May, 1996

# The role of coastal nursery habitats in determining the long-term productivity of prawn populations in the Northern Prawn Fishery

Final Report to the Fisheries Research & Development Corporation (FRDC Project 92/45)

> CSIRO Division of Fisheries Cleveland Marine Laboraties



DIVISION OF FISHERIES

# The role of coastal nursery habitats in determining the long-term productivity of prawn populations in the Northern Prawn Fishery

## CONTENTS

Section		Page
1. Summary		i
2. Recommendations		v
List of Publications		vii
List of Figures		х
List of Table	S	xiii
3. Backgrou	nd	1
4. Seagrasse	s and mangroves	
4.1	Seagrass distribution and growth	3
4.2	Production of mangrove litter	12
4.3	Decomposition of seagrass and mangrove leaves	17
5. Juvenile p	prawns in seagrass	
5.1	Defining critical settling and juvenile habitat	24
5.2	Seasonal and interannual patterns in recruitment to seagrass	26
5.3	Settlement	29
5.4	Effect of density on growth and survival	37
5.5	Feeding of small juveniles	46
5.6	Assessing contribution of seagrass and mangroves to prawns	49
5.7	Predation	50
5. Use of mangroves by prawns and fish		69

# 1. SUMMARY

This study has investigated factors that limit the populations of juvenile prawns in their nursery habitats and the factors that affect the nursery habitats themselves. The broad aims of the project were:

- To describe factors which determine the carrying capacity of juvenile nursery habitats for tiger prawns (*Penaeus esculentus* and *Penaeus semisulcatus*).
- To describe factors which limit the distribution of seagrass species that form important nursery habitats for juvenile tiger prawns.
- Examine the distribution and abundance of juvenile banana prawns (*Penaeus merguiensis*) in different mangrove communities.
- To classify mangrove communities and describe their productivity.

In addition to investigating these aims through experiments and collecting data in the field, data from past FIRTA funded projects on juvenile tiger prawns were analysed in greater detail to better define the critical nursery habitats for tiger prawns and when small prawns recruit to these habitats.

# Seagrasses and tiger prawns

# Factors affecting seagrasses

The amount of light reaching the seagrass affected their growth in both the subtidal waters of the western Gulf of Carpentaria (Groote Eylandt), and in the intertidal waters of the eastern Gulf of Carpentaria (Embley River estuary): the growth of seagrasses increased as the amount of available light reaching them increased.

The seagrasses in the Embley Estuary were not nutrient limited — their growth and nutrient content in the tissues did not change after the addition of fertiliser.

Both the large *Enhalus acoroides* and the much smaller *Halodule uninervis* survived short periods of exposure to water temperatures of 45 °C. However, after two months-*E. acoroides* grew fastest at temperatures of 30 and 35 °C, but died at 40 °C. *Enhalus acoroides* and *H. uninervis* also survived a wide range of salinities (0 - 45 %), which combined with their temperature tolerance, helps explain why they are two of the dominant species in the intertidal waters of the eastern Gulf of Carpentaria, where freshwater runoff is greater than in the western Gulf.

# Critical nursery habitat for tiger prawns

The more detailed analyses of data collected from Groote Eylandt showed that virtually all postlarvae and most juvenile tiger prawns were caught in the intertidal and

ì

shallow subtidal waters ( $\leq 2.0$  m deep). It is likely, therefore, that only the seagrass beds in shallow waters of the Northern Prawn Fishery act as important settlement and nursery areas for tiger prawns. Catches of juvenile brown tiger prawns (*Penaeus esculentus*) were highest where the biomass of seagrass was highest.

The importance of seagrass and algae to grooved (*Penaeus semisulcatus*) and brown tiger prawns was evaluated by comprehensively analysing past data collected from the Embley River estuary. The grooved tiger prawn was found at all sites during the pre-wet season, but after the onset of the wet season, they disappeared along with the algae, from upstream algal sites. The brown tiger prawn was found almost exclusively on the downstream seagrass sites. The results from this study highlight the importance of algal beds as nursery areas to grooved tiger prawns.

Juvenile grooved tiger prawns were abundant in the Embley River estuary for up to 7 months (October to April) of the year and often had a bimodal distribution in abundance during this period. The bimodal distribution suggests that recruitment to the offshore fishery probably occurs over 2 periods during the year, rather than only 1 as was previously thought. This highlights the importance of taking into account seasonal variation in recruitment when estimating stock and recruitment relationships. Environmental variation seemed to have little effect on juvenile prawn abundances; the major influence was the number of postlarvae reaching the seagrass from offshore.

#### Settlement

Experiments with artificial seagrass showed that tiger prawn postlarvae settle in greater numbers on structured habitats (i.e. seagrass and algae) than bare substrate. Predation on newly settled tiger prawn postlarvae appeared to be low. The rate of settlement of planktonic animals differed greatly between sites on different sides of the Embley River estuary, which suggests that currents have an important influence on the number of prawn postlarvae arriving at a seagrass bed.

#### Effect of density on growth and survival

The growth rate of small grooved tiger prawns declined with density of prawns stocked in enclosures (0.9 m<sup>2</sup> in basal area) on intertidal seagrass beds. However, good growth rates were recorded at higher densities (3–5 times) than those normally found on these seagrasses. Growth rates were higher on the seagrass bed with higher biomass and the large-leaved *Enhalus acoroides* than on the bed with the low biomass and the much smaller-leaved *Halodule uninervis*. These results suggest that recruitment is one of the factors limiting the numbers of prawns found on tropical

ü

seagrass beds and that the carrying capacity of high biomass seagrass beds for juvenile tiger prawns is greater than that of low biomass beds.

## Feeding

Small juvenile grooved tiger prawns fed throughout the day and the night, even when seagrass beds were exposed at low tide. They fed mainly on diatoms, filamentous algae and copepods in both the pre-wet and late-wet seasons. Other common prey items included ostracods, insect larvae, and nematodes. Feeding was reduced when prawns moulted, which took place every 3 days. The diet of juvenile tiger prawns in an intertidal seagrass bed and a subtidal algal bed was very similar, despite the marked differences in type and location of these nursery habitats.

## Contribution of mangroves and seagrass to food web

Multiple stable isotope analysis was used to assess the contribution of mangroves and seagrass to the food webs supporting juvenile penaeid prawns in the Embley River estuary and to those supporting larger prawns in Albatross Bay. Mangroves made little contribution to the food web of prawns in offshore waters, despite the export of large amounts of mangrove material during the wet season. In the estuary, mangroves only contributed to the food web of juvenile prawns in upstream mangrove creeks: their contribution was very low in downstream seagrass beds adjacent to mangrove forests. In these seagrass beds, juvenile prawns were deriving their nutrition from seagrasses or the epiphytes on seagrass.

## Predation on juvenile tiger prawns in seagrass

Although prawns were found in the guts of 37 different fish species, the major impact on penaeid populations was due to seven species: queenfish (*Scomberoides commersonianus*), threadfin salmon (*Eleutheronema tetradactylum*), milk shark (*Rhizoprionodon acutus*), Hamilton's anchovy (*Thryssa hamiltoni*), golden-lined whiting (*Sillago analis*), scalloped perchlet (*Ambassis nalua*) and the fringe-eyed flathead (*Cymbacephalus nematophthalmus*). Fewer postlarvae and small prawns were eaten than expected, possibly because there is a large range of other small 'prawn-like' prey in the seagrass beds. Predation on grooved tiger prawns was greatest when the prawns were most abundant.

A tethering device was developed to estimate predation rates experimentally in the field. Preliminary results indicate that predation of juvenile tiger prawns is lower in dense seagrass (60 shoots per m<sup>2</sup>) than on bare substrate. This device has the potential to assess predation rates in different types of seagrass much more rapidly than through sampling the predators of prawns. However, further work is needed to

iii

estimate the effects of the tethers on the behaviour of the prawns and predation rates on them.

#### Mangroves and banana prawns

#### Mangrove communities and litter production

The mangroves of the Embley river were classified into three main communities by remote sensing and field surveys: those dominated by *Rhizophora* (28 km<sup>2</sup>), *Ceriops* (26 km<sup>2</sup>) or *Avicennia* (15 km<sup>2</sup>). The *Rhizophora* forests, which produced most litterfall, were the tallest, had the greatest canopy cover and the greatest surface area of ground structures or potential refuges for juvenile fish and crustaceans. All of the litter produced by the *Rhizophora* forests was quickly exported by the tides to other parts of the estuary, which contrasts with the *Ceriops* and *Avicennia* forests, where the litterfall was only exported in the wet season.

Seagrass leaves decomposed more rapidly than mangrove leaves, and both seagrass and mangrove leaves decomposed more quickly in the wet season and in the subtidal zone.

#### Distribution of banana prawns and fish

We found that small banana prawns (*Penaeus merguiensis*) and fish use large areas of the mangrove forests fringing a small creek when they are inundated at high tide. The prawns and small fish move well into the mangroves and in doing so, probably gain some protection from predation by larger fish, which remain near the mangrove fringe. Small banana prawns had no preference for a particular type of mangrove forest. The importance of particular areas of mangroves to juvenile prawns probably depends more on the local topography and water currents within the mangrove forest, than on the type of mangrove.

#### 2. RECOMMENDATIONS

- Despite their importance to the Northern prawn Fishery and the increasing number of environmental pressures on them especially from developments associated with mining, the current distribution of critical nursery habitats is not well documented, particularly outside the Gulf of Carpentaria. The mangroves and seagrasses of the NPF should be mapped. The most cost effective way of doing this would be through a combination of remote sensing and field surveys. This information would be invaluable when sections of the NPF are faced with proposals for development and for assessing future changes in the extent of nursery habitats and the likely impact on the fishery.
- With the extensive amount of information that has been gathered on the biology, fishery and habitats in the Northern Prawn Fishery, it would be timely to develop a Geographic Information System for the region with information on catchments, mangroves, seagrasses, juvenile prawns and commercial prawn catch and effort patterns. This would allow a greater integration of diverse data sets and possible management options, than has been possible in the past. It would also make a large amount of information available to industry, managers and researchers in an easily understandable form.
- The critical nursery habitats of tiger prawns have been defined as a relatively narrow, shallow belt of seagrass. We also found that different seagrasses provide different value as nursery habitats for tiger prawns. Past data on seagrass distribution and biomass needs to be evaluated with commercial tiger prawn catch data to assess the commercial productivity of tiger prawns offshore from different types of seagrass beds. Shallow seagrass areas are often the most susceptible to disturbance and developments and must continue to be protected. Further information on the rehabilitation of tropical seagrasses would also be worthwhile when assessing the likely impacts of developments.
- Under experimental conditions, some seagrass beds were able to support much higher densities of juvenile tiger prawns than are found in nature. These results suggest that it may be possible to enhance natural populations of tiger prawns by stocking natural seagrass beds with aquaculture reared animals.

- Since banana prawns use all of the mangrove forests in small creeks where abundances of prawns are high, these areas should continue to be protected. Requests for permits to impact mangroves should continue to be carefully evaluated.
- Several new techniques were developed during this study: remote sensing to map mangroves; artificial seagrass units to study the settlement of postlarvae and early juvenile tiger prawns; tethers to estimate predation rates on juvenile tiger prawns; and a large stake net to study the distribution of prawns and fish in different mangrove forests. The artificial seagrass units and stake nets can be used to increase our understanding of the biology of prawns immediately e.g. in studying the use of mangroves in areas where banana prawns are less abundant than they are in small mangrove creeks. However, further work is required to assess more fully the affects of the tethers and their impacts on the behaviour of the prawns and predation rates on them, in different habitats.

## List of Publications

The following publications were completed as part of FRDC 92/45 with funding from FRDC and CSIRO. Other sources of funding for some publications are also shown.

## 4. Seagrass and mangroves

- 4.1 Factors affecting the distribution and growth of seagrasses in the Gulf of Carpentaria: light, temperature, salinity and nutrients (Part of this work was supported by an Australian Research Council grant to Dr W. Dennison at the University of Queensland.)
- Kenyon RA, Conacher CA, Poiner IR (CSIRO editing). Seasonal growth and reproduction of *Enhalus acoroides* (L.f.) Royle in a shallow water embayment in the western Gulf of Carpentaria, Australia. for *Aquatic Botany*.
- Conacher CA, Pendrey RP (CSIRO Internal Review). Long term temperature experiment on *Enhalus acoroides*. for *Aquatic Bolany*
- 4.2 Production of mangrove litter in the Embley River estuary, north-eastern Gulf of Carpentaria
- Conacher CA, O'Brien CJ, Horrocks J, Kenyon RA (in press). Litter production and accumulation in mangrove communities in the Embley River estuary, northeastern Gulf of Carpentaria, Australia. *Marine and Freshwater Research*.
- Long BG, Vance DJ, Conacher CA (1992). Remote sensing helps identify links between mangroves and prawns. *Australian Fisheries* **51(7)**: 22–23.

4.3 Rates of decomposition of seagrass and mangrove leaves

Conacher CA, Kenyon RA, O'Brien CJ, Loneragan NR (CSIRO internal review). Decomposition of mangrove and seagrass leaves in the Embley River estuary, north-eastern Gulf of Carpentaria, Australia. *Marine and Freshwater Research*.

## 5. Seagrass and tiger prawns

5.1 Critical nursery habitats for juvenile tiger prawns

- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122**: 213-223.
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* 119: 133–143.
- Loneragan NR, Wang YG, Kenyon RA, Staples DJ, Vance DJ, Heales DS (1995).
  Estimating the efficiency of a small beam trawl for sampling tiger prawns
  *Penaeus esuclentus* and *P. semisulcatus* in seagrass by removal experiments.
  *Marine Ecology Progress Series* 118: 139–148.
- 5.2 Seasonal and annual patterns of recruitment of juvenile *Penaeus semisulcatus* to seagrass beds in the Embley River
- Vance DJ, Haywood MDE, Heales DS, Staples DJ (in press). Seasonal and annual variation in abundance of postlarvae and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series.*

vii

5.3 Habitat selection by postlarvae and small juvenile prawns

- Kenyon RA, Loneragan NR, Hughes JM 1995. Habitat type and light affect sheltering behaviour of juvenile tiger prawns (*Penaeus esculentus*) and success rates of their fish predators. *Journal of Experimental Marine Biology and Ecology* **192:** 87–105.
- Kenyon RA, Loneragan NR, Hughes JM, Staples DJ (submitted). Habitat type influences the microhabitat preferences of juvenile tiger prawns (*Penaeus esculentus* Haswell) and (*Penaeus semisulcatus* De Haan). *Estuarine Coastal and Shelf Science* January 1996.
- Kenyon RA 1995. The abundance of fish and crustacean postlarvae on portable artificial seagrass units: daily sampling provides quantitative estimates of the settlement of new recruits. Ecological System Enhancement Technology'95 Conference, October/November, 1995, Tokyo, Japan.
- Kenyon RA, Haywood MDE, Heales DS, Loneragan NR, Pendrey RC (CSIRO internal review). The abundance of fish and crustacean postlarvae on portable artificial seagrass units: daily sampling provides quantitative estimates of the settlement of new recruits. for *Journal of Experimental Marine Biology and Ecology*
- Lui H, Loneragan NR (submitted) Size and time of day affect the response of postlarvae and early juvenile grooved tiger prawns *Penaeus semisulcatus*De Haan (Decapoda: Penaeidae) to natural and artificial seagrass in the laboratory. *Journal of Experimental Marine Biology and Ecology* (Dr Lui Heng was funded by the Chinese Academy of Sciences for a 12 month Post-doctoral research fellowship.)
- 5.4 Effect of density on the growth of juvenile grooved tiger prawns *Penaeus semisulcatus* in seagrass beds of the Embley River estuary
- 5.5 Diet, feeding behaviour, and moult cycle of juvenile *Penaeus semisulcatus* in seagrass beds
- Heales DS, Vance DJ, Loneragan NR (in press). Field observations of moult cycle, feeding behaviour, and diet of small juvenile tiger prawns *Penaeus semisulcatus* in a tropical seagrass bed in the Embley River, Australia. *Marine Ecology Progress Series*
- Heales DS (CSIRO editing). The feeding of grooved juvenile tiger prawns *Penaeus smisulcatus* in a tropical estuary: a comparison of diets in intertidal seagrass and subtidal algal beds. *Marine and Freshwater Research*
- 5.6 Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study (Funding for this section of the work was also obtained from an Australian Research Council small grant to Drs Bunn and Loneragan, administered by Griffith University.)
- Bunn SE, Loneragan NR, Kempster MA (1995). Effects of acid washing samples on stable isotope ratios of C and N in penaeid shrimp and seagrass: implications for food web studies using multiple stable isotopes. *Limnology and Oceanography* 40: 622–625.
- Loneragan NR, Bunn SE, Kellaway DM (submitted). Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study. *Oecologia*.

5.7 Predation of juvenile tiger prawns in seagrass beds of the Embley River

- Haywood MDE (1995). Rates at which post-larval prawns and are digested by a small predatory fish and the implications for predation studies. *Journal of Fish Biology* 47: 337–340.
- Haywood, MDE, Pendrey RC (submitted). A new design for a submersible chronometric tethering device for studying predation in different habitats. *Marine Ecology Progress Series*.

## 6. Utilization of mangrove habitats by juvenile banana prawns and fish

- Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (in press). How far do prawns and fish move into mangroves? Distribution of juvenile banana prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series*
- Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (1996). How far do juvenile banana prawns and fish move into mangroves? *Professional Fisherman*. April 1996, 28-32.

## List of figures

## 4. Seagrass and mangroves

- 4.1 Factors affecting the distribution and growth of seagrasses in the Gulf of Carpentaria: light, temperature, salinity and nutrients
  - 4.1.1 The mean growth per shoot of *Enhalus acoroides* at different depths at (a) Sg1 and (b) Sg2 in the Embley River estuary and (c) at Groote Eylandt.
  - 4.1.2 The mean growth per m<sup>2</sup> of *Enhalus acoroides* at different depths at (a) Sg1 and (b) Sg2 in the Embley River estuary and (c) at Groote Eylandt.
  - 4.1.3 The mean growth per m<sup>2</sup> of *Halodule uninervis* at different depths in (a) Sg1 and (b) Sg2 in the Embley River estuary and (c) at Groote Eylandt.
  - 4.1.4 The mean growth (a) per shoot and (b) per m<sup>2</sup> of *Cymodocea serrulata* at different depths at Groote Eylandt.
  - 4.1.5 The mean grow rate of *Enhalus acoroides* (a) in the first 19 days of the experiment and (b) after 90 days at different temperatures in indoor aquaria.
  - 4.1.6 The net photosynthesis of leaf tissue of *Enhalus acoroides* in the laboratory at (a) different temperatures and (b) different salinities.
- 4.2 Production of mangrove litter in the Embley River estuary, north-eastern Gulf of Carpentaria
  - 4.2.1 Map showing river and creek sampling sites in the Embley River in northeastern Australia.
  - 4.2.2 Mean leaf litterfall of dominant species in each forest, over each collection period.
  - 4.2.3 Mean accumulation of litter (excluding wood) in each forest.
- 4.3 Rates of decomposition of seagrass and mangrove leaves

## 5. Seagrass and tiger prawns

- 5.1 Critical nursery habitats of juvenile tiger prawns
- 5.2 Seasonal and annual patterns of recruitment of juvenile *Penaeus semisulcatus* to seagrass beds in the Embley River
  - 5.2.1 Postlarvae and juvenile catches at two-weekly intervals from September 1986 to May 1992 for the seagrass site.
  - 5.2.2 Mean monthly catches of postlarvae and juveniles over six years for the seagrass site.
- 5.3 Habitat selection by postlarvae and small juvenile prawns
  - 5.3.1 Artificial Seagrass Units used to quantify postlarval tiger prawn settlement ~ and bare trays used as "controls".
  - 5.3.2 The Embley River estuary and the location of sites Sg 1, Sg 2 and Bare 1 among seagrass and bare habitats.
  - 5.3.3 The catch of tiger prawn juveniles and postlarvae, as well as other species, in Artificial Seagrass Units placed among seagrasses and beam trawls made through the same seagrasses.
  - 5.3.4 The catch of (a) tiger prawn postlarvae, (b) blue swimmer crab settlers and (c) potential fish predators on Artificial Seagrass Units and bare trays, set on bare substrate, with and without predator exclusion mesh.

x

- 5.3.5 The catch of blue swimmer crab settlers from (a) Artificial Seagrass Units and bare trays set on bare substrate and (b) trawls over bare substrate at 3 sites in the Embley River estuary.
- 5.4 Effect of density on the growth of juvenile grooved tiger prawns *Penaeus semisulcatus* in seagrass beds of the Embley River estuary
  - 5.4.1 (a) Enclosure and enclosure base and (b) retrieval net used in experiments to study the growth of juvenile tiger prawns *Penaeus semisuclatus* at different densities.
  - 5.4.2 Mean catches of tiger prawns (a) postlarvae, (b) juvenile *Penaeus semisulcatus* and (c) juvenile *Penaeus esculentus*, taken in beam trawls in April, October and November at Sg1 and Sg2 in this study (1994), and in previous studies in the Embley River estuary.
  - 5.4.3 Proportion of juvenile tiger prawns *Penaeus semisulcatus* remaining at the end of density experiments and the starting numbers in enclosures on (a) Sg1 during the late-wet season, (b) Sg1 during the pre-wet season and (c) Sg2 during the pre-wet season.
  - 5.4.4 Growth rates per week of juvenile tiger prawns *Penaeus semisulcatus* in enclosures in (a) carapace length, (b) wet weight and (c) dry weight in the late-wet (March/April) and pre-wet (October and November) seasons at Sg1 and Sg2 in the Embley River estuary.
  - 5.4.5 The frequency of occurrence (%) of different prey items in the diet of juvenile tiger prawns *Penaeus semisulcatus* (a) stocked in enclosures at different densities and (b) caught in beam trawls on Sg1, in the late-wet (April) season of 1994 in the Embley River estuary.
- 5.5 Diet, feeding behaviour, and moult cycle of juvenile *Penaeus semisulcatus* in seagrass beds
  - 5.5.1 *Penaeus semisulcatus.* Mean percentage of combined premoult and ecdysis stage from two 24 h studies and mid-April sampling.
  - 5.5.2 *Penaeus semisulcatus*. Mean foregut fullness for juveniles in all moult stages except ecdysis, from combined pre-wet and late wet season 24 h studies.
  - 5.5.3 *Penaeus semisulcatus*. Frequency of occurrence of prey items from foreguts of juveniles from one pre-wet season 24 h and one late wet season 24 h study.
- 5.6 Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study
- 5.7 Predation of juvenile tiger prawns in seagrass beds of the Embley River
  - 5.7.1 Map of the Embley River showing seagrass sites (Sg1 and Sg2) used for sampling tiger prawns and fish.
  - 5.7.2 Prawn Predation Indices for (a) fish caught in the gill nets and (b) beam trawl and beach seine on seagrass beds in the Embley River.
  - 5.7.3 *Penaeus semisulcatus*. Length frequency of postlarvae and juveniles (a) caught in beam trawls and (b) found in guts of predatory fish caught in gill nets, beam trawls and beach seine at SG1 and SG2 during October 1993 and April 1994.
  - 5.7.4 *Penaeus semisulcatus*. Mean number on the seagrass beds (Sg1 and Sg2) versus the total number found in fish guts during the pre-wet and early dry seasons.

