Port of Karumba Seagrass Monitoring Baseline Surveys

QUEENSLAND GOVERNMENT

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

PORTS CORPORATION QUEENSLAND

• Dry-season (October) 1994 • Wet-season (March) 1995

Rasheed, M.A., Lee Long, W.J., McKenzie, L.J., Roder, C.A., Roelofs, A.J. & Coles, R.G.

EcoPorts Monograph Series No.4

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December 1996

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PORTS CORPORATION QUEENSLAND

QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

QUEENSLAND GOVERNMENT

ISSN 1326-4338
ISBN 0 7242 7529 0
Published December 1996
by the Ports Corporation of Queensland

GPO Box 409
Brisbane Qld 4001
Telephone 07 3224 7088
Facsimile 07 3224 7234

The EcoPorts Monograph Series is published by the Ports Corporation of Queensland to disseminate information about and results from its corporate environment program.

Cover Image
Hover Craft used for seagrass surveys at Karumba (Photograph: QDPI, 1995)

ACKNOWLEDGMENTS

The authors are grateful to David Reid (QDPI, Mareeba) and Bruce Mapstone (CRC Reef Research Centre) for assistance with statistics and design of monitoring schemes. We are grateful to Ian Baxter (Le Provost Dames and Moore), Steve Raaymakers (Ports Corporation of Queensland) and Louise Johns (QDPI, Northern Fisheries Centre) for the assistance with field work. We are grateful to Dot Caesar and Shirley Veronise (QDPI, Northern Fisheries Centre) for assistance with prawn identification; and Phil Hales and Sue Helmke (QDPI, Northern Fisheries Centre) for assistance with fish identifications. We also thank Terry Webb (QDPI, Mareeba) for assistance with GIS base map preparation and Steve Raaymakers for comments on the draft manuscript. This project was funded by the Ports Corporation of Queensland, and the Queensland Department of Primary Industries.

The correct citation of this document is:

Rasheed, M.A., Lee Long, W.J., McKenzie, L.J., Roder, C.A., Roelofs, A.J. and Coles, R.G. (1996). 'Port of Karumba Seagrass Monitoring, Baseline Surveys - Dry-season (October) 1994 and Wet-season (March) 1995'. <u>*Ports Corporation of Queensland EcoPorts Monograph Series*</u> *No 4. (PCQ, Brisbane) 49 pp.*

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↳ EXECUTIVE SUMMARY

Key Results

1. 1422 ± 100 ha of seagrass habitat was recorded around the mouths of the Norman and Bynoe Rivers in the dry-season (October) 1994 survey and 1312 ± 53 ha in the wet-season (March) 1995 survey.

2. Two seagrass species were found: *Halodule pinifolia* and *Halophila ovalis*.

3. In both the dry and wet season surveys, most seagrass occurred in a continuous meadow between the Norman and Bynoe River Mouths (Alligator Bank).

4. On both sampling occasions, seagrass distribution was patchy on Elbow Bank, which is exposed to northerly winds and seas.

5. High turbidity and resulting low light levels were the likely cause of seagrasses being restricted to intertidal areas in both surveys.

6. Extensive dugong feeding trails were recorded throughout the seagrass meadows at Karumba in both the dry-season (1994) and wet-season (1995) surveys. Considerably more dugong feeding trails were recorded during the wet-season (March) 1995 survey than the dry-season (October 1994) survey.

7. Three species of penaeid prawns were collected in the dry-season (October) 1994 survey. *Metapenaeus burkenroadi* was the most common species collected followed by the commercially targeted brown tiger prawn (*Penaeus esculentus*) and the endeavour prawn (*Metapenaeus endeavouri*). Nine species of penaeid prawns were collected in the wet-season (March) 1995 survey. Unidentified juvenile *Metapenaeus* species were the most common species collected followed by the commercially targeted banana prawn (*Penaeus merguiensis*).

8. Seventeen fish taxa were collected in the dry-season (October) 1994 survey. The family Lethrinidae (emperors) were the most common followed by Platycephalidae (flatheads). Four species of commercial importance (31% of the total catch) were collected. At least 16 fish taxa were collected in the wet-season (March) 1995 survey. The family Engraulididae were the most common followed by the Gobiidae. Three species of commercial importance (0.5% of the total catch) were collected.

