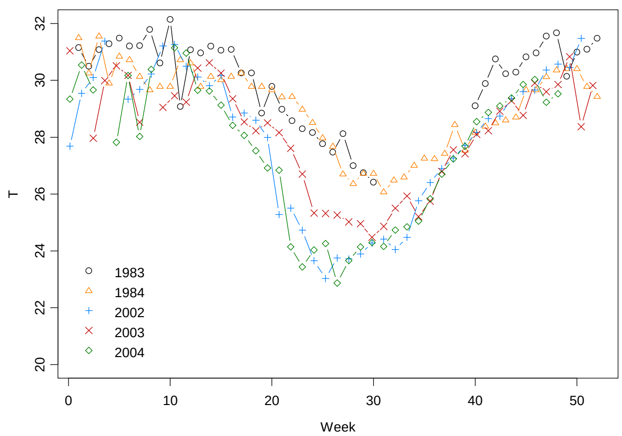

Figure 96: Mean daily surface-water temperature in the northern Groote area.

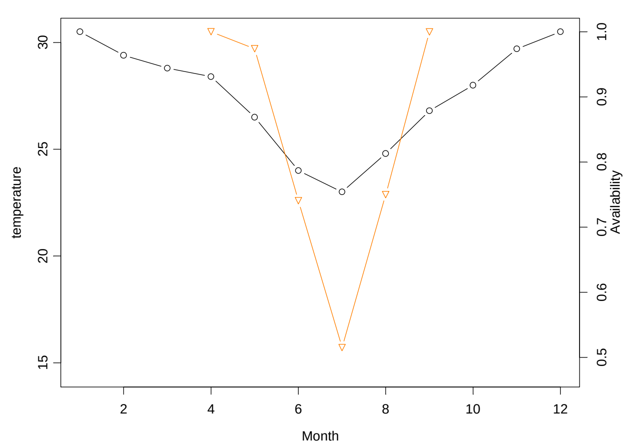

Figure 97: The estimates of availability (∆) over month (Somers and Wang 1997) and the mean surface-water temperature (○) in 1984.

To see the potential relationship between availability and water temperature, we overlaid the 1984 water temperature on the availability estimates in Figure 97. The lowest availability coincides with the lowest temperature. Between April and September grooved tiger prawns *(P. semisulcatus)* are only partially available to the fishery. Although temperature may serve as a major trigger for prawn migration, it seems difficult to associate the prawns full availability with a threshold value of temperature; particularly as the seasonal change in availability was estimated based on the 1984 data only. However, a concave shape can probably approximate the pattern of availability over time each year. The depth of the shape may vary and the location of the bottom point may shift backwards or forwards from year to year, as described in Figure 98.

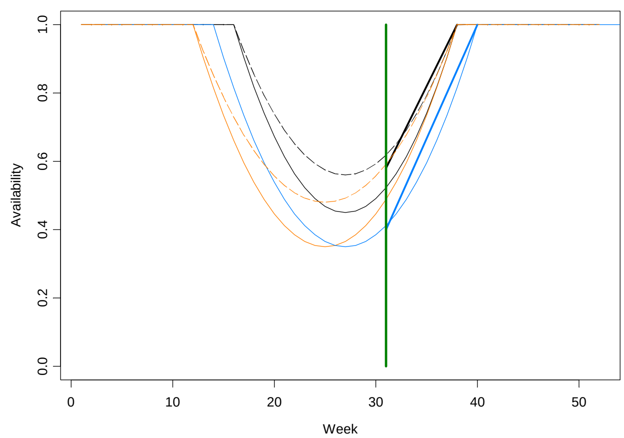

Figure 98: Temporal patterns of prawn availability and its variation.

9.3 Recruitment pattern of grooved tiger prawns

Tiger prawns are believed to spawn continuously throughout the year. However, there are two spawning peaks (Crocos and van der Velde 1995), and as a result, recruitment also assumes a bimodal distribution over time. Juveniles (≤20 mm carapace length) recruit to the fishery in the warmer months of the year (October-April). Very few juveniles were caught during the colder months (May-October) (Somers et al. 1987, Figure 99). Given this recruitment pattern, we can assume that the prawn population undergoes a simple depletion process, either by only natural death when no fishing occurs or by both natural and fishing death when a fishery is in operation.

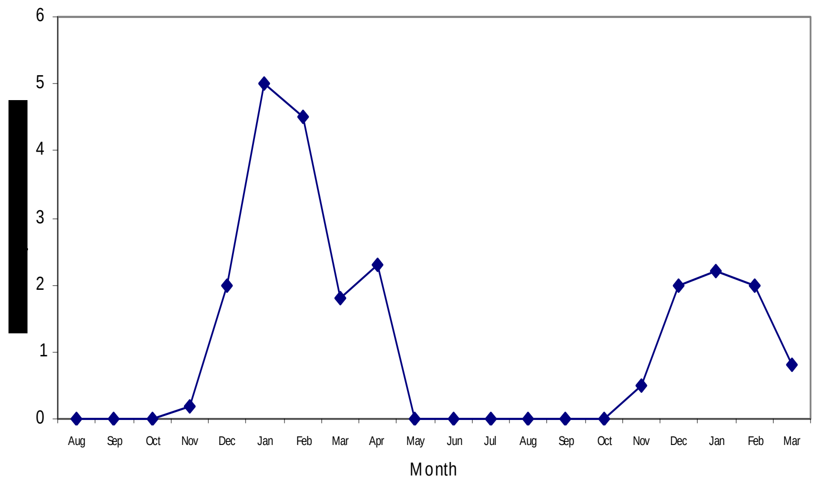

Figure 99: Seasonal recruitment pattern for grooved tiger prawns *(P. semisulcatus)* (Somers et al. 1987). Study area and fishery dependent and independent data

Stock assessment of the tiger prawns in the Gulf of Carpentaria has very much relied on commercial catch and effort statistics. Like any other fisheries, fishing power of the NPF fleet has increased over time with improved technology in navigation, communication and fish searching. The changes in fishing power are confounded with the variation of stock abundance, which makes a reliable estimation of fishing power creep difficult. Unfortunately, tiger prawn stock assessment is very sensitive to fishing power changes. It is clear that extra information, such as fishery independent data, is needed to break the confounding linkages between variation in stocks and the continuous creep in fishing power, to improve the stock assessment.

In an attempt to make full use of fishery independent data, we selected the northern Groote area because an intensive grid-survey was carried in that area each month from August 1993 to March 1985 (see Somers et al. 1987). The catch rates of grooved tiger prawns *(P. semisulcatus)* estimated from the survey were depicted together with the monitoring survey in 2002-2004 in Figure 100.

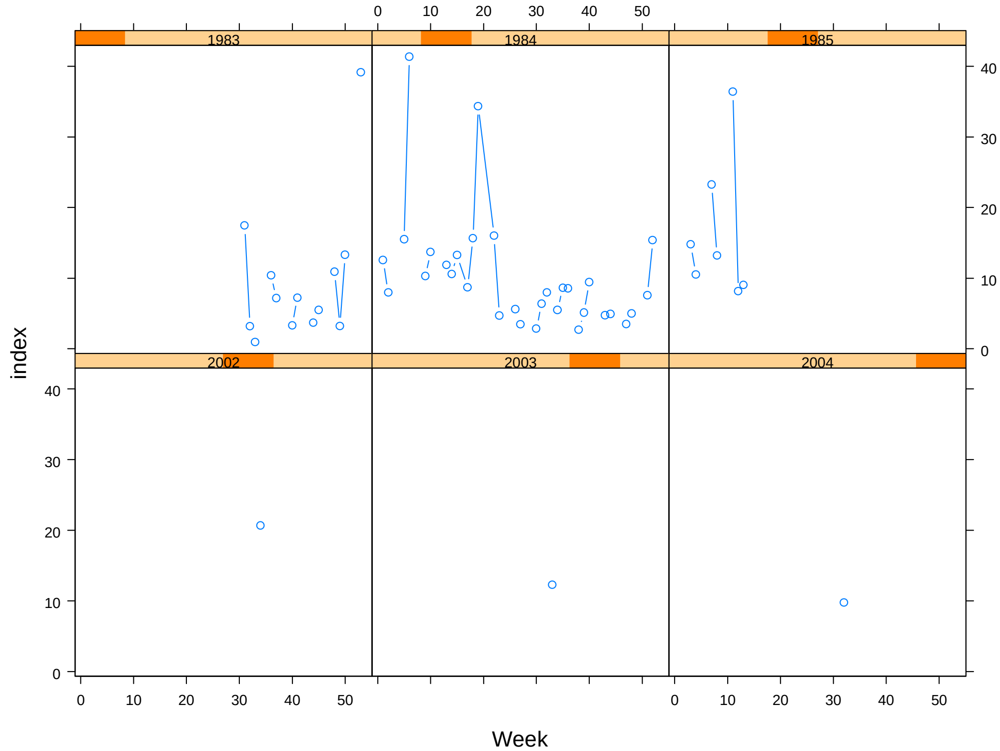

Figure 100: Survey abundance indices (prawns per hectare) for the northern Groote area estimated from the Maxim survey in 1983-1985 and the NPF monitoring survey in 2002-2004.

The weekly abundance indices estimated from the Maxim survey in 1983-1985 were very variable. Sometimes, the difference in catch rates between two consecutive weeks amounted to 3-4 times. This extent of variation is difficult to explain because their corresponding standard errors do not suggest that the extraordinary large catch rates are the result of a few large catches in the area. The NPF monitoring project in 2002-2004 surveyed twice a year: once in January/February and once in July/August. To support the simplicity of the prawn population dynamic modelling, the current analysis focused on the period in which no recruitment enters the fishery and used only the July/August survey data (Figure 100).

The catch statistics of grooved tiger prawns *(P. semisulcatus)* from the selected study area were calculated from log-book data and are presented in Figure 101. The most noticeable aspect is that fishing was year-round in 1983-84, but occurred only after August 31st (Week 36) in 2002-2004. As the NPF fishery does not have catch statistics for each tiger prawn species, the weekly catches of grooved tiger prawns *(P. semisulcatus)* were split from catches of brown tiger prawns based on the species composition data collected in the Maxim survey for 1983-1984; and by the species split project for 2002 and 2003; and by the model developed by the species split project for 2004.

The effort statistics corresponding to the catches are shown in Figure 102. Effort that targets grooved tiger prawns *(P. semisulcatus)* was estimated using a split based on the assumption that a boat from which more than 50% of the catch is grooved tiger prawns *(P. semisulcatus)* is classified as targeting grooved tiger prawns. It is worth mentioning that the pattern of effort over time is very similar to what is seen from the pattern of catch (Figure 101).

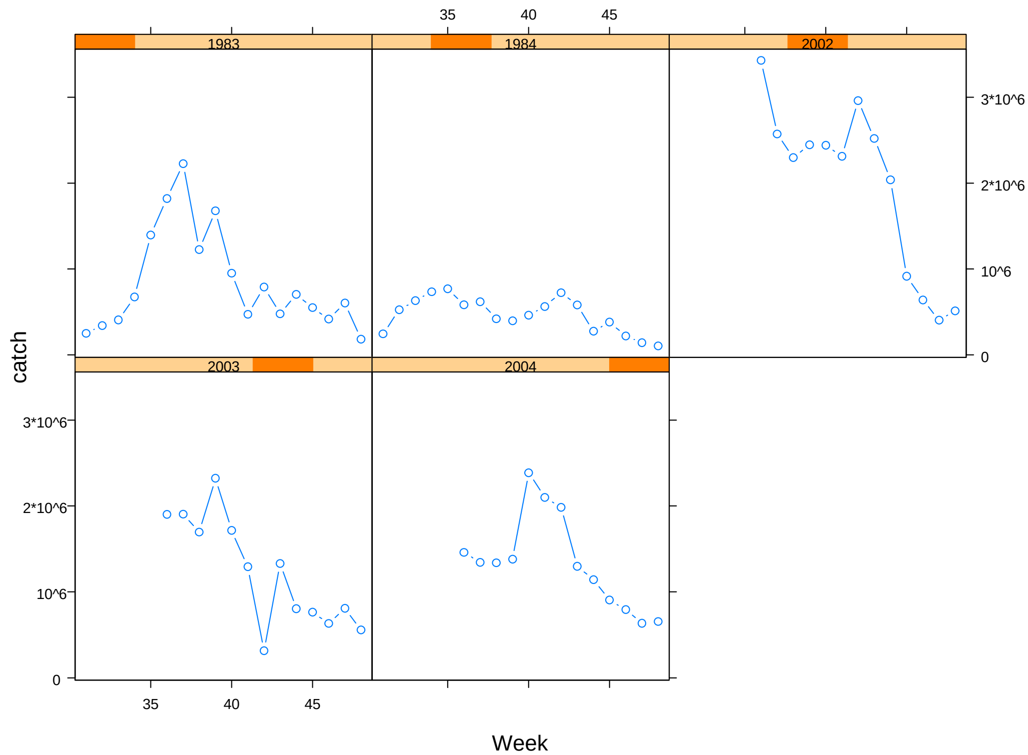

Figure 101: Commercial catch statistics (prawns per week) for grooved tiger prawns *(P. semisulcatus)* in the study area in 1983-84 and 2002-2004.

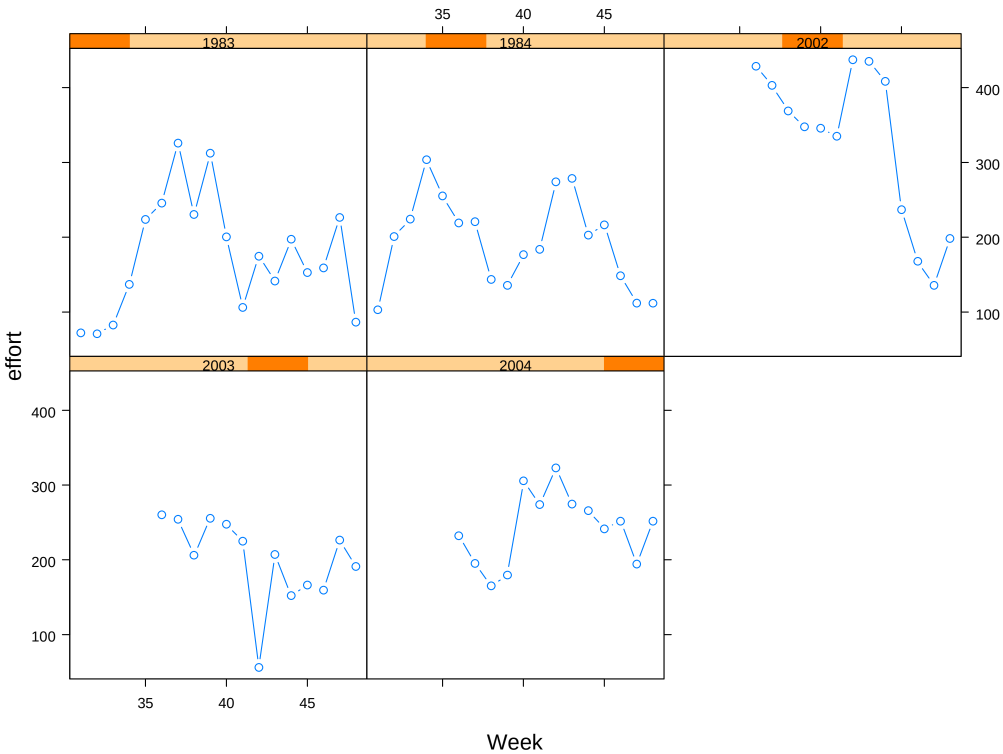

Figure 102: Weekly fishing effort (boat-days) spent on grooved tiger prawns *(P. semisulcatus)* in the study area in 1983-84 and 2002-2004.

9.4 A model to estimate availability together with recruitment and catchability coefficients

Grooved tiger prawns *(P. semisulcatus)* have negligible recruitment between May and October (Figure 99), and therefore, the population experiences a depletion process during this period. For optimum use of the 1983-84 Maxim survey data, we consider the period from Week 31 to Week 45, corresponding to the end of July to the beginning of November.

The depletion process that a prawn population undergoes under fishing can be described by the following equation,

$$N_{y,w+1} = N_{y,0} e^{-\sum_{w=1}^{w} Z_{y,w}}$$

where $N_{y,0}$ is the initial number of prawns in year y; $N_{y,w}$ is the number of prawns at week w in year y; $Z_{y,w}$ is the total mortality rate at week w in year y, which is a function of fishing effort E and natural mortality rate M,

$$Z_{y,w} = M + F_{y,w}$$

where

$$F_{y,w} = q_y E_{y,w}$$

Catch is then calculated by the following modified fishing equation,

$$C_{y,w} = N_{y,w} \frac{F_{y,w}}{Z_{y,w}} (1 - e^{-Z_{y,w}}) A_{y,w}$$

where A is availability of the prawn stock, which changes with time within a fishing season and varies from year to year as depicted in Figure 98. We focus on the period from Week 31 to Week 45 in this study, and the concave pattern can be approximated by a line that can reflect the vertical change and horizontal shift in availability. The line assumes the form below,

$$A_{y,w} = \begin{cases} a_y + b_y w & w < T \\ 1 & w >= T \end{cases}$$

where *a* and *b* are coefficients that define the line and T is the week in which prawns become fully available to the fishery.

Under the assumption that the deviation between the observed and predicted values of the catch has a log-normal distribution, the likelihood of the observed catch data given the model parameters is

$$L_c = \prod_y \prod_w \frac{1}{\sigma_c \sqrt{2\pi}} e^{-\frac{(\ln C_{y,w} - \ln \hat{C}_{y,w})^2}{2\sigma_c^2}}$$

where σ_c is the standard deviation associated with log-catch. Similarly, the likelihood for the survey catch rates is as follows,

$$L_s = \prod_y \prod_w \frac{1}{\sigma_{y,w} \sqrt{2\pi}} e^{-\frac{(\ln N_{y,w} - \ln(\hat{I}_{y,w} / \tau))^2}{2\sigma_{y,w}^2}}$$

where $\sigma_{y,w}$ is the standard deviation of log-indices derived from the survey. The total likelihood is then

$$L_{total} = L_c L_s$$

Minimizing the negative log-total likelihood gives estimates of the parameters in the above model.

9.5 Results

We fitted the above model to the catch and effort statistics, together with the fishery independent survey data in 1983-84 and 2002-2004. The model has a total of 22 parameters, that is, 5 cohort sizes at Week 31 ($N_{y,0}$), 5 catchability coefficients (q_y), 10 availability parameters (a_y and b_y) plus a scale parameter (τ) and σ_c. There are too many parameters to be estimated. Also, as apparent in the above fishing equation, $N_{y,0}$ and availability $A_{y,w}$ are highly correlated. Therefore, we considered only the case where the parameters that define availability are constant, meaning availability changes with week each year, but its temporal pattern remains unchanged between years. This reduces the number of parameters to be estimated to 14. The fit of the model to the data successfully produced estimates for the 14 model parameters.

Although the fit to catch data was very good (actually too good), the estimated catchability coefficients were not consistent with the common concept that catchability has increased over time (due to improvements in technology such as navigation, communication, fish searching and gear-machinery). We then added another likelihood to force the model-estimated Ny,0 to follow more closely with the survey indices. The indices for 1983 and 1984 were direct survey catch rates in Week 31 and for 2002-2004 they were adjusted back to Week 31 by e^M for each week,

$$L_R = \prod_y \frac{1}{\sigma_R \sqrt{2\pi}} e^{-\frac{(ln\, N_{y,0} - ln(\, I_{y,0} / \tau\,))^2}{2\sigma_R^2}}$$

As L_R has only 5 data points, we gave it a weighting factor of 10. The log-likelihood of the model then becomes,

$$ln\, L_R = ln\, L_c + ln\, L_s + 10\, ln\, L_R$$

This kind of treatment attracts criticism as it is somehow subjective, but in practice it is not unreasonable.

9.5.1 *The fit of catch at week*

The fit of grooved tiger catches *(P. semisulcatus)* at week was very good (Figure 103). All the mode-estimates of weekly-catches-in-number are very close to the catch statistics, and no serious bias trends can be detected as the lines of estimates and data are crisscrossed by each other.

9.5.2 *The fit of population sizes to indices*

A comparison between the model-estimated population sizes and survey abundance indices of the grooved tiger prawns *(P. semisulcatus)* is shown in Figure 104. Firstly, for 2002-2004, there was only one point of survey data each year and therefore the survey data had very limited impact on the estimates of the population depletion tacks. Although monthly surveys were carried out in 1983-84, the estimated population track did not follow the survey indices well in 1983, but better in 1984 (Figure 104). It seems that the high variability in the survey indices are partially the difficulties for the model fit.

Due to the addition of the likelihood L_R in the fit, the estimated initial population sizes at Week 31 were very close to those estimated from survey abundance indices (Figure 105). It must be noted, however, that this result is very much a consequence of the weighting factor.