#### 6. Utilisation of mangrove habitats by juvenile banana prawns and fish

- 6.1 Map showing the stake-net sampling sites and mangrove communities in the Embley River estuary, Gulf of Carpentaria, Australia.
- 6.2 *Penaeus merguiensis.* Mean stake net catches for 2 samples at each of *Rhizophora* A, *Rhizophora* B and *Ceriops* sites from 22 to 27 November 1992.
- 6.3 Summary of all fish caught in 2 samples at each of *Rhizophora* A, *Rhizophora* B and *Ceriops* A sites from 22 to 27 November 1992. (a) mean number, (b) mean number of species, (c) mean length, and (d) mean weight.
- 6.4 *Penaeus merguiensis.* Stake net catches and the maximum observed tide height for each sample from 22 to 31 March 1993.

#### List of Tables

#### 4. Seagrass and mangroves

- 4.1 Factors affecting the distribution and growth of seagrasses in the Gulf of Carpentaria: light, temperature, salinity and nutrients
- 4.2 Production of mangrove litter in the Embley River estuary, north-eastern Gulf of Carpentaria
  - 4.2.1 Morphological characteristics of the mangrove forests.
- 4.3 Rates of decomposition of seagrass and mangrove leaves
  - 4.3.1 Mean time taken for 50% of the leaf material of each species to decompose, based on exponential regressions, in the intertidal and subtidal and in the wet and dry seasons.
  - 4.3.2 Mean initial %C, %N, C:N ratio,  $\delta^{13}$ C and  $\delta^{15}$ N of mangrove and seagrass leaf tissue in the dry and wet seasons.

#### 5. Seagrass and tiger prawns

- 5.1 Critical nursery habitats of juvenile tiger prawns
- 5.2 Seasonal and annual patterns of recruitment of juvenile *Penaeus semisulcatus* to seagrass beds in the Embley River
- 5.3 Habitat selection by postlarvae and small juvenile prawns
  - 5.3.1 Total numbers of juvenile penaeid prawns, crustaceans, fish and other fauna from Artificial Seagrass Units and bare trays deployed in seagrass habitat and on bare substrate in the Embley River estuary in November 1993.
  - 5.3.2 Mean numbers of juvenile penaeid prawns, crustaceans and fish from Artificial Seagrass Units and bare trays deployed in seagrass habitat and on bare substrate at Sg1 in the Embley River estuary in October 1993.
- 5.4 Effect of density on the growth of juvenile grooved tiger prawns *Penaeus semisulcatus* in seagrass beds of the Embley River estuary
  - 5.4.1 Number of enclosures stocked at each density of juvenile tiger prawns *Penaeus semisulcatus*, and the range of durations in days that prawns were in enclosures during different experiments.
  - 5.4.2 Mean salinity, temperature and seagrass biomass during experiments on the effects of density on the growth of grooved tiger prawns (*Penaeus semisulcatus*) in seagrass beds in the Embley River estuary.
  - 5.4.3 Regression relationships between the number of juvenile grooved tiger prawns *Penaeus semisulcatus* in enclosures and growth rate for the prewet and late-wet seasons.
  - 5.4.4 Mean growth rates of juvenile tiger prawns *Penaeus semisulcatus* in enclosures on two seagrass beds in the Embley River estuary.
  - 5.4.5 Mean growth rates of juvenile tiger prawns *Penaeus semisulcatus* estimated from cohort analysis of prawns catches in different seagrass beds.
- 5.5 Diet, feeding behaviour, and moult cycle of juvenile *Penaeus semisulcatus* in seagrass beds

XIII

- 5.6 Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study
- 5.7 Predation of juvenile tiger prawns in seagrass beds of the Embley River
  - 5.7.1 Stomach contents of fish from intertidal seagrass beds in the Embley River.
  - 5.7.2 Percentage contribution by dry weight of prey items in the stomach contents of fish from intertidal seagrass beds in the Embley River.
  - 5.7.3 *Penaeus semisulcatus*. Mean density of postlarvae and juveniles, numbers found in fish guts, total Prawn Predation Indices (PPI) and mortality indices at sites in the Embley River during the pre-wet and early dry seasons 1993/94.
  - 5.7.4 Mean density of prawns and 'prawn-like' animals caught in a series of 10 drop traps at SG1 in the pre-wet season of 1994.

#### 6. Utilisation of mangrove habitats by juvenile banana prawns and fish

#### 3. BACKGROUND

Research on prawns in their nursery grounds of the Northern Prawn Fishery has established the general importance of different habitat types and when prawns are found in these habitats. However, research has been concentrated in the Gulf of Carpentaria and little is known about the factors that affect prawns in their nurseries. The work completed in this study has built on previous work in attempting to increase our understanding of how mangroves and seagrasses act as nursery habitats for juvenile prawns. It has also focussed on evaluating the relative importance of different types of mangroves and seagrasses to juvenile prawns.

Parts of this Project have been accepted for publication, or are being prepared for publication in scientific journals and other media (see List of Publications, p vii).

#### Habitat studies (Section 4)

The productivity of the Northern Prawn Fishery (one of Australia's most valuable fisheries) is dependent on coastal nursery habitats. In previous studies CSIRO has mapped the distribution and determined the productivity of seagrasses in the Gulf of Carpentaria. We have also studied the regeneration of seagrass beds after Cyclone Sandy (March 1985) in the south-western Gulf of Carpentaria.

The work presented in Section 4 of this report examines the characteristics of the critical nursery habitats (both mangroves and seagrass) themselves, and factors that affect them: The physical factors that may affect the growth and distribution of seagrasses are examined in Section 4.1; The distribution of mangroves within the Embley Estuary are mapped and classified, and the productivity and physical structure of the main mangrove communities are described and compared to global values in Section 4.2; and The decomposition of mangrove and seagrass leaves was studied in the Embley River to understand how quickly material can enter the food chain via the detritus pathway in Section 4.3.

Work in Section 4 was coordinated and lead by Carol Conacher. The work on the effects of fertilisation on seagrass in Section 4.1 was carried out in collaboration with Dr W. Dennison and his group at the Department of Botany, University of Queensland.

#### Tiger prawns and seagrass (Section 5)

Because of the high value of tiger prawns to the Northern Prawn Fishery and concerns about whether the current catch rates are sustainable, more work was undertaken in this section of the Project than in other areas. Previous studies have examined the types of nursery habitat that are important and when juvenile tiger prawns recruit to them. However, we know little about the processes that affect juvenile prawns in these habitats. Part of this project has analysed past data in much greater detail to better define the nurseries (Section 5.1) and the timing of recruitment to the nurseries (Section 5.2). The other work in this section looks at the important processes in seagrass beds: Settlement (Section 5.3); Growth of prawns at different experimental densities (Section 5.4); Feeding (Section 5.5); Whether Mangroves and Seagrasses contribute to the food web of juvenile prawns (Section 5.6) and Predation (Section 5.7). We also examined how these processes are affected by the type of seagrass andits characteristics.

Work in Section 5 was coordinated and lead by the following people: 5.1 Defining critical habitats — Neil Loneragan and Mick Haywood; 5.2 Seasonal and interannual patterns — David Vance; 5.3 Settlement — Rob Kenyon; 5.4 Effects of density — Neil Loneragan; 5.5 Feeding — Don Heales; 5.6 Contribution of seagrass and mangroves — Neil Loneragan; 5.7 Predation — Mick Haywood. Bob Pendrey developed many of the new techniques in this proposal. Experimental work on the settlement of tiger prawn postlarvae was carried with Dr Liu Heng while she was funded by a Postdoctoral Fellowship from the Institute of Oceanology, Chinese Academy of Sciences. Work on assessing the contribution of mangroves and seagrasses to the food web of juvenile prawns was carried out with Dr Stuart Bunn and Ms Dominica Kellaway at the Faculty of Environmental Sciences, Griffith University.

#### Banana prawns and mangroves (Section 6)

As with the work on tiger prawns, previous studies of juvenile banana prawns have concentrated on defining the critical nursery habitats and when juvenile banana prawns recruit to their nursery habitats. These studies have highlighted the importance of mangrove-lined creeks but we did not know how much of the mangrove forests are used by prawns. In this section we developed techniques to sample prawns and fish within the mangrove forest to help us understand how much of the mangrove forest is used, and whether different types of mangroves are used to the same extent by banana prawns. Work in this section was coordinated and lead by David Vance.

# 4.1 Factors affecting the distribution and growth of seagrasses in the Gulf of Carpentaria: light, temperature, salinity and nutrients

## Introduction

Seagrasses provide an important source of food and shelter for a diverse range of marine organisms (Bell and Pollard 1989), and also structure ecosystems, and stabilise coastlines (Larkum et al. 1989). In tropical Australia, seagrass beds provide valuable habitats for many recreationally and commercially important species, particularly grooved (*P. semisulcatus*) and brown tiger prawns (*P. esculentus*). These prawns are dependent on seagrass and algal beds for habitat during their postlarval and juvenile stages (Loneragan et al. 1994, Haywood et al. 1995).

Approximately 14 species of seagrass are found in northern and north-eastern tropical Australia. Most of these species have a disjunct distribution, and are found on the western side of the Gulf of Carpentaria, in Torres Strait, and on the north-eastern coast of Queensland; only a few species are found on the eastern side of the Gulf of Carpentaria. In the eastern Gulf of Carpentaria, seagrass beds are usually found in estuaries and are dominated by *Enhalus acoroides* and *Halodule uninervis*, with some *Halophila ovalis* (Poiner et al. 1987).

While the seagrasses of northern and north-eastern tropical Australia have been mapped and classified into communities (Poiner et al. 1987), little is known of the factors controlling their distribution. Light, temperature, salinity, nutrient availability and water movements all affect the primary productivity, and hence the distribution of seagrasses (Hillman et al. 1989).

We used a combination of field, aquarium and laboratory experiments to determine the influence of light, temperature, salinity, and nutrient availability on the growth of tropical seagrasses.

## Methods

## Field experiments

Field experiments were undertaken in the Embley River, in the north-eastern Gulf of Carpentaria and at Groote Eylandt in the north western Gulf. The dominant seagrasses in the Embley River are *Enhalus acoroides* and *Halodule uninervis*, with very sparse *Halophila ovalis*. Most seagrasses in this estuary are intertidal. In contrast, 8 species of seagrass are found at Groote Eylandt, often in seagrass beds with more than one species, and in both intertidal and subtidal waters.

We measured the light, depth, temperature, nutrient and salinity regimes on the seagrass beds and determined their growth, distribution, density and morphology at two sites (Sg1 and Sg2) in the Embley River and at two locations at Groote Eylandt. In the Embley River, we also completed a nutrient enrichment experiment to test whether the growth of seagrasses was limited by nutrients.

## (a) Depth

Because the transmission of light is attenuated by water, seagrasses growing in deeper water usually receive less light than those growing in shallow water. In the Embley River, we measured the growth of *Enhalus acoroides* and *Halodule uninervis* at two inter-tidal sites (Sg1 and Sg2) at different depths in the dry (June 1993) and wet (March 1994) seasons. The mean maximum depth at Sg1 ranged from 1.2 to 1.5 m in June 1993 and from 1.5 to 2.0 m in March 1994. The mean maximum depth at Sg2 was about 0.5 m shallower than that at Sg1 in both June (0.7 to 1.0 m) and March (1.0 to 1.5 m).

At Groote Eylandt, we measured the growth of *Enhalus acoroides* (subtidal beds: mean maximum depth = 2.1 to 3.1 m), *Halodule uninervis* (intertidal beds: mean maximum depth = 0.8 to 1.2 m) and *Cymodocea serrulata* (subtidal beds: mean maximum depth = 2.1 to 4.5 m) at different depths at the start of the wet season in December 1994.

The growth of *Enhalus acoroides* and *Cymodocea serrulata* was measured using a leaf marking technique: leaves were marked just above the meristem and left to grow for approximately 10 days. As the outer most leaves do not grow, the difference in the 'position of the tag between the younger leaves and the oldest leaf gives an estimate of growth. Because of its small size, the growth of *Halodule uninervis* was measured using a rhizome tag: a tag was placed behind the terminal shoot of a rhizome and new growth was estimated from the number of new shoots produced over a given time period. Seasonal data for seagrass growth on Groote Eylandt from previous

studies were also re-analysed. Incident light and light attenuation within the water column were measured when the seagrass beds were covered with water, between 10 am and 4 pm during the growth experiments.

#### (b) Nutrient enrichment

We fertilised seagrass beds in the Embley River to see if growth was limited by nutrient availability. In December 1993, slow release fertiliser (N, P, and N + P) was added to 3 m<sup>2</sup> plots in a mixed bed of *E. acoroides* and *H. uninervis*. The plots were marked and the seagrasses left to grow for 3 months. In March 1994, the growth of each species in each treatment was measured as described above; the shoot density and morphology of each species was determined; and the nutrient content of seagrass leaft tissue and the soil were measured in the fertilised and control plots. The rates of nitrogen fixation and sulfate reduction were also measured.

#### Laboratory experiments

#### (a) Long term affect of temperature on growth

The response of *Enhalus acoroides* to different temperatures was measured in indoor aquaria. Plants were collected from the Embley River in November 1993 and air freighted to the CSIRO Marine Laboratories at Cleveland. They were then acclimated in indoor aquaria for 4 months. In March 1994, plants were randomly assigned to one of 6 different temperatures (15, 20, 25, 30, 35 and 40°C) and allowed to grow for 105 days. The morphology and growth of the plants were measured at the beginning and at the end of the temperature trials.

#### (b) Short term affects of temperature and salinity on photosynthesis

The short term response of the leaf tissue of *E. acoroides* and *H. uninervis* to changes in temperature, salinity and light were measured using a 'Clarke' type oxygen electrode. Small (approx 1cm<sup>2</sup>) pieces of leaf tissue were put into the oxygen electrode chamber and their rates of photosynthesis and respiration were measured at different temperatures (15 – 47.5 °C), salinities (0 – 45 ‰) and light levels (0 – 1 500 µE). The seagrass tissue was acclimated in the chamber for approximately 3 min<sup>-</sup> before the above rates were measured over the next 5 – 10 minutes.

#### Results

#### Field experiments

#### (a) Depth

In general, turbidity at the seagrass beds around Groote Eylandt was lower than in the Embley River. At Groote Eylandt, light decreased with depth at all sites where growth measurements were made.

In the intertidal seagrass beds of the Embley River, incident light and light reaching the seagrass, was higher in the dry than the wet season. However, in the Embley River the mid-depth and deep sites frequently received more light than the shallow sites due to differences in water turbidity. In the dry season, light reaching the seagrass beds was highest at the mid and deepest depths at both sites. In the wet season, light was highest at the middle depth at one site and there was no difference between depths at the other site.

#### Enhalus acoroides

Shoot density was much higher at Sg1 (up to 70 shoots  $m^{-2}$ ) in the Embley River than at Sg2 or at Groote Eylandt (< 10 shoots  $m^{-2}$ ). At Sg1, shoot density was very low in the high intertidal, highest in the mid intertidal and then decreased with depth. At Sg2 and at Groote Eylandt shoot density was highest at the shallowest sites and decreased with depth.

The growth of *E. acoroides* per shoot was higher on Groote Eylandt (60 mm shoot  $^{-1}$  day  $^{-1}$ ) than at Sg1 or Sg2 (< 50 mm shoot  $^{-1}$  day  $^{-1}$ ) (Fig. 4.1.1). However, growth per m<sup>2</sup> was highest at Sg1 in the Embley River (Fig. 4.1.2) because of the high shoot density at this site.

In the Embley River, the growth per shoot of *E. acoroides* was slightly higher in the dry season than the wet. At Sg1, growth per shoot decreased with depth, however, growth per  $m^2$  followed the density pattern, i.e. it was very low in the high intertidal, highest in the mid intertidal and then decreased with depth. At Sg2 and Groote Eylandt there was no difference in growth per shoot with depth. However, growth per  $m^2$  decreased with depth at Groote Eylandt.

At Groote Eylandt, leaf length increased with depth. In contrast, in the Embley River it decreased with depth except in the very high intertidal at site Sg1. In the Embley River, leaf length was lower in the dry season than the wet. Leaf width did not vary with depth or season.

## Halodule uninervis

In the Embley River, the growth of *H. uninervis* on both a per shoot basis (i.e. shoots per shoot) and on a unit area basis (i.e. shoots per  $m^2$ ) decreased as depth increased (Fig. 4.1.3). However, on Groote Eylandt while new shoot production per shoot was highest in shallower water, shoot production per square meter was highest in the middle depth (Fig 4.1.3). The leaf length and width of *H. uninervis* did not vary in any consistent pattern with depth.

## Cymodocea serrulata

The shoot density of *C. serrulata* was very low at the shallow and deep water sites at Groote Eylandt. The growth per shoot was highest in the deep water site, but growth per  $m^2$  was highest in the middle depth (Fig. 4.1.4). The maximum leaf length of *C. serrulata* was significantly higher in deeper than shallow water. However, leaf width did not change with depth.

## (b) Nutrient enrichment

Although the interstitial and adsorbed sediment nutrient concentrations increased, the growth and tissue nutrient content of the seagrasses did not change after fertilisation. The natural concentrations of nutrients of the seagrass tissue in the Embley River estuary were high compared to those in other regions (Duarte 1990). Nitrogen fixation and sulphate reduction rates in the seagrasses of the Embley River estuary were low compared to those from other regions, and were positively correlated with the ratio of below:above-ground biomass.

## Laboratory experiments

## (a) Long term affect of temperature on growth

At the beginning of the temperature trials, the growth rate of *Enbalus acoroides* leaves increased with temperature between 15 and 35 °C, with a maximum at 35 °C (Fig.4.1.5). The growth of leaves at 15 and 40 °C was very low. After 105 days, the growth rate of *E. acoroides* leaves was highest at 30 °C and all the plants at 15 and 40 °C had died. The morphology of the plants also changed with temperature. Plants <sup>-</sup> growing at 30 °C had significantly longer and broader leaves than those growing at 20 °C.

# (b) Short term affects of temperature and salinity on photosynthesis

The light level for maximum photosynthesis was about 350  $\mu$ E for both *Enhalus acoroides* and *Halodule uninervis*. The net rate of photosynthesis, which is the sum of oxygen production (photosynthesis) and oxygen consumption (respiration) was highest between 25 and 35 °C for both species of seagrass (Fig 4.1.6a). At water

temperatures below 25 °C, respiration, photosynthesis and net photosynthesis were low, whilst above 35 °C, photosynthesis decreased and respiration increased, resulting in low net photosynthesis. Despite this trend, there was still positive net photosynthesis at 45 °C.

The net photosynthesis of both *E. acoroides* and *H. uninervis* was positive throughout the range of salinities we tested (0 - 45 %), with the highest net photosynthesis between 10 and 35 ‰ (Fig 4.1.6b).

#### Discussion

#### Depth

In general light decreased with depth. However, in the shallow intertidal sites in the Embley River, light was often low due to very high water turbidity. Light levels reaching the seagrass were higher on Groote Eylandt than in the Embley River, and light levels in the Embley River were higher in the dry season than in the wet. Similarly, growth per shoot of *Enhalus acoroides* tended to decrease with decreasing light; it was higher on Groote Eylandt than in the Embley River; and in the Embley River was higher in the dry season than in the wet. This suggests that the availability of light has a major affect on the growth of *E. acoroides* in these beds.

However, when growth is measured on the basis of area (i.e. per m<sup>2</sup>), it becomes obvious that other factors are also important. In general, differences in shoot density were much greater than differences in growth per shoot, and growth per m<sup>2</sup> therefore follows the patterns in shoot density, with lowest shoot density and growth per m<sup>2</sup> in the high-intertidal, and highest in the mid-intertidal, particularly at Sg1. Growth per m<sup>2</sup> then decreased with increasing depth. Other factors which may affect shoot density and consequently growth per m<sup>2</sup> include desiccation at low tide; high temperatures on the intertidal flats; differences in sediment composition; and differences in water movement.

The growth of *Halodule uninervis* in the Embley River was highest in the shallowest water. However, as turbidity was also high in the shallow water, growth was not correlated with available light when the beds were inundated. This suggests that these beds are capable of photosynthesising unhindered, when they are exposed by the tide.

Although the growth of individual shoots of *Cymodocea serrulata* at Groote Eylandt increased with depth and with decreasing light, growth per  $m^2$  decreased. Therefore,

as depth increases and light decreases, the production of new shoots by *C. serrulata* must decrease.