9. Abundances of fish, prawns and other crustacea were greater on the high seagrass biomass Alligator Bank site than on the lower biomass Elbow Bank site in the dry-season (1994) survey.

10. Abundances of crustacea (excluding prawns) in the wet-season (March) 1995 survey were low compared with the dry-season (October) 1994 survey. In contrast, the abundance of juvenile prawns was high. The abundance of fish was similar in both surveys. Differences may be a result

of high freshwater runoff in the wet-season (March) 1995 or seasonal differences in recruitment of faunal species.

11. A future monitoring strategy and sampling design for both summer and winter was determined based on the results of the dry-season (October) 1994 and wet-season (March) 1995 surveys.

Key Issues resulting from both surveys

1. Juveniles of commercially important fish species were lower in abundance in the wet-season (March) survey than the dry-season (October) survey on Karumba seagrass meadows.

2. Karumba seagrass meadows are a locally important food resource for dugong. Frequency of feeding trails indicate that the use of these meadows by dugongs may be periodic and perhaps seasonal.

3. Results from these and previous surveys (Coles *et al*. in prep) indicate that Karumba seagrass meadows are less productive commercial prawn nursery grounds compared with other meadows in the south eastern gulf of Carpentaria. High abundances of non-commercial prawn species were found on Alligator bank and may represent an important food source for commercial finfish populations.

4. The seagrass species, *Halodule pinifolia* and *Halophila ovalis* found in these surveys are considered pioneering species and are likely to vary in biomass and abundance seasonally and from year-to-year.

5. Measures of change in seagrass meadows should not be based solely on the detection of statistically significant changes in seagrass biomass, but should include other information gained from mapping and surveys. The following indicators of change could be used, where necessary to raise cautionary “flags”:

    a) three consecutive changes of biomass in one direction, leading to a **trend** in biomass change (even if not statistically significant);

    b) a measurable change in areal extent of seagrass meadows;

    c) a change in seagrass species composition.

↳ 1. INTRODUCTION

1.1. Consultancy Brief

The Ports Corporation of Queensland (PCQ) is the port authority for the Port of Karumba. PCQ has identified seagrass meadows as performing an important role in Karumba's marine ecology. The Port of Karumba is currently subject to a proposal by Century Zinc Limited (CZL) to develop a lead and zinc export facility, and part of the proposal involves dredging of the port entrance. Dredging the port entrance for vessels with live cattle export is being considered. PCQ would be responsible for any such dredging, and has commissioned a number of environmental and engineering studies to assess and manage potential impacts on the marine environment by this and other future port developments. This seagrass study is part of these wider studies. Specifically the following three objectives were set:

❶ *Establish a wet-season and dry-season baseline of seagrass distribution in the Port of Karumba.*

❷ *Estimate seagrass biomass for the major areas of seagrass habitat.*

❸ *Determine the most suitable seagrass meadows for future wet-season and dry-season monitoring programs.*

❹ *Develop monitoring schemes and sampling strategies for future seagrass monitoring that will be statistically defensible.*

The results of the dry-season (October 1994) and wet-season (March 1995) surveys form the baseline for further ongoing monitoring at the Port of Karumba. PCQ will use the results of this monitoring to help identify any possible detrimental effects of port operations and developments on seagrasses and assist in formulating management measures for the port.

This monograph details the results from the wet- and dry-season baseline surveys undertaken in October 1994 and March 1995.

1.2. Site Description

Karumba is a small coastal community located in the south-eastern Gulf of Carpentaria, Queensland (Figure 1). Karumba has existing port facilities on the Norman River, which service recreational and commercial fishing industries, cargo shipment to other Gulf destinations and the export of livestock. The coastal waters around Karumba support gillnet (including barramundi) and mud crab fishing industries, and offshore there is commercial trawling for export quality banana and tiger prawns.

The coastal plain surrounding the Karumba area is typically flat with low relief rising to approximately 10 m above sea level. Livestock grazing is the major land use for the Norman River catchment and there are no major secondary industries.