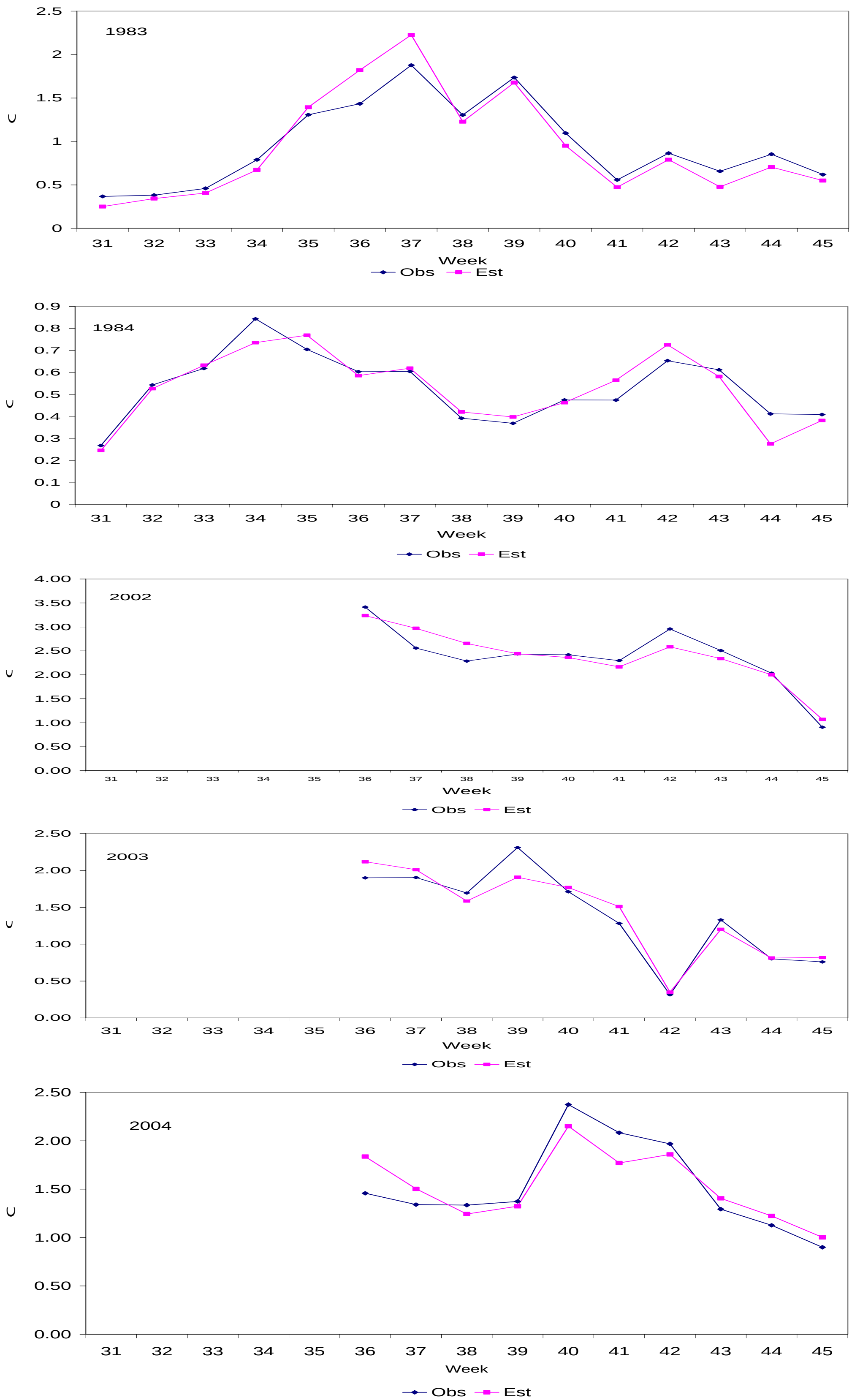

Figure 103: The fit of catch-at-week (millions) for 1983-84 and 2002-2004.

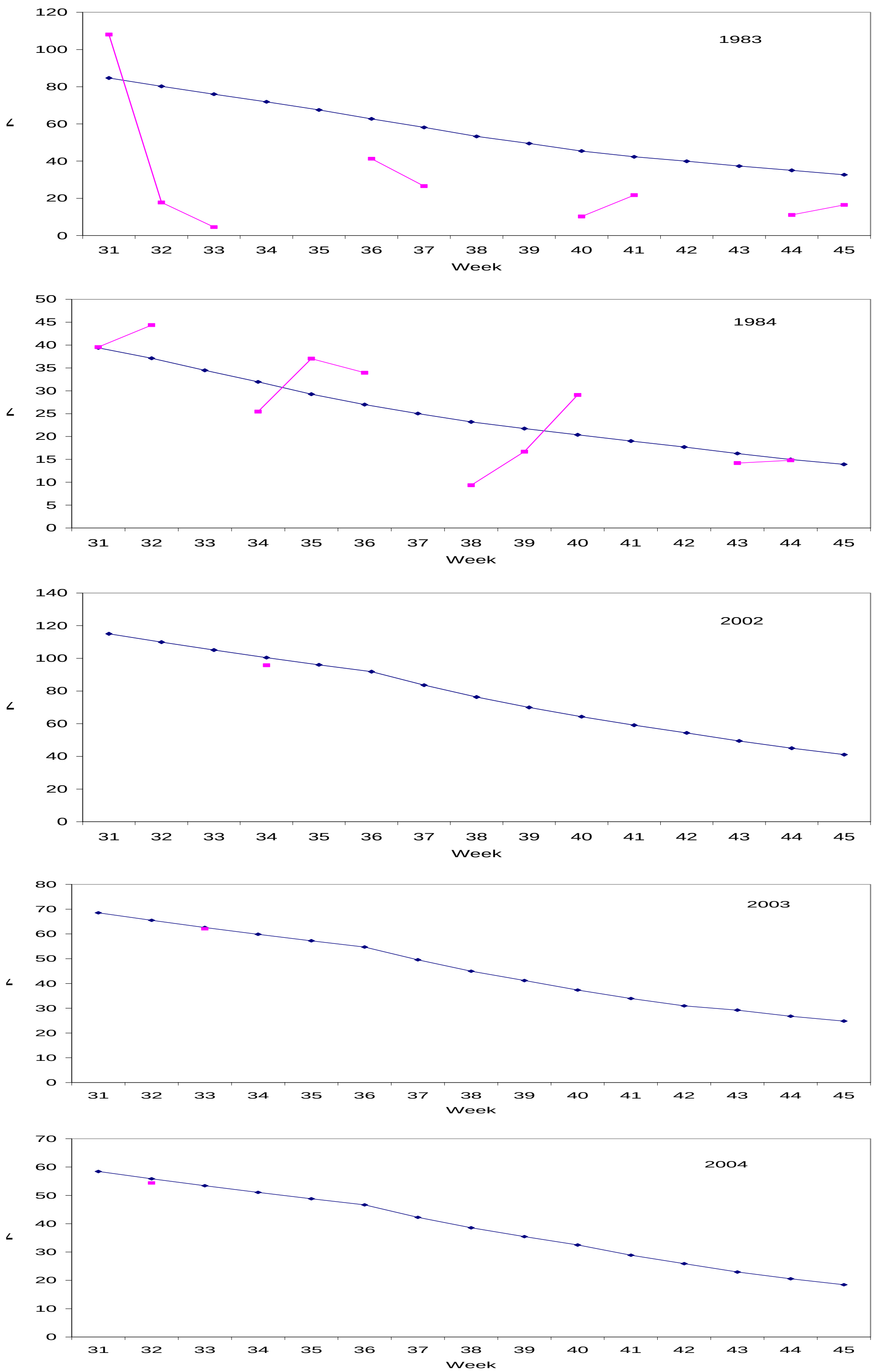

Figure 104: The fit of the population abundance to survey indices for 1983-84 and 2002-2004.

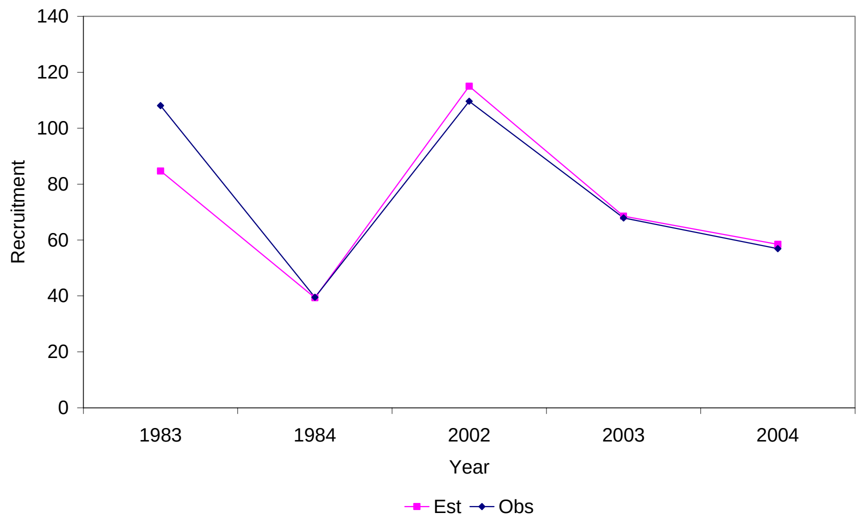

Figure 105: Comparison between the estimates of prawn numbers at Week 31 by the model and by the survey indices.

The temporal change in availability of grooved tiger prawns *(P. semisulcatus)* in the northern Groote area are depicted in Figure 106, which has values very similar to Figure 97 which was derived by Somers and Wang (1997). However, it should be remembered that this availability represents only an average over the five-year period of 1983-84 and 2002-2004.

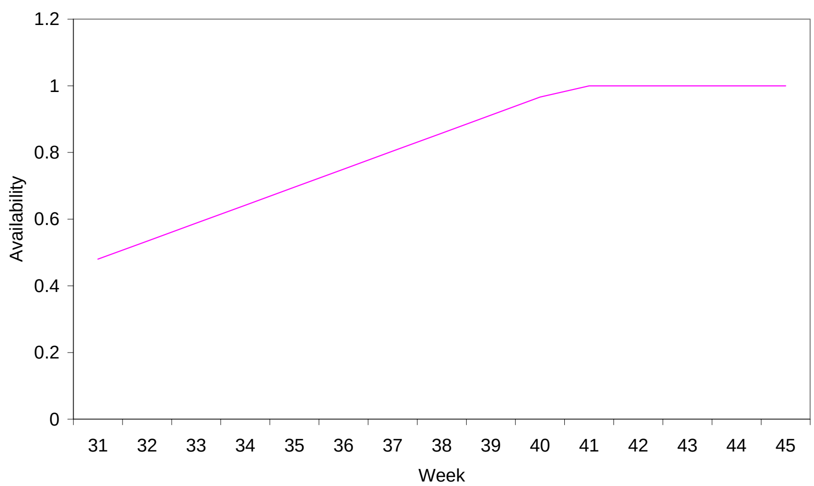

Figure 106: The temporal pattern of availability over time estimated by the model.

In general, the catchability (or 'ability to catch') of the fishing fleet for grooved tiger prawns *(P. semisulcatus)* increased over the five-year period (Figure 107). However, the catchability coefficient for 2002 was estimated to be lower than those for 1983-1984. This was caused by the high survey catch rate in 2002 and because a high abundance estimate is always tied with a low catchabilty coefficient due to the confounding between the two parameters (see more in Discussion).

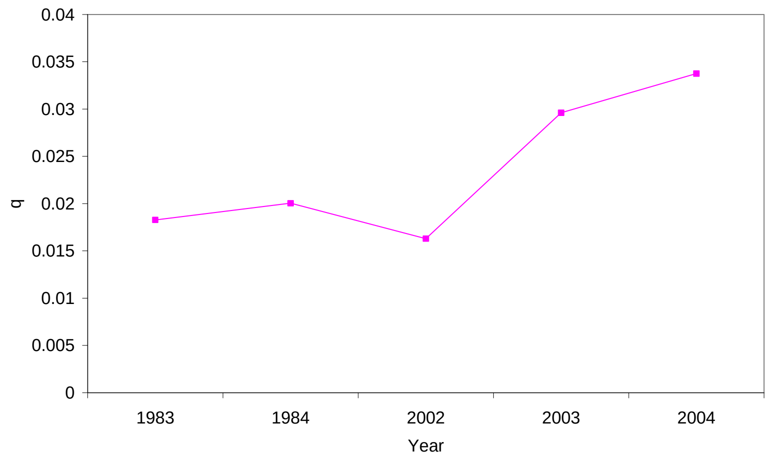

Figure 107: Estimates of the fleet's catchability coefficients (10^{-3}) in the northern Groote area.

9.6 Discussion

The model developed in this study was designed to use both commercial catch and effort statistics, together with fishery independent survey data, to produce estimates of 1) temporal change in prawn availability within a season, and 2) the fleet's fishing efficiency each year. The model was applied to the northern Groote area where more survey data are available and grooved tiger prawns *(P. semisulcatus)* are the major species. Although the preliminary results are promising, further refinement is required.

1. The model produced estimates for catchability coefficients (or 'ability to catch' coefficients), availability and recruitment simultaneously. However, there is a high degree of confounding between these three parameters. No study has ever tried to estimate the three types of parameters simultaneously for the NPF. The fishing power project (Dichmont et al. 2003) concluded that fishing power and stock abundance are seriously confounded, and that without additional abundance information the reliable estimation of fishing power creep seems impossible. There is a great hope that the present monitoring project can provide abundance indices that can be used to reduce the confounding, and thus improve the estimation of fishing power creep in the NPF. Unfortunately, the July/August survey is scheduled at a time when a considerable proportion of grooved tiger prawns *(P. semisulcatus)* are offshore on their migration. As a result, besides the catchability and abundance issues we face another serious problem, availability on the fishing grounds. The model developed in this study incorporates availability parameters and in theory should be able to estimate the three parameters simultaneously. However, the model's capacity has been limited by the insufficient information contained in the catch/effort statistics and the survey indices.

2. The lack of information and contrast in the data lead to the model's failure to break the confounding effect between model parameters. The most apparent dependency between two variables is between mean recruitment and the catchability coefficient, q, with a correlation coefficient of -0.992 (Table 35). This means that a higher recruitment is always accompanied by a lower catchability coefficient. Less noticeable is the correlation between the availability parameter, a, and the mean R, as demonstrated by the correlation coefficient of 0.81 (Table 35). This relationship supports the conclusion that abundance, catchability and availability are tied together. To estimate them simultaneously is too ambitious given the data available. Actually, we have made a concession in fitting the model to the data by assuming the availability pattern does not change from year to year. However, this assumption is unrealistic and leads to a significant compromise in how we can standardize the survey abundance indices to the same time point.

3. The limited contribution of survey data to the reduction of parameter confounding may be attributed to the fact that the recent surveys produced only a single data point over the population depletion process from Week 31 to Week 45. The one data point had very limited power in constraining the fit of the stock depletion process for 2002-2004; as the likelihood was more likely to be dominated by 1983-84 in which monthly survey indices were available. Consequently, the model seems to have failed to capture the change in abundance between years, which is important because only a large contrast in abundance over years can be expected to disassociate the confounding relationship between the abundance and catchability coefficients. The additional likelihood (L_R) was adopted to place more weight on the between-year pattern of prawn abundance. Although subjective, it did produce a better fit between the abundance estimates from the model and the survey indices.

   The NPF monitoring project carries out annual recruitment surveys in January/ February as well. During a CSIRO in-house seminar, it was suggested to extend the modelling period from Week 31 back to include the period from January to June, so there were at least two data points available for 2002-2004. This change should strengthen the influence of survey data in the fit. However, extension to January may make the population dynamic modelling much more difficult because: (1) fishing occurred throughout the year and only 50%-60% of the tiger prawn catches were grooved tiger prawns *(P. semisulcatus)* in 1983-84. Therefore, the modelling of prawn availability requires covering not only the period of increasing availability but also that of decreasing trend (Figure 98). This will increase the number of parameters to be estimated; (2) the usefulness of the January/February survey catch rates as recruitment indices is questionable because a large proportion of recruitment occurs between February to May (Figure 102), and the catch rates in July/August are not always lower than those in January/February as they should be (Table 36); very much depending on the timing of recruitment. A balance between benefit and cost may make this option not very attractive.

4. This study selected a typical area in the northern Groote area in order to make full use of the survey data, in particular the Maxim survey in 1983-84. However, the fishery and prawn stock in this small area may not be fully comparable with those of the whole Gulf, in both terms of prawn migration and fishing fleet dynamics. For example, the catch at Week 41 in 2003 was unusually low, not comparable with those in neighbouring weeks (Figure 102). This kind of sudden change is unlikely to happen for the Gulf-wide fishery, but it is real for a small area (a detailed check showed that most vessels operating in the northern Groote area in the previous week switched to the south Groote in Week 41). The sudden change in catch in an area may hint at potential differences in the availability and catchability of prawns between a small area such as north Groote and the whole Gulf.

Table 35: Correlation matrix of the estimated parameters

Parameters	Value	Std De	log(τ)	mean log®	log(R-dev1)	log(R-dev2)	log(R-dev3)	log(R-dev4)	log(R-dev5)	log(q-dev1)	log(q-dev2)	log(q-dev3)	log(q-dev4)	log(q-dev5)	log(q)	a	b
log(τ)	-1.10	0.30	1.00														
mean log(R)	4.23	0.19	-0.97	1.00													
log(R-dev1)	0.21	0.08	-0.27	0.29	1.00												
log(R-dev2)	-0.56	0.07	0.08	-0.06	-0.23	1.00											
log(R-dev3)	0.51	0.07	-0.04	-0.01	-0.26	-0.24	1.00										
log(R-dev4)	0.00	0.07	-0.11	0.11	-0.23	-0.26	-0.21	1.00									
log(R-dev5)	-0.16	0.07	0.35	-0.35	-0.31	-0.18	-0.20	-0.26	1.00								
log(q-dev1)	-0.21	0.10	0.30	-0.31	-0.93	0.24	0.23	0.21	0.32	1.00							
log(q-dev2)	-0.12	0.10	0.14	-0.13	0.17	-0.85	0.19	0.20	0.25	-0.20	1.00						
log(q-dev3)	-0.33	0.09	-0.13	0.16	0.28	0.22	-0.92	0.23	0.16	-0.26	-0.24	1.00					
log(q-dev4)	0.27	0.10	0.03	-0.03	0.23	0.24	0.22	-0.92	0.24	-0.23	-0.25	-0.23	1.00				
log(q-dev5)	0.40	0.10	-0.34	0.32	0.28	0.16	0.22	0.26	-0.92	-0.31	-0.29	-0.17	-0.25	1.00			
log(q)	-1.84	0.28	0.97	-0.99	-0.28	0.07	-0.01	-0.10	0.34	0.30	0.13	-0.15	0.03	-0.32	1.00		
a	0.48	0.07	-0.91	0.81	0.18	-0.13	0.13	0.13	-0.32	-0.24	-0.13	0.05	-0.03	0.34	-0.84	1.00	
b	0.05	0.01	0.44	-0.31	-0.01	0.10	-0.16	-0.12	0.20	0.06	0.12	0.06	0.02	-0.25	0.30	-0.67	1.00

Table 36: Comparison of catch rates (prawns per hectare) of grooved tiger prawns *(P. semisulcatus)* between the January/February and July/August surveys in 2002-2004.

Year\Area	**Groote**		**Vanderlins**		**Mornington**	
	Jan/Feb	Jul/Aug	Jan/Feb	Jul/Aug	Jan/Feb	Jul/Aug
2002		12.2		3.4		0.5
2003	14.4	6.4	17.1	4.6	0.1	<0.1
2004	4.2	6.1	6.7	4.4	0.7	0.1

5. Another approach of potential importance is to use additional information to estimate availability coefficients. As discussed in the section of “Prawn migration and availability”, availability may be expressed as a function of water temperature. However, the difficulty here is that no observed temperature data are available; although temperature data, at least sea surface temperature, can be obtained from other sources. The only option may be to integrate the temperature-availability relationship into the population dynamic model and to estimate all the parameters together.

This project has focused on the monitoring of the prawn and byproduct species through scientific surveys and is deemed to have only 15% research content as planned in its proposal. The life of the project is also short, only one year. Therefore, both resources and time do not allow the interplay of survey timing, prawns availability and fishing power creep to be fully explored as part of the current project. The importance and significance of catchability and availability parameters in stock assessment, and of the means to utilize the fishery independent survey data, deserve further investigation in the up-coming monitoring projects in the near future.

9.7 References

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Somers, I., Crocos, P.J., and Hill, B.J. 1987. Distribution and abundance of the tiger prawns *Penaeus esculentus* and *P. semisulcatus* in the North-western Gulf of Carpentaria, Australia. Australian Journal of Marine and Freshwater Research 38:63-78.

APPENDIX A: FUTURE SURVEY COSTS

The total cost of the future surveys proposed is slightly higher that what was budgeted for in 2004/05. Details are listed for August and January surveys separately in Table 37-Table 38.