#### Nutrients

The nutrient content of the tissues of *Enhalus acoroides* and *Halodule uninervis* in the Embley River is high compared to those of seagrasses in other regions. The growth and tissue nutrient contents of seagrasses were not affected by fertilisation and thus the growth of seagrasses in the Embley River is probably not nutrient limited. Nutrient input in the Embley River, particularly during the wet season is likely to be high. In addition, as the sediment particle size in the river is small there may be high absorption rates of nutrients to particles which may retain nutrients for the growth of seagrasses during the dry season and account for the low rates of nitrogen fixation.

#### Temperature

In the short term laboratory experiments, the net photosynthesis of *Enhalus acoroides* was highest between 25 and 35 °C, whilst in the long term aquarium experiments growth was initially highest at 35 °C and then at 30 °C. These results suggest that *Enhalus acoroides* can maintain high net photosynthesis at high temperatures for short periods, but not for longer periods. In field experiments on Groote Eylandt, the growth of *E. acoroides* increased with water temperature and was significantly higher when the water temperature was 30 °C or higher (Kenyon et al., CSIRO editing).

In the short term experiments, both *E. acoroides* and *Halodule uninervis* continued to have positive net photosynthesis at temperatures as high as 40 °C. In the long term experiments, *E. acoroides* died after two months at 40 °C. The ability to survive at least short periods at very high temperatures enhances the ability of these seagrasses to survive and persist on the intertidal flats of the Gulf of Carpentaria, where water temperatures can exceed 40 °C.

#### Salinity

Both *Enhalus acoroides* and *Halodule uninervis* continued to have positive net photosynthesis over a broad range of salinities, with the highest net photosynthesis between 10 and 35 ‰. *Halodule uninervis* is tolerant of a wide range of salinities, and to fluctuations in salinity, and is found in estuaries and hypersaline lagoons (den Hartog 1970). In contrast, although our experiments show that *E. acoroides* tolerates a wide range of salinities, at least in the short term, it is not usually found in very high or very low salinity conditions in the field. The ability of these two species to withstand short term decreases in salinity helps explain their broad distribution in the Gulf of Carpentaria, both in the western Gulf where only small changes in salinity changes are recorded, and in the eastern Gulf, where much larger changes are found. Seagrass such as *Cymodocea serrulata*, that are only found on the western side of the Gulf, are probably less tolerant of decreases in salinity than *E. acoroides* and *H. uninervis* (den Hartog, 1970).

#### Conclusions

Approximately 14 species of seagrass are found in northern and north-eastern tropical Australia. They provide critical habitats for the postlarvae and juvenile stages of tiger prawns. However, about 11 species of seagrass are found in the western Gulf of Carpentaria and only 3 on the eastern Gulf of Carpentaria. We used a combination of field, aquarium and laboratory experiments to examine some of the factors which may control the growth and distribution of tropical seagrasses.

In subtidal waters of the western Gulf of Carpentaria (Groote Eylandt), the growth of *Enhalus acoroides, Halodule uninervis* and *Cymodocea serrulata* decreased as depth increased and light reaching the seagrass decreased. However, on intertidal seagrass beds in the eastern Gulf of Carpentaria (Embley River estuary) this was not the case. In these seagrass beds, the turbidity of the water often increased in shallower water, resulting in less light reaching the seagrass than in deeper water. In addition, in shallower intertidal water, seagrasses were exposed for longer than in deeper intertidal water, which may also have affected their growth. While exposure by the tide results in high levels of light reaching the seagrass, it may also result in a decrease in growth, resulting from e.g. desiccation.

The seagrasses in the Embley Estuary were not nutrient limited — their growth and nutrient content in the tissues did not change after the addition of fertiliser. However, the natural concentrations of nutrients in the tissue seagrasses were comparatively high in this estuary.

Long term aquarium experiments on the effects of temperature on the growth of *Enhalus acoroides* showed that growth was greatest from 30 – 35 °C. In short term experiments on the effects of temperature on growth, both *E. acoroides* and *Halodule uninervis* continued to photosynthesise at 45 °C. However, in the longer term experiments *E. acoroides* died after two months at 40 °C. The ability of these plants to withstand very high temperatures, at least in the short term, helps them to colonise and persist in a wide range of conditions found in the intertidal and shallow subtidal waters of tropical Australia.

Both *Enhalus acoroides* and *Halodule uninervis* also photosynthesised over a wide range of salinities (0 - 45 %); which combined with their temperature tolerance helps explain why they are two of the dominant species on the eastern Gulf of Carpentaria, where catchments are larger, and rainfall and freshwater discharge are higher than in the western Gulf of Carpentaria.

#### References

- Bell JD, Pollard D (1989). Ecology of fish assemblages and fisheries associated with seagrasses. *In: Biology of Seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region.* pp 565–609. eds: Larkum AWD, McComb AJ, Shepherd SA. Aquatic Plant Studies 2. Elsevier.
- Den Hartog C (1970). *The seagrasses of the world*. North-Holland, Amsterdam, 275 pp.
- Duarte CM (1990). Seagrass nutrient content. *Marine Ecology Progress Series* **67:** 201–207.
- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122:** 213–223.
- Hillman K, Walker DI, Larkum AWD, McComb AJ (1989). Productivity and nutrient limitation. In: Biology of Seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region. pp 635–685. eds: Larkum AWD, McComb AJ, Shepherd SA. Aquatic Plant Studies 2. Elsevier.
- Larkum AWD, McComb AJ, Shepherd SA (1989). Introduction. In: Biology of Seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region. pp 1 – 73. eds: Larkum AWD, McComb AJ, Shepherd SA. Aquatic Plant Studies 2. Elsevier.
- Kenyon RA, Conacher CA, Poiner IR (CSIRO editing). Seasonal growth and reproduction of *Enhalus acoroides* (L.f.) Royle in a shallow water embayment in the western Gulf of Carpentaria, Australia. for *Aquatic Botany*.
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* 119: 133– 143.
- Poiner IR, Staples DJ, Kenyon RA (1987). Seagrass communities of the Gulf of Carpentaria, Australia. *Australian Journal of Marine and Freshwater Research* 38: 121–31.



Figure 4.1.1. Mean growth per shoot (+1SE) of *Enhalus acoroides* at different depths at (a) Sg1 and (b) Sg2 in the Embley River estuary, and (c) at Groote Eylandt.



Figure 4.1.2. Mean growth per  $m^2$  (+1SE) of *Enhalus acoroides* at different depths at (a) Sg1 and (b) Sg2 in the Embley River estuary, and (c) at Groote Eylandt.



Figure 4.1.3. Mean growth rate (+ 1SE) of *Halodule uninervis* at different depths at (a) Sg1 and (b) Sg2 in the Embley River estuary, and (c) at Groote Eylandt.



Figure 4.1.4. Mean growth rate (+ 1SE) of *Cymodocea serrulata* at different depths at Groote Eylandt in mm per shoot per day and in mm per m2 per day.











# 4.2 Production of mangrove litter in the Embley River estuary, north-eastern Gulf of Carpentaria

#### Introduction

Mangrove forests are important nursery areas for many species of finfish and crustaceans (Odum and Heald 1972, Hatcher et al. 1989, Vance et al. in press a, Section 6). In the Northern Prawn fishery juvenile banana prawns are found in shallow water in or near mangroves, but are rarely found in other shallow water habitats. The importance of mangroves as nursery areas is attributed to their productivity and the 'refuge' habitat they provide. In this study the mangroves of the Embley river were mapped and classified and then the productivity and physical structure of the main mangrove communities were described and compared to global values. The results of this Section have been published (Long et al. 1992, Conacher et al. in press).

#### Methods

The Embley River (12° 37'S 141° 52'E ), in the north-eastern Gulf of Carpentaria, is in the wet-dry tropics of Australia, where there are strong seasonal differences in climate. Eighty-four percent of the rainfall falls between November and March (Vance et al. in press b).

#### Mapping and classification

Remotely sensed data from satellites were used to map the distribution of mangroves in the river. The satellite images were then processed and divided into community types and the validity of these community types was confirmed by field surveys, particularly in regions where communities bordered each other.

Once the mangroves were classified we studied two sites in each of the three mangrove communities (*Rhizophora*, *Avicennia* and *Ceriops*) along a small creek flowing into the Embley River, and two sites in *Rhizophora* forest along the main river  $\tilde{}$  (Fig 4.2.1).

At each site we recorded the number of trees, saplings and seedlings of each mangrove species, and visually estimated the canopy cover and canopy height within two randomly placed 100 m<sup>2</sup> quadrats. The number, height, diameter and length of all mangrove structures from ground level to 1 m were measured in two 1 m<sup>2</sup> quadrats at each site. From these measurements we calculated the surface area below 1 m or

'ground structure' provided by the mangrove forests. Means and standard errors were then calculated for each sampling time and site.

## Litterfall

Litter traps were set at each site in March 1993 and emptied every two months for one year. The material from the litter traps was sorted by genera and separated into leaves, stipules, twigs, wood, flowers, fruit and seedlings. The number of flowers and stipules were counted and all components were dried to constant weight at 60° C and then weighed.

## Litter accumulation

At the beginning of the experiment (March 1993), and then each time the litter traps were emptied, accumulated litter was also collected from the forest floor. The material from the forest floor was sorted and dried in the same way as the material from the litter-traps.

## Data analysis

Means and standard errors were calculated for all the physical structures that were measured and monthly and annual means were calculated for the all components of the litterfall in traps and the accumulated litter on the ground.

Differences between sites in the amounts of both litterfall and accumulated litter were tested by Analysis of Variance (ANOVA). The assumptions of homogeneity of variance were examined for each ANOVA by plotting the relationship between the  $\ln(variance)$  and  $\ln(mean)$ . Where necessary, heterogeneity was removed by either  $\ln(x)$  or  $\ln(x + 10)$  transformations.

## Results

## Mapping and classification

There are three main mangrove communities in the river: the *Rhizophora* forest along <sup>–</sup> the river edge, which is dominated by *Rhizophora stylosa* Griff; the *Ceriops* forest on slightly higher ground, dominated by *Ceriops tagal* var. *australis* (Perr.) C.B. Rob.; and the *Avicennia* forest further inland, dominated by *Avicennia marina* var. *eucalyptifolia* (Zipp. ex Miq.) N.C. Duke.

In the Embley River there are approximately  $28 \text{ km}^2$  of *Rhizophora*,  $26 \text{ km}^2$  of *Ceriops* and about  $15 \text{ km}^2$  of *Avicennia* forest. The *Rhizophora* forests were the tallest, with a mean canopy height of 17 m. These forests also had the greatest canopy cover and

area of ground structure (Table 4.2.1). Although mangrove trees were densest in the *Ceriops* forest, with about 3700 *Ceriops* trees per hectare, the ground structure in this forest was much less than in the *Rhizophora* forests (Table 4.2.1). The *Avicennia* forest had the lowest mean trunk density, canopy height, canopy cover and ground structure.

#### Litterfall

The total litterfall was significantly higher in the *Rhizophora* forests than in the *Ceriops* and *Avicennia* forests. The total litterfall did not differ significantly between the river and creek *Rhizophora* forests and a mean value was therefore calculated for all the *Rhizophora* communities i.e. over both the river and creek sites.

In the *Rhizophora* and *Avicennia* forests, there were seasonal changes in leaf fall rates, with the lowest rates from June to October (dry season), increasing over the wet season. In contrast, the leaf fall rates in the *Ceriops* forest were relatively stable from March to October (dry season) but decreased with the onset of the wet season (December) (Fig 4.2.2).

#### Litter accumulation

Leaves, twigs and wood were the main components of the accumulated ground litter in all the mangrove forests. Over 78% (by weight) of the accumulated litter in each forest was from the dominant species (93% in the *Rhizophora* and *Ceriops* forests, and 78% in the *Avicennia* forest).

Significantly more ground litter accumulated in the *Ceriops* and *Avicennia* forests than in the *Rbizophora* forests. In the *Avicennia* and *Ceriops* forests, the amount of accumulated litter was greatest between July and January and least in March; in the *Rbizophora* forests there was no difference in the amount of accumulated litter throughout the year (Fig 4.2.3).

#### Discussion

The *Rhizophora* forests in the Embley River are highly productive in terms of litterfall and are probably growing under favourable conditions. *Rhizophora* forests were the tallest, had the greatest canopy cover and the greatest surface area of ground structures (due to their prop roots) or potential refuges for juvenile finfish and crustaceans in this study. Little of the litter produced by the *Rhizophora* forests accumulated on the forest floor and most was quickly exported by the tides to other parts of the estuary.
Litterfalls in the *Ceriops* and *Avicennia* forests in the Embley River were lower than expected for trees of this height in this latitude (Saenger and Snedaker 1993). These forests are probably subject to water and salinity stress for much of the year. The litter that accumulates on the forest floor in the *Ceriops* and *Avicennia* forests is exported to the estuary in the wet season from November to March, when both tides and rainfall are higher. This exported litter may provide ephemeral habitats for juvenile finfish and crustaceans in the river.

### Conclusions

The mangroves of the Embley river can be classified into three main communities: those dominated by *Rhizophora*, *Ceriops* or *Avicennia*. In the Embley River there are approximately 28 km<sup>2</sup> of *Rhizophora*, 26 km<sup>2</sup> of *Ceriops* and about 15 km<sup>2</sup> of *Avicennia* forest.

The *Rhizophora* forests in the Embley River are highly productive in terms of litterfall and are probably growing under favourable conditions. *Rhizophora* forests were the tallest, had the greatest canopy cover and the greatest surface area of ground structures or potential refuges for juvenile finfish and crustaceans in this study. All of the litter produced by the *Rhizophora* forests was quickly exported by the tides to other parts of the estuary.

The litterfalls in the *Ceriops* and *Avicennia* forests in the Embley River were lower than expected for trees of this height found at this latitude. These forests are probably subject to water and salinity stress for much of the year. The litter that accumulates on the forest floor in the *Ceriops* and *Avicennia* forests is exported to the estuary in the wet season from November to March, when both tides and rainfall are high. This exported litter may provide ephemeral habitats for juvenile finfish and crustaceans in the river.

#### References

- Conacher CA, O'Brien CJ, Horrocks J, Kenyon RA (in press). Litter production and accumulation in mangrove communities in the Embley River estuary, north-eastern Gulf of Carpentaria, Australia. *Marine and Freshwater Research.*
- Hatcher BG, Johannes RE, Robertson AI (1989). Review of research relevant to the conservation of shallow tropical marine ecosystems. Oceanography and Marine Biology Annual Reviews 27: 337–414.
- Long BG, Vance DJ, Conacher CA (1992). Remote sensing helps identify links between mangroves and prawns. *Australian Fisheries* **51(7)**: 22–23.

- Odum WE, Heald EJ (1972). Trophic analyses of an estuarine mangrove community. *Bulletin of Marine Science* 22: 671–737.
- Saenger P, Snedaker SC (1993). Pantropical trends in mangrove above ground biomass and annual litterfall. *Oecologia* **96:** 293–299.
- Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (in press a). How far do prawns and fish move into mangroves? Distribution of the juvenile banana prawn, *Penaeus merguiensis*, and fish in a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series*.
- Vance DJ, Haywood MDE, Heales DS, Staples DJ (in press b). Seasonal and annual variation in abundance of postlarvae and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series*.



# Figure 4.2.1 Map showing river and creek sampling sites in the Embley River in north-eastern Australia.



Figure 4.2.2 Mean litterfall ( $\pm$  1SE) of dominant species in each mangrove forest, over each collection period. Mean for *Rhizophora* is for both the River and Creek sites.



Figure 4.2.3 Mean ( $\pm$  1 SE) accumulation of litter (excluding wood) in each mangrove forest (g per m<sup>2</sup>). Mean for *Rhizophora* is for both River and Creek sites

Forest	Canopy	Canopy	Tree density	Ground	
	height (m)	cover (%)	(trees.ha <sup>-1</sup> )	structure	
				$(m^2.m^{-2})$	
Rhizophora-estuary	$17.5 \pm 2.5$	85 ± 5.0	$1200 \pm 210$	$1.5 \pm 0.3$	
<i>Rhizophora</i> -creek	$17 \pm 3.5$	$80 \pm 0.0$	$500 \pm 220$	$0.5 \pm 0.2$	
Ceriops-creek	11 ± 1.5	58 ± 11.1	$3700 \pm 920$	0.002 ± 0.0016	
Avicennia-creek	$6 \pm 1.7$	$16 \pm 5.0$	$500 \pm 90$	$0.0009 \pm 0.00007$	

4

Table 4.2.1.Mean (± 1 SE) morphological characteristics of the mangrove forests in<br/>the Embley River estuary.

## 4.3 Rates of decomposition of seagrass and mangrove leaves

## Introduction

In tropical estuaries mangroves and seagrasses are often the major primary producers. However, their roles as a food source and trophic base are difficult to discern (Zieman et al. 1984). The production of mangroves and seagrass varies considerably between sites and community types (Robertson, 1988). Only a small proportion of seagrass and mangrove production is grazed directly by herbivores, so a significant proportion enters the detrital pool (Rice and Tenore 1981). Consequently, it is important to understand the dynamics of the detrital cycle when considering the food chain of an estuary (Robertson, 1988). In addition, detritus, provides an ephemeral habitat for organisms, both where it is formed and where it may be moved to.

The chemistry of detritus changes as it decomposes. Usually the carbon:nitrogen ratio decreases, and the relative nitrogen content increases, with time after the initial leaching period (Rice and Tenore 1981). These changes may have important implications for the nutrition of animals that consume detritus.

The stable isotope ratios of carbon ( $\delta^{13}$ C) of an organism closely reflect the stable isotope ratios of the source material it feeds on and  $\delta^{13}$ C has therefore been used to trace the primary sources of marine food chains. Whilst the stable isotope ratios for mangroves and seagrass are distinct, they may change with decomposition.

In this study we compared the rate of decomposition of mangroves and seagrasses in the Embley River estuary. We compared the decomposition rates of leaves of different species in intertidal and subtidal positions, in the wet and in the dry season. We also examined changes in carbon and nitrogen concentrations and the changes in isotopic ratios during decomposition.

#### Methods

The Embley River estuary (12° 37'S 141° 52'E), in the north-eastern Gulf of Carpentaria, Australia, is in the wet-dry tropics where there is strong seasonal variation in climate. There are two main species of seagrass: *Enhalus acoroides* (L.f.) Royle and *Halodule uninervis* (Forske.) Aschers. and three main mangrove communities: the *Rhizophora, Ceriops* and *Avicennia* forests (Long et al. 1992) in the river.

There were two decomposition experiments: one beginning in June 1993 in the dry season and running for 10 months; and one starting in December 1993 in the wet

season and running for four months. At the beginning of each experiment, mature leaves of the mangroves *Rhizophora stylosa*, *Ceriops tagal* and *Avicennia marina*, and the seagrasses *Enhalus acoroides* and *Halodule uninervis* were collected. Leaves of the seagrass *Halophila ovalis* were also collected for the dry season experiment.

Samples of leaves were weighed and placed in mesh bags. Mangrove leaf bags were placed in either the mangrove forest where they were collected (intertidal) or in a creek (subtidal) adjacent to the fringing mangroves. Seagrass leaves were also placed in the seagrass bed where they were collected (intertidal), and in deeper water adjacent to the seagrass bed (subtidal). Samples were then collected after approximately 4 and 8 days and then about every 2 months over the following year.

In the laboratory the ash free dry weight, %C, %N,  $\delta^{13}$ C and  $\delta^{15}$ N were determined. Data were then analysed using exponential regressions to determine the rates of change in the above variables and analysis of variance was used to test whether the rates of change differed between species and seasons.

#### Results

#### Leaf decomposition

The rates of decomposition depended on the source material, the season, and whether the samples decomposed in the subtidal or intertidal. The time for fifty percent of the material to decompose ranged from 299 days for *Ceriops tagal* mangrove leaves placed in the intertidal in the dry season, to 5 days for leaves of the mangrove *Rhizophora stylosa* and the seagrass *Enhalus acoroides* placed in the subtidal in the wet season (Table 4.3.1).

Seagrass leaves decomposed much more rapidly than mangrove leaves. Of the seagrasses, *Halophila ovalis and E. acoroides* decomposed more rapidly than *Halodule uninervis*. Of the mangroves, *R. stylosa* leaves decomposed faster than *Avicennia marina* leaves, followed by *C. tagal* (Table 4.3.1).

Both seagrasses and mangroves decomposed more quickly in the wet season than in the dry season, and decomposition in the subtidal was quicker than decomposition in the intertidal (Table 4.3.1).

#### Carbon and nitrogen content

The initial carbon contents of the mangrove leaves (*R. stylosa*, *C. tagal* and *A. marina*) were similar to each other and similar in the wet and dry seasons. In contrast, the

initial carbon contents of the seagrass leaves (*H. uninervis* and *E. acoroides*) were significantly lower in the wet season than in the dry season and lower than those of the mangroves (Table 4.3.2). Although the initial carbon content did not change significantly with time, there was a slight tendency for carbon content to decrease during an experiment.

The leaves of the mangrove *A. marina*, and those of the seagrass *E. acoroides*, had the highest initial concentrations of nitrogen followed by the mangroves R. *stylosa*, *C. tagal* and the seagrass *H. uninervis*. In the dry season, the nitrogen contents in *A. marina* and *E. acoroides* were twice as high as the other species; in the wet season they were approximately 1.5 times as high (Table 4.3.2).

The nitrogen content of *R. stylosa*, *C. tagal*, and *H. uninervis* leaves did not change significantly with time, in any of the treatments. In contrast, the nitrogen content in the dry season decreased in *E. acoroides* leaves in both the subtidal and intertidal, and decreased in subtidal *A. marina* leaves in both seasons.