Table 37: Budget for the August Survey 2005

Staff	Time	Cost	
Project Manager	6 weeks	$14,172	
Statistician/Modeller	9 weeks	$31,942	
Field Manager/Biologist	6 weeks	$18,098	
Field Biologists (salary+sea allowance)	14 weeks	$36,015	
Total salaries		$100,227	
Operating			
Data entry		$760	
Freight / sample storage		$5,000	
Consumables		$4,000	
Nets		$5,000	
Trawler charter		$103,500	
CSIRO Overheads		$65,411	
Total Operating		$183,671	
Travel			
Airfares		$6,000	
Transit accommodation & expenses		$2,790	
Total travel		$8,790	
Total module cost			$292,686
CSIRO contribution			$ 39,000
AFMA/Industry cost			**$253,688**

Table 38 Budget for the January Survey 2005

Staff	**Time**	**Cost**	
Project Manager	6 weeks	$14,172	
Statistician/Modeller	10 weeks	$33,137	
Field Manager/Biologist	6 weeks	$18,150	
Field Biologists (salary+sea allowance)	19 weeks	$50,973	
Total salaries		$116,432	
Operating			
Data entry		$8,600	
Freight / sample storage		$9,750	
Consumables		$7,100	
Nets		$8,500	
Trawler charter		$168,500	
CSIRO Overheads		$85,818	
Total Operating		$288,268	
Travel			
Airfares		$9,000	
Transit accommodation & expenses		$4,100	
Total travel		$13,100	
Total module cost			$417,800
CSIRO CONTRIBUTION			$56,000
AFMA/INDUSTRY COST			**$361,800**

Total cost – August and January	**$710,487**
CSIRO contribution	$ 95,000
Total AFMA/INDUSTRY COST	**$615,487**

APPENDIX B: PLOTS OF CATCH RATES FOR THE JANUARY 2005 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 Research
NPF Monitoring Cruise – January 2005
Preliminary Results

CSIRO

Australian Government
Australian Fisheries Management Authority

Australian Government
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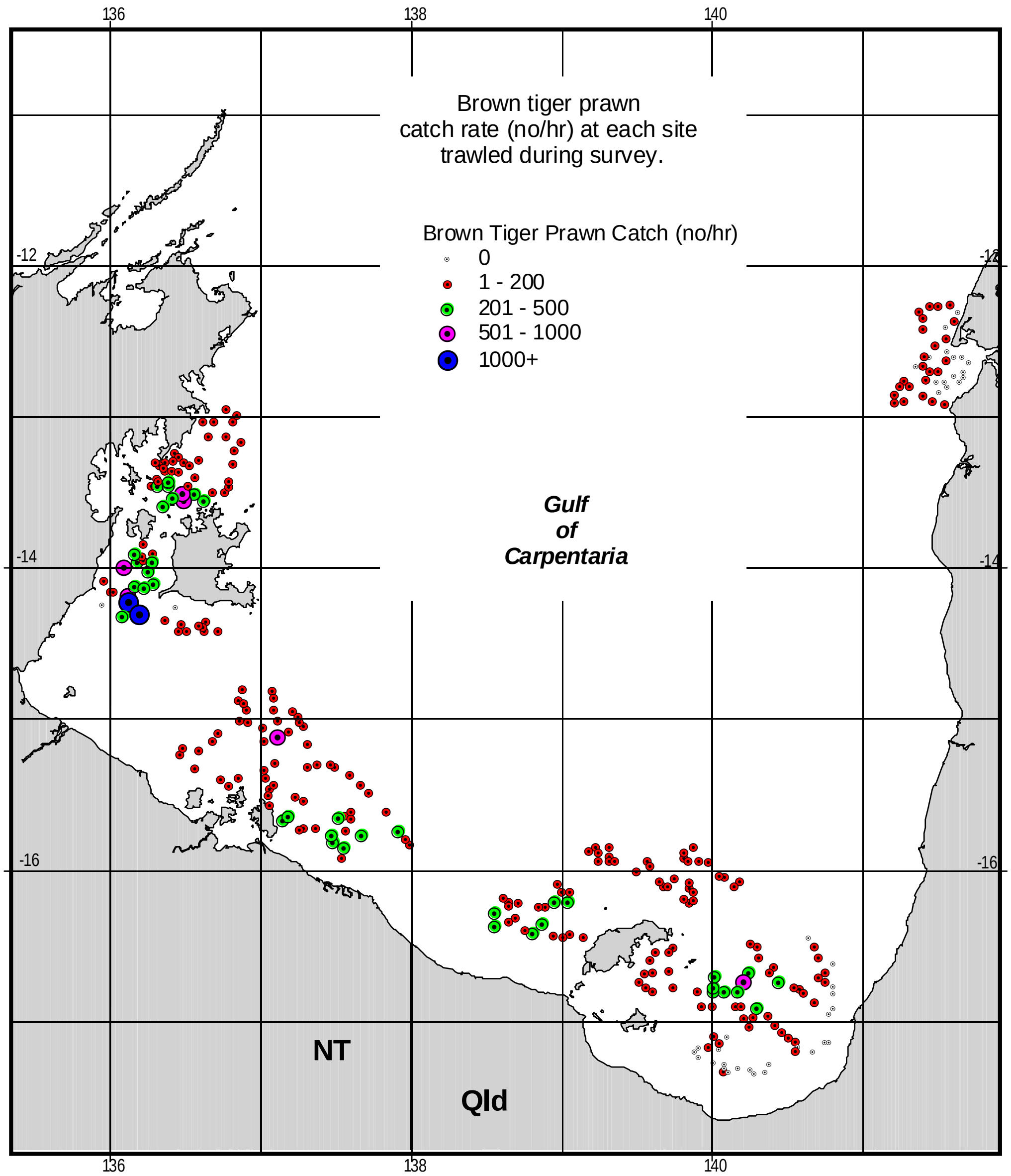

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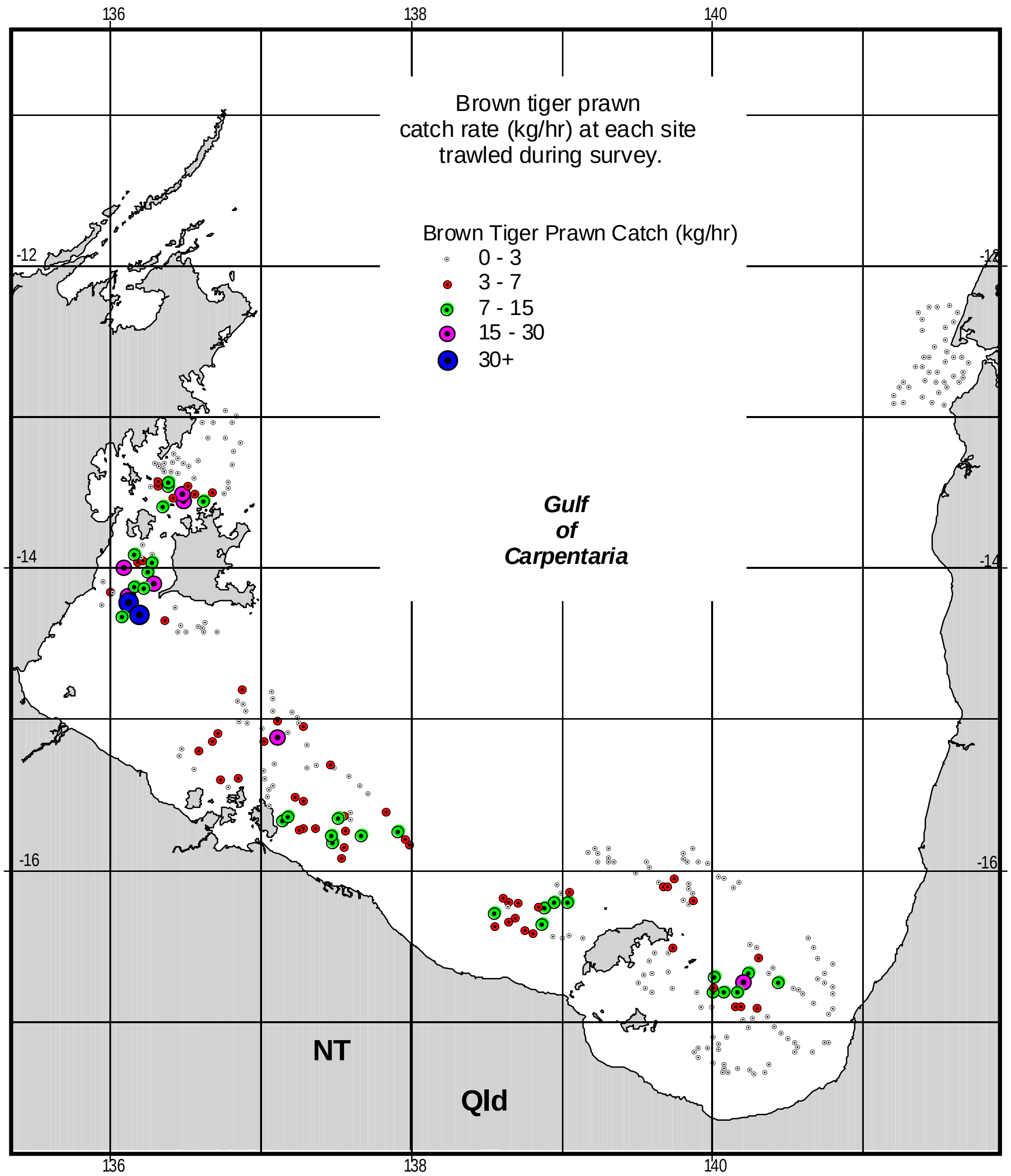

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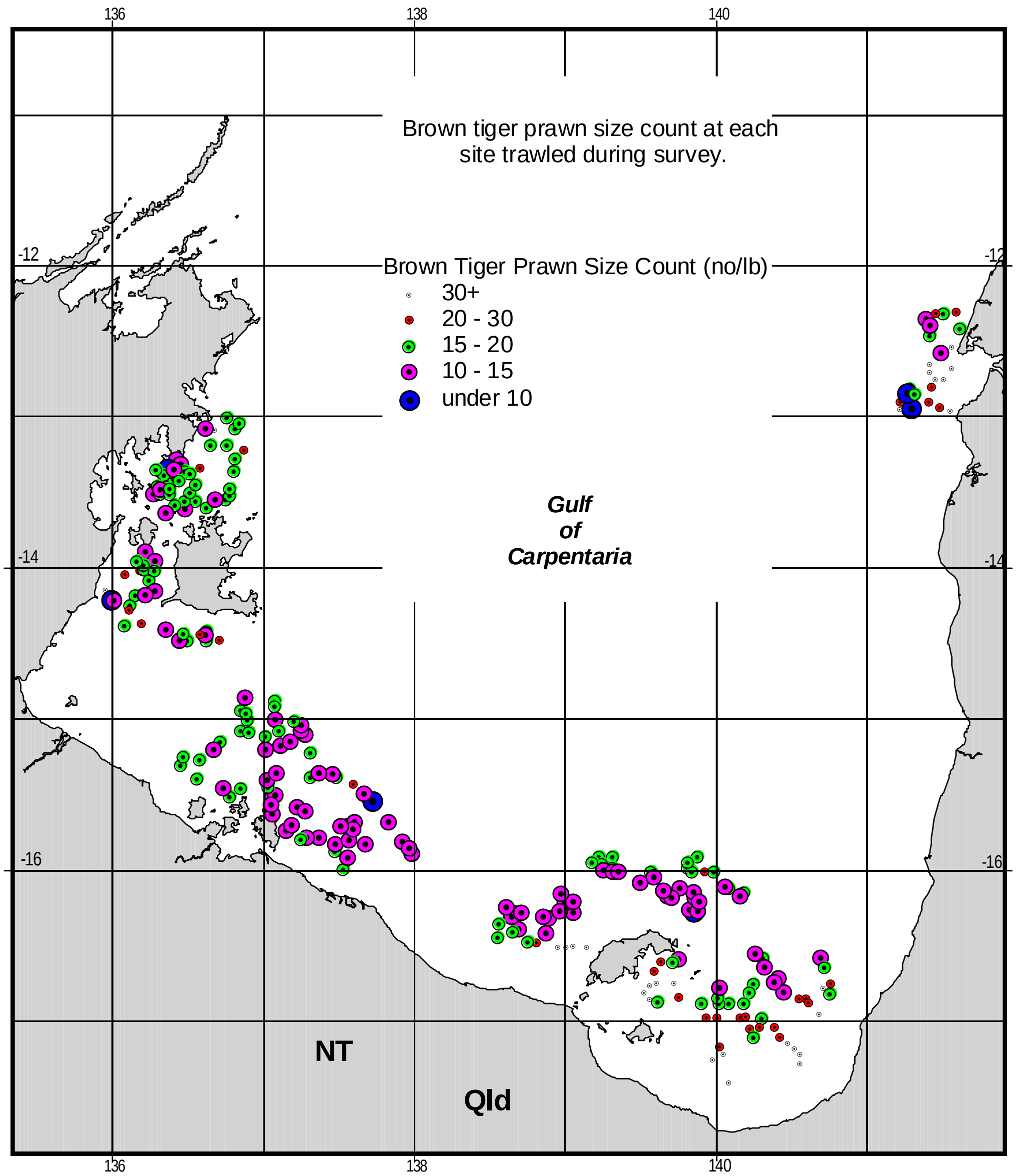

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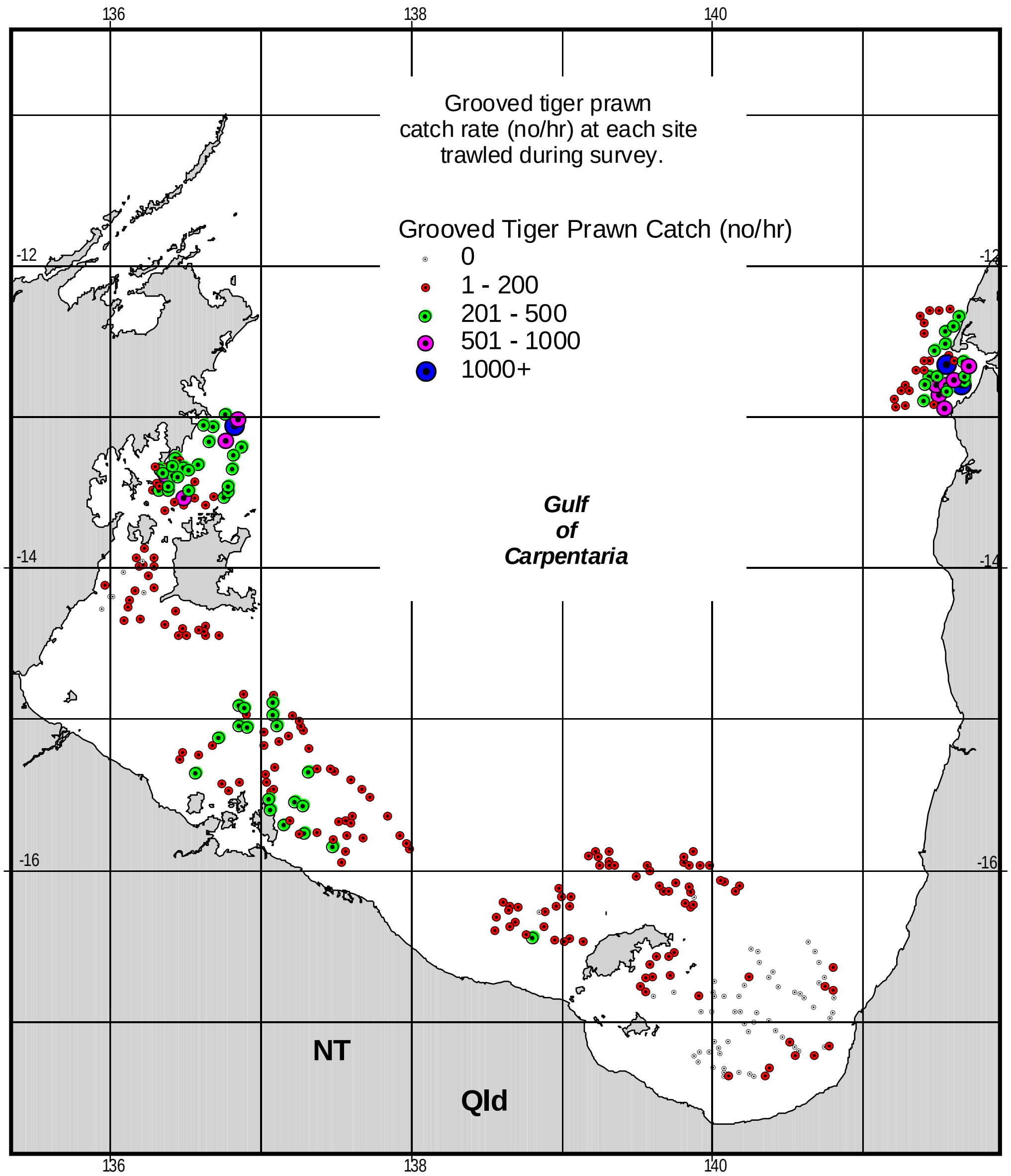

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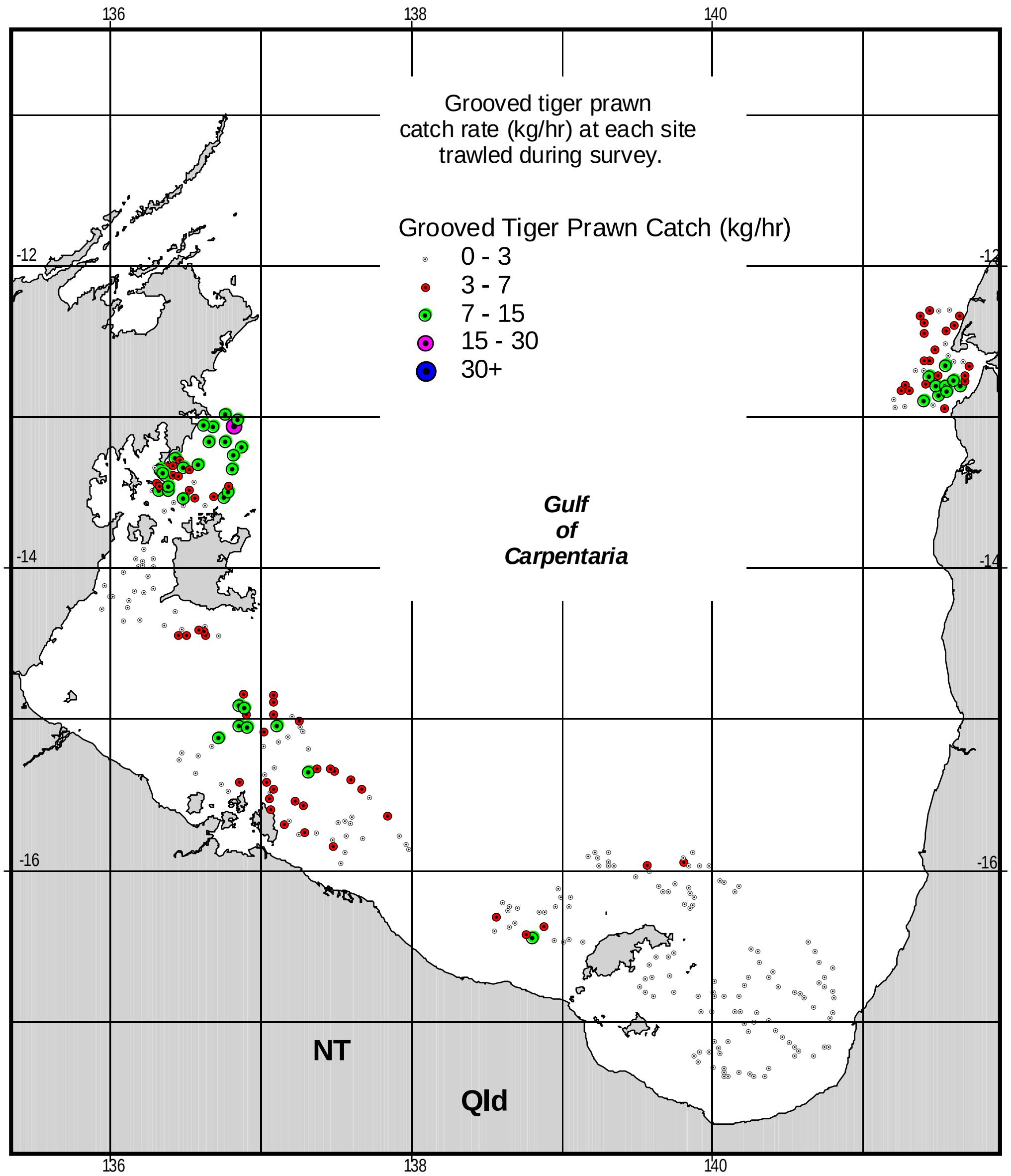

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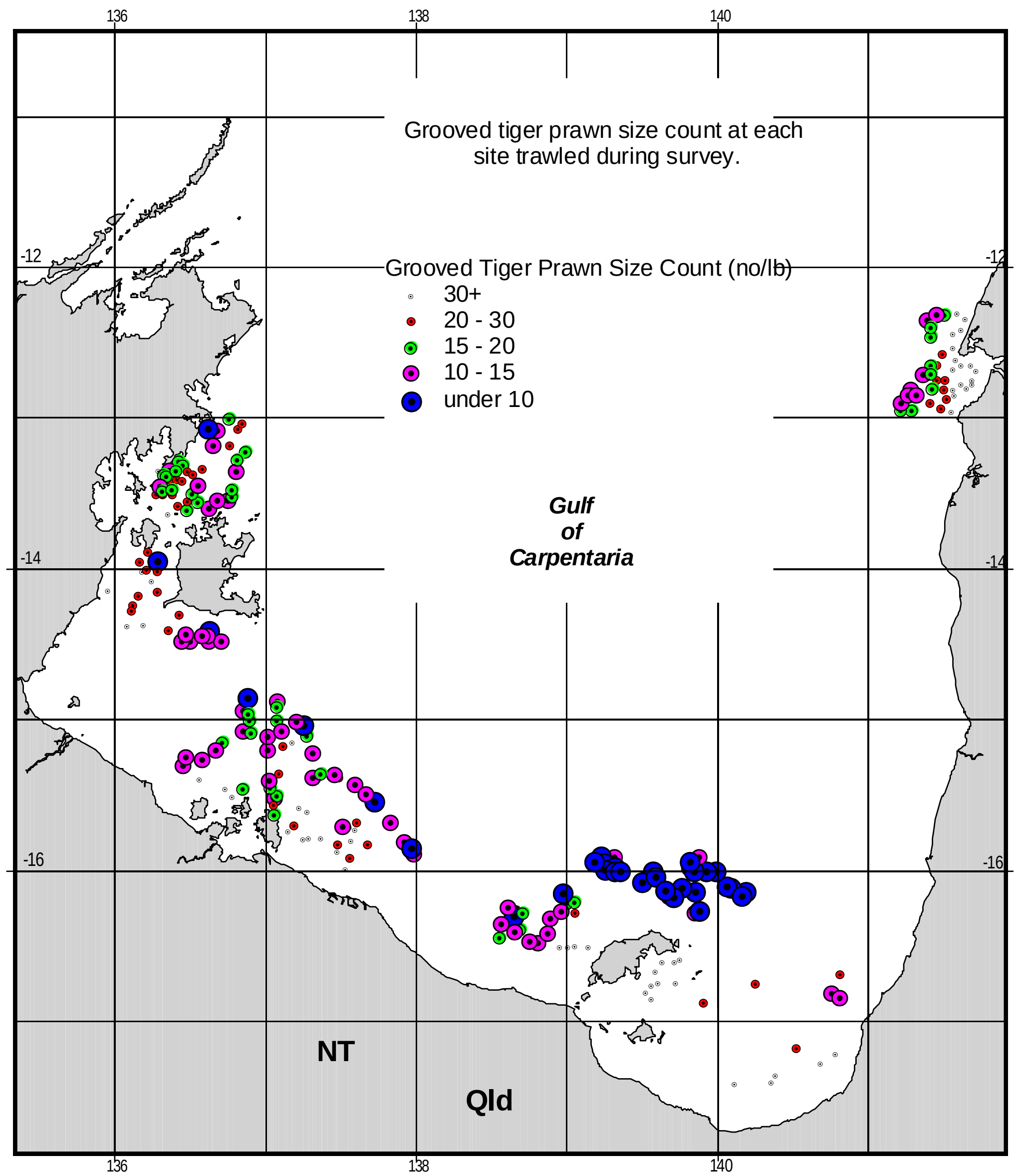

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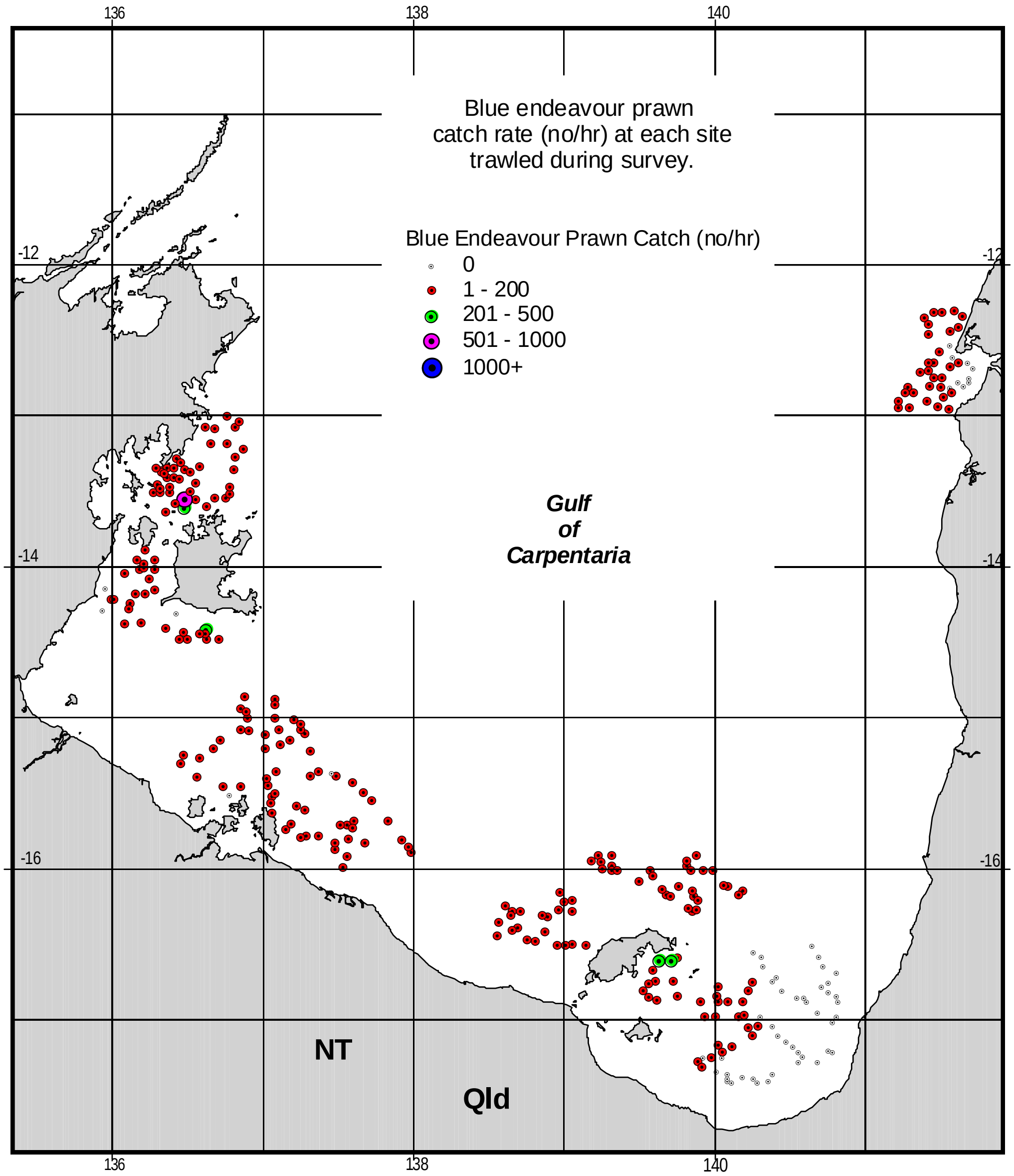

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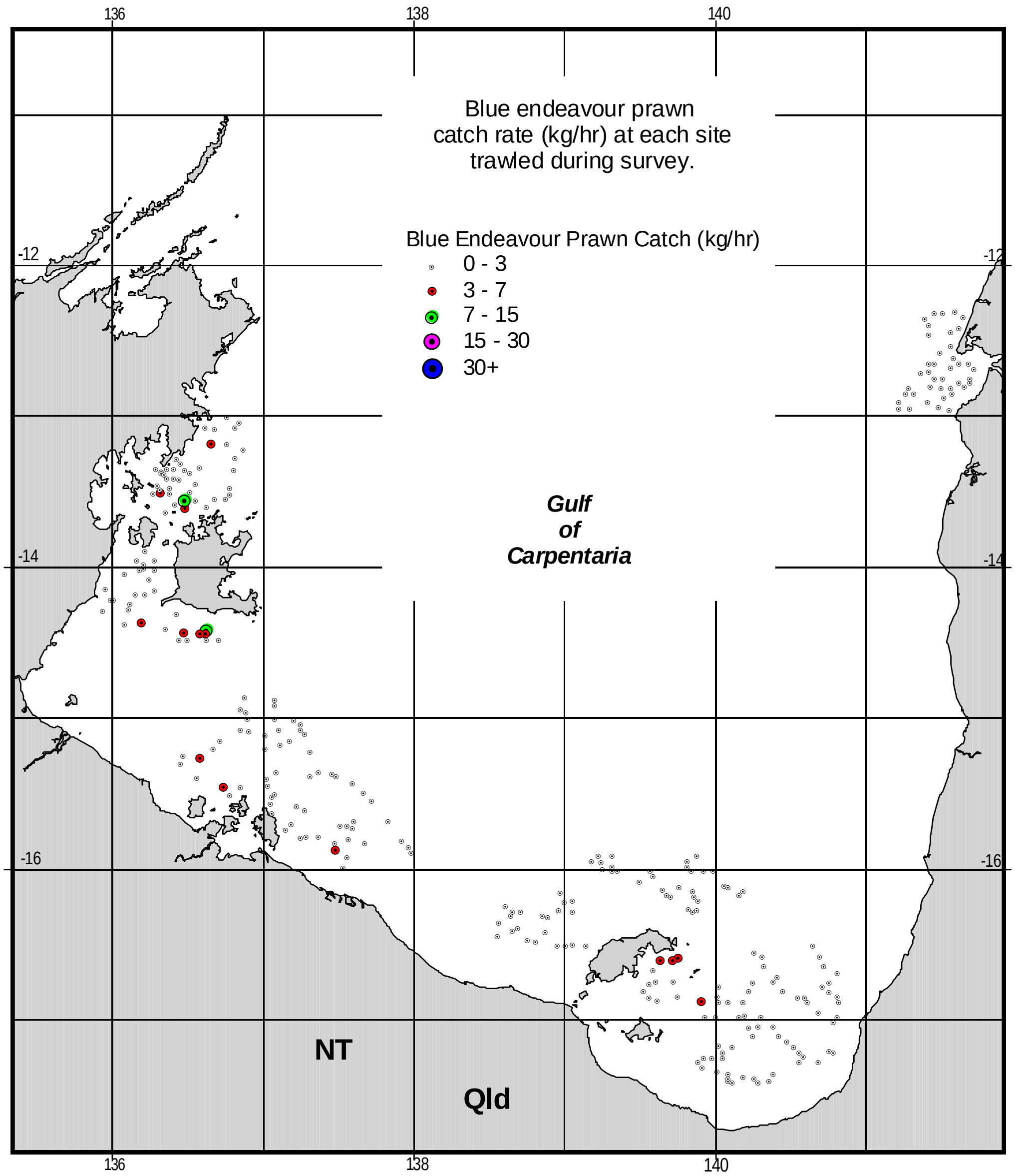

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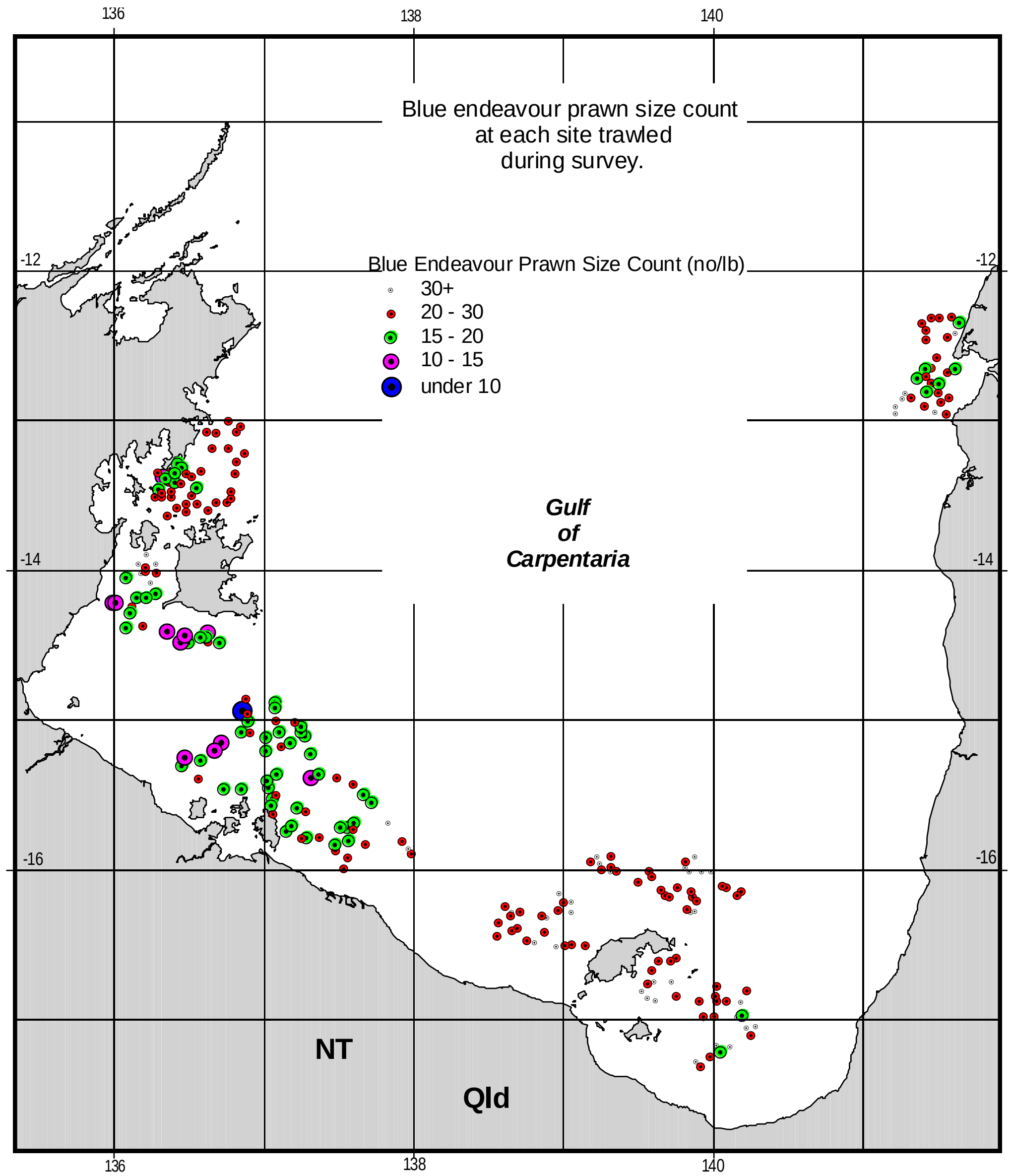

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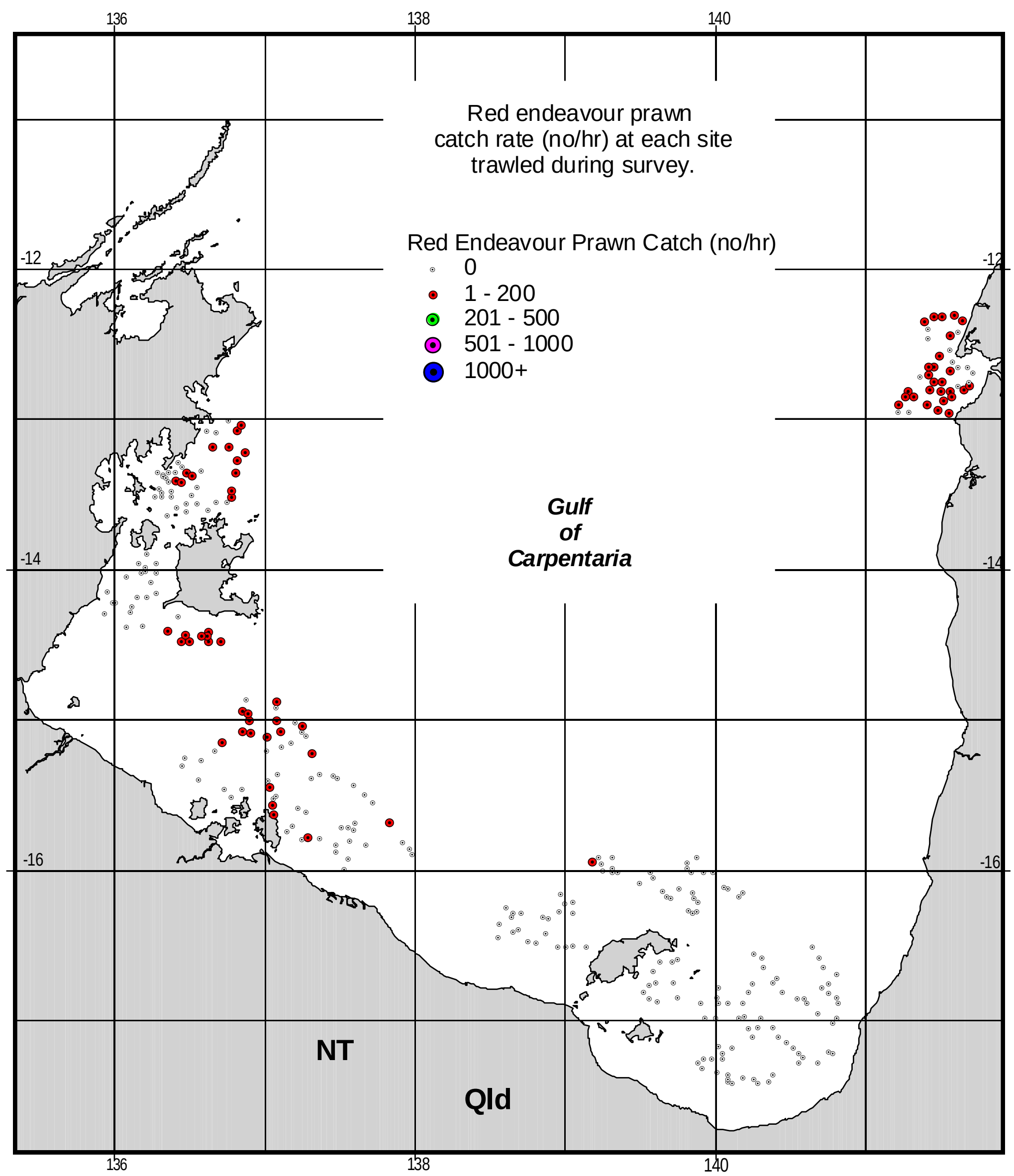

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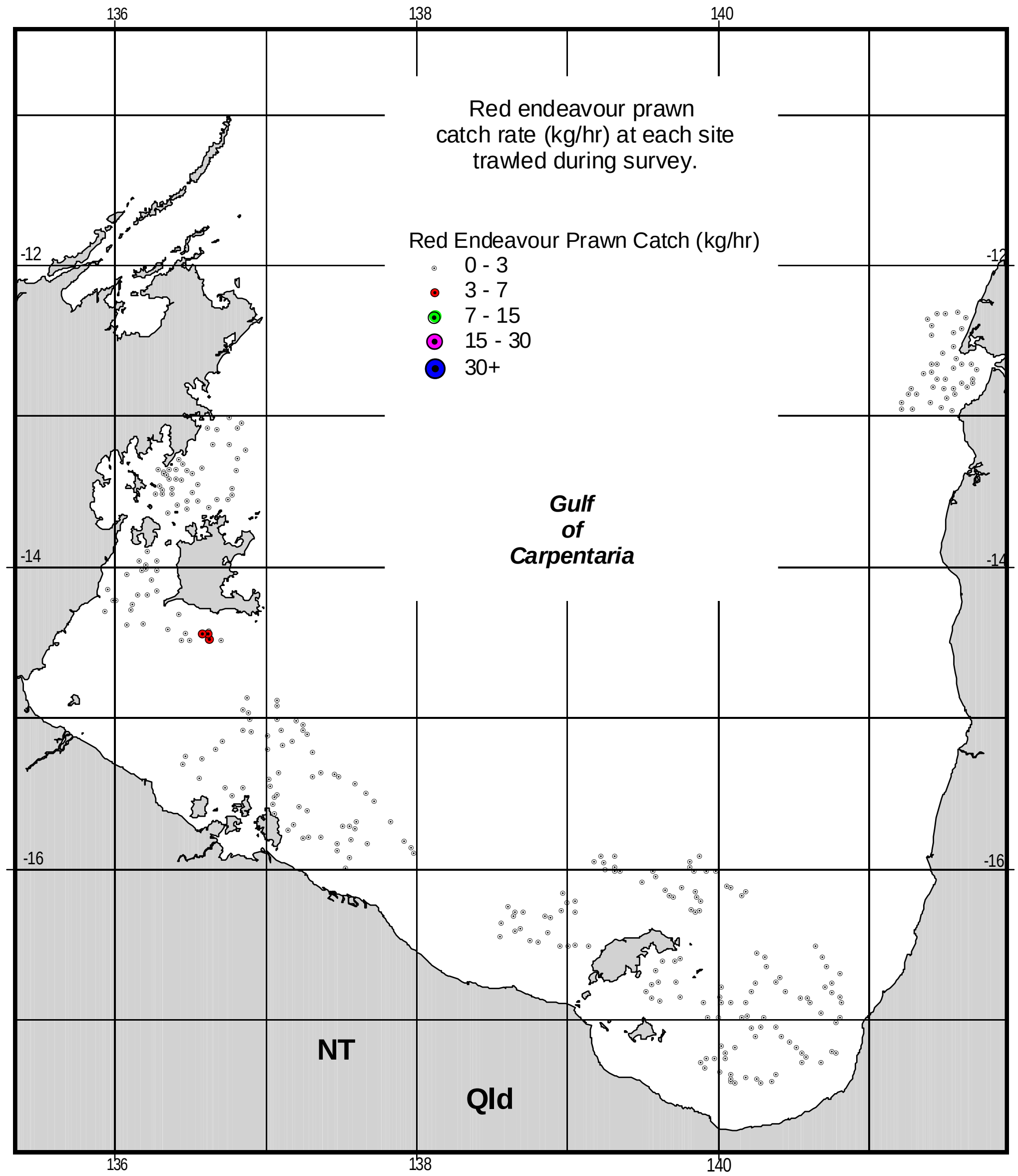

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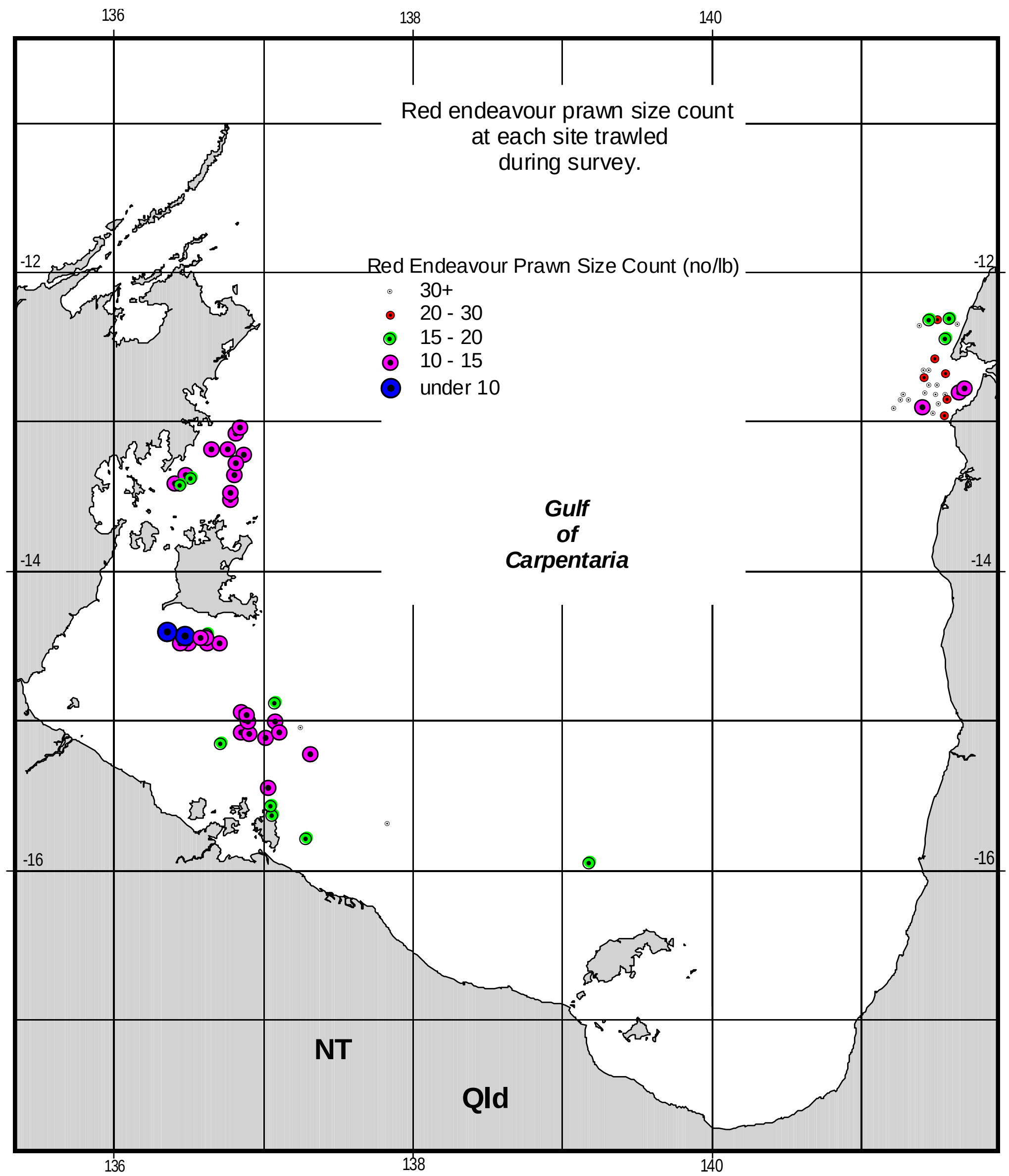