Leaves of the mangroves *Ceriops tagal* and *R. stylosa* had the highest initial carbon:nitrogen ratios, followed by H. *uninervis, A. marina* and *E. acoroides*. There was no difference between the wet and the dry season C:N ratio in *R. stylosa* and *A. marina*, whereas it was lower in the wet than the dry season for *C. tagal*. *H. uninervis* and *E. acoroides* (Table 4.3.2).

In the dry season in the intertidal zone, the carbon:nitrogen ratios decreased with time, with the exception of *E. acoroides*, in which the C:N ratio initially increased then decreased, and *A. marina*, in which the C:N ratio remained stable. The greatest decrease in carbon:nitrogen ratios throughout the experiment was found in *H. uninervis* and *R. stylosa* leaves in the dry season and the intertidal zone.

## Stable isotope ratios of carbon ( $\delta^{13}C$ ) and nitrogen ( $\delta^{15}N$ )

The initial  $\delta^{13}$ C values for leaves of the mangroves *R. stylosa*, *C. tagal* and *A. marina* (range of means = -30 to -27‰) were significantly lower, by about 15‰, than those for the seagrasses *H. uninervis* and *E. acoroides*. in both seasons (-13 to -10‰, Table 4.3.2). The initial  $\delta^{13}$ C values did not differ significantly between Seasons and although the Species x Season interaction was significant, the initial  $\delta^{13}$ C values differed by at most only 1 – 2‰ between the wet and the dry season (Tables 4.3.2).

The  $\delta^{13}$ C values of both mangrove and seagrass leaves changed relatively little during the decomposition experiments. In the intertidal, the  $\delta^{13}$ C values of mangrove leaves

had a maximum change of 1‰ for *R. stylosa* in the wet season. The subtidal mangrove leaves varied more in their  $\delta^{13}$ C values than those in the intertidal: the  $\delta^{13}$ C value of *R. stylosa* increased from -30 to -27‰ in the wet season and from -28 to -26‰ in the dry season. Like mangrove leaves, the  $\delta^{13}$ C values of seagrass leaves varied more in the subtidal than the intertidal, but the maximum change was only 2‰.

The initial  $\delta^{15}$ N values of seagrass and mangrove leaves differed significantly between Seasons and among Species, and the Season x Species interaction was also significant. In the dry season, the initial  $\delta^{15}$ N values ranged from 1.8 to 3.1% for mangrove leaves and from 1.7 to 2.6% for seagrass leaves (Table 4.3.2). The initial  $\delta^{15}$ N values of *R. stylosa* (5.4%) and *C. tagal* (5.5%) were higher in the wet than in the dry season, while those of *A. marina* did not differ between Seasons. The  $\delta^{15}$ N of *E. acoroides* and *H. uninervis* did not differ significantly between Seasons.

The  $\delta^{15}$ N values of *R. stylosa* and *C. tagal* decreased with time in the subtidal, particularly during the wet season when values of -3 and -5% were recorded after 115 days. The  $\delta^{15}$ N values of these species also decreased with time in the intertidal during the wet season, but only to 0‰. The  $\delta^{15}$ N values of the seagrass *H. uninervis* decreased with time in both the intertidal and subtidal locations, and during both the wet and dry seasons. A minimum value of -5% was recorded for this species after 180 d in the intertidal during the dry season. In contrast, the  $\delta^{15}$ N values of *E. acoroides* remained constant or increased over time, except in the subtidal during the wet season.

#### Discussion

In our study, the leaves of the seagrass *Enhalus acoroides*, which had the lowest C:N ratio and highest nitrogen content, decomposed most quickly in all situations, whereas the mangroves *C. tagal* and *R. stylosa* which had the highest C:N ratios and lowest %N, decomposed more slowly. As well as these differences between species, there were also differences within a species: *E. acoroides* and *H. uninervis* had lower C:N ratios in the wet season than the dry and decayed more quickly at this time.

In addition, leaf material placed in drier intertidal locations decomposed more slowly than those placed in moist positions. For example, in the intertidal, the less frequently the site was inundated by tides, the slower the material decayed, irrespective of the initial N content and C:N ratios. The results of our study agree with the suggestion that the decomposition rates of plants are positively correlated with nitrogen concentration and moisture availability; and negatively correlated with C:N ratios (Enriquez et al. 1993).

Most of the variation in the decomposition rates in our study can probably be attributed to the interaction of the %N, C:N ratio and moisture availability. However, some other factors may also have a role. For example, there was no change in the nitrogen content, nor C:N ratio, of the mangrove leaves for *A. marina* and *R. stylosa* between the dry and the wet season. However, in the subtidal position, where the samples were constantly saturated the decomposition rate of *A. marina* was slower in the wet than in the dry, and was faster for *R. stylosa*. This may have been due to changes in temperature or salinity, and/or the biochemical composition of the leaves.

Litter is produced throughout the year in the mangrove forests of the Embley River estuary, with peak litter production for *R. stylosa* and *A. marina* in the wet season and for *C. tagal* in the dry (see Section 4.2 and Conacher et al. In press). Litter does not collect in the *R. stylosa* forest but is rapidly transported by tides to the estuary throughout the year. In contrast, due to the infrequent inundation of the *C. tagal* and *A. marina* forests during the dry season, litter from these forests accumulates until the wet season, and is then flushed into the estuary. Consequently, most decomposition of mangrove material takes place subtidally and in the wet season. In the wet season, subtidal *Rhizophora stylosa* leaves decompose very quickly and little material would accumulate. In contrast, ephemeral banks of *A. marina* and *C. tagal* leaves may form, thus providing habitat for small organisms.

The role of mangroves and seagrasses in providing the nutritional requirements of **consumers** is poorly known. It has been suggested that a C:N ratio of less than 17 is required for proper animal nutrition (Russell Hunter 1970 in Klump and Van der Valk 1984), and that as the C:N ratio decreases with decomposition, the nutritional value increases (Klump and Van der Valk 1984). In our study, initial carbon:nitrogen ratios ranged from 21 to 45 for all species of mangrove and seagrass, except *E. acoroides*, which was less than 17. The carbon:nitrogen ratios of all species except *E. acoroides* tended to decrease or remain stable with time: those for *E. acoroides* increased with time. These results suggest that the nutritional status of *E. acoroides* may be adequate for animal nutrition when it is fresh, but decreases as it decomposes. The nutritional status of the other species of seagrass and mangrove, however, starts low and may improve as decomposition progresses. However, it is not known whether the concentrations of nitrogen, and decreases in the C:N ratios during decomposition of leaf detritus, increase the nutritional value of this material for higher consumers (Robertson 1988).

Table 4.3.2 Mean (±1 SE) initial values for the %C, %N, C:N ratio,  $\delta^{13}C$  and  $\delta^{15}N$  of mangrove

Species	Season	% carbon	% nitrogen	C:N ratio	δ13C	δ15 <sub>N</sub>
Mangroves						
Rhizophora stylosa	dry	43.4 ± 0.11	$1.05 \pm 0.037$	41 ± 1.4	$-28 \pm 0.17$	$2.8 \pm 0.14$
	wet	42.3 ± 0.40	$1.08 \pm 0.062$	39 ± 2.4	$-30 \pm 0.14$	5.4 ± 0.22
Ceriops tagal	dry	$41.8 \pm 0.30$	0.92± 0.018	45 ± 0.6	$-29 \pm 0.22$	3.1 ± 0.09
	wet	43.0 ±0.26	$1.21 \pm 0.030$	36 ± 1.0	$-28 \pm 0.23$	5.5 ± 0.53
Avicennia marina	dry	39.0 ± 0.20	1.96 ± 0.062	$20 \pm 0.7$	-28 ±0.13	1.8 ±0.04́
	wet	44.8 ± 0.66	$2.11 \pm 0.027$	21 ± 0.1	-27 ± 0.26	2.0 ±0.11
Seagrasses						
Enhalus acoroides	dry	32.5 ±0.52	2.05 ±0.070	16 ± 0,57	$-10 \pm 0.10$	$2.6 \pm 0.11$
	wet	22.9 ± 1.04	1.70 ± 0.0-i9	$13 \pm 0.30$	$-10 \pm 0.19$	$1.8 \pm 0.28$
Halodule uninervis	dry	36.5 ± 0.50	$0.90 \pm 0.024$	$41 \pm 0.8$	$-12 \pm 0.1$	$1.7 \pm 0.08$
	wet	24.5± 1.31	$1.02 \pm 0.028$	$24 \pm 1.9$	$-13 \pm 0.3$	2.7 ± 1.21

4

and seagrass leaves in the wet and dry season.

Table 4.3.1Mean ( $\pm$  1 SE) time taken in days for 50% of the leaf material of each<br/>species to decompose, based on exponential regressions, in intertidal and<br/>subtidal regions and in the wet and dry seasons. nd = no data.

Species	Di	ry season	We	Wet season		
	Intertidal	Subtidal	Intertidal	Subtidal		
Mangroves						
Rhizophora stylosa	$178 \pm 20.6$	51 ± 3.2	$7 \pm 1.8$	5 ± 1.3		
Ceriops tagal	$299 \pm 40$	66 ± 6.9	$103 \pm 21$	61 ± 9.8		
Avicennia marina	$260 \pm 28$	$20 \pm 2.5$	70 ± 6.5	$52 \pm 10.8$		
Seagrasses						
Enhalus acoroides	$11 \pm 1.6$	$18 \pm 1.3$	$6 \pm 0.3$	$5 \pm 0.6$		
Halodule uninervis	$62 \pm 9.6$	$35 \pm 9.0$	$5 \pm 0.7$	$6 \pm 0.7$		
Halophila ovalis	$2 \pm 0.3$	nd	nd	nd		

### Conclusions

Detritus from mangroves and seagrasses has an important role in the food chain of estuaries and also in the supply of habitat for juvenile and small organisms. In this study we measured the rate of decomposition of mangrove and seagrass leaves; and their carbon and nitrogen content, and stable isotope ratios during decomposition. We compared these factors between different species of mangroves and seagrass, at different tidal heights (intertidal and subtidal) and therefore different immersion times, and in different seasons (wet and dry).

Seagrass leaves decomposed more rapidly than mangrove leaves, and both seagrass and mangrove leaves decomposed more quickly in moister conditions. Seagrass leaves placed in the subtidal zone in the wet season decomposed faster than all other combinations of leaves, tide height and season.

Rates of decomposition are also influenced by the initial %N and the C:N ratio in the plant material. In our study, leaves of the seagrass *Enhalus acoroides*, which had the lowest C:N ratio and highest nitrogen content, decomposed fastest in all situations, whereas the mangrove leaves of *Ceriops tagal* and *Rhizophora stylosa*, which had the highest C:N ratios and lowest %N, decomposed more slowly. As well as these differences between species, there were also differences within a species: the seagrasses *E. acoroides* and *Halodule uninervis* had lower C:N ratios in the wet than the dry season and decayed more quickly during the wet season.

Our results and those of other studies indicate that whilst initial nutrient concentration and moisture conditions have important roles in determining the rates of decomposition, these factors alone cannot be used to predict decomposition rates. • Other factors, which may be location, season or species specific, also have an important role.

#### References

Conacher CA, Kenyon RA, O'Brien CJ, Loneragan NR (CSIRO internal review). Decomposition of mangrove and seagrass leaves in the Embley River estuary, north-eastern Gulf of Carpentaria, Australia. *Marine and Freshwater Research*.
Enriquez S, Duarte CM, Sand-Jensen K (1993). Patterns in decomposition rates among photosynthetic organisms: the importance of detritus C:N:P content. *Oecologia* 94: 457–471.

Klump DW, Van der Valk A (1984). Nutritional quality of seagrasses (*Posidonia australis* and *Heterozostera tasmanica*): comparison between species and stages

of decomposition. Marine Biology Letters 5: 67–83.

- Rice DL, Tenore KR (1981). Dynamics of carbon and nitrogen during the decomposition of detritus derived from marine macrophytes. *Estuarine Coastal and Shelf Science.* **13:** 681–690.
- Robertson AI (1988). Decomposition of mangrove leaf litter in tropical Australia. *Journal of Experimental Marine Biology and Ecology*. **116:** 235–247.
- Russell-Hunter WD (1970). Aquatic productivity: an introduction to some basic aspects of biological •ceanography and limnology. Collier-MacMillan, London, England.
- Zieman JC, Macko SA, Mills AL (1984). Role of seagrasses and mangroves in estuarine food webs: Temporal and spatial changes in stable isotope composition and amino acid content during decomposition. *Bulletin of Marine Science* 35: 380–392.

#### 24

**5.1 Defining the critical nursery habitat for juvenile tiger prawns** The critical nursery habitats of tiger prawns in the Gulf of Carpentaria were determined by analysing in much greater detail, the data collected in previous projects at Groote Eylandt (FIRTA 82/13) and in the Embley River estuary (FIRTA 89/13). These studies have now been published (Loneragan et al. 1994, Haywood et al. 1995).

The population dynamics of small tiger prawns (Penaeus esculentus and Penaeus semisulcatus) were studied at three sites around north-western Groote Eylandt, Gulf of Carpentaria, Australia, between August 1983 and August 1984. Seagrasses typical of open coastline, reef-flat and river mouth communities were found in the shallow depths ( $\leq 2.5$  m) at these sites. The temperature and salinity of the bottom waters did not differ among the shallowest depths of the three sites and mean values at night ranged from 21.9 to 32.0°C, and from 30.1 to 37.5‰. Data from fortnightly sampling with beam trawls showed that virtually all postlarvae (c 90%) were caught in the intertidal and shallow subtidal waters ( $\leq 2.0$  m deep). At one site, where the relationship between seagrass biomass, catches and depth could be studied in detail, high catches were confined to seagrass in shallow water, within 200 m of the high water mark. This was despite the fact that seagrass beds of high biomass  $(> 100 \text{ g} \cdot \text{m}^{-2}$  between August and February) were found nearby, in only slightly deeper water (2.5 m). It is likely, therefore, that only the seagrass beds in shallow waters of the Gulf of Carpentaria act as important settlement and nursery areas for tiger prawns. In general, catches of tiger prawn postlarvae (both Penaeus esculentus and Penaeus semisulcatus) and juvenile P. esculentus on the seagrass in the shallowest waters at each site, were higher in the tropical pre-wet (October-December) and wet (January-March) seasons, than at other times of the year. Juvenile P. semisulcatus catches were highest in the pre-wet season. While seasonal differences accounted for the highest proportion of variation in catches of tiger prawn postlarvae and juvenile P. semisulcatus, site was the most important factor for juvenile P. esculentus. In each season, catches of juvenile *P. esculentus* were highest in the shallow open coastline seagrass, where the biomass of seagrass was highest. The fact that the type of seagrass community appears to be more important to juvenile *P. esculentus* than to postlarvae, suggests that characteristics of the seagrass community may affect the survival or emigration of postlarval tiger prawns. Few prawns (<10%) from the seagrass communities in shallow waters exceeded 10.5 mm in carapace length. Despite the intensive sampling, growth was difficult to estimate because postlarvae recruited to the seagrass beds over a long period, and the residence times of juveniles in the sampling area were relatively short (c eight weeks).

.

We evaluated the importance of seagrass and algae to two species of tiger prawns (Penaeus semisulcatus and P. esculentus) by detailed sampling at four sites (two seagrass, two algae) in the Embley River estuary, and through sampling 26 sites in 7 adjacent estuaries at one time. Samples of tiger prawns were collected in the Embley River estuary with a small beam trawl at night every two weeks from September to May for two years (1990 to 1992). The two seagrass sites, which were 11 and 13 km from the river mouth, showed less seasonal variation in salinity than the two algal sites, which were 15 and 20 km from the river mouth. The algal beds at the two upstream sites almost disappeared during the wet season, but the biomass of seagrass did not change significantly between the wet and dry seasons. The grooved tiger prawn (*Penaeus semisulcatus*), the main species at all sites, comprised 88% of the total tiger prawn catch over the two years. They were found at all sites during the pre-wet season, but after the onset of the wet season, they disappeared along with the algae, from the upstream sites. The brown tiger prawn (P. esculentus) was found almost exclusively (97% of the total catch) on the seagrass sites downstream. In the study of several estuaries, juveni e Penaeus semisulcatus were caught at all 26 sites, and *P. esculentus* were caught in much smaller numbers, at 16 sites. Approximately equal numbers of *P. semisulcatus* were caught in algal and seagrass beds. Very few animals larger than 10 mm carapace length of either species, were caught. The results from this study highlight the importance of algal beds as nursery areas for one species of tiger prawn (Penaeus semisulcatus).

#### References

- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122**: 213–223.
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* 119: 133– 143.

## 5.2 Seasonal and annual patterns of recruitment of juvenile *Penaeus semisulcatus* to seagrass beds in the Embley River

### Introduction

In the past, most penaeid prawn fisheries have been managed on the basis that the spawning stock was not limiting and that any annual variation in recruitment to the fisheries was determined by environmental variation. However, recent studies have challenged this assumption. For example, recruitment of adult brown tiger prawns, *Penaeus esculentus*, to the fishery in Exmouth Gulf, Western Australia was shown to be related to spawning stock, and management measures were subsequently introduced to protect the spawning stock (Penn and Caputi 1986).

In the Gulf of Carpentaria tiger prawn fishery, in the absence of clear evidence for either a strong stock-recruitment relationship or a dominant environmental influence on catches, a conservative management approach was adopted, including seasonal closures and a reduction in fishing effort to protect the spawning stock. This management strategy, although appropriate in the short-term, is potentially wasteful in that fisheries income would be needlessly lost if the variation in recruitment was, in fact, not affected by spawning levels.

In order to refine this management strategy, we needed to determine the pattern of recruitment to the fishery as well as the extent to which recruitment is affected by environmental variation. A key problem in this fishery is the uncertainty surrounding the number of recruitment periods and early studies produced conflicting evidence for both one and two recruitment periods per year. The current management regime, developed in response to declining catches in the 1980s, is based on only a single period of recruitment to the fishery.

To provide the information needed to validate or modify the management strategy for the grooved tiger prawn (*Penaeus semisulcatus*) fishery in the Gulf of Carpentaria, we initiated a six-year study of all life history stages of grooved tiger prawns in the Embley River and offshore areas in the northeastern Gulf of Carpentaria (FRDC 85/85 and 89/13). There were two major objectives. The first was to identify seasonal recruitment patterns and the range of annual variation in those patterns. The second was to determine whether environmental factors might be controlling recruitment. Full details of this Section have been accepted for publication (Vance et al. in press).

#### **Results and discussion**

We studied the two-weekly, seasonal and annual variation in abundance of postlarval and juvenile grooved tiger prawns on a seagrass and an algal bed in the Embley River, using beam trawls, over six years, from September 1986 to May 1992. Catches of postlarvae and juveniles in the estuary showed strong seasonal variation; they were highest just before and during the wet season, from September to April each year (Fig. 1). Catch rates often had a bimodal distribution each year, but the relative size of each recruitment peak varied considerably between years. In four years the highest postlarval and juvenile catches were just before the wet season (in November or December) but in two years, the highest catches were during the wet season (in March). Long-term sampling over several years is clearly necessary to identify seasonal patterns in abundance and the range of variation in these patterns for juvenile prawns. Total catches of postlarvae and juvenile prawns also varied substantially between years.

When data for all six years of the study were combined, the postlarvae and juveniles showed two clear peaks of recruitment, in October and April for postlarvae and in November and March for juveniles (Fig. 2). The bimodal juvenile catch distribution suggests that recruitment to the offshore adult fishery should occur over two periods during the year. This bimodality has important implications for the management of the fishery.

We found that environmental variation in the estuary had very little overall effect on the abundances of juvenile grooved tiger prawns. Rainfall was the most important environmental variable in our analyses but it only explained a small proportion of the variation in catch. Increased rainfall during the wet season resulted in a lower catch of postlarvae at the seagrass and algal sites but its major influence was through reducing the amount of algal nursery habitat during the wet season. The mean sea level, or the amount of time that the seagrass bed was exposed, also seemed to be important; increased exposure of the seagrass bed was associated with decreased catches of *Penaeus semisulcatus*. Overall, the most important factor in determining the abundance of juvenile *Penaeus semisulcatus* in the estuary was the number of postlarvae that arrived and settled on the seagrass and algal beds.

a

#### Conclusions

- Juvenile grooved tiger prawns were abundant in the estuary for up to 7 months of the year and often had a bimodal distribution in abundance during this period.
- The bimodal distribution suggests that recruitment to the offshore fishery probably occurs over 2 periods during the year rather than only 1 as was previously thought.
- Environmental variation seemed to have little effect on juvenile prawn abundances; the major influence was the settlement of postlarvae from offshore.

#### References

Penn JW, Caputi N (1986) Spawning stock-recruitment relationships and environmental influences on the tiger prawn (*Penaeus esculentus*) fishery in Exmouth Gulf, Western Australia. Aust J Mar Freshwater Res 37: 491-505
Vance DJ, Haywood MDE, Heales DS, Staples DJ (in press). Seasonal and annual variation in abundance of postlarvae and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series*.



Figure 5.2.1. Postlarvae and juvenile catches at two-weekly intervals from September 1986 to May 1992 for the seagrass site. pw=pre-wet season; w=wet season; ed=early-dry season; d=dry season.



Time (months)

Figure 5.2.2. Mean monthly catches  $(\pm 1 \text{ SE})$  of postlarvae and juveniles over 6 years for the seagrass site. Standard errors less than 0.03 are not shown.

#### 5.3 Habitat selection by postlarvae and small juvenile prawns

#### Introduction

The density of juvenile tiger prawns on seagrass beds is determined by many factors including:- the numbers of postlarval prawns initially settling from the water column, migration of juveniles to and from the seagrasses, mortality due to predation or other factors and the availability of food in the seagrass. When assessing the productivity of coastal nursery habitats, each of these factors must be taken into account. For example, the abundance of tiger prawns on a seagrass bed will never be high if few postlarvae arrive at the bed (McNeil et al. 1992). Alternatively, high numbers of postlarval prawns may recruit to a seagrass bed, only to decline dramatically as juveniles due to predation or migration (Loneragan et al. 1994).