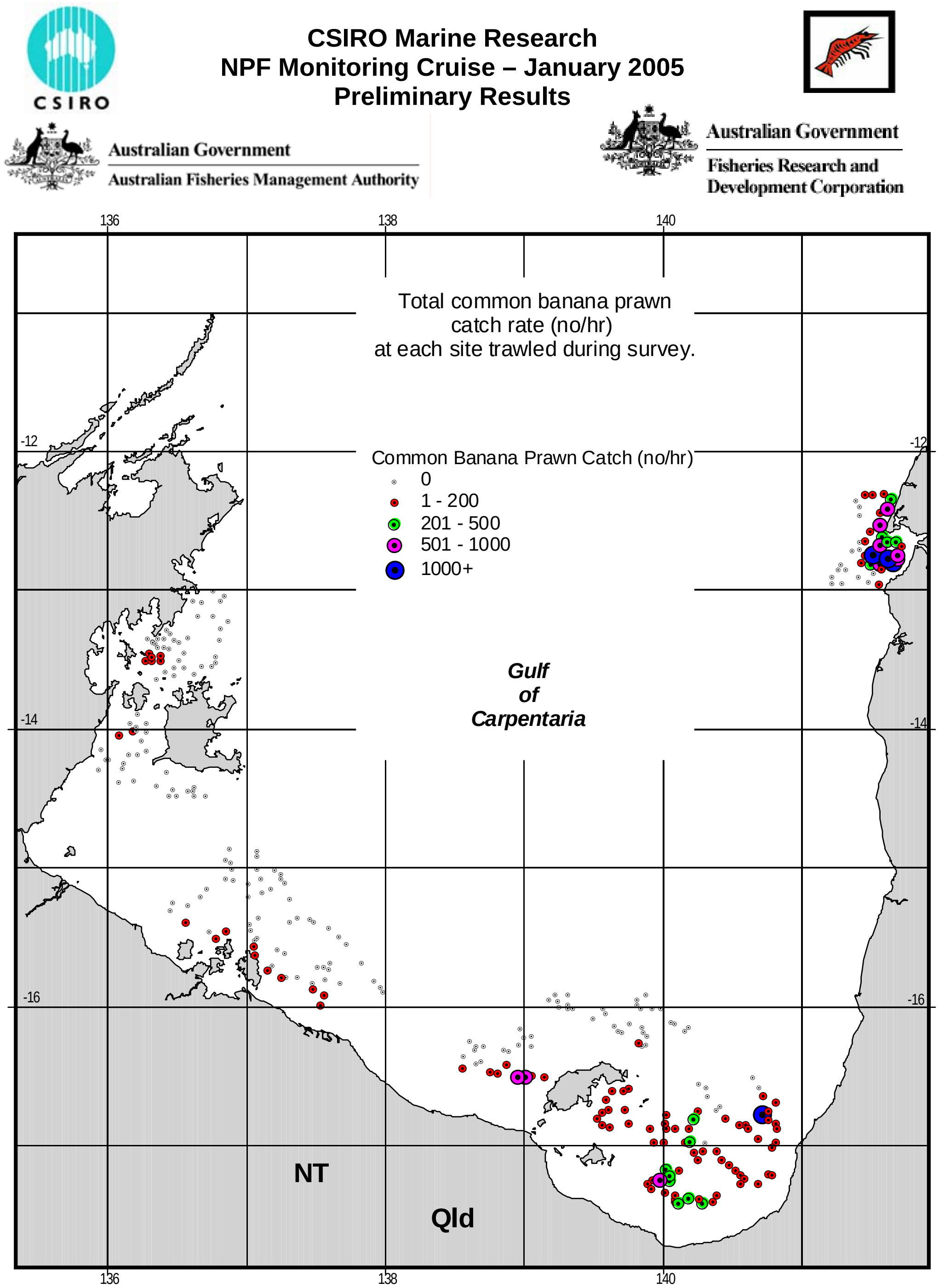
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NPF Monitoring Cruise – January 2005
Preliminary Results
Australian Government
Australian Fisheries Management Authority
Australian Government
Fisheries Research and Development Corporation
136
138
140
Total common banana prawn catch rate (no/hr) at each site trawled during survey.
Common Banana Prawn Catch (no/hr)
0
1 - 200
201 - 500
501 - 1000
1000+
-12
-14
-16
Gulf of Carpentaria
NT
Qld

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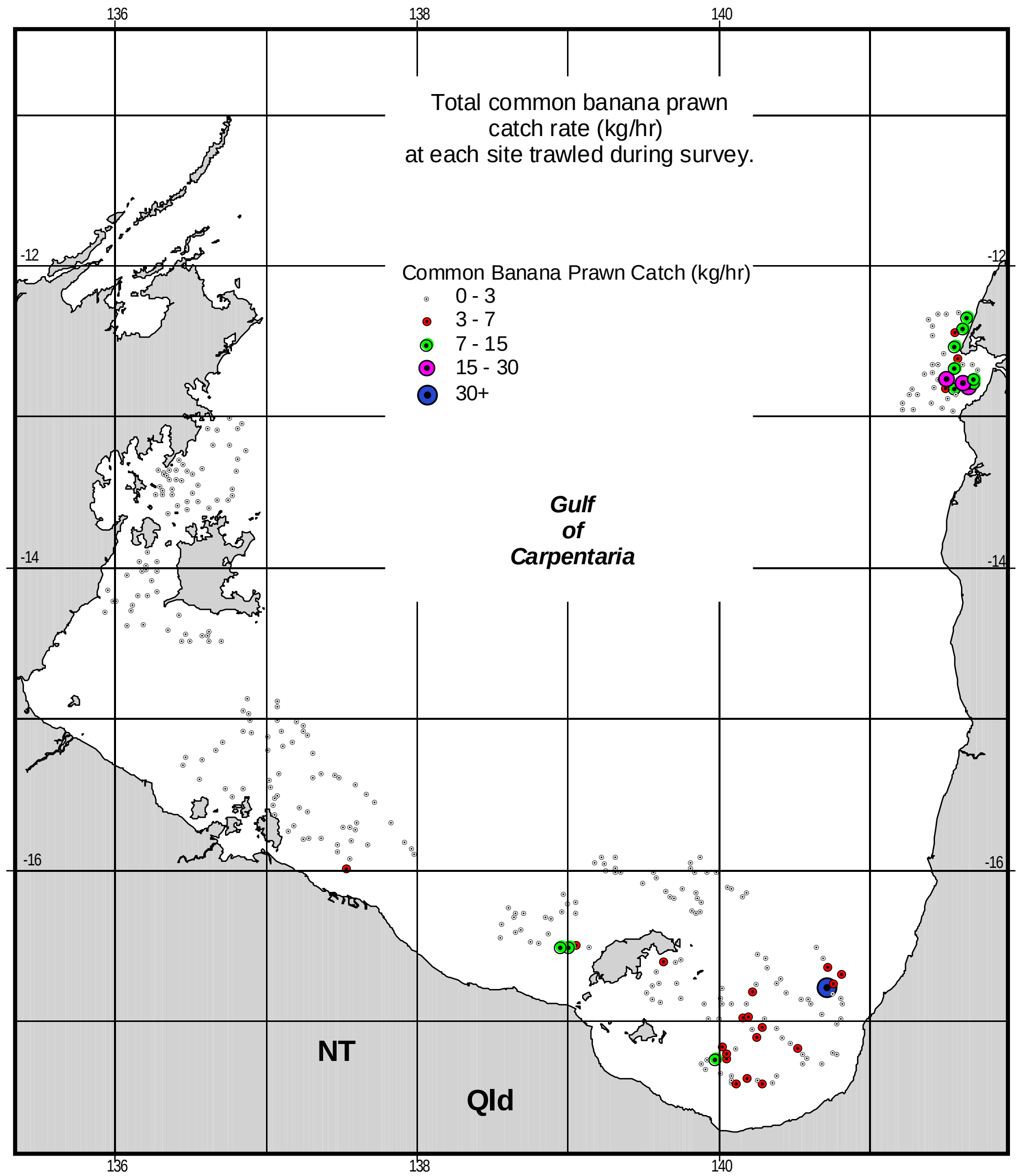

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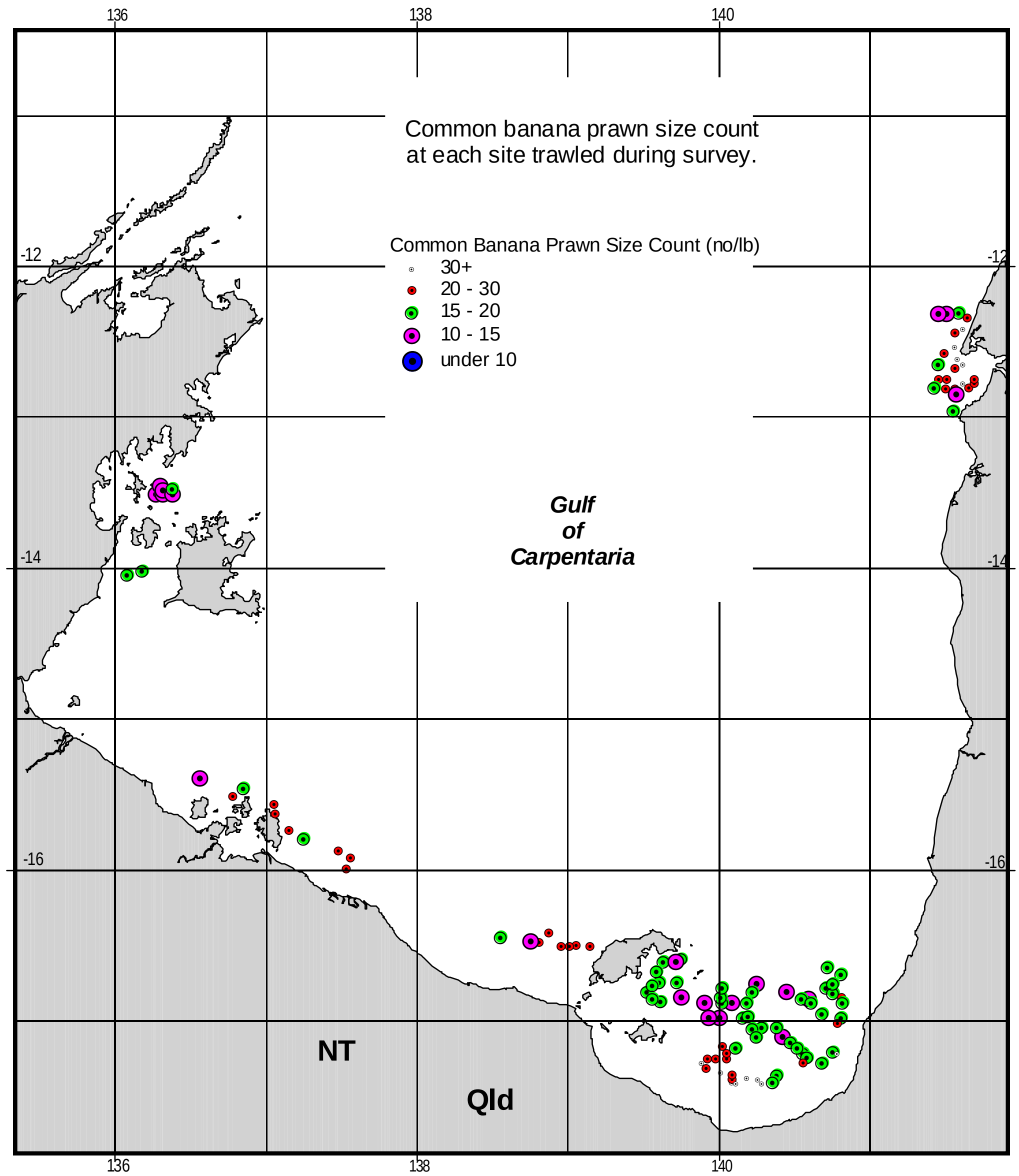

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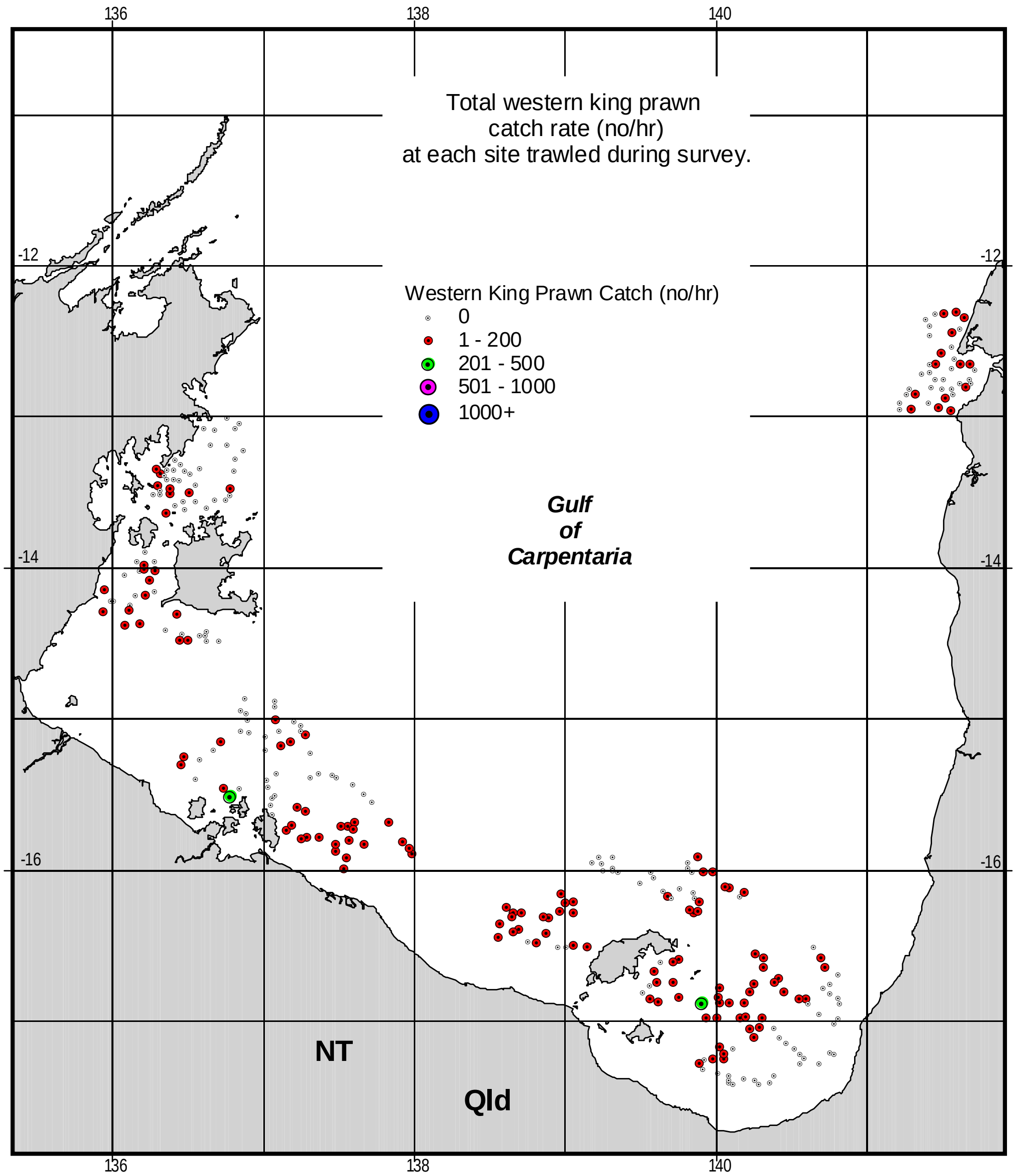

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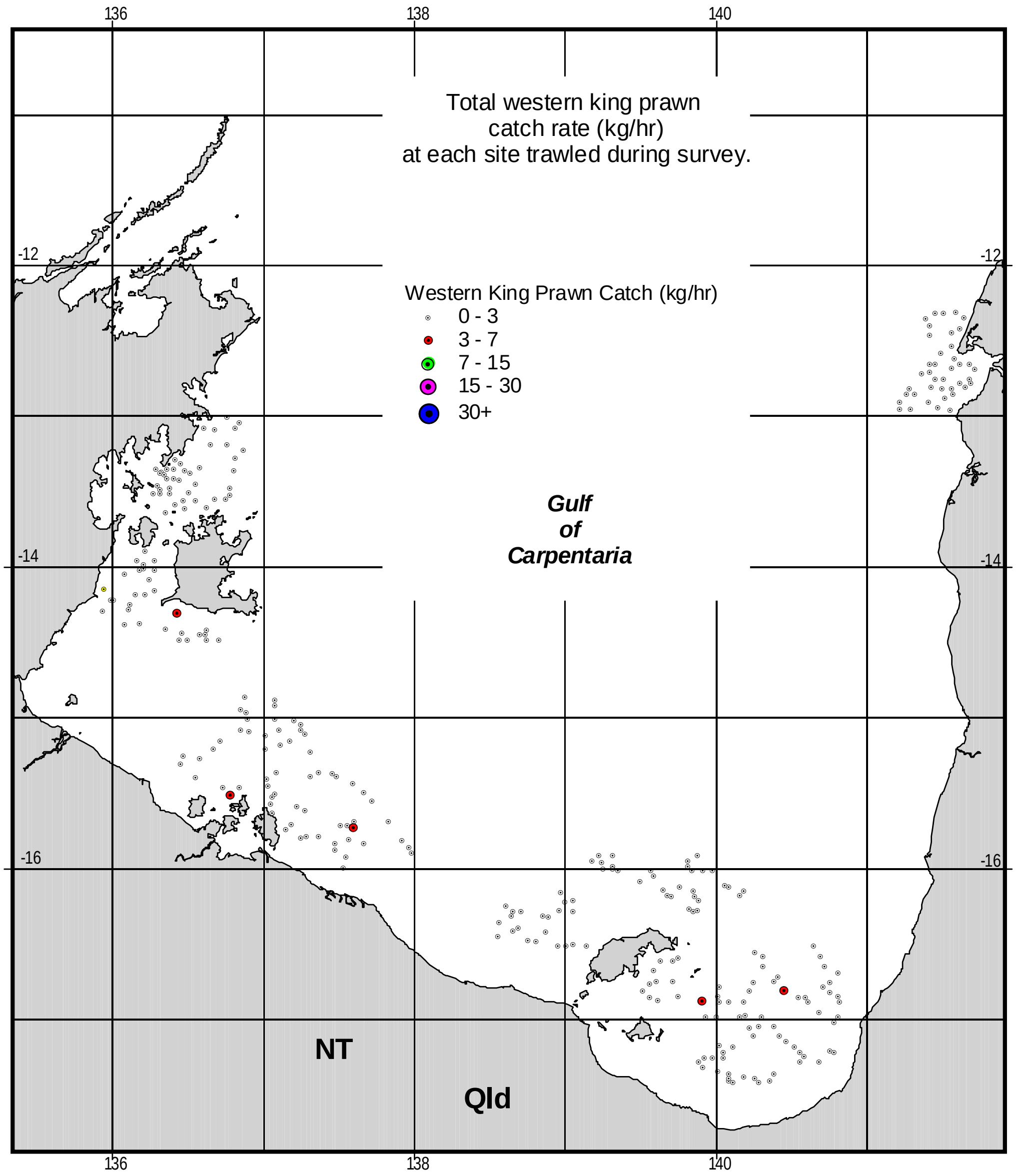

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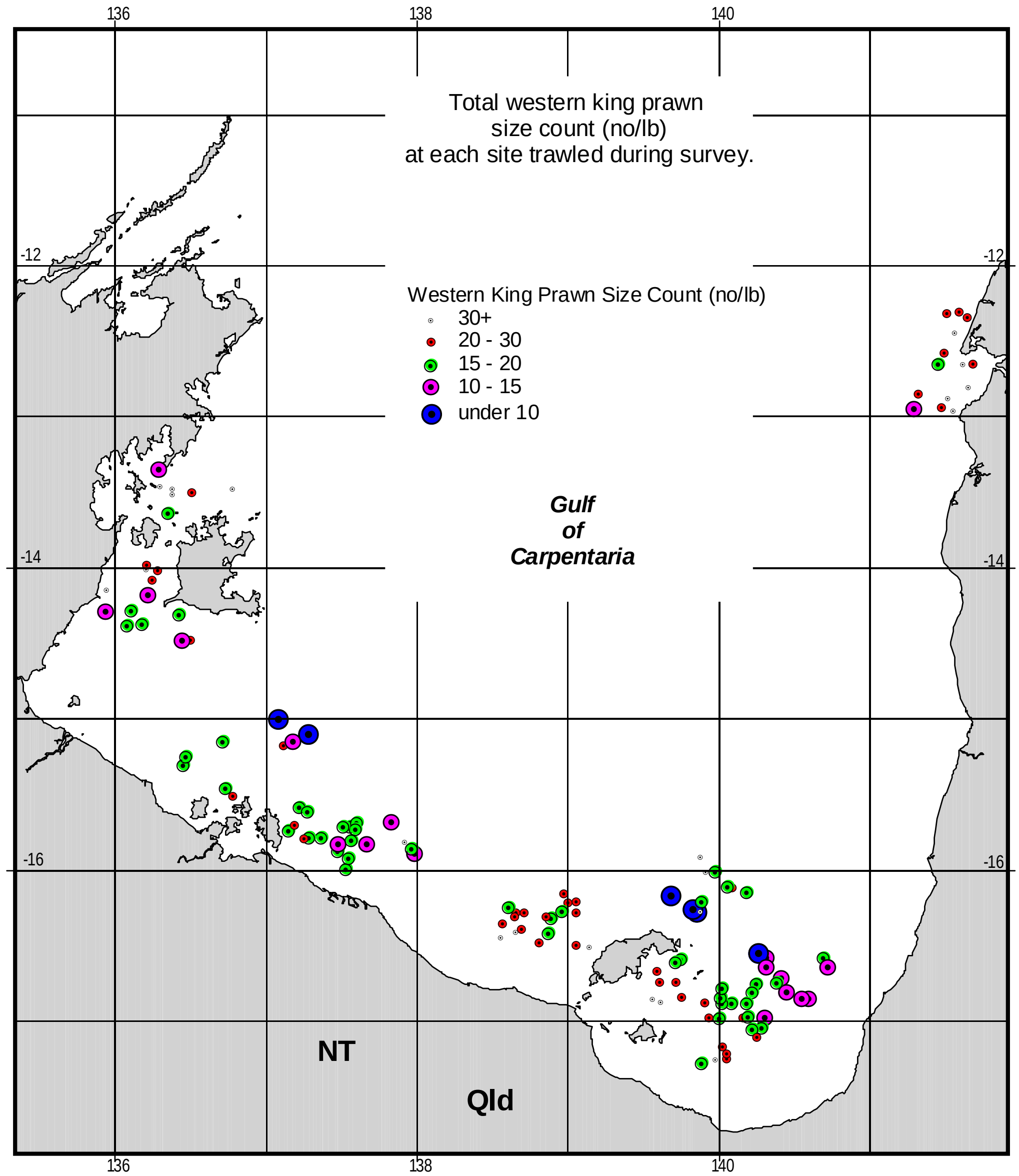

APPENDIX C: PLOTS OF CATCH RATES FOR THE AUGUST 2004 SPAWNING SURVEY

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:

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Preliminary Results

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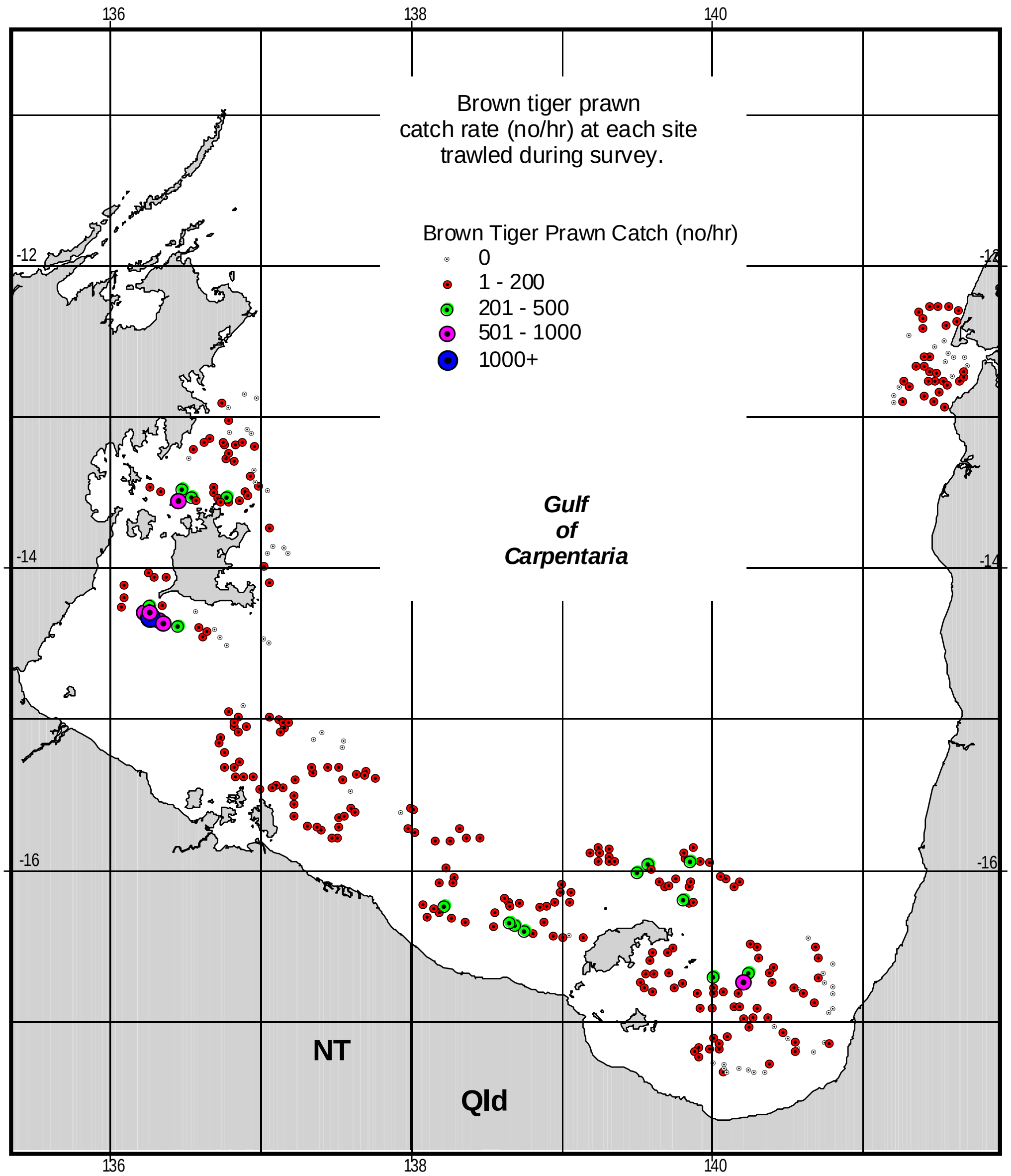

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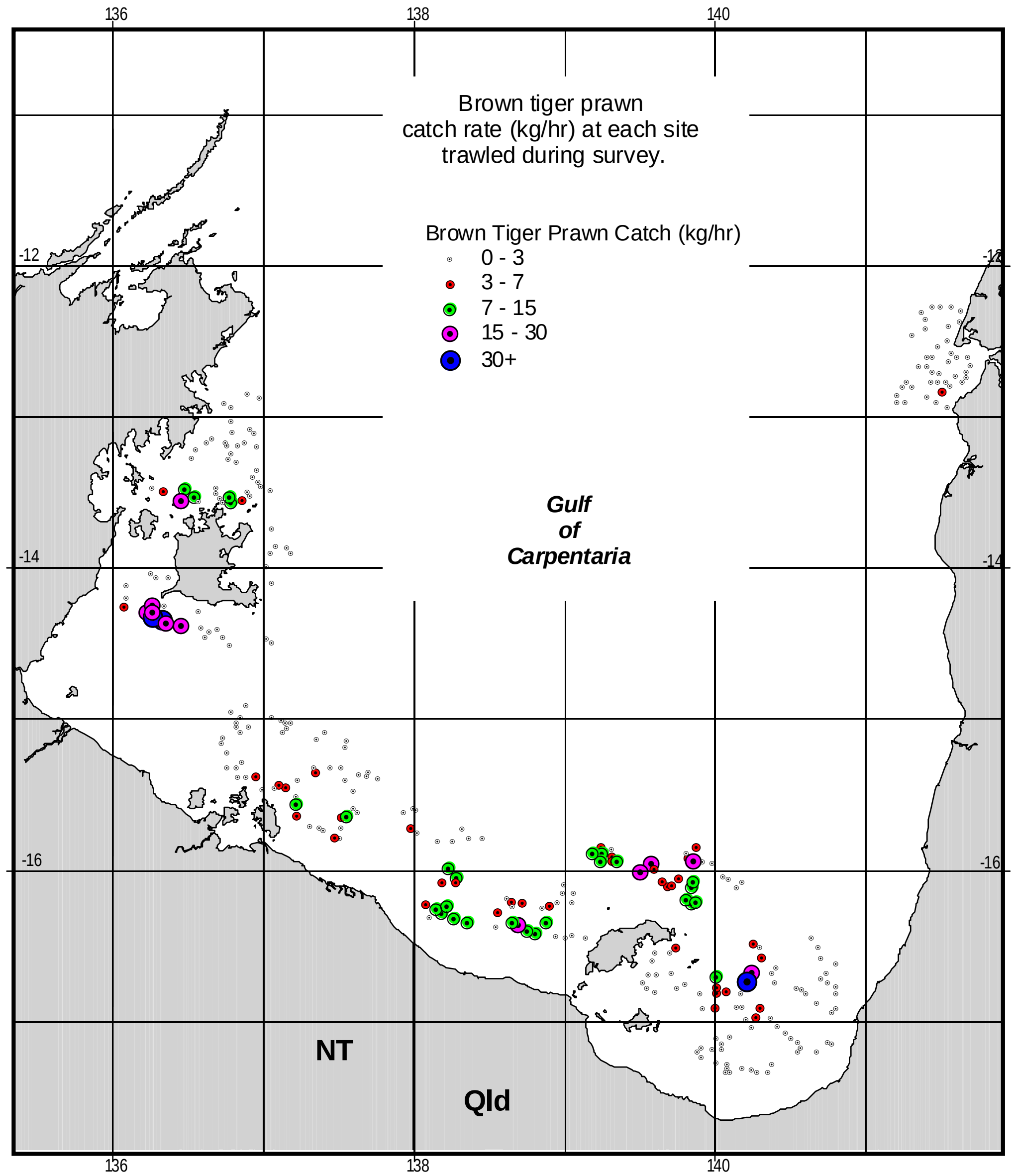

CSIRO Marine Research
NPF Monitoring Cruise – August 2004
Preliminary Results

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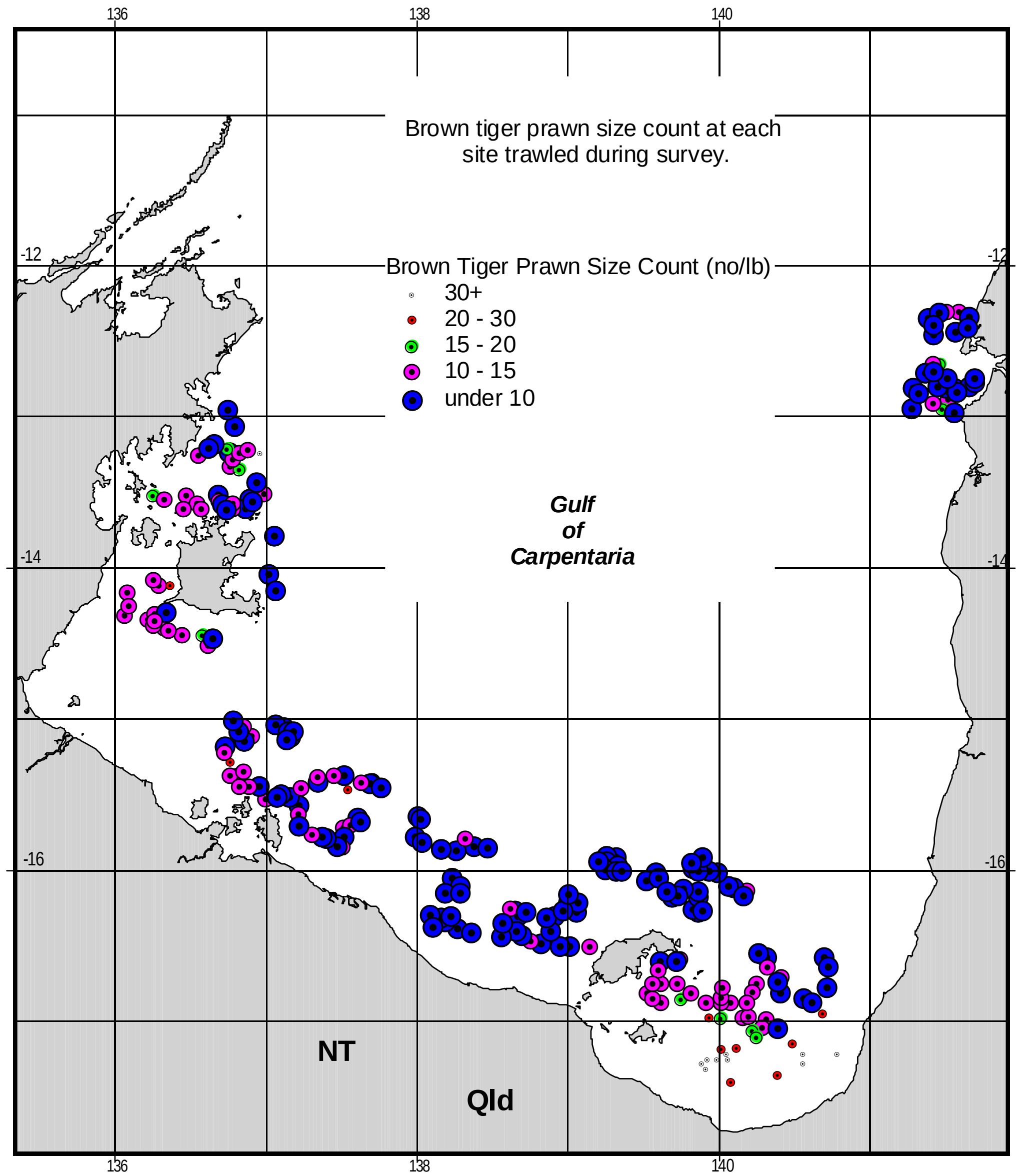

CSIRO Marine Research
NPF Monitoring Cruise – August 2004
Preliminary Results

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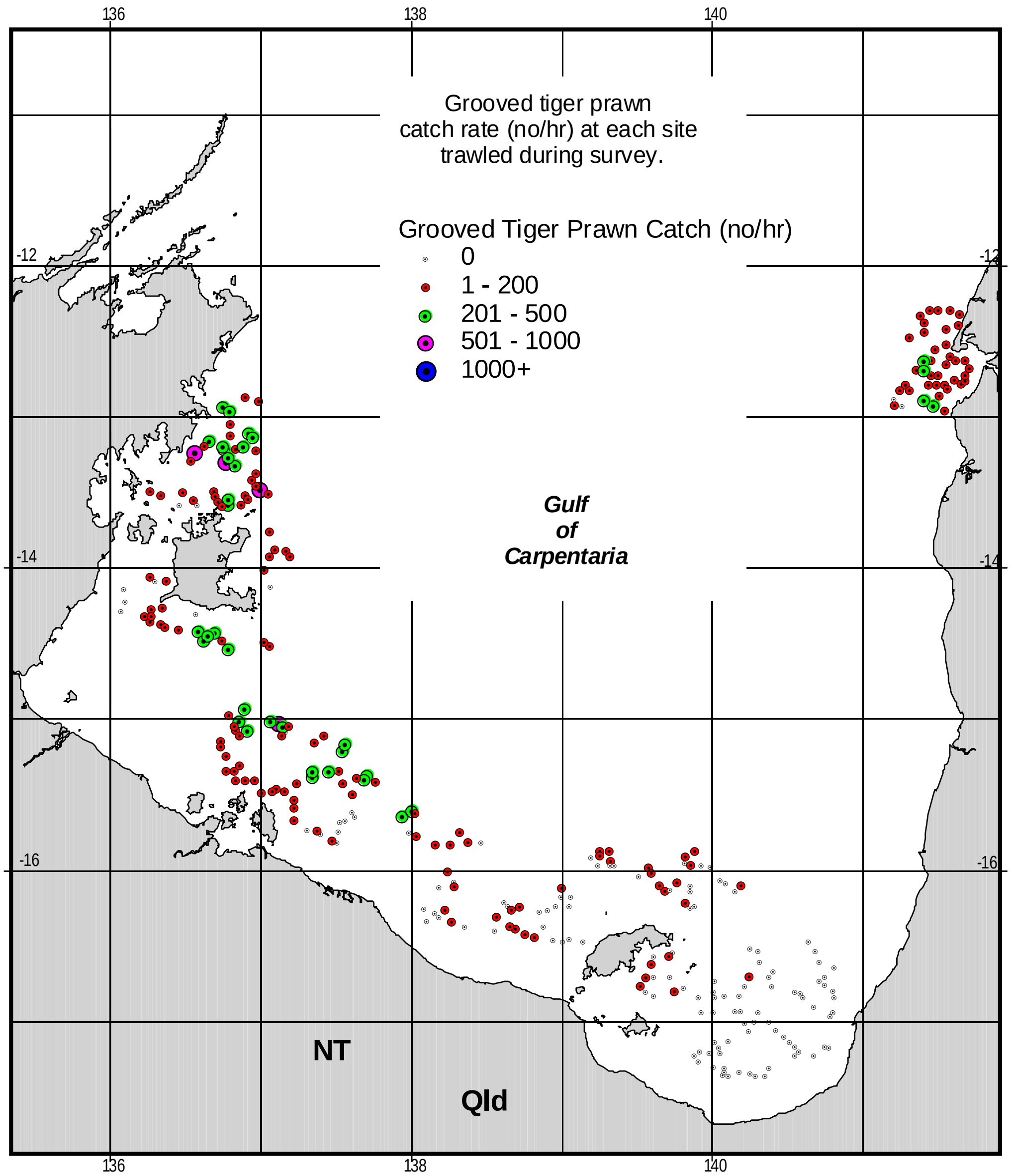

CSIRO Marine Research
NPF Monitoring Cruise – August 2004
Preliminary Results

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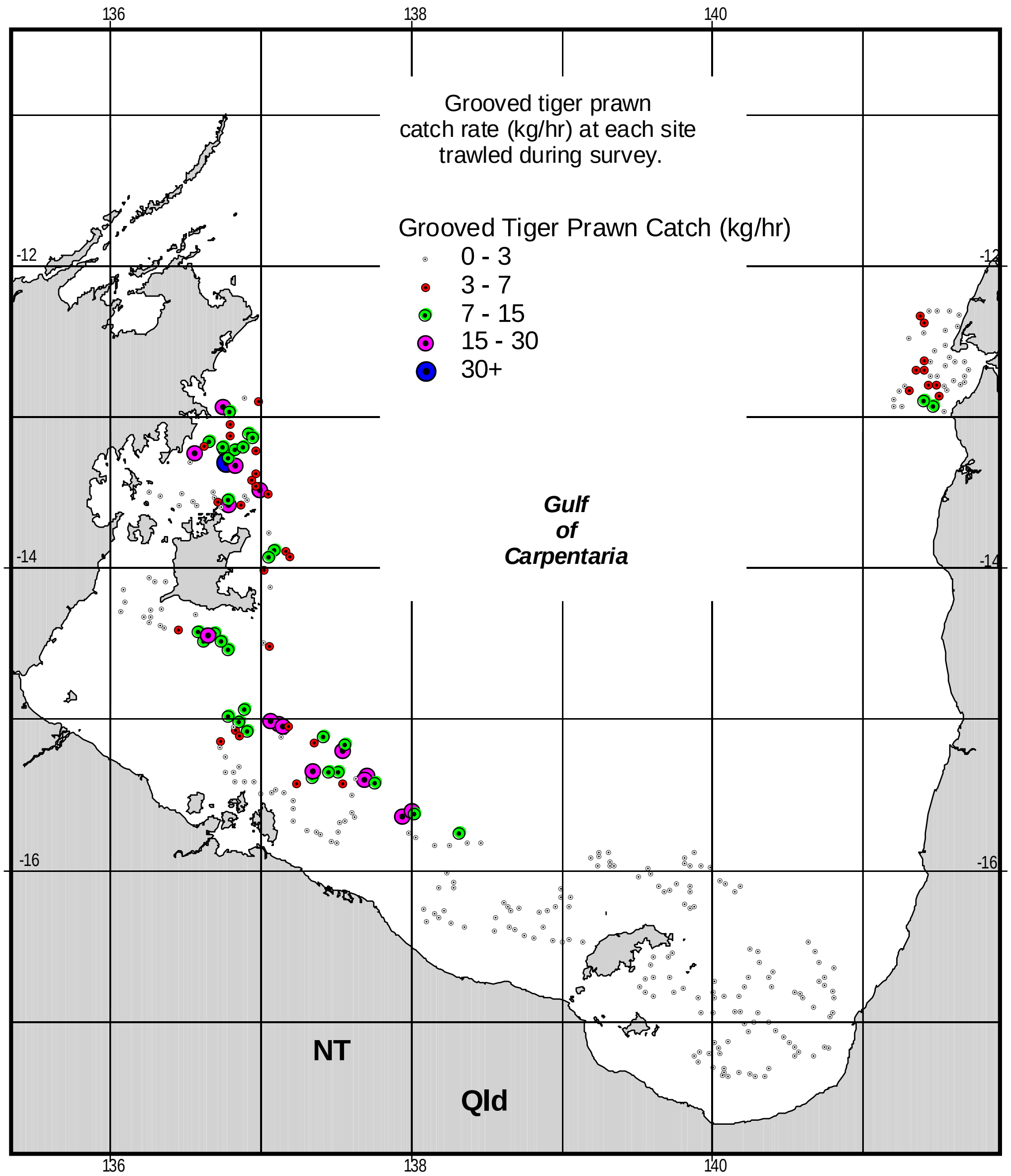
Fisheries Research and Development Corporation