The aim of this study was therefore to find out more about factors determining the initial arrival of postlarval prawns onto estuarine nursery habitats and the survival of postlarvae immediately after settlement. Traditional methods of sampling prawn populations, such as beam trawling, do not test for cues to settlement or account for the effects of predation on prawn populations in different habitats.

In particular, we wanted to know:

- do postlarvae settle in greater abundances on seagrasses than bare habitats?
- what is the settlement density of prawns per day?
- does predation reduce the abundance of newly-settled prawns in some habitats more than others?
- do settlement rates vary at different locations within an estuary?

We also completed laboratory experiments to determine whether postlarvae prefer natural seagrass to artificial seagrass and bare substrate. The results of this work have been summarised in a manuscript by Lui and Loneragan (submitted)

#### Methods

We developed Artificial Seagrass Units (ASUs) which could be deployed one day and harvested 24 h later (Fig. 5.3.1). The number of postlarvae collected on the trays provided an estimate of settlement of postlarvae from the water column. The size of animals considered to be newly-settled postlarvae was  $\leq 2.9 \text{ mm}^4$  carapace length for tiger prawns,  $\leq 20 \text{ mm}$  carapace width for blue swimmer crabs and  $\leq 35 \text{ mm}$  total length for commercial fish. The ASUs were deployed to sample penaeid prawn postlarvae that were settling on seagrasses at three sites in the Embley River estuary. The ASUs were deployed twice during peak recruitment times in the pre-wet season

(November, 1993 and October, 1994) and once during high recruitment times in the post-wet season (April, 1994).

To determine the effectiveness of the ASUs in measuring postlarval settlement rates, we initially set the ASUs within natural seagrass beds in the Embley River (Fig. 5.3.2; Sg 1). We compared the density of prawn postlarvae and juveniles in ASUs with the densities from trawls made through the same seagrass beds. Catches in trawls were converted to densities from the relative efficiencies of the beam trawl determined for postlarvae (66%), juvenile *P. semisulcatus* (46%) and juvenile *P. esculentus* (49%) (Loneragan et al. 1995).

To test if tiger prawn postlarvae would settle on Artificial Seagrass Units placed away from natural seagrass, we placed ASUs on bare substrate 30 m from natural seagrasses, at Sg 1, and compared the density of tiger prawn postlarvae from the ASUs on bare substrate to those within the natural seagrass. We also contrasted the densities of tiger prawn postlarvae on the ASUs with those on "control" bare trays, placed alongside the ASUs.

The effect of predators on the abundance of newly-settled postlarvae was tested by covering 50% of the Artificial Seagrass Units and bare trays with monofilament mesh (13 mm stretch mesh), supported 50 cm above the tray, to exclude fish and other potential predators of postlarval prawns from the trays. The mesh was secured at the base of the trays to try and prevent juvenile fish entering the tray under the mesh. We then compared the abundance of postlarvae on ASUs with and without mesh and made the same comparison for bare trays.

To determine if the settlement of tiger prawn postlarvae was different at separate locations within the estuary, we placed Artificial Seagrass Units on bare substrate at 3 locations, separated by about 2 kilometres across the Embley River. These were; Sg 1, on the south bank, Sg 2, on a central bank and Bare 1, on the north bank of the estuary. These sites were 30 m, 100 m and 1000 m, respectively, from natural seagrass beds (Fig. 5.3.2).

#### **Results and Discussion**

## Field experiments

The densities of tiger prawns on Artificial Seagrass Units (ASUs) placed in the seagrass beds at Seagrass 1 was similar to the numbers in beam trawl catches (corrected for catchability) from adjacent seagrass habitat (Fig 5.3.3). Similar species were caught in the ASUs and beam trawls. The ASUs were, therefore, effective at catching a range of animals which were present on the seagrass beds.

During the experiments in November 1993, the Artificial Seagrass Units were colonised by 21 taxa while the bare trays were colonised by 20 of the same taxa (Table 5.3.1). The numbers of some species differed markedly between the ASUs and bare trays (Table 5.3.1). The postlarvae and juveniles of 5 commercial species of penaeid prawns, 2 commercial species of crab (blue swimmer crabs, *Portunus pelagicus*; mud crabs, *Scylla serrata*) and 3 commercial species of fish (snapper, *Lutjanus russelli*; estuarine cod, *Epinephelus suillus*; flathead, *Platycephalus indicus*) were found on the ASUs. Tiger prawns, *Penaeus semisulcatus* and *P. esculentus* comprised 97% of the total prawn catch on the ASUs (Table 5.3.1).

The postlarvae of some of the following species settled on the Artificial Seagrass Units in sufficient numbers for statistical analysis. Tiger prawns, (both *P. semisulcatus* and *P. esculentus*), blue swimmer crabs and two species of commercial fish, cod and snapper, were found (Table 5.3.1).

#### Effect of habitat structure on settlement

Tiger prawn postlarvae settled in the Artificial Seagrass Units placed on bare substrate, however, their density  $(0.12\pm0.05 \text{ m}^{-2} \text{ d}^{-1})$  was lower than in ASUs placed within seagrass beds  $(0.26\pm0.08 \text{ m}^{-2} \text{ d}^{-1})$  (Table 5.3.2). On bare substrate, the postlarval density in ASUs was higher than their density on bare trays placed nearby  $(0.01\pm0.01 \text{ m}^{-2} \text{ d}^{-1})$  (Table 5.3.2). Tiger prawn postlarvae seemed to use the presence of seagrass as a cue to settlement and settled on artificial seagrass habitat when it was placed in areas that were previously bare.

On bare substrate, few tiger prawn postlarvae were found on the bare trays with no predator exclusion mesh, however, many postlarvae were found on the bare trays with the exclusion mesh (Fig. 5.3.4). Similar densities of postlarvae were found on the ASUs, both with and without exclusion mesh (Fig. 5.3.4). The density of tiger prawn postlarvae on the bare trays with the exclusion mesh was greater than that on the ASUs, (either with or without exclusion mesh) (Fig. 5.3.4). The abundance of blue swimmer crab postlarvae was similar on ASUs and bare trays, regardless of the presence of the exclusion mesh (Fig. 5.3.4).

Despite keeping out large fish predators, the density of many smaller predatory fish was not significantly different among the bare trays with or without exclusion mesh, or the ASUs with or without exclusion mesh (Fig. 5.3.4). The fish must have found a

way under the mesh. In particular, the density of some predatory fish (e.g. estuarine cod) was greater on the bare trays with exclusion mesh than on those without the mesh. The predation pressure in the exclusion mesh trays is therefore likely to have been no different to the predation pressure on trays without the exclusion mesh. Presumably, no more postlarvae were being eaten on the trays without exclusion than those with exclusion. Thus, the greater abundances of tiger prawn postlarvae on the bare "exclusion" trays is probably due to greater settlement rather than reduced predation.

As postlarval numbers were high on the bare trays with exclusion mesh, the mesh, which became fouled and visible, seems to have provided a structured habitat on the bare trays that attracted postlarval prawns to settle. Despite being made of a completely different type of material to artificial seagrass, the mesh was attractive to prawn postlarvae. These results, like those of others (Bell et al. 1986a,b), suggest that for some species, any form of structured habitat is better than bare substrate, and that pelagic postlarvae will settle to become benchic on any structured habitat, regardless of its structural complexity.

#### Effect of location on settlement

The abundance of penaeid prawns at the three sites across the Embley River estuary was very low in October 1994, at a time when they are usually present in high densities (Vance et al. in press). The numbers of prawns were too low to make statistical comparisons of densities between sites.

However, postlarvae of the crab, *Portunus pelagicus*, with a life history strategy similar to that of tiger prawns (Potter et al. 1983, Kailola et al., 1993), were abundant at this time. The abundance of crab postlarvae on the Artificial Seagrass Units varied between sites and was highest at Bare 1 on the north bank, which was about 1000 m from the nearest seagrass bed (Fig. 5.3.5). Trawls on the bare habitat at all sites found few crabs (< 0.01 m<sup>-2</sup>), suggesting that the ASUs attract settlers that would not settle from the plankton unless seagrass is present. The high densities of crab postlarvae at the bare site suggests that tidal advection of potential settlers may not be the same across the estuary or that settlers may accumulate on ASUs when they are deployed distant from natural seagrass and represent the only available habitat for settlement. Although differences in abundance across the estuary were only shown for blue swimmer crab postlarvae, tiger prawns also reach seagrass habitats on advective currents. Consequently, the delivery of more tiger prawn postlarvae to some areas than others may result in greater abundances of juvenile tiger prawns in some beds of seagrass compared to others.

Past FRDC projects have shown that different seagrass communities around Groote Eylandt support different abundances of juvenile prawns and that juvenile abundances may not reflect the abundances of newly settled postlarvae some weeks beforehand (Loneragan et al. 1994). Habitat selection by larger juveniles and predation events in habitats of different leaf morphology and shoot densities may be important (Kenyon et al. 1995). The results of this study using ASUs show that different delivery rates of postlarvae to the seagrass communities may also be an important factor. Artificial Seagrass Units may be used in the future to test the effects of seagrass shape and size on the settlement of postlarval prawns. Measuring settlement in different habitats provides valuable information on the processes that determine the distribution of juvenile prawns.

### Conclusions

- A similar group of animals was collected in Artificial Seagrass Units and beam trawls which suggests that the ASUs are used like natural seagrass
- Tiger prawn postlarvae settled in greater abundances on structured habitat (either artificial seagrass or bare trays with mesh) than bare habitat.
- The rate of settlement of tiger prawn postlarvae was about  $0.12 0.26 \text{ m}^{-2} \text{ d}^{-1}$ .
- The presence of potential predators did not seem to affect the abundance of settlers, although this may change as the postlarvae grow in size.
- The rate of settlement of blue swimmer crabs differed greatly between sites within the estuary, separated by short distances. Currents, therefore, can have an important influence on the number of prawn postlarvae arriving at a site.

#### References

- Bell JD, Westoby M (1986a). Abundance of macrofauna in dense seagrass is due to habitat preference, not predation. *Oecologia*. **68:** 205–209.
- Bell JD, Westoby M (1986b). Importance of local changes in leaf height and density tofish and decapods associated with seagrasses. *Journal of Experimental* -*Marine Biology and Ecology* **104:** 249–274.
- Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, McNee A, Grieve C (1993). *Australian Fisheries Resources.* Bureau of Rural Resources, Canberra, Australia. 422 pp.
- Kenyon RA, Loneragan NR, Hughes JM (1995). Habitat type and light affect sheltering behaviour of juvenile tiger prawns (*Penaeus esculentus*) and success rates of their fish predators. *Journal of Experimental Marine Biology and Ecology* 192: 87–105.
- Lui H, Loneragan NR (submitted). Size and time of day affect the response of postlarvae and early juvenile grooved tiger prawns *Penaeus semisulcatus* De Haan (Decapoda: Penaeidae) to natural and artificial seagrass in the laboratory. *Journal of Experimental Marine Biology and Ecology*.

- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria. *Marine Biology* **119**: 133–143.
- McNeil SE, Worthington DG, Ferrell DJ, Bell JD (1992). Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. *Australian Journal of Ecology* **17**: 359–365.
- Potter IC, Chrystal PJ, Loneragan NR (1983). The biology of the blue manna crab Portunus pelagicus in an Australian estuary. Marine Biology **78:** 75–85.
- Vance DJ, Haywood MDE, Heales DS, Staples DJ (1996). Seasonal and annual variation of postlarval and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series*.

Table 5.3.1.Total numbers of juvenile penaeid prawns, crustaceans, fish and other<br/>fauna from Artificial Seagrass Units and bare trays deployed in seagrass<br/>habitat and on bare substrate in the Embley River estuary in November<br/>1993.

Species	Habitat and settlement tray type				Total
	Seagrass		Bai	re	
	ASU	Bare tray	ASU	Bare tray	
Prawns					
Juvenile grooved tiger	55	6	20	3	84
Juvenile brown tiger	4	2	8	1	15
Tiger prawn postlarvae	14	11	11	1	37
Greasyback	3	16	43	202	264
Penaeus monodon	0	0	1	0	1
Penaeus merguiensis	0	0	2	1	3
Penaeus latisulcatus	1	0	0	0	1
Decapod crustaceans					
Blue swimmer crabs-all sizes	33	2	44	13	92
Carids	482	42	241	13	778
Alphaeid shrimp	10	3	37	1	51
Sergestid	14	25	69	185	293
<u>Fish</u>					
All fish	127	410	28	141	706
Commercial fish species	18	10	14	7	49
Other crustaceans	819	170	63	54	1106
<u>Molluscs</u>	308	300	812	564	1984
Echinoderm	21	22	0	0	43
TOTAL CATCH	1891	1009	1379	1179	5458
TOTAL TAXA	21	20	18	18	21
no. of deployments	28	28	35	35	251

4

Table 5.3.2. Mean numbers (± 1 SE, m<sup>-2</sup> d<sup>-1</sup>) of juvenile penaeid prawns, crustaceans and fish from Artificial Seagrass Units and bare trays deployed in seagrass habitat and on bare substrate at Sg1 in the Embley River estuary in October 1993. Commercial fish species are snapper, *Lutjanus russelli*; cod, *Epinephelus suillus*; and flathead, *Platycephalus indicus*.

Species	Habitat and settlement tray type				
	Seagrass		Bare		
	ASU	Bare tray	ASU	Bare tray	
Prawns					
Juvenile grooved tiger	1.84±0.32	0.20±0.10	0.22±0.06	0.03±0.02	
Juvenile brown tiger	0.08±0.05	0.06±0.05	0.14±0.08	$0.04 \pm 0.04$	
Tiger prawn postlarvae	0.26±0.08	0.39±0.14	0.12±0.05	$0.01 \pm 0.01$	
Greasyback	$0.04 \pm 0.02$	0.49±0.15	0.71±0.17	3.11±0.40	
Other Crustaceans					
Carids	14.81±2.51	1.48±0.64	3.88±0.61	0.25±0.08	
Blue swimmer crab	0.77±0.20	0.09±0.06	0.37±0.10	0.24±0.09	
Alphaeid shrimp	0.37±0.19	0.04±0.03	0.88±0.23	$0.04 \pm 0.04$	
Sergestid	0.50±0.44	0.95±0.47	1.22±0.45	2.38±1.01	
<u>Fish</u>					
All fish	3.13±0.67	16.46±5.32	0.52±0.14	3.63±0.92	
Commercial fish species	0.26±0.07	0.19±0.06	0.11±0.03	0.05±0.02	
(no of sets)	(28)	(28)	(35)	(35)	



1.

.

Figure 5.3.1 Artificial Seagrass Units used to quantify postlarval tiger prawn settlement and bare trays used as "controls".



1 <u>1</u>

Figure 5.3.2.



Figure 5.3.3 The catch of tiger prawn juveniles and postlarvae, as well as other species, in Artificial Seagrass Units placed among seagrasses and beam trawls made through the same seagrasses

.



Figure 5.3.4 The catch of (a) tiger prawn postlarvae, (b) blue swimmer crab settlers and (c) potential fish predators on Artificial Seagrass Units and bare trays, set on bare substrate, with and without predator exclusion mesh



Figure 5.3.5 The catch of blue swimmer crab settlers from (a) Artificial Seagrass Units and bare trays set on bares substrate and (b) trawls over bare substrate at 3 sites in the Embley River estuary.

## 5.4. Effect of density on the growth of juvenile grooved tiger prawns *Penaeus semisulcatus* in seagrass beds of the Embley River estuary

#### Introduction

Postlarvae and early juvenile tiger prawns recruit to shallow water nursery habitats in the Gulf of Carpentaria over two main periods of the year: the pre-wet season (September to December) and the late-wet season (February to May) (Vance et al. in press, Section 5.2). After recruiting to their inshore nurseries, the postlarvae and early juvenile stages are found in much higher densities in intertidal and shallow subtidal seagrass and algal beds than in deeper waters (Loneragan et al. 1994, Haywood et al. 1995, Section 5.1). The densities of juvenile tiger prawns around Groote Eylandt vary with the type of seagrass: higher densities are found on seagrasses with higher biomass, and longer and wider leaves than those with less biomass and shorter leaves (Loneragan et al. 1994, Section 5.1). In contrast to postlarval banana prawns, which can reach densities of up to 60 per m<sup>2</sup> in mangrove creeks (Haywood and Staples 1993), the density of postlarval and juvenile tiger prawns rarely exceed 2 to 4 per  $m^2$ (Loneragan et al. 1994, Vance et al. in press). What limits the densities of juvenile tiger prawns and what are the maximum densities of tiger prawns that seagrass beds can support? How is the carrying capacity of seagrass for juvenile tiger prawns affected by the type of seagrass bed?

We were interested in investigating how many tiger prawns a seagrass bed can support in the absence of predators, and therefore developed a technique to study the growth of prawns at different densities in natural seagrass beds. We investigated whether the relationship between growth and density differed between the two main times of high abundance (pre-wet and late-wet seasons); and whether it differed between different types of seagrass beds: one dominated by the large seagrass *Enhalus acoroides*; and one where the much smaller *Halodule uninervis* and *Halophila ovalis* are the main species, in the Embley River estuary. We studied the small early juvenile stages (3 to 6 mm in carapace length) because this is by far the most abundant size-class found on seagrass beds of tropical Australia (Loneragan et al. ~ 1994, Vance et al. in press).
#### Methods

#### Study area

The Embley River estuary (12° 40' S, 141° 50' E) (Fig. 1) contains several large (>3 ha) intertidal beds of seagrass (*Enhalus acoroides, Halodule uninervis* and *Halophila ovalis*) and smaller (approximately 1 ha) subtidal beds of algae. We studied the growth of juvenile tiger prawns (*Penaeus semisulcatus*) stocked at different densities of prawns on two seagrass beds: Sg1 — dominated by the tall, broad leaved *Enhalus acoroides* (leaves up to 1 m long), which grows at low shoot densities; Sg2 — dominated by the much shorter leaved *Halodule uninervis* and *Halophila ovalis* (leaves < 0.1 m long), which grow at much higher shoot densities.

#### Enclosures

Prawns were stocked in enclosures (see below) with a square aluminium base (0.95 m sides, basal area =  $0.90 \text{ m}^2$ ) (Fig. 5.4.1a). The enclosures were about 1 m high and covered with 100 µm mesh, supported on 4 aluminium rods, which curved inwards at the top. This very fine mesh was chosen to exclude most planktonic animals from migrating into the enclosures with the tide and therefore restricted the potential prey items of the prawns to those that were located mainly in the seagrass when the enclosures were deployed.

After trials in Moreton Bay, an experiment using 12 enclosures and juvenile prawn densities of 4, 16 and 32 per enclosure was completed in the Embley River estuary in November 1993. However, after 10 days animals such as mud crabs (*Scylla serrata*) had burrowed under many of the enclosures allowing prawns to escape. In further experiments, an extension was added to the base of each enclosure to limit the effects of burrowing animals. The extension was made of aluminium plate (20 cm deep), welded into a square frame and pushed into the substrate to a depth of 20 cm. The enclosure was then fitted tightly into the extension frame.

The effect of the enclosures on dissolved oxygen, light and temperature were measured in Moreton Bay by placing a logger inside and outside the enclosures. Over a 4 day period, dissolved oxygen inside the enclosures differed by less than 0.5 units from the sea water outside the enclosure; temperature by less than 0.2°C. However, the light could be reduced by about 10% inside the enclosures compared with the outside environment.

#### Stocking prawns in enclosures

Juvenile grooved tiger prawns were collected from Sg1 in a small beam trawl (1  $\times$  0.5 m mouth, with 2 mm square mesh in the body and 1 mm mesh in the codend) and

transported to the laboratory in aerated 25 l plastic drums. The carapace lengths of the prawns were then measured to the nearest 0.1 mm under a binocular microscope fitted with a graduated eye piece. Prawns were then placed in aerated plastic containers and stocked in the enclosures (see below), usually within 24 h of their capture. The carapace length (CL), total length, and wet and dry weights of a subsample of prawns caught using the beam trawl on Sg1 were also measured at the start and end of each experiment to determine the relationship between CL and both wet and dry weight.

#### Experimental design

Following the preliminary experiments in Moreton Bay during 1992 and 1993 and in the Embley River estuary in November 1993, 3 experiments were completed in the Embley River estuary in 1994: one in the late-wet season (March/April) and two in the pre-wet season (between October and December, Table 5.4.1). Enclosures were assembled and placed on the intertidal seagrass beds at low tide, usually 1 or 2 days before they were stocked with prawns. Before placing the enclosure on the seagrass, the seagrass was disturbed by sweeping a garden rake across the area, in an attempt to displace fish and prawns from the area.

The densities of prawns stocked in the enclosures ranged from 4 to 32 (Table 5.4.1) and the sizes from 3.4 to 6.7 mm carapace length (CL). However, within each enclosure, the size range of prawns was less than 1 mm CL in 95% of the enclosures and less than 0.5 mm CL in 80% of the enclosures. Three or four rows of between 4 and 6 enclosures were placed in a area of approximately 30 m by 30 m, with a distance of about 5 m between enclosures within a row, and 10 m between adjacent rows of enclosures. Within a row of enclosures, densities of prawns were randomly assigned to enclosures.