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Preliminary Results

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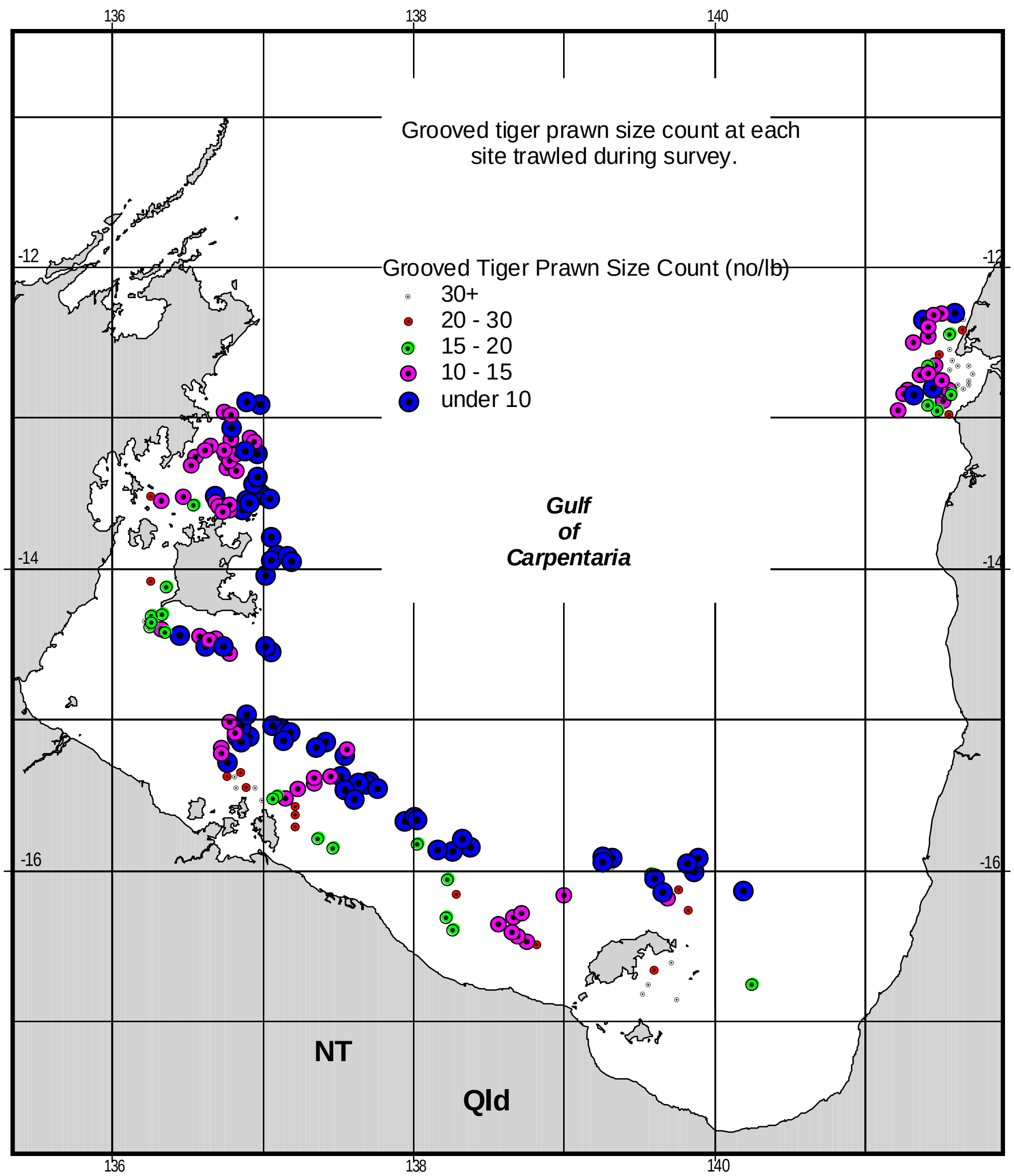

CSIRO Marine Research
NPF Monitoring Cruise – August 2004
Preliminary Results

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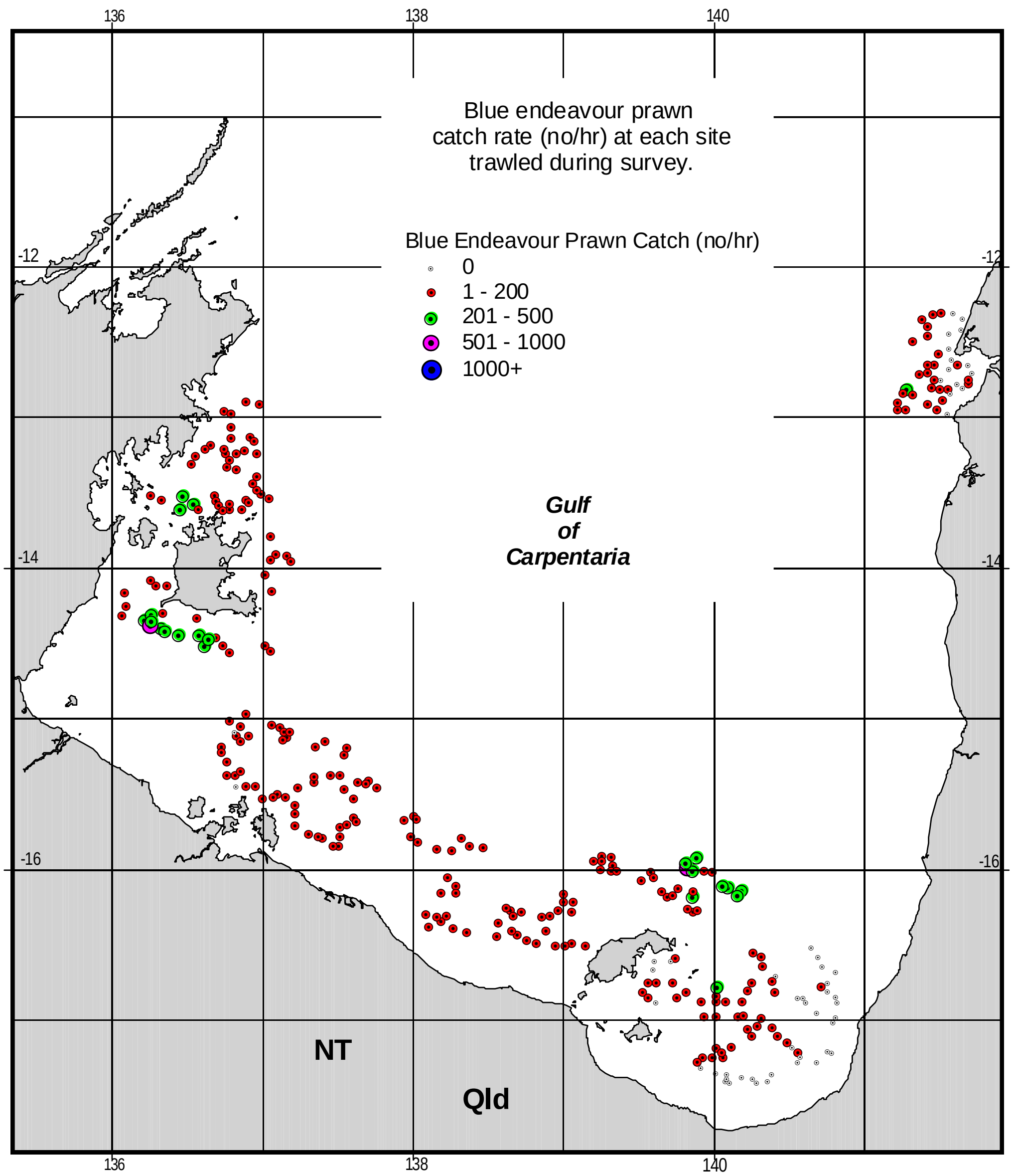

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NPF Monitoring Cruise – August 2004
Preliminary Results

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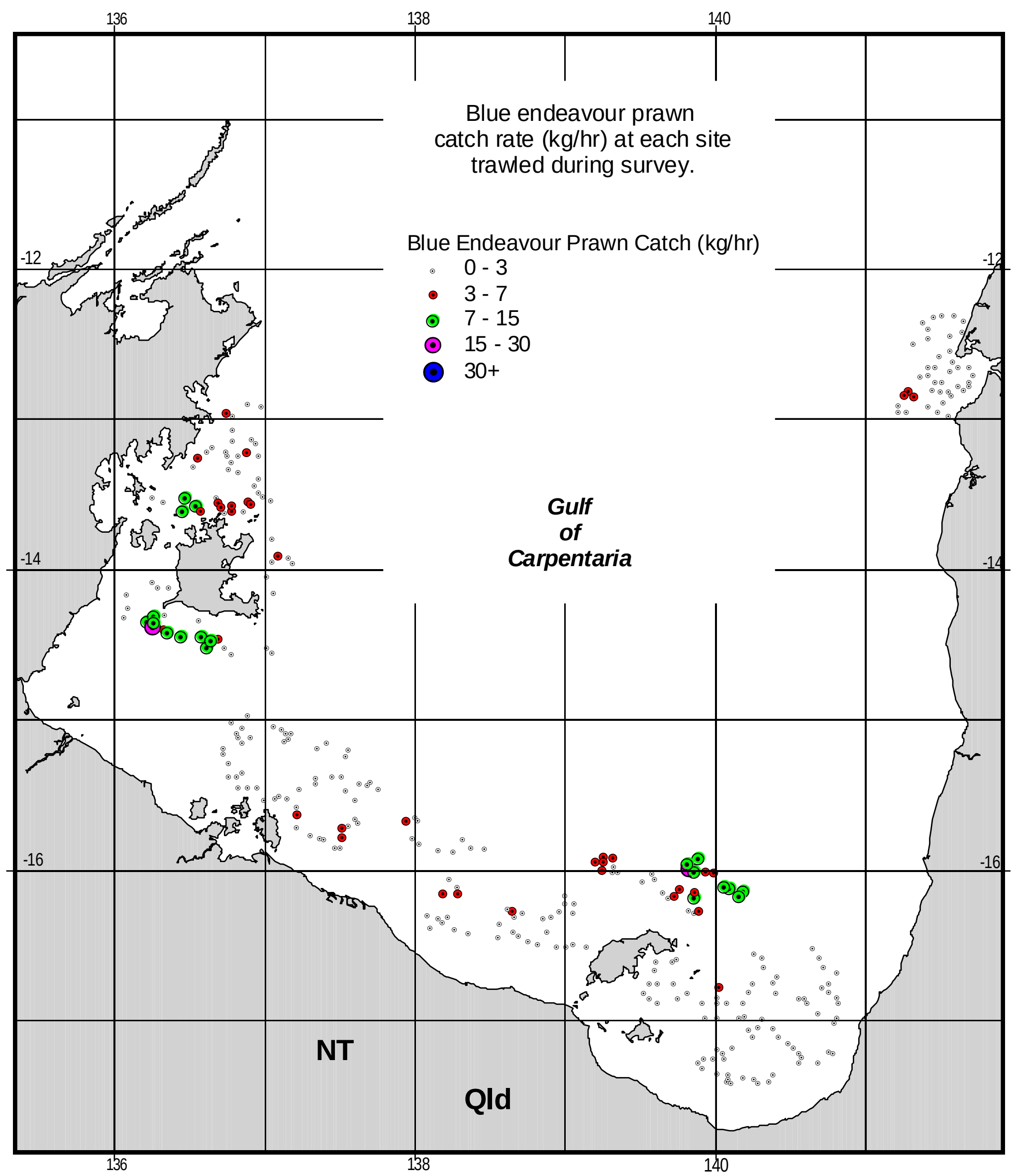

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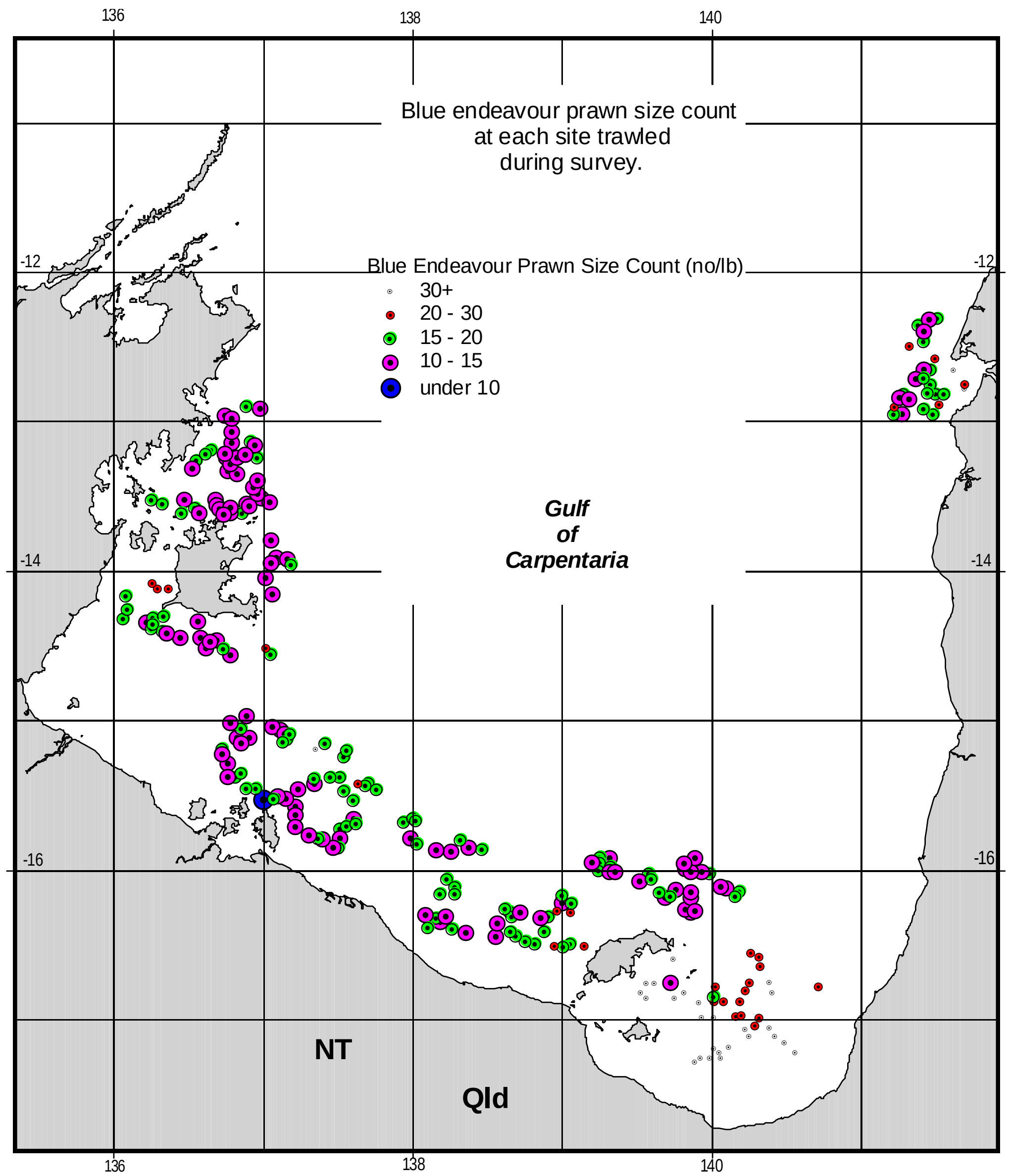
NPF Monitoring Cruise – August 2004
Preliminary Results

Australian Government
Australian Fisheries Management Authority

Australian Government
Fisheries Research and Development Corporation



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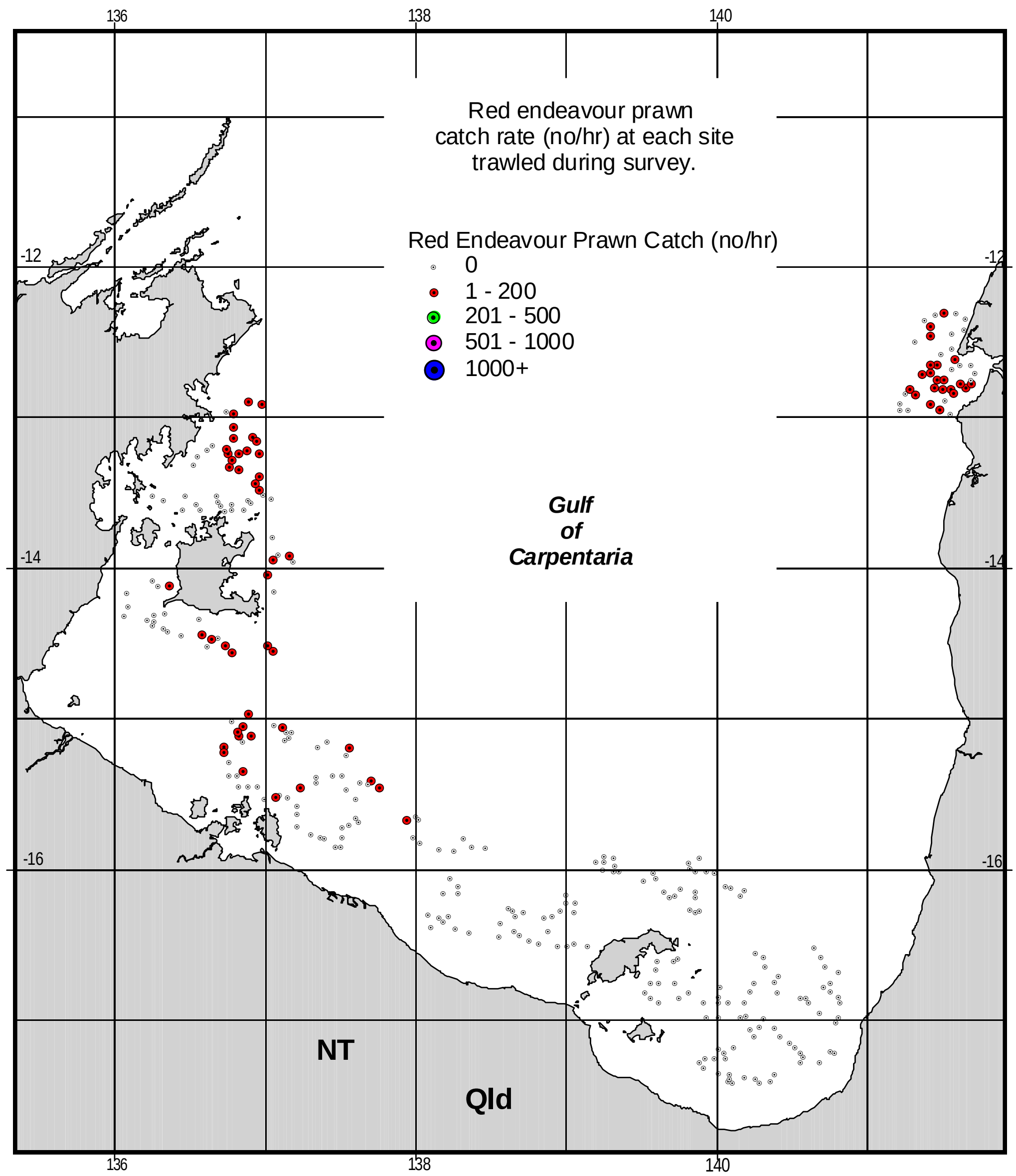

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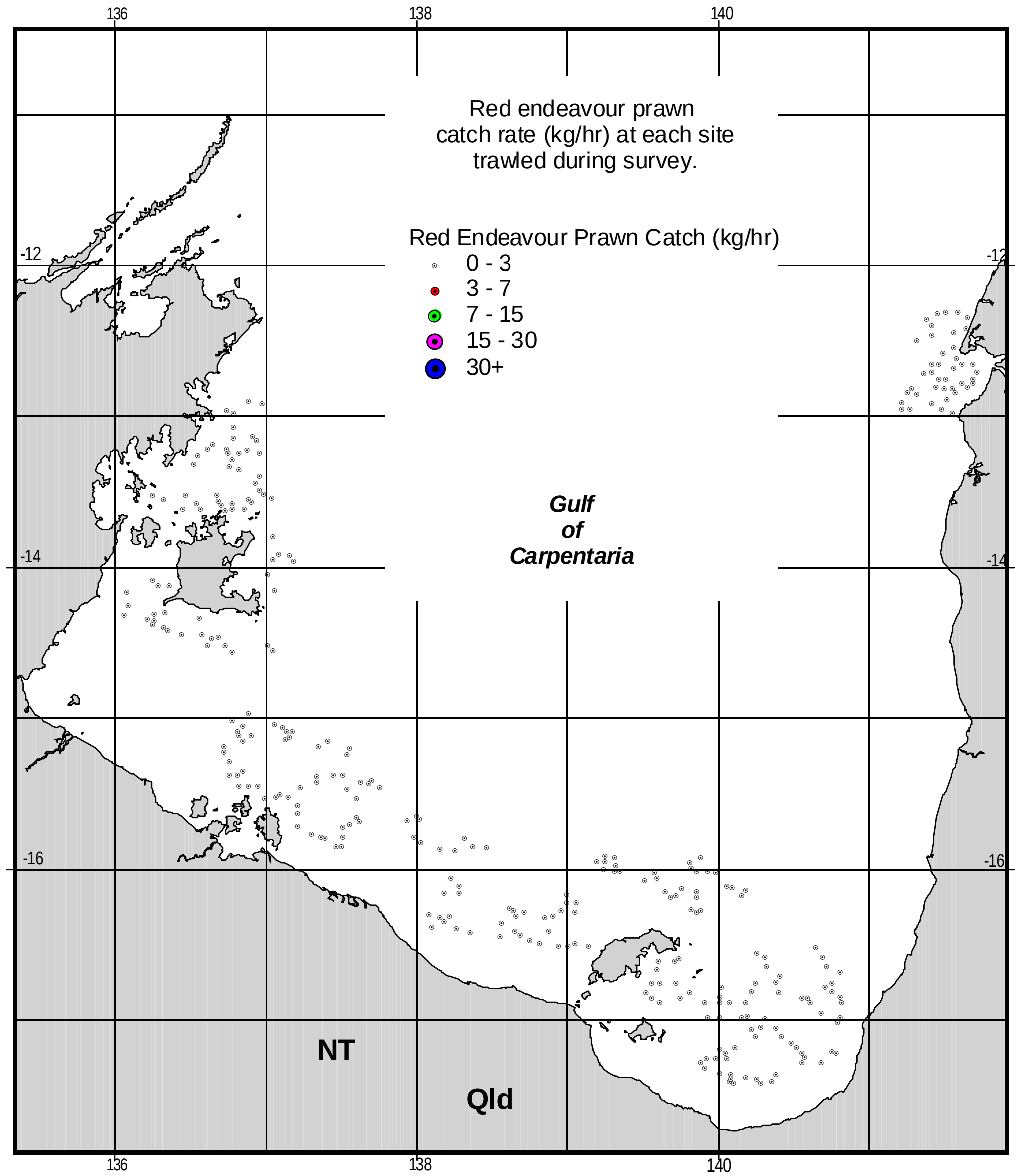