#### Retrieving prawns from enclosures

Prawns were retrieved from enclosures between 13 and 22 d after stocking them by placing a square retrieval net (1 m x 1 m base, 1.8 m high, Fig. 5.4.1b) constructed of 2 mm mesh over the enclosure, pushing the base of the net into the substrate and removing the enclosure from inside the retrieval net (see below for further details of the retrieval net). The seagrass and substrate within the retrieval net were swept with a hand operated scoop-net ( 30 x 10 cm mouth with 2 mm mesh net). Prawns and fish were bagged and placed in a brine slurry. After about 5 min of scooping, the substrate was further disturbed by drawing a blind with attached nozzles (see below) across the base of the retrieval net and sealing the base in 2 - 3 min. The square net was then lifted into a boat, prawns and fish were placed in brine. The retrieval net had a rigid aluminium base (1 x 1 m), slightly larger than an enclosure. Floats were attached to the top of the net to elevate the mesh above the water and prevent prawns escaping (Fig. 5.4.1b). Within the rigid base, a multi-nozzle water-jet and semi-rigid plastic blind could be drawn from the open position across the mouth of the base to seal the base. When placed on the substrate and activated, the water-jet directed sprays of water at the substrate, dislodging prawns and fish into the water column. The plastic blind, immediately behind the nozzles, was drawn across the base of the retrieval net, which prevented the animals from returning to the substrate. In a fully closed position, the blind closed off the mouth of the rigid base, trapping any fish and prawns disturbed from the substrate.

Samples were transported to the laboratory where they were frozen. Prawns and fish were identified to species wherever possible, measured (carapace length, total length, wet and dry weight). Prawns from the late-wet experiment were only wet-weighed because the contents of their foreguts were also examined. The moult stage of prawns and their gut fullness were estimated and the frequency of occurrence of different items in the diet was calculated for all prawns retrieved from the enclosures (following Heales et al. in press).

After prawns and fish had been removed from all enclosures, the seagrass was sampled within a 0.25 m square quadrat from the central region of the enclosure's position. Seagrass shoots were counted and all above-ground and below-ground vegetation was removed from within the quadrat. The vegetation was returned to the laboratory where the species of seagrass were identified, and the above and below ground components separated and dry weighed.

## Beam trawl sampling

Beam trawls were used to sample the postlarvae and juvenile tiger prawns on the seagrass beds at the time of each experiment. Two 100 m trawls were made parallel to the shore between two permanent markers every 7 d from 27 March to 24 April 1994 in the late-wet or early-dry season and from 6 October to 2 December 1994 in the pre-wet season. Two sites about 200 m apart were sampled on Sg1 (4 trawls every 7 d) and one site on Sg2 (2 trawls). The salinity and temperature of the water and the water depth were measured at the time of sampling. Samples of prawns were taken on ice to the laboratory where they were frozen before being sorted, identified and measured to the nearest 0.5 mm carapace length.

The mean numbers of postlarvae and juvenile prawns of each species were calculated for the time periods when the experiments were carried out: late-wet = 25 March to 30 April (April); pre-wet 1 = 10 October to 5 November (October); pre-wet 2 = 9 November to 7 December (November), and for each year of the studies by Haywood et al. (1995) and Vance et al. (in press).

## Estimation of growth rates

The mean carapace length was calculated for the prawns in each enclosure at the start and the end of each experiment. The relationships between CL and wet and dry weight were used to estimate the mean wet and dry weights of the prawns at the start of each experiment. Mean wet and dry weights were calculated for prawns at the end of the experiment. The weekly growth rates were estimated from the difference in mean CL, wet and dry weight between the start and end of the experiment, and adjusting for the duration of the experiment (days):

e.g. growth in carapace length =  $(CL_{end} - CL_{start})/days \times 7$ 

The relationships between growth rate and numbers of prawns at the start and end of the experiment were calculated by linear regression for each season (late-wet and prewet) and location. Because larger numbers of the low density enclosures i.e. 4 prawns per enclosure, had more than 30% of the original prawns remaining at the end of each experiment, differences in growth rates between experiments at these lower densities were tested by one-way ANOVAs of the data for Sg1. In the pre-wet season, differences in growth rates in low density enclosures between Sg1 and Sg2 were tested by t-test. Growth rates were transformed using log<sub>10</sub> in all of the above analyses.

Growth rates for juvenile tiger prawns caught in beam trawls on Sg1 and Sg2 were estimated from the data collected in previous studies (Haywood et al. 1995, Vance et al. in press) by cohort analysis following Haywood and Staples (1993). This method assumes that the population is closed to immigration and emigration and that juvenile prawns of all sizes are equally vulnerable to the beam trawl. Unfortunately, cohort analysis could not be used to estimate growth from the data collected by beam trawls in the current study because cohorts were difficult to identify and follow over the relatively short sampling period (4 - 6 weeks).

## **Results and discussion**

## Seagrass characteristics, salinity and temperature

The mean biomass of seagrass in enclosures at Sg1 in both the pre-wet and late-wet seasons was about 70 to 80 g m<sup>-2</sup>, which is much higher than the 4 to 14 g m<sup>-2</sup> found

at Sg2 (Table 5.4.2). The total biomass of seagrass recorded at these two sites is similar to that recorded in the pre-wet seasons of 1990/91 and 1991/92 (Haywood et al. 1995). The mean temperature of the water was about 30 °C during both the pre-and late-wet seasons and was similar at Sg1 and Sg2 (Table 5.4.2). The mean salinity was about 7‰ lower in the late-wet (29‰) than the pre-wet season of 1994 (36.4‰, Table 5.4.2).

## Numbers of postlarvae and juveniles on seagrass beds

During the times of the enclosure experiments the mean catches of postlarvae in beam trawls were higher in each sampling period on Sg1 than Sg2, but not in previous years (Fig. 5.4.2). In 1994, the highest mean catch of postlarvae at Sg1 was 85 per 100 m<sup>2</sup> in November, whereas the highest means at Sg2 were 10 - 15 per 100 m<sup>2</sup> in October and November. Assuming a net efficiency of about 66% for postlarvae (Loneragan et al. 1995), the peak densities of postlarvae were about 120 per 100 m<sup>2</sup> on Sg1 and 20 per 100 m<sup>2</sup> on Sg2.

In 1994, the mean catches of juvenile *Penaeus semisulcatus* in 1994 were highest in November on both Sg1 (80 per 100 m<sup>2</sup>) and Sg2 (44 per 100 m<sup>2</sup>) (Fig. 5.4.2), which allowing for the efficiency of the net for sampling juveniles (35 to 47%, Loneragan et al. 1995) gives density estimates of about 170 - 230 per 100 m<sup>2</sup> on Sg1 and 94 - 125 per 100 m<sup>2</sup> on Sg2. In previous years, mean catch rates of juvenile *P. semisulcatus* were similar in April, October and November at Sg1. Mean catch rates varied more both within and between months at Sg2 than at Sg1. Mean catch rates of juvenile *Penaeus esculentus* were much lower than those for *P. semisulcatus* (Fig. 5.4.2). The total maximum densities of juvenile tiger prawns on Sg1 during the enclosure experiments were about 200 – 250 per 100 m<sup>2</sup>.

#### Number of prawns at the end of experiments

The highest proportions of prawns were retrieved from enclosures in the late-wet season on Sg1 (Fig. 5.4.3a). At this time, recovery rates were highest (75 to 100%) in the 4 prawns per enclosure treatment. No prawns were recovered from one of the 32 prawns per enclosure replicates. The variation in the proportions of prawns recovered from enclosures was higher in the pre-wet season experiments than in the post-wet season. Recovery rates at Sg2 were very low.

Some of the variation in recovery rates is probably due to predators remaining within the seagrass after the enclosure had been put in place. Prawns may also have been able to escape from very small spaces created by slight shifts in the positions of the enclosures in relation to their bases, or through some catastrophic event within an enclosure. For these reasons, we have not used the data from the enclosures to estimate mortality rates at different densities, only growth rates. However, we expect that mortality may increase at high densities through greater interactions between prawns, the possibility of more cannibalism when prawns moult, and a reduction in food.

We have only estimated growth rates where more than 30% of the stocked prawns were recovered from the enclosures. On Sg1, a total of 51 enclosures were stocked with prawns on Sg1, and 28 contained more than 30% of the original prawns at the end of the experiments (Table 5.4.1). At Sg2, only 7 of the 28 enclosures stocked with prawns had more than 30% of the original prawns. In some cases, the enclosures at Sg2 had lifted from their bases due to very strong winds in October 1994.

#### Growth at different densities

Growth rates were more highly correlated with the final number of prawns in the enclosures than the initial numbers (Table 5.4.3), which suggests that prawns either escaped or died soon after stocking in the enclosures. The final numbers of prawns in the enclosures have therefore been used as a closer approximation to the density of prawns over the duration of an experiment.

The highest growth rates in carapace length (CL) at Sg1 were recorded at final numbers of 4 to 6 prawns per enclosure, with a maximum of 1.62 mm CL per week. All except 3 estimates for these final numbers exceeded 1 mm CL per week (Fig. 5.4.4a). In general, the growth rates decreased as the final numbers of prawns in the enclosures increased, with 4 values of between 0.7 and 0.8 mm CL per week at final densities of 19 to 31 prawns at Sg1 (Table 5.4.3). The minimum growth rate recorded at Sg1 was 0.36 mm CL per week at a final density of 14 prawns.

The growth rates in the pre-wet season at Sg2 ranged from 0.16 to 0.81 mm CL per week, and were lower than those for the same final density at Sg1 (Fig. 5.4.4a). Only two growth rates at Sg2 exceeded 0.50 mm CL per week. The rate of change in wet and dry weight of prawns with their final densities (Fig. 5.4.4b,c) followed a similar pattern to those for carapace length. However, the variation in growth rates in weight at low final densities was greater than that for CL.

At Sg1 and Sg2, growth rates declined significantly with increasing numbers at the end of the experiment (Table 5.4.3). At Sg1, the relationship between growth rate (in CL) and final density explained 82% of the variation in the late-wet season and 45% in the pre-wet season. Using these relationships, a growth rate of 1 mm CL per week would

be achieved at Sg1 at a density of about 8-9 prawns per  $m^2$  in the late-wet season and 5.5 to 6.5 prawns in the pre-wet season.

At Sg1, growth rates in CL, wet and dry weight at final densities of 4 - 6 prawns per enclosure, did not differ among the late-wet and the two pre-wet season experiments (for CL F<sub>2,14</sub> = 0.20, P = 0.82; for wet weight F<sub>2,14</sub> = 1.61, P = 0.23; and for dry weight F<sub>1,10</sub> = 3.06, P = 0.11). The pooled growth rates for prawns at this density at Sg1 (1.28 ± 0.05 mm CL per week) were about 2 to 2.5 times higher than those at Sg2 (0.61 ± 0.09 mm CL per week, Table 5.4.4). These results suggest that the higher biomass of seagrass at Sg1 can support greater numbers of prawns than the low biomass seagrass at Sg2.

The mean growth rates of juvenile *P. semisulcatus* estimated from cohort analysis were about 1 mm CL per week at both Sg1 and Sg2 (Table 5.4.5) at maximum mean densities of prawns were 1.5 - 2.3 per m<sup>2</sup> on Sg1 and 0.5 - 1.3 per m<sup>2</sup> on Sg2; much lower than the densities in enclosures that could support a growth rate of 1 mm CL per week (5 - 9 on Sg1). The lower growth rates estimated from cohort analysis could be related to violations of the assumptions of cohort analysis, or a positive effect of enclosures on the growth of prawns. Because the recruitment of postlarval tiger prawns is continuous and juveniles emigrate from tropical seagrass beds at a small size, cohort analysis could well underestimate the growth rates of juvenile tiger prawns.

## Diet of prawns in enclosures

The mean gut fullness of juvenile *Penaeus semisulcatus* (as described in Section 5.5 of this report) in enclosures on Sg1 did not differ between final densities of 3 - 5, 8 - 14, and 18 - 20 prawns per enclosure during the late-wet season; mean gut fullness ranged from 7.7 (3 - 5 prawns) to 8.2 (18 - 20 prawns). It was also similar to that of prawns caught in beam trawls and scoop-nets on Sg1 in 24 h studies during the late-wet season (Heales et al. in press).

The frequencies of occurrence of the main food items in the foreguts of prawns caught in beam trawls were similar to those of prawns after about two weeks in enclosures on Sg1. In the enclosures, the frequencies of occurrence of the main items were also very similar at the different prawn densities in the enclosures with unidentified matter, diatoms, copepods and filamentous algae exceeding 90% in all cases (Fig. 5.4.5). However, 6 categories of diet (ostracods, foraminiferans, kinorhynchs, unidentified eggs, oligochaetes and bryozoans) were found more frequently in prawns from enclosures with final densities of 3 - 5 prawns, than either of the higher densities. Five items (foraminiferans, ostracods, polychaetes, kinorhynchs and oligochaetes) were also found more frequently in prawns from enclosures with 10 - 14 than 18 - 20 prawns. These results suggest that the diet of the juvenile prawns has been affected at the higher densities and this could account for the lower growth rates as density increases.

## Conclusions

- The growth rate of small grooved tiger prawns declined with density of prawns stocked in enclosures (0.9 m<sup>2</sup> in basal area) on intertidal seagrass beds. However, good growth rates were recorded at higher densities (2 4 times) than those normally found on these seagrasses.
- Growth rates were higher on the seagrass bed with higher biomass and the largeleaved *Enhalus acoroides* than on the bed with the low biomass and the much smaller-leaved *Halodule uninervis*. In the absence of predators, the carrying capacity of high biomass seagrass beds for juvenile tiger prawns is therefore likely to be greater than that of low biomass beds.

#### References

- Haywood MDE, Staples DJ (1993). Field estimates of growth and mortality of juvenile banana prawns (*Penaeus merguiensis* de Man). *Marine Biology* 116: 407–416.
- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122:** 213–223.
- Heales DS, Vance DJ, Loneragan NR (in press). Field observations of moult cycle, feeding behaviour, and diet of small juvenile tiger prawns *Penaeus semisulcatus* in a tropical seagrass bed in the Embley River, Australia. *Marine Ecology Progress Series*
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* **119:** 133–143.
- Loneragan NR, Wang YG, Kenyon RA, Staples DJ, Vance DJ, Heales DS (1995). Estimating the efficiency of a small beam trawl for sampling tiger prawns *Penaeus esculentus* and *P. semisulcatus* in seagrass by removal experiments. *Marine Ecology Progress Series* **118**: 139–148.
- O'Brien, C. J. (1994). Population dynamics of juvenile tiger prawns *Penaeus* esculentus in south Queensland, Australia. *Marine Ecology Progress Series* **104**: 247–256.
- Vance DJ, Haywood MDE, Heales DS, Staples DJ (in press). Seasonal and annual variation in abundance of postlarval and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series*.



(b) retrieval net



Figure 5.4.1 (a) Enclosure and enclosure base and (b) retrieval net used in experiments to study the growth of juvenile tiger prawns *Penaeus semisulcatus* at different densities.



Figure 5.4.2 Mean catches (+1SE) of tiger prawns (a) postlarvae, (b) juvenile *Penaeus* semisulcatus and (c) juvenile *Penaeus esculentus*, taken in beam trawls in April (A), October (O) and November (N), at Sg1 and Sg2 in this study (1994) and in previous studies in the Embley River estuary. CL = carapace length.



Figure 5.4.3 Proportion of juvenile tiger prawns *Penaeus semisulcatus* remaining at the end of density experiments and the starting numbers in enclosures on (a) Sg1 during the late-wet season, (b) Sg1 during the pre-wet season, and (c) Sg2 during the pre-wet season.



Figure 5.4.4 Growth rates per week of juvenile tiger prawns*Penaeus semisulcatus* in enclosures calculated as (a) carapace length, (b) wet weight, and (c) dry weight in the late-wet (March/April) and pre-wet (October and November) seasons at Sg1 and Sg2 in the Embley River estuary. Dashed line on (a) shows a growth rate of 1 mm carapace length per week.

Figure 5.4.5 *Penaeus semisulcatus.* Frequency of occurrence of prey items from the foreguts of juvenile tiger prawns (a) caught in beam trawls and scoop nets over 24 h periods in the pre-wet and late-wet seasons and (b) at different final densities in enclosures in the late-wet season.



Frequency of occurrence (%)

Table 5.4.1Number of enclosures stocked at each density of juvenile tiger prawns<br/>(*Penaeus semisulcatus*), and the range of durations in days that prawns<br/>were in enclosures, during different experiments. The number of<br/>enclosures in which more than 30% of the initial prawns were retrieved is<br/>in parentheses.

Seagrass bed and season	Days	Density (no per enclosure)								
		4	8	16	32	total				
Sg1										
Late-wet (April, 94)	15 <b>-</b> 18	4 (4)		4 (3)	4 (3)	12 (10)				
Pre-wet (October, 94)	13 – 16	5 (4)	5 (3)	5 (3)	_	15 (10)				
Pre-wet (November, 94)	14 – 21	6 (5)	6 (2)	6 (0)	6 (1)	24 (8)				
Total: Sg1		15 (13)	11 (5)	18 (6)	13 (4)	51 (28)				
Sg2										
Pre-wet (October, 94)	12 – 17	5 (2)	5 (2)	5 (0)		15 (4)				
Pre-wet (November, 94)	22			6 (3)		6 (3)				
Total: Sg2		5 (2)	5 (2)	11 (3)		21 (7)				

Table 5.4.2Mean (± 1 SE) salinity, temperature and seagrass biomass during<br/>experiments on the effects of density on the growth of grooved tiger<br/>prawns (*Penaeus semisulcatus*) in seagrass beds in the Embley River<br/>estuary, north-eastern Gulf of Carpentaria, Australia. — = no samples<br/>taken.

Variable and Season	Mean (± 1 SE) for seagrass bed							
	Sg1	(n)	Sg2	(n)				
Salinity								
Late-wet (April, 94)	$29.3 \pm 0.28$	(24)	$29.4 \pm 0.29$	(14)				
Pre-wet (October, 94)	$36.4 \pm 0.05$	(8)	$36.9 \pm 0.23$	(4)				
Pre-wet (November, 94)	$35.7 \pm 0.11$	(8)	$35.9 \pm 0.00$	(2)				
Temperature			- ° *					
Late-wet (April, 94)	$29.9 \pm 0.25$	(24)	$29.2 \pm 0.17$	(14)				
Pre-wet (October, 94)	$29.2 \pm 0.45$	(8)	$29.0 \pm 0.66$	(4)				
Pre-wet (November, 94)	$30.5 \pm 0.26$	(8)	$30.9 \pm 0.00$	(2)				
Seagrass biomass								
Post-wet (April, 94)	78.6 ± 4.18	(21)	$4.71 \pm 0.81$	(10)				
Pre-wet (October, 94)	69.7 ± 4.96	(15)	$13.7 \pm 1.46$	(3)				
Pre-wet (November, 94)	67.9 ± 9.62	(21)		_				

Table 5.4.3Regression relationships between the number of juvenile grooved tiger<br/>prawns *Penaeus semisulcatus* in enclosures and growth rate (growth in<br/>mm carapace length per week) for the late-wet and pre-wet seasons.

Site and season	Equation	r <sup>2</sup>	(n)					
x = number of prawns at the end (nos end) of the experiment								
Sg1								
Late-wet	$\log \text{growth} = 0.31 - 0.34 \log(\text{nos end})$	0.82***	(10)					
Pre-wet	log growth = 0.30 – 0.38 log(nos end)	0.45**	(18)					
Sg2								
Pre-wet	log growth = 0.0006 – 0.058(nos end)	0.53+	(7)					
x = number of prawns	s at the end (nos start) of the experiment							
Sg1								
Late-wet	$\log \text{ growth} = 0.26 - 0.24 \log(\text{nos start})$	0.60**	(10)					
Pre-wet	$\log \text{ growth} = 0.30 - 0.34 \log(\text{nos start})$	0.40**	(18)					
Sg2								
Pre-wet	log growth = -1.97 – 0.026 nos start	0.200.20	(7)					
	$+ = 0.05 < P \le 0.10; ** = 0.001 < P \le 0.01$							

Table 5.4.4Mean growth rates of juvenile tiger prawns *Penaeus semisulcatus* in<br/>enclosures on two seagrass beds on the Embley River estuary. T-tests<br/>showed that growth rates were significantly higher on Sg1 than Sg2 in all<br/>cases.

Growth measurement	Mean growth rate per week (± 1 SE)								
	Sg1	(n)	Sg2	(n)					
Carapace length (mm)	$1.28 \pm 0.05$	(17)	$0.61 \pm 0.09$	(4)					
Wet weight (g)	$0.11\pm0.008$	(17)	$0.051 \pm 0.017$	(4)					
Dry weight (g)	$0.026 \pm 0.003$	(12)	$0.0096 \pm 0.0031$	(4)					

Table 5.4.5Mean growth rates (± 1 SE) for juvenile tiger prawns Penaeus<br/>semisulcatus estimated from cohort analysis of prawn catches in<br/>different seagrass beds. n = number of cohorts.

Location and season	Growth rate in m	(n)	
	length pe	er week	
	Mean (± 1SE)	range	
Penaeus semisulcatus			
Embley River, Sg1, wet	$1.08 \pm 0.15$	0.63 – 1.62	(5)
Embley River, Sg2, wet	1.4		(1)
Embley River, Sg1, pre-wet	$0.98 \pm 0.05$	0.62 – 1.21	(13)
Embley River, Sg2, pre-wet	$1.05 \pm 0.04$	0.91 – 1.26	(8)
Mean for Embley River	$1.02 \pm 0.04$	0.62 – 1.62	(27)

from Haywood MDE, CSIRO Division of Fisheries, unpublished data

# 5.5 Diet, feeding behaviour, and moult cycle of juvenile *Penaeus semisulcatus* in seagrass beds

## Introduction

Newly settled juvenile tiger prawns, both grooved and brown, use vegetated intertidal areas as primary nursery sites in the Gulf of Carpentaria (Staples et al. 1985, Coles and Lee Long 1985, Loneragan et al. 1994). In the Embley River estuary, small grooved tiger prawns (*Penaeus semisulcatus*) also use subtidal algal beds as primary nursery sites (Haywood et al. 1995). Little is known about the diet, feeding behaviour, the timing of moulting, or the duration of the moult period of small tiger prawns. Such information is critical to furthering our understanding of how and why small prawns settle and survive in some nursery areas but not others.