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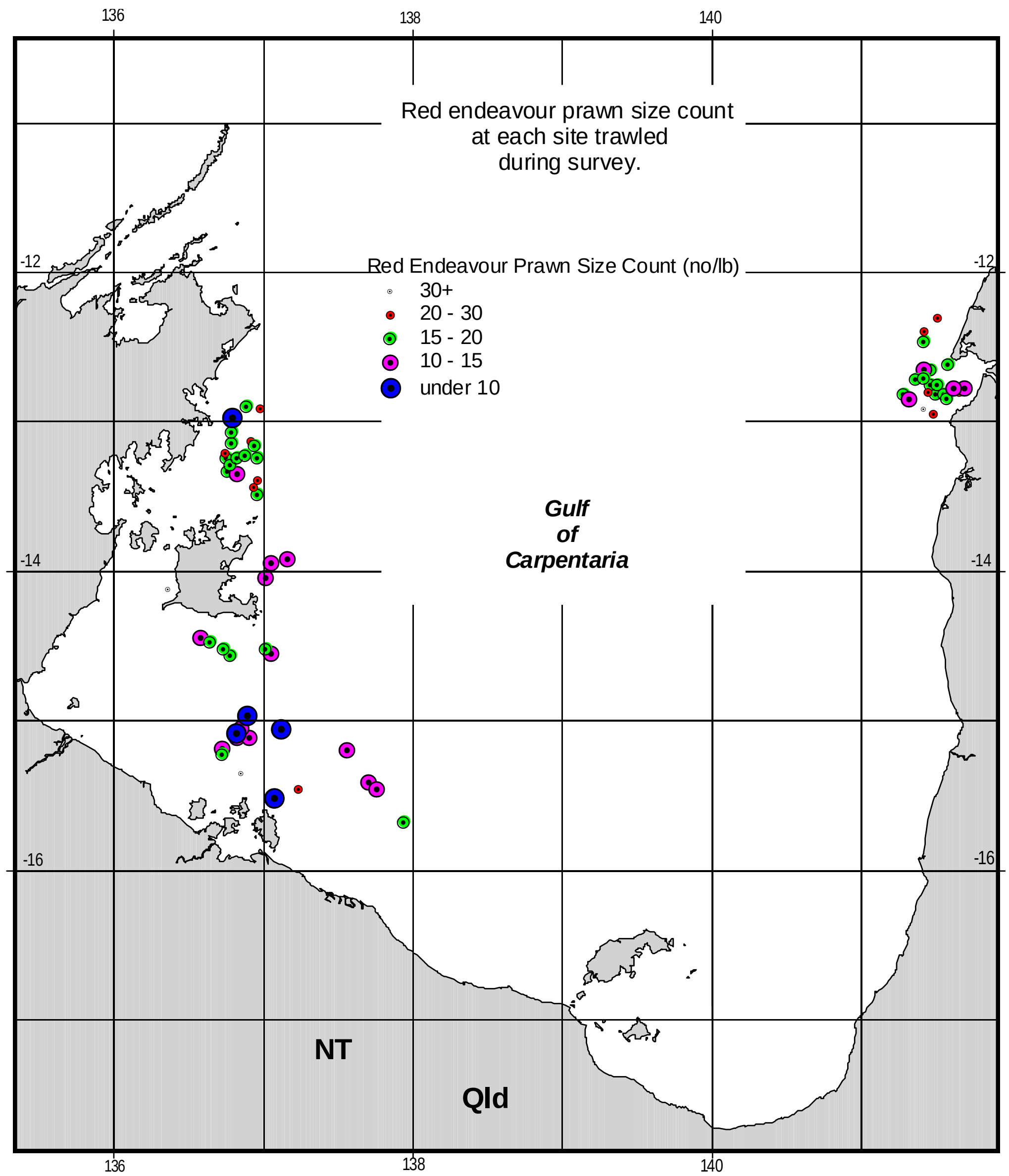

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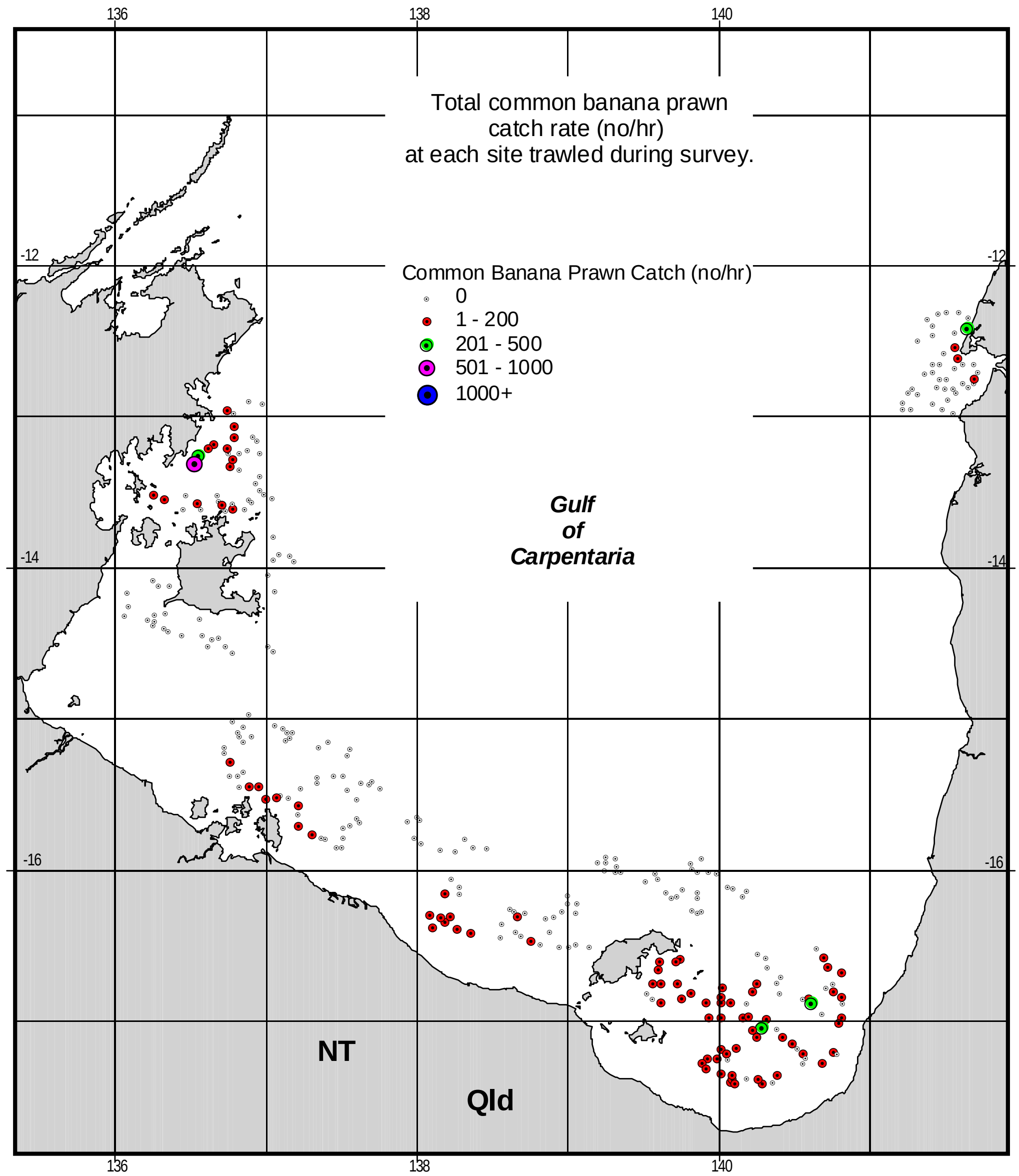

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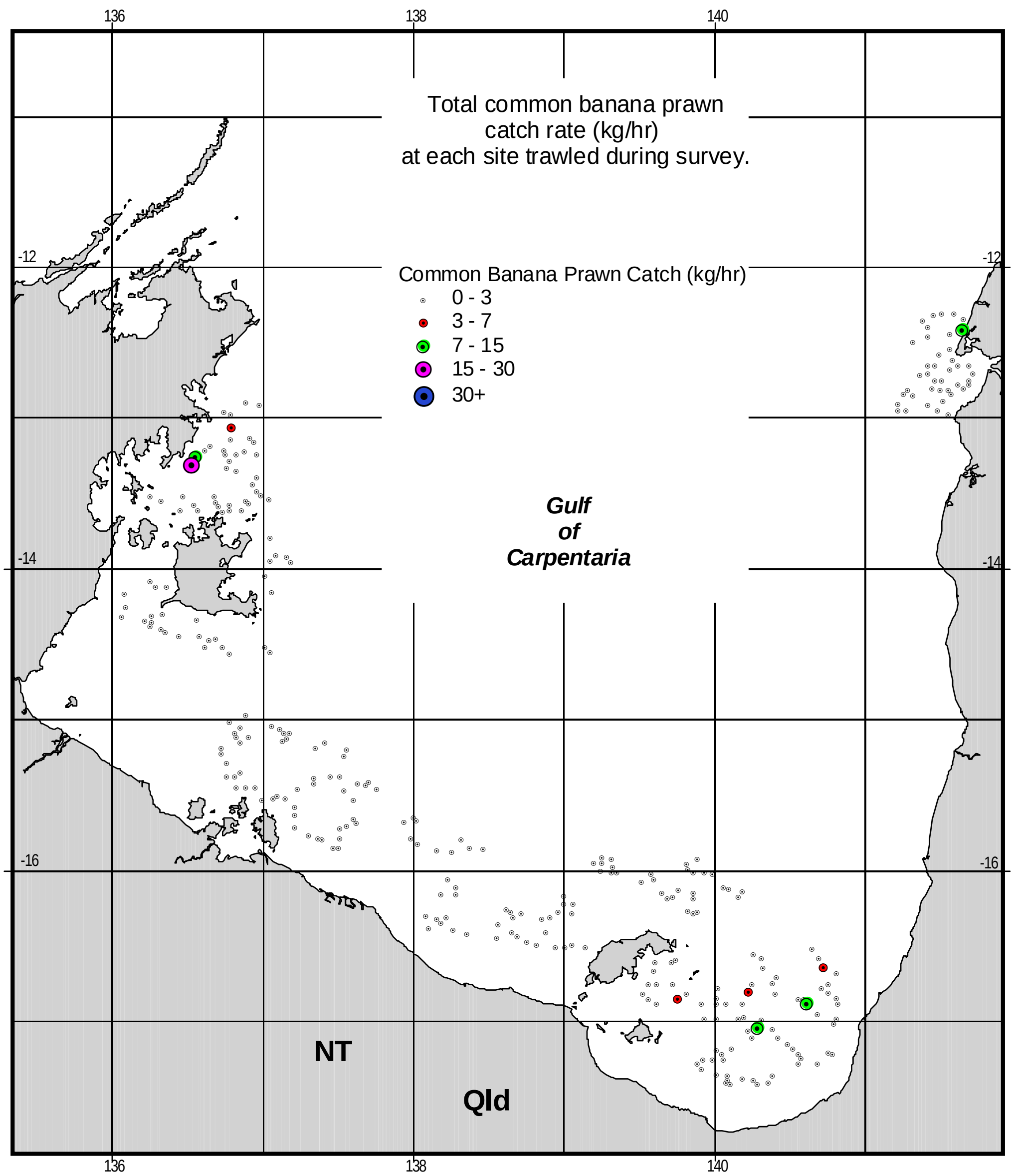

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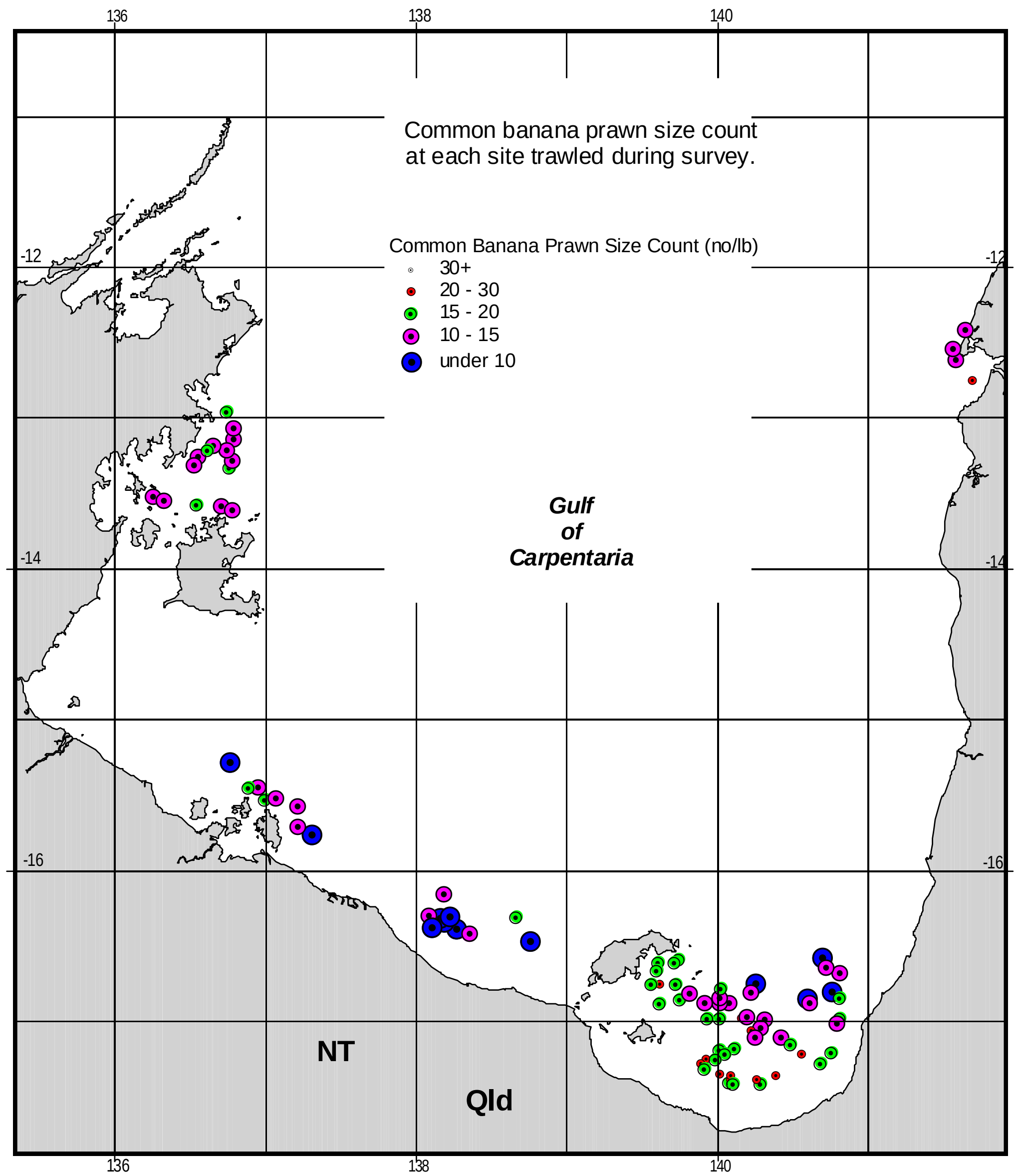

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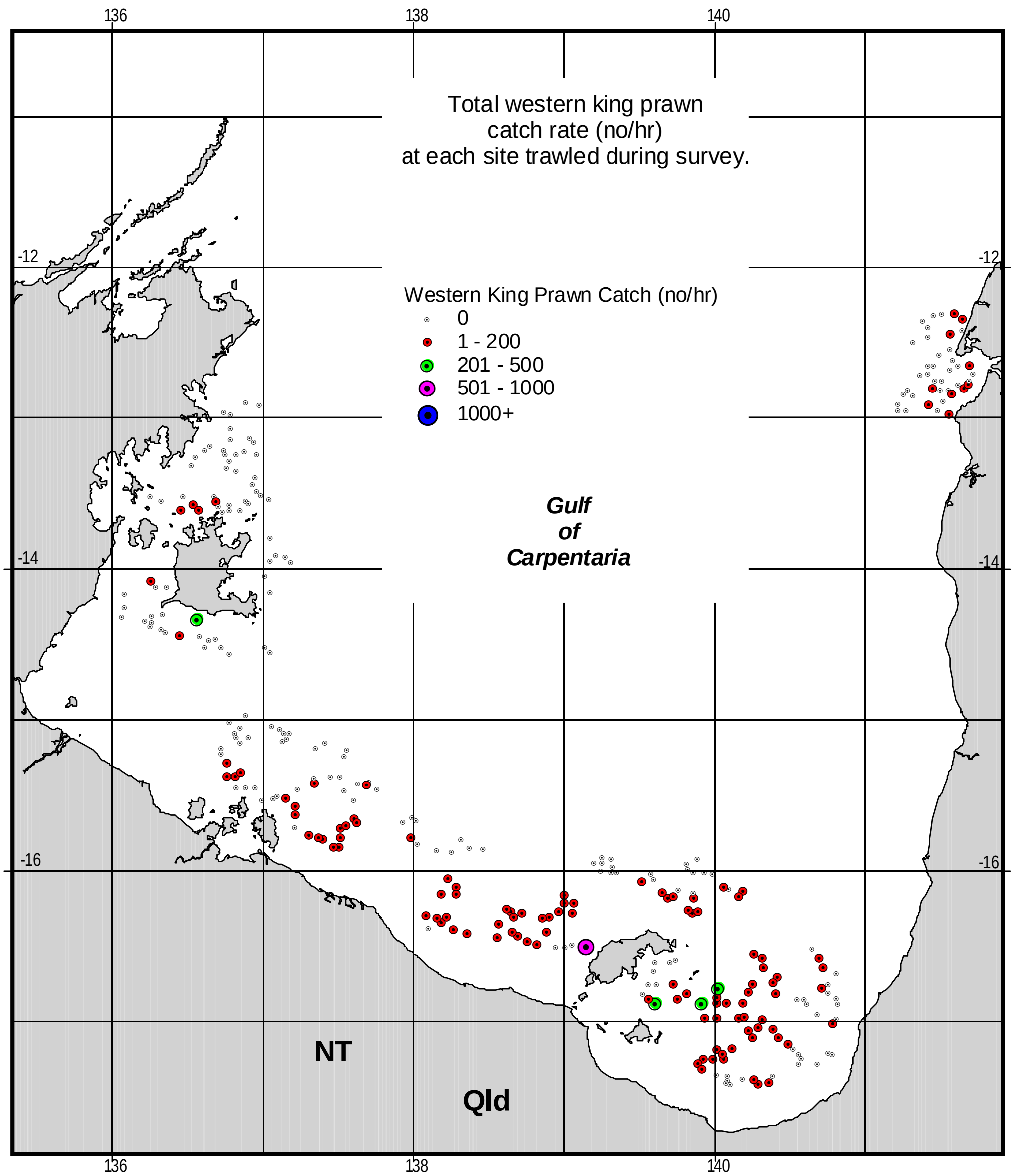

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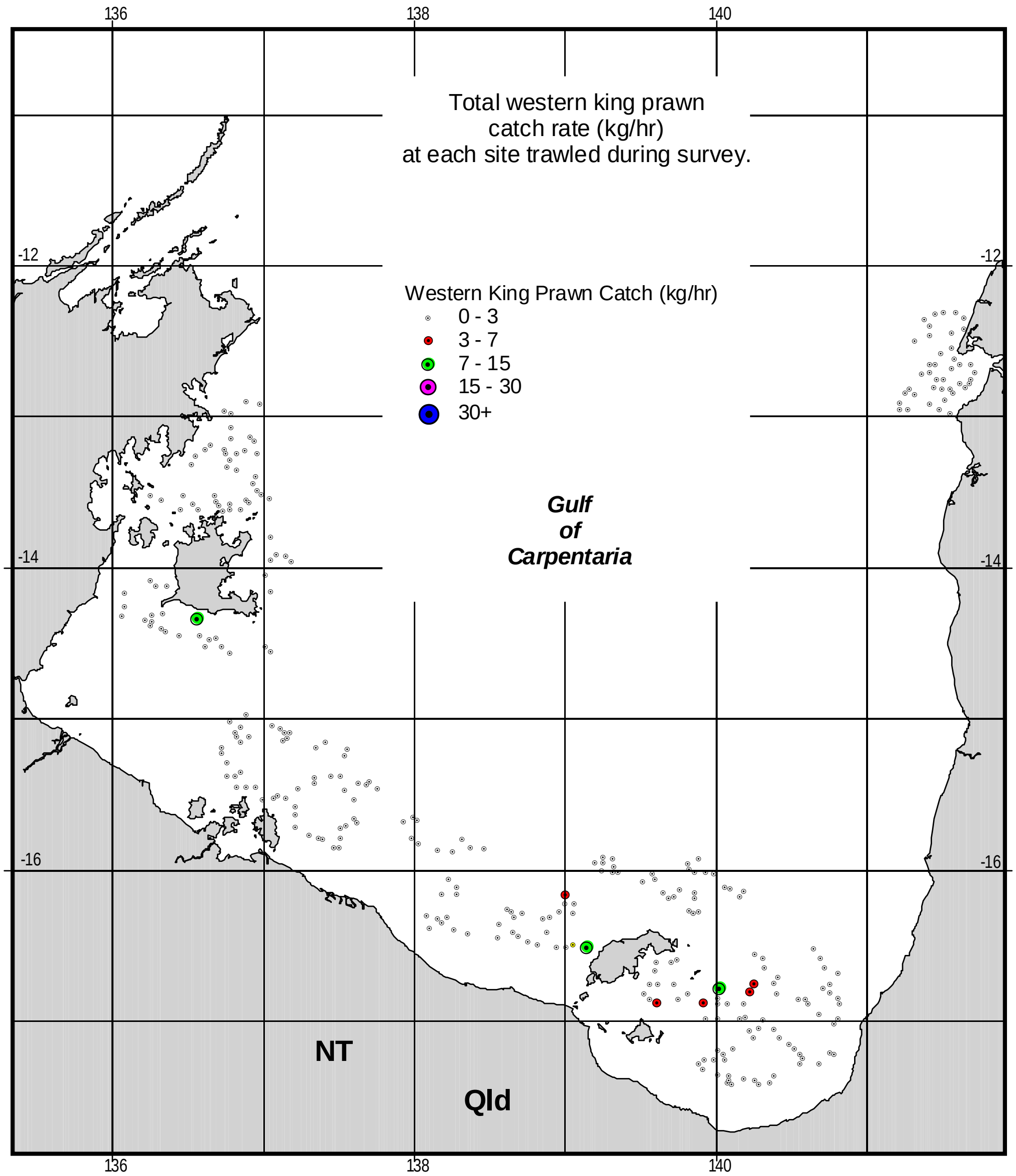

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