## Methods, Results and Discussion

We sampled juvenile *Penaeus semisulcatus* (with a small beam trawl) at two hour intervals over two 24 hour periods, one in the pre-wet season (November 1993) and another in the late wet season (March 1994). Small tiger prawns between 2.5 and 5mm carapace length moulted on average every three days with ecdysis (moulting) only occurring in early evening. A moult period of 3 days was calculated from the percentage of juveniles (in premoult and ecdysis) which were known to moult on a given night (Fig 1.). This is the first time moult period of small juveniles has been estimated from field studies. These field estimates of moult duration are similar to those obtained in the laboratory for the brown tiger prawn (*Penaeus esculentus*) and the banana prawn (*Penaeus merguiensis*) (Staples and Heales 1991, O'Brien 1994).

Small grooved tiger prawn juveniles had high levels of food (mean around 7) in their foreguts throughout day and night in the combined 24 hr periods (Fig. 2), including the day time low tides which occurred at mid-day. Foregut fullness was estimated on a scale of 0 to 10, with 0 being empty and 10 denoting full. Further field experiments showed that small juveniles passed both hard and soft prey items through their foreguts in less than two hours when they were feeding and also when food was unavailable. In order to maintain high levels of foregut fullness, the prawns must therefore have been feeding frequently throughout the 24h period.

In field experiments, the moulting process, ecdysis, was affected the feeding rate of late premoult prawns in the last few hours preceding the moult. Feeding was reduced or ceased and the empty foregut was everted when the old exoskeleton was discarded at ecdysis.

Diet varied little between seasons with copepods, diatoms and filamentous algae being recorded in almost every foregut (Fig. 3). Other prey items that were found in more than 25% of foreguts included insect larvae (non biting midge larvae), ostracods, nematodes, foraminaferans and an unidentified parasite.

The diets of two size groups of small tiger prawns (2.5-5 mm and 5.0-9 mm CL) from an intertidal seagrass site in the main river were also compared with that from a vastly different subtidal algal bed nursery site within a small mangrove creek in October 1994. Copepods, diatoms, and filamentous algae once again were recorded in most foreguts from both sites. Insect larvae which were very common in the intertidal seagrass site, were absent from the subtidal algal site. Decapods were much more common in the foreguts of the larger prawns. Larger juveniles emigrate from the nursery areas around this size range (5-9 mm CL) and this group had a wider range of diet than the smaller prawns. The two different nursery areas provided refuges for similar suites of prey items important for the growth of newly settled postlarvae and juveniles, and as such, they must be protected.

These results show that small tiger prawns feed frequently at all stages of day and night and tidal cycles, on a wide range of dietary items; have rapid passage rates of food through their foreguts, and moult in early evening at intervals of around three days.

## Conclusions

- Small juvenile tiger prawns had high indexes of foregut fullness both in the day and at night, even when seagrass beds were exposed at low tide. Passage rates of food through the foregut were also rapid and suggested that feeding occurred regularly throughout the 24h period.
- Small tiger prawns moulted every 3 days and moulting occurred in early evening. ~
- Small juvenile tiger prawns (2.5-5mm CL) fed mainly on diatoms, filamentous algae and copepods in both the pre-wet and late-wet seasons. Other common prey items included ostracods, insect larvae, and nematodes.
- The diet of both small and larger (5 8 mm CL) juveniles in two very different nursery habitat types (an intertidal seagrass bed along the main river and a

subtidal algal bed inside a small creek) was very similar. Larger prawns ate more decapods than smaller prawns at both sites .

#### References

- Coles RG, Lee Long WJ (1985). Juvenile prawn biology and the distribution of seagrass prawn nursery grounds in the southeastern Gulf of Carpentaria. In: Rothlisberg PC, Hill BJ, Staples DJ (eds) Second Australian National Prawn Seminar. NPS2, Cleveland, Australia, pp 55-60.
- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122**: 213–223.
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* **119:** 133–143.
- Staples DJ, Vance DJ, Heales DS (1985). Habitat requirements of juvenile penaeid prawns and their offshore fisheries. In: Rothlisberg PC, Hill BJ, Staples DJ (eds) Second Australian National Prawn Seminar. NPS2, Cleveland, Australia, pp 47– 54.

Fig. 5.5.1. <u>Penaeus semisulcatus</u>. Mean percentage  $(\pm 1 \text{ SE})$  of combined premoult and ecdysis stage from two 24 h studies and mid-April sampling. n = number of samples. The pooled numbers of prawns at each time are shown in parentheses.



Fig. 5.5.2. <u>Penaeus semisulcatus</u>. Mean foregut fullness ( $\pm$  1 SE) for juveniles in all moult stages except ecdysis, from combined pre-wet and late wet season 24 h studies; n ranged from 19 to 50 for each time.



Fig. 5.5.3. <u>Penaeus semisulcatus</u>. Frequency of occurrence (%) of prey items from foreguts of juveniles from one pre-wet season 24 h and one late wet season 24 h study. Foreguts examined from prawns in all moult stages except ecdysis.



## 5.6 Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study

We used multiple stable isotope analysis to investigate the importance of mangroves, seagrasses and other primary sources to the food webs supporting penaeid prawns in the Embley River estuary and adjacent off-shore waters in the north-eastern Gulf of Carpentaria, Australia. The full results of this studied have been either published (Bunn et al. 1995) or submitted for publication (Loneragan et al. submitted). Mangroves, seagrass and seston/macroalgae were well separated on the basis of their  $\delta^{13}$ C values in both the dry and the wet seasons. In contrast, only seston (phytoplankton and zooplankton) and macroalgae, which had similar  $\delta^{13}$ C values, were separated by their  $\delta^{15}$ N values. The primary source of carbon supporting food webs of several species of juvenile penaeid prawns clearly depended on the location within the estuary. The  $\delta^{13}$ C values of juvenile prawns (<u>Penaeus esculentus</u>, P. semisulcatus and Metapenaeus spp.) in seagrass beds were close to those of seagrass, particularly in the dry season. This was despite the proximity of the seagrass to mangroves and the presence of mangrove detritus in the seagrass beds. In contrast, juvenile prawns (P. semisulcatus, Metapenaeus spp. and P. merguiensis) in an upstream mangrove creek had  $\delta^{13}$ C values that were midway between those of mangroves and seagrass, and close to those of seston and macroalgae during the dry season. This habitat was the only one within the estuary where mangroves could make a significant contribution to the carbon assimilated by juvenile prawns, but only if the remainder of the carbon is ultimately derived from a seagrass source. The potential contribution of mangrove carbon to food webs supporting juvenile prawns in both mangrove and seagrass sites was higher in the wet season than in the dry season. In contrast to juvenile prawns, the  $\delta^{13}$ C values of adults in offshore waters were very similar in magnitude. They were much higher than the values for mangrove leaves, indicating that their carbon came from another source, possibly benthic microalgae or seagrass detritus. Therefore, the considerable amount of terrestrial/mangrove carbon exported from tropical estuaries during the wet season is unlikely to contribute to food webs supporting adult prawns.

#### References

- Bunn SE, Loneragan NR, Kempster MA (1995). Effects of acid washing samples on stable isotope ratios of C and N in penaeid shrimp and seagrass: implications for food web studies using multiple stable isotopes. *Limnology and Oceanography* 40: 622–625.
- Loneragan NR, Bunn SE, Kellaway DM (submitted). Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable isotope study. *Oecologia*.

## 5.7 Predation of juvenile tiger prawns in seagrass beds of the Embley River

## Introduction

Intertidal and shallow subtidal seagrass and algal beds are critical nursery habitats for postlarval and juvenile tiger prawns and, at times, very large numbers of postlarvae recruit to these habitats from offshore. However their abundance can decrease rapidly following settlement on the seagrass and algal beds. One possible cause is predation. The importance of predation by fish has already been demonstrated for large juvenile penaeids (Salini et al. 1990, Brewer et al. 1995). However, previous studies have not found much evidence of predation on small prawns. Recent laboratory studies have shown that both postlarvae and small juvenile prawns are digested very rapidly in fish guts and this may be why earlier work has not been able to identify major predators of small prawns (Haywood 1995). We examined predation on postlarval and small juvenile tiger prawns by using a range of sampling techniques that ensured we would sample a broad range of fish and by sampling in the critical nursery habitat i.e. shallow seagrass. We also monitored the juvenile tiger prawn population at the same time to try and relate mortality rates to predation levels.

In order to test whether predation on juvenile tiger prawns varies between seagrass beds with different amounts of seagrass we adopted two approaches. Firstly, we sampled fish predators at two seagrass beds: one with much higher biomass of seagrass than the other. Secondly we tethered prawns in different habitats to compare predation rates among different seagrass shoot densities.

#### Methods

#### Fish and prawn sampling

We collected samples of fish and prawns from two intertidal seagrass beds in the Embley River (SG1 and SG2) (Fig. 5.7.1). The dominant seagrass at SG1 was *Enhalus acoroides*, a large seagrass with long, broad, strap-like leaves, up to 1 m long. The small (< 10 cm long), fine-leafed seagrasses, *Halophila ovalis* and *Halodule uninervis* dominated the second site, SG2.

Fish were collected from both sites using a variety of techniques including gill nets, beach seining and beam trawling during October 1993 (pre-wet season) and April 1994 (early dry season). This is the time of peak abundance of juvenile *Penaeus semisulcatus* in this area (Vance et al. in press).

We used a fleet of four 60 m long monofilament nets (50, 75, 100 and 150 mm stretch mesh). Nets were deployed before dusk on a flooding tide at both sites for 2 nights during each sampling period (22-25/10/93 and 14-17/4/94). All fish were removed from the nets and identified. Standard length and weight were measured and the guts removed, bagged and immediately placed in a slurry of frozen seawater and salt.

A beach seine (60 m long, 2 m drop, 19 mm stretch mesh) with cod-end was used from a 5 m punt fitted with a submersible net-roller device that kept the lead line on the bottom while the net was being retrieved. This device was necessary to operate the seine because the seagrass beds at SG1 and SG2 are not adjacent to beaches which would allow a beach seine to be operated in the normal way. Areas sampled by seine were 50 - 200 m offshore at SG1 and about 1.5 km offshore at SG2 The seine was laid in a circle (swept area of about 290 m<sup>2</sup>) on the downstream side using a 2.8 m punt powered by an electric motor.

A small beam trawl (1.• x 0.5 m mouth; 2.5 m long; 2 mm mesh net in the body; 1 mm mesh cod-end, was also used to sample fish and prawns at both seagrass beds. Beam trawl samples were taken every 7 days from 30 September 1993 to 3 November 1993 in the pre-wet season and from 27 March 1994 to 24 April 1994 in the early dry season. On each sampling date, two trawls were made (from a 4.8 m dinghy at  $\approx 0.5$  m.s<sup>-1</sup>) between two permanent markers placed 100 m apart on each of the seagrass beds. Trawls were made at night as close to high tide as possible. All fish and prawns were collected from the beam trawls.

All fish were weighed and their standard lengths measured. Their stomachs were removed and the contents analysed by the gravimetric method (Hyslop 1980). Prawns from the beam trawl samples were measured to the nearest 0.5 mm carapace length.

We used drop traps to collect data on the densities of small benthic animals on the seagrass beds. These consisted of a  $0.8 \ge 0.8 \ge 0.8$ 

We estimated a relative measure of predation on penaeids as the product of the catch rates and the proportion of penaeids in the diet of each fish species (Prawn Predation Index [PPI]; Salini et al. 1990). The PPI was calculated separately for gill nets and the other fishing methods since gill net catch rates are expressed in terms of g h<sup>-1</sup> whereas the beam trawl and beach seine catch rates are expressed as g m<sup>-2</sup>. A total PPI for each site and season and fishing method was calculated as the sum of the product of each species' PPI and the number of that species caught at each site and season.

We calculated a mortality index for the juvenile *Penaeus semisulcatus* populations by estimating the total mortality over all size classes using catch curves for each site and season.

## Tethering

Tethering studies have been used widely to compare predation levels on small prey items across different habitats (e.g. Heck and Thoman 1981). Usually a tether (often monofilament line) is attached to the prey animal, the other end being fixed to the substrate, in the habitat of interest. The prey animals are left for a period, usually  $\leq 1$  day, before being checked. The numbers of prey surviving in each habitat are then compared.

A major problem with this general technique is that the duration of the experiment is critical. For example, if the experiment is too short, none of the prey will be taken. Conversely, if the experiment is too long, all the prey from all treatments will be taken. We developed a chronographic tethering device to overcome these problems by enabling us to record the time of predation of each tethered prawn (Haywood and Pendrey submitted; see technical appendix). More information per animal was also recorded because "survival time" was measured rather than just the survival or loss of prawns.

Two types of tethering experiment were done. Firstly, we used 1 m<sup>2</sup> plots of artificial seagrass to compare the effect of different shoot densities on predation rates. Secondly, we compared predation rates on bare substrate (near SG1) with those in natural *Enhalus acoroides* (SG1) and *Halodule uninervis* (SG2) beds.

Artificial seagrass plots had 0, 15 or 60 shoots m<sup>2</sup> attached to the weld-mesh with plastic cable ties. The seagrass was designed to simulate *Enhalus acoroides* and each shoot was composed of 4 "leaves" (1.5 cm wide x 40 cm high) attached to 1 m<sup>2</sup> sheets of galvanised weld-mesh (70 mm squares). Four prawns were tethered to each plot, which were deployed just before dusk and recovered within 12 h.

## **Results and discussion**

## Overall diets

A total of 5321 fish from 132 different species were caught; 1291 were caught in the gill nets, while 4030 in the seine and beam trawl. Sixty-five percent of these fish had some food in their guts. We only analysed species in which there were 10 or more guts containing food (40 species).

Some species ate a wide variety of prey types e.g. *Acentrogobious caninus* and *Amniataba caudavittatus*. However, in most species a particular prey type was dominant e.g. teleost prey in *Scomberoides commersonianus, Carcharbinus cautus, Platycephalus indicus* and *Eleutheronema tetradactylum* (Tables 5.7.1 and 5.7.2). A few species ate only a single type of food e.g. *Secutor ruconius*: copepods; *Siganus canaliculatus*: algae.

Crustaceans (other than penaeids, stomatopods and brachyurans) were the most dominant prey type in terms of frequency of occurrence and dry weight, with over half (24) of the 40 fish species examined having a frequency of occurrence of crustaceans of 25% or more. In 20 species of fish, the percent dry weight contribution of crustaceans was 25% or more (Table 5.7.1). This contrasts with a previous study in the Embley River in which teleosts were the dominant prey type (Salini et al. 1990). This may be because the Salini et al. (1990) study focused on the capture of larger fish than our study.

Teleost prey was the dominant prey category in 9 of the species in terms of precent dry weight and 6 species in terms of precent frequency of occurrence. Molluscs were most important in the diets of *Drombus palackyi*, *Chelonodon patoca*, *Gerres abbreviatus*, *G. oyena* and *Monocanthus chinensis*. Annelids featured in the diets of many of the smaller species in particular *Chelonodon patoca*, *Herklotsichtbys lippa*, *Gerres oyena*, *Leiognathus decorus*, *L. equulus*, *L. splendens* and *Thryssa hamiltoni*.

## Penaeids in the diet of fish

A total of 845 penaeid prawns were found in the guts of 382 fish of 36 different species, although only 18 of these had 10 or more guts containing food. Salini et al. (1990) found penaeids in the guts of 37 fish species, 17 of which were the same species as those we identified. The reason there is not more overlap in the species found with penaeids in their guts is probably because our study focused more on small predators. In addition, the fish from the Salini et al. (1990) study were caught from mangroves creeks as well as seagrass beds. The most common species of prawns found in fish guts were grooved tiger prawns (*Penaeus semisulcatus -* 287 prawns) and greasy backs (unidentified *Metapenaeus* spp. - 268 prawns). In one *Scomberoides commersonianus* (queenfish) stomach, we found 72 juvenile *P. semisulcatus*. In some cases, prawns from gut contents were digested to a state where identification to species was not possible.

Unidentified *Metapenaeus* spp. featured in the gut contents of most of the penaeid predators, and were the dominant prey ( $\geq$ 50%) in 12 species of fish. Tiger prawns were an important prey item ( $\geq$  25% of the dry weight of penaeids) in 15 species of fish (*Penaeus semisulcatus*: 9 species; *P. esculentus*: 5 species and unidentified tiger prawns: 1 species)

### Predation Impact on Prawns

A total of 690 penaeids were found in guts of fish caught in the gill nets compared to 155 penaeids from guts of fish caught in the beam trawl and seine.

*Scomberoides commersonianus* (queenfish) were by far the most important penaeid predator caught in the gill nets (Fig. 5.7.2a). *Eleutheronema tetradactylum* (threadfin salmon), *Rhizoprionodon acutus* (milk shark), *Arius proximus* (catfish) and *Lates calcarife*r (barramundi) were also important penaeid predators. Although penaeids were only 3.2% of the diet (by weight) of catfish, we caught large numbers of them (490), which accounts for their relatively high impact on penaeids. Salini et al. (1990) also found queenfish to be the most important penaeid predator, along with barramundi and *Polydactylus sheradini* (king salmon). The differences in the secondary species are probably because Salini et al. sampled mangrove areas as well as seagrass.

The four species caught in the beam trawls and seines that had the greatest impact on penaeids were: *Thryssa hamiltoni* (Hamilton's anchovy), *Sillago analis* (golden-lined whiting), *Ambassis nalua* (scalloped perchlet) and *Cymbacephalus nematophthalmus* (fringe-eyed flathead) (Fig. 5.7.2b).

The total Prawn Predation Index (PPI) for gill nets was highest at SG2 in the pre-wet season and lowest at SG2 in the early dry. There was little seasonal difference in the PPI at SG1 (Table 5.7.3). The very high PPI for SG2 in the pre-wet was driven largely by a catch of 218 queenfish compared with 35 from SG1 during the same season.

The total Prawn Predation Index for the other nets (seine and beam trawl) was always higher at SG1 than SG2. There was little seasonal change in total PPI at SG2 compared with SG1 which was highest in the early dry season.

### Size range of tiger prawns eaten

The size of *P. semisulcatus* caught in beam trawls on the seagrass ranged from 1 - 20 mm CL in size. Forty-eight percent of the catch were postlarvae (1 - 2 mm CL) and there was a smaller mode at about 5 mm CL (Fig. 5.7.3a). The size of juvenile *Penaeus semisulcatus* found in fish guts at both sites during both seasons ranged from 2 - 20 mm CL, with a mode at 6 mm CL (Fig. 5.7.3b). Only 2.5% of the *P. semisulcatus* from fish guts were postlarvae.

Although we caught three times as many fish in the beam trawl and beach seine as we caught in the gill nets, only 22 of the 287 *P. semisulcatus* found in fish guts were caught in the beam trawl and beach seine, and they were all  $\leq 8$  mm CL.

Despite the fact that we targeted small fish by using beam trawls and seines, the small prawns were under-represented in the predator's gut contents. One reason for the low numbers of postlarval and small juvenile tiger prawns found in fish guts may be that predators of small 'prawn-like' prey have a much larger choice of prey species than predators of larger 'prawn-like' prey. From a series of 10 drop traps on the *Enhalus acoroides* beds (SG1) at Weipa, we found much higher densities of small (< 30 mm total length) 'prawn-like' species (e.g. carids, amphipods, alphaeids, isopods, sergestids, tanaeids, mysids and stomatopods) than prawns themselves (Table 5.7.4). In contrast, very few of these animals (apart from the prawns) grow much larger than this, so predators of larger crustaceans are more likely to prey on prawns.

## Site/season Comparison

Mean numbers of *Penaeus semisulcatus* caught in the beam trawls were greater during the pre-wet season and were higher at the *Enhalus acoroides* site (SG1) than at the *Halophila/Halodule* (SG2) bed (Table 5.7.3). This pattern matches that shown for these sites during 1990 - 1992 (Haywood et al. 1995).

The seasonal trend for numbers of *Penaeus semisulcatus* found in guts of predatory fish was similar at both sites. The number of *P. semisulcatus* found in the guts during both seasons at both sites increased as the number of *P. semisulcatus* caught on the seagrass beds increased (Fig. 5.7.4). Although the number of data points is small, this result suggests that for *P. semisulcatus*, seagrass structure is not important in providing protection from predation. One reason for this may be related to the behaviour of

juvenile *P. semisulcatus*. On dark nights, many *P. semisulcatus* swim up in the water column, above the seagrass, where it is unlikely to offer any protection. Since our sampling was always done shortly after the new moon and the major predators were queenfish, which are pelagic, this may explain why seagrass was not important in reducing predation at the high seagrass biomass site (SG1).

The *P. semisulcatus* mortality index (highest negative number indicates highest mortality) increased with the number of *P. semisulcatus* found in fish guts (Table 5.7.3), suggesting that predation by fish is the major cause of mortality for these prawns.

## Tethering

Laboratory studies have shown that while tethering obviously restricts the swimming behaviour of juvenile prawns, it does not affect their ability to bury or the time spent buried.

The results of the first series of field tethering experiments (October 1994), using the artificial seagrass and *Penaeus semisulcatus*, showed that both the numbers of animals surviving, and the time that they survived predation, was greater on the high shoot density treatment (full details are given in Haywood and Pendrey submitted; see the technical appendix).

In the second experiment (November - December 1994) we tethered *Penaeus semisulcatus* on bare areas (SG1), *Halodule uninervis* (SG2) and *Enhalus acoroides* (SG1) beds by attaching the chronograph and tethered prawn to a 2.5 m long stake to facilitate deployment and recovery. There were no differences between predation rates in any of the treatments, possibly because the stakes may have been acting as fish attracting devices, swamping any differences between treatments; or the tethered prawns may have been eaten by a predator, whose efficiency was not affected by seagrass cover.

Subsequent laboratory studies have shown that our results may have been affected by blue swimmer crabs (*Portunus pelagicus*). At some times of the year, these crabs are common on the seagrass beds around Weipa. We have filmed blue swimmer crabs with both tethered and untethered tiger prawns. The crabs are rarely able to catch untethered prawns, but always catch and eat the tethered prawns. Blue swimmer crabs hunt by smell rather than sight, and so whether the prawns are tethered in seagrass or on bare habitat makes little difference to their ability to detect and capture them.

During our third series of experiments at Weipa (April 1995) we were unable to catch sufficient numbers of *P. semisulcatus*, so we used *P. esculentus*. We anchored the chronographs with no structure above the substrate, except for the chronograph itself to minimise the possibility that our devices were acting as fish attracting devices We also moored crabs pots in the area for three nights after the experiment was \_ completed, but caught no blue swimmer crabs. We found that predation was higher on the bare area compared to that in the natural *Enbalus acoroides*.

### Conclusions

- Although penaeids were found in the guts of 37 different fish species, the major impact on penaeid populations is due to three fish species caught by the gill nets: *Scomberoides commersonianus* (queenfish), *Eleutheronema tetradactylum* (threadfin salmon) and *Rhizoprionodon acutus* (milk shark), and four species caught in the beach seine and beam trawl: *Thryssa hamiltoni* (Hamilton's anchovy), *Sillago analis* (golden-lined whiting), *Ambassis nalua* (scalloped perchlet) and *Cymbacephalus nematophthalmus* (fringe-eyed flathead).
- Postlarvae and small prawns are under-represented in fish gut contents possibly because predators of small 'prawn-like' prey have a far greater choice of species compared to predators of large 'prawn-like' prey. Postlarval prawns are much less abundant in seagrass than other small 'prawn-like' prey (e.g. amphipods and carids). In contrast, larger juvenile prawns are probably the most abundant 'prawn-like' crustaceans on the seagrass and were abundant in the gut contents.
- Predation of *Penaeus semisulcatus* was greatest when the prawns were most abundant.
- The *Penaeus semisulcatus* mortality index followed a similar pattern to the number of *P. semisulcatus* found in the fish guts, suggesting that predation by fish is the major cause of mortality in juvenile *P. semisulcatus*.
- We developed a submersible chronographic tethering device that enabled us to demonstrate that high seagrass shoot density reduced predation on juvenile *Penaeus esculentus*. However, care must be taken when interpreting the results from this type of experiment since interactions with other factors can lead to erroneous results.

#### References

- Haywood MDE, Vance DJ, Loneragan NR (1995). Seagrass and algal beds as nursery habitats for tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in a tropical Australian estuary. *Marine Biology* **122**: 213-223.
- Heck KL Jr., Thoman TA (1981). Experiments on predation-prey interactions in vegetated aquatic habitats. *Journal of Experimental Marine Biology and Ecology* 53: 125-134.
- Loneragan NR, Kenyon RA, Haywood MDE, Staples DJ (1994). Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. *Marine Biology* 119: 133-143.
- Salini JP, Blaber SJM, Brewer DT (1990). Diets of piscivorous fishes in a tropical Australian estuary, with special reference to predation on penaeid prawns. *Marine Biology* 105: 363-374.
- Haywood MDE (1995). Rates at which post-larval prawns and are digested by a small predatory fish and the implications for predation studies. *Journal of Fish Biology* 47: 337-340.
- Haywood MDE, Pendrey RC (submitted). A new design for a submersible chronometric tethering device for studying predation in different habitats. *Marine Ecology Progress Series*.
- Hyslop EJ (1980). Stomach contents analysis a review of methods and their application. *Journal of Fish Biology* **17:** 411-429.
- Vance DJ, Haywood MDE, Heales DS, Staples DJ (in press). Seasonal and annual variation in abundance of postlarval and juvenile grooved tiger prawns, *Penaeus semisulcatus* (Decapoda: Penaeidae), and environmental variation in the Embley River, Australia: a six-year study. *Marine Ecology Progress Series*.

Table 5.7.1. Stomach contents of fish from intertidal seagrass beds in the Embley River. Percentage frequency of occurrence of each prey items is the percentage of each fish species having at least one of the prey items in the gut. This only includes those species of fish in which 10 or more stomachs contained food.

			Percentage Frequency of Occurrence								
Fish Species	Nf	Ne	Ann	Bra	Сер	Сги	Mol	Oth	Pen	Sto	Tel
Acentrogobius caninus	19	10	17	8	ŗ.	29	17	21	-	÷	<b>-</b> 8
Ambassis nalua	40	30	6	~	T	18	-	41	18	-	16
Ambassis vachellii	74	54	13	1	2	63	1	22	~	÷	1
Amniataba caudavittatus	16	10	18	6	÷	41	3	18	9	6	ř.
Anodontostoma chacunda	46	3	-	-	-	-	ŕ	100	-	7	Æ
Apogon ruppelli	121	30	11	1	÷	84	_	-	2	-	1
Arius proximus	257	103	9	17	-	30	4	11	11	7	12
Butis butis	162	74	5	-	ε	82	1	2	6	-	4
Carcharhinus cautus	18	3	-	3	10	7	7	-	10	17	47
Centrogenys vaigiensis	92	29	19	9	5	57	-	2	11	e	2
Chelonodon patoca	10	1	12	-	÷	24	36	28	-	ŝ	-
Cymbacephalus nematophthalmus	23	8	-	17	÷	14	-	6	33	-	31
Drombus palackyi	20	6	8	4	2	32	40	12	-	1	4
Eleutheronema tetradactylum	54	8	1	3	2	2	2	1	30	10	48
Epinephelus suillus	63	52	1	7	5	58	1	1	16	ξ	15
Favonigobius melanobranchus	17	30	4	-	ų.	52	4	35	Ę	1	4
Gerres abbreviatus	23	19	34	9	-	20	26	11	4	4	-
Gerres juvenile	36	114	14	z	÷.	69	7	10	÷	÷	4
Gerres oyena	55	49	46		4	9	31	14	2	1	5
Gnathanodon speciosus	24	34	-	5	÷	34	5	8	23	2	23
Herklotsichthys lippa	49	12	60	-	1	34	3	4	7	ę	Ξ.
Leiognathus decorus	60	7	25	1	4	47	15	13	÷	+	-
Leiognathus equulus	92	28	32	-	4	42	6	19			-
Leiognathus splendens	60	20	27	1	÷.	50	4	17	4	÷.	1
Lethrinus lentjans	19	56	16	-	÷	40	4	32	1	÷.	8
Lutjanus russelli	78	16	7	3	5	52	-	6	21	÷.	11
Monocanthus chinensis	21	72	6	2		18	27	48	-	4	
Nematolosa come	34	4	_	1	ā.	-	-	100	2	÷.	2
Pelates auadrilineatus	137	111	9	1	2	46	4	39	1	_	1

FRDC 92/45: 5.7 Predation on tiger prawns May 1996

Pelates sexlineatus	43	5	6	2	-	2	2	87	-	-	-
Platycephalus indicus	17	23	-	-	-	19	-	5	19	-	57
Rhizoprionodon acutus	62	10	-	1	1	7	2	1	27	20	40
Sardinella albella	20	-	12	-	-	42	4	42	-	-	-
Scomberoides commersonianus	231	41	-	Н	1	5	6	2	33	-	53
Secutor ruconius	14	4	-	-	-	100	-	-	-	-	-
Siganus canaliculatus	25	15	-	-	-	-	-	100	-	-	-
Sillago lutea	12	2	28	17	-	11	-	17	6	11	11
Stolephorus carpentariae	10	1	8	-	-	77	15	-	-	-	-
Terapon puta	321	160	12	1	÷	51	3	29	2	-	3
Thryssa hamiltoni	28	14	25	-	Ū.	42	-	-	25	5_	8

N<sub>f</sub>, Number of stomachs containing food; N<sub>e</sub>, Number of empty stomachs; Ann, Annelida; Bra, Brachyura; Cep, Cephalopoda; Cru, Crustacea; Mol, Mollusca; Oth, Other; Pen, Penaeidae; Sto, Stomatopoda; Tel, Teleostei

đ

Table 5.7.2. Percentage contribution by dry weight of prey items in the stomach contents of fish from intertidal seagrass beds in the Embley River. This only includes those species of fish in which 10 or more stomachs contained food.

	Percentage contribution by dry weight									t
Fish species	length range (r	nna)nn	Bra	Сер	Cru	Mol	Oth	Pen	Sto	Tel
Acentrogobius caninus	28 - 92	39.5	13.1	Ŧ	19.4	21.2	3.4		-	3.5
Ambassis nalua	32 - 85	1.5	<u>e</u>	-	9.8	7	16.7	30.8	÷	41.2
Ambassis vachellii	17 - 48	49	0	÷	26.5	4	24	5	2	0.5
Amniataba caudavittatus	71 - 170	23.9	5.6	÷	33.6	0.2	19.2	9	8.5	=
Anodontostoma chacunda	63 - 82	-	-	÷	-	=	100	-	7	4
Apogon ruppelli	15 - 63	5.5	0.1	-	83	5	~	10.7	1	0.7
Arius proximus	110 - 665	3.8	45.9	8	17.1	1	7	3.2	10.9	11.3
Butis butis	16 - 76	1.5	-	4	60.8	0.1	2.3	26.7	-	8.7
Carcharhinus cautus	418 - 1300	~	0.4	0.1	0.5	0.2	-	0.3	2.5	96
Centrogenys vaigiensis	14 - 70	12.6	18.7	-	55.2	-	0.2	11.5	F	1.9
Chelonodon patoca	17 - 54	66.4	-	÷	2.4	27	4.2	ŗ	ŝ	~
Cymbacephalus nematophthalmus	69 - 257	_	13	4	6.7	-	0.1	25.7	Ļ	54.4
Drombus palackyi	20 - 37	5.6	4.5	1	25.4	42.4	7.5	-	5	14.6
Eleutheronema tetradactylum	290 - 465	-	0.7	2.2	0.4	0.2	0.5	17.9	5.2	72.8
Epinephelus suillus	18 - 270	0.1	21.2	τ	37.9	-	-	15.4	2	25.3
Favonigobius melanobranchus	17 - 29	8.5	-	4	44.2	1.6	40.4	8	÷	5.3
Gerres abbreviatus	44 - 195	1.8	23.3	Ę	0.2	74.6	0.1	÷	÷	Ę
Gerres juvenile	13 - 36	26.5		÷	64.7	2.6	6.3	÷	4	4
Gerres oyena	40 - 77	73.3	1	4	0.1	23.4	3.2	1	Ļ	1
Gnathanodon speciosus	230 - 360	-	8.3	÷	87.1	0.2	1.5	2	0.1	0.7
Herklotsichthys lippa	46 - 65	89.3	-	÷	9.3	0.1	1.3	5	ž	1
Leiognathus decorus	21 - 73	38.8	0.2	4	52.8	7.3	1	-	4	1
Leiognathus equulus	32 - 58	46.8	_	÷.	28.5	2.2	22.6	+	4	-
Leiognathus splendens	21 - 58	31.2	0.1	÷.	66.3	0.5	1.8	1	-	0.1
Lethrinus lentjan	14 - 90	17.9	-	5	43.3	17.5	10.6	4	4	10.8
Lutjanus russelli	17 - 140	0.4	0.2	E.	22.9	-	1.1	23	4	52.5
Monocanthus chinensis	12 - 87	1.2		÷.	1.6	<b>3</b> 7.1	60	,	4	e
Nematolosa come	41 - 180	-		1	-	-	100	J	1	-
Pelates quadrilineatus	15 - 180	0.5	0.1	-	1.5	1.7	96.2		-	0.1
Pelates sexlineatus	27 - 140	1.2	0.7		0.3	-	97.7			-

Platycephalus indicus	121 - 410	~	-	-	3.1	~	-	0.8	-	96
Rhizoprionodon acutus	418 - 687	2	0.2	2.4	3.1	0.4	0.1	10.5	16.1	67.3
Sardinella albella	52 - 60	16.2	ī.	-	48.4	-	35.4	-	-	-
Scomberoides commersonianus	105 - 880	5	4	0.2	0.4	0.6	0.3	18.9	÷.	79.5
Secutor ruconius	25 - 32	÷	÷	÷	100	e. F	-	7	÷	٦
Siganus canaliculatus	23 - 44	-	5	÷	-	ŝ	100	4	÷	2
Sillago lutea	82 - 210	5.5	7.3	Ę.	50.4	7	0.3	3.3	21.4	12
Stolephorus carpentariae	37 - 46	1.2	-	ŧ	98.4	0.4	~	-	÷	-
Terapon puta	14 - 142	15.7	2.2	4	32.7	2.6	15.5	5,2	ģ	26
Thryssa hamiltoni	85 - 175	31.1	-	2	11.7	-	-	34.6	٤.	22.5

Ann, Annelida; Bra, Brachyura; Cep, Cephalopoda; Cru, Crustacea; Mol, Mollusca; Oth, Other; Pen, Penaeidae; Sto, Stomatopoda; Tel, Teleostei

4

Table 5.7.3. *Penaeus semisulcatus*. Mean density (per 100 m<sup>2</sup>) of postlarvae and juveniles, numbers found in fish guts, total Prawn Predation Indices (PPI) and mortality indices at sites in the Embley River during the pre-wet and early dry seasons 1993/94. Other methods = beach seine and beam trawl.

	Sg	g1	Sg2				
	pre wet	early dry	pre wet	early dry			
mean density (per 100 m <sup>2</sup> )	585 ± 108.9	168 ± 13.9	$304 \pm 77.3$	21 ± 9.6			
number in guts	129	62	92	6			
PPIgill nets/1,000,000	16.7	17.0	65.8	6.6			
PPIother methods/10	12.9	29.3	5.6	6.3			
Mortality index	-0.54	-0.47	-0.46	-0.19			

4
Table 5.7.4. Mean density ( $\pm$  1 SE) of prawns and 'prawn-like' animals (<30 mm total length) caught in a series of 10 drop traps at SG1 on 16/10/94.

4

Species	mean density (no/m <sup>2</sup> )
Penaeus esculentus	$0.3 \pm 0.21$
Penaeus semisulcatus	$0.3 \pm 0.21$
unidentified tiger prawn	$0.5 \pm 0.24$
stomatopod	$1.4 \pm 0.75$
Metapenaeus endeavouri	$1.6 \pm 0.52$
mysid	$1.6 \pm 0.47$
tanaeid	$2.0 \pm 0.47$
<i>Metapenaeus</i> spp.	$3.6 \pm 0.9$
sergestid	$3.6 \pm 0.7$
isopod	$4.8 \pm 1.2$
alphaeid	$5.6 \pm 1.85$
amphipod	$11.9 \pm 2.57$
carid	59.8 ± 7.63



Figure 5.7.1 Map of the Embley River showing seagrass sites (SG1 and SG2) used for sampling tiger prawns and fish



Prawn Predation Index

Figure 5.7.2. Prawn Predation Indices for (a) fish caught in the gill nets and (b) beam trawl and beach seine on seagrass beds in the Embley River. Fish species listed are those in which at least 10 stomachs contained food.







Figure 5.7.4. *Penaeus semisulcatus*. Mean number on the seagrass beds (SG1 and versus the total number found in fish guts during the pre-wet and early dry seasons.

# 6. Utilisation of mangrove habitats by juvenile banana prawns and fish

## Introduction

Mangrove forests are considered to be important nursery areas for prawns and fish, including many species of commercial importance. However, in many countries, including Australia, they are under increasing pressure from housing, aquaculture, tourism and mining developments. In the Gulf of Carpentaria, infrastructure associated with mining ventures has the potential to impact on mangrove areas, and it is likely that the number of coastal developments across the NPF will increase in the future. It is critical for the future management of these forests that we understand more clearly the relationships between prawns, fish and mangroves and exactly why mangroves are important to them.

We have known for many years that juvenile banana prawns are associated with mangrove-lined river systems; in fact, we have found that parts of the Gulf of Carpentaria that have the most mangrove-lined river systems also support the largest catches of adult banana prawns offshore. However, the relationship between mangroves, juvenile prawns and offshore catches is not very clear-cut. In this project, we aimed to identify the most important mangrove habitat types for juvenile banana prawns. The specific questions we asked were:

• how much of the mangrove forests do juvenile prawns use?

• are all mangrove species equally important to the juvenile prawns? Full details of the sampling and results of the first year's work have been accepted for publication (see Vance et al. 1996, in press).

## Methods

We used a stake net to determine the distribution of prawns and fish within the mangrove forests. This involves waiting until the prawns and fish have moved into the mangrove forests at high tide, then completely enclosing a section of the mangroves with the stake net, waiting until the tide goes out, and then collecting all the animals that are trapped by the net. This sampling has been done at the fringe of mangrove forests before but nobody in the world has ever sampled discrete areas inside mangrove forests.



Figure 6.3 Summary of all fish caught in 2 samples at each of *Rhizophora* A, *Rhizophora* B and *Ceriops* A sites from 22 to 27 November 1992. (a) mean number, (b) mean number of species, (c) mean length, and (d) mean weight.



Figure 6.4 *Penaeus merguiensis*. Stake net catches and the maximum observed tide height for each sample from 22 to 31 March 1993.

The stake net used to enclose each site was 100 m long by 2 m high. The mesh was small enough (2 mm) to catch most *Penaeus merguiensis* from the time they arrive in the estuary as postlarvae (1 to 2 mm carapace length), as well as small fish. Galvanised chain (8 mm diameter) was inserted in a hem along the base of the net. A codend with mouth opening of 1.0 m by 0.5 m ( 2 and 1 mm mesh) was fitted to one section of the net to concentrate trapped animals. For all samples the stake net was set as close as possible to high tide using a small dinghy.

Preparing each site for stake netting was very time consuming. A pathway, up to 1.5 m wide, had to be cut through the mangroves to allow the net to be set from a small dinghy. Prop roots, peg roots and small seedlings were cut off at ground level so that the bottom of the stake net would sit closely on the substrate and some large trees had to be removed to allow access to the forest.

There are three main mangrove communities in the Weipa area, characterised by their dominant species: the red mangrove, *Rhizophora stylosa*, the yellow mangrove, *Ceriops tagal* var *australia* and the white mangrove, *Avicennia marina* var *eucalyptifolia*, although several other species occur in each community (Long et al. 1992). The structure of each of these mangroves is very different. Red mangroves have prop roots that are often so dense that it is not possible to put a foot on the ground, whereas yellow and white mangrove forests are much more open and it is usually possible to walk freely through these mangroves. The white mangroves have many small peg roots up to several cm high that provide a large quantity of structure close to the ground. We sampled all three of these communities in a small creek about 17 km upstream from the mouth of the Embley River at Weipa.

#### **Results and Discussion**

In the first year of the project (November 1992) we sampled at three sites, in two of the mangrove communities, the red (*Rhizophora* A and B) and yellow (*Ceriops* A) mangroves (Fig. 6.1). We found that juvenile banana prawns moved substantial distances into the mangroves (at least 43 m) at high tide. Also, there were no significant differences between catches of juvenile banana prawns at the three sites (Fig. 6.2). In other words the prawns showed similar preference for both types of mangrove forests, despite their very different structures.

The distribution of fish was quite different from the prawns. More fish and more fish species were caught at the mangrove fringe than at the most inland site. Also, fish at the fringe site were larger and heavier than fish caught at the inner site (Fig. 6.3). Virtually all the larger predatory fish such as barramundi, catfish, flathead and trevally were caught only at the mangrove fringe.

In March 1993 we sampled more extensively in *Rhizophora* forest close to the creekmangrove fringe (*Rhizophora* A, B and C) (Fig. 6.1) and found that the densities of juvenile banana prawns at each site in the mangroves were negatively correlated with the maximum tide height recorded for each sample ( $R^2$ =0.79, p=0.003, n=8) (Fig. 6.4). The correlation was significant for all sizes of prawns caught. This suggests that the prawns were moving further into the mangrove forest from the creek fringe as the tide height increased. However, they were not just following the water's edge into the mangroves, as prawns were still caught at the creek mangrove fringe when the water had inundated the inland mangrove fringe. Juvenile *P. merguiensis* appear, therefore, to use a large part of the mangrove forest.

In the second and third year of the project, the number of sites was increased and in 1994/1995, we sampled four sites in *Rhizophora* (A, C, D, E), two in *Ceriops* (A, B) and two in *Avicennia* (A, B) forest (Fig. 6.1). The results of this sampling showed that juvenile banana prawns were widespread throughout the mangrove forest and confirmed our earlier conclusion that the prawns had no preference for particular mangrove types. Catches at the Ceriops B site were very similar to catches at the Avicennia B site, only about 30 m away.

However, the juvenile banana prawns did not seem to use all parts of the forest equally; catches of prawns at *Ceriops* A on the western or downstream side of the mangrove forest were consistently much higher than catches of prawns at *Ceriops* B on the eastern or upstream side of the forest (on average, over six times as high). We believe that this distribution is a related to the position at which prawns first enter the mangrove forest and local water current patterns within the mangroves. By setting small trap nets at the creek mangrove fringe we found that nearly all prawns entered the mangrove forest through the low-lying *Rhizophora* rather than the more elevated *Ceriops* forest. Further work is needed to more clearly understand these local patterns of mangrove use.

71

## Conclusions

- We found that the small prawns and fish use large areas of the mangrove forests when they are inundated at high tide.
- The prawns and small fish probably gain some protection from predation by the larger fish by moving well into the mangroves.
- Juvenile banana prawns had no preference for particular mangrove types.
- The importance of particular areas of mangroves to juvenile prawns probably depends more on local topography and water currents than on the type of mangrove.

#### References

- Long BG, Vance DJ, Conacher CA (1992). Remote sensing helps identify links between mangroves and prawns. *Australian Fisheries* **51(7):** 22–23.
- Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (in press). How far do prawns and fish move into mangroves? Distribution of juvenile banana prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series*
- Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR, Pendrey RC (1996). How far do juvenile banana prawns and fish move into mangroves? *Professional Fisherman*. April 1996, 28-32.



Figure 6.1. Map showing the stake-net sampling sites and mangrove communities in the Embley River, Gulf of Carpentaria, Australia.

.