Karumba has a tropical monsoon rainfall pattern with a mean annual rainfall of 922 mm of which the majority falls between December and March. Temperature ranges from 14.1-27.3°C in July to 24.6-32.2°C in December (Anon 1994).

1.3. General Seagrass Ecology

Seagrass meadows in northern Queensland support important commercial species of juvenile penaeid prawns and fish (Coles *et al*. 1993; Watson *et al*. 1993). Seagrasses are essential food for dugong, *Dugong dugon* (Miller), and green sea turtles, *Chelonia mydas* (Linnaeus) (Lanyon *et al*. 1989) and act as "nutrient and sediment sinks" (Short 1987). Seagrasses in coastal regions play important roles in maintaining sediment stability and water clarity. Coastal seagrass meadows are therefore an important resource economically and ecologically.

The growth of seagrasses depends on several factors including the availability of light (Dennison 1987; Williams and Dennison 1990), nutrients (Orth 1977; Erftemeijer 1994), water temperature and salinity (Bulthuis 1987; Zieman 1975). Activities that lead to a change in these factors, such as runoff from agriculture and turbidity from dredging, could potentially have a negative impact on seagrass growth and distribution. Seagrasses show measurable growth responses to changes in ambient water quality conditions and can therefore be used as effective indicators of environmental health (Dennison *et al*. 1993).

Tropical seagrass meadows are subject to temporal changes, varying seasonally and between years (Mellors *et al*. 1993; McKenzie 1994). The potential for widespread seagrass loss has been well documented and the causes of loss can be natural such as cyclones and floods (Poiner *et al.* 1989), or due to human influences such as agricultural runoff (Preen *et al*. 1995), industrial runoff (Shepherd *et al*. 1989), oil spills (Jackson *et al.* 1989) and dredging (Pringle 1989).

1.4. Port of Karumba Seagrasses

An aerial seagrass survey of the Gulf of Carpentaria between 1982 and 1984 failed to locate any seagrass in the vicinity of Karumba and the Norman River (Poiner *et al.* 1987). Aerial surveys alone, however, are unlikely to reveal the full extent of seagrass meadows in this area as highly turbid water conditions limit the usefulness of aerial surveys to very low tides. Low density or patchy meadows of the fine-leaved *Halodule* species are also easily missed in aerial surveys, even at low tide.

Seagrasses in the Karumba area were mapped by QDPI in October 1986 as part of a broadscale seagrass survey of the Gulf of Carpentaria (Coles *et al*. in prep.). They recorded three species of seagrass (*Halodule uninervis*, *Halodule pinifolia* and *Halophila ovalis*) on the mud banks to the east and west of the Norman River mouth. Four species of penaeid prawns were collected in beam trawls over this area, including *Penaeus esculentus* (brown tiger), *Penaeus semisulcatus* (grooved tiger) *Penaeus latisulcatus* (western king) and *Penaeus merguiensis* (banana).

Reconnaissance aerial seagrass surveys conducted by Dames and Moore for CZL in October 1993 and April 1994 described an area of approximately 1000 ha of monogenic *Halodule* species (Hilliard *et al*. 1994a, 1994b; Poiner *et al.* 1994). Numerous dugong feeding trails were also recorded.

The present dry-season (October) 1994 and wet-season (March) 1995 surveys examine the distribution and abundance of seagrasses and describe their associated macrofaunal communities. It was considered important to establish both wet- and dry-season baselines for Karumba seagrasses to develop effective seagrass monitoring programs for the Port of Karumba.

➷ 2. METHODS

2.1. Seagrass Distribution and Abundance

Seagrass distribution and biomass surveys were conducted on the shallow mud and sand banks adjacent to the mouth of the Norman River between the 10 -13 October, 1994 and the 14 -16 March, 1995. Survey sites were located along transects and at selected locations, based on aerial photographs (15 September 1994) and preliminary reconnaissance by helicopter. Estimates of above-ground biomass (3 replicates), species composition, % cover of algae and sediment characteristics were recorded at each site by an observer on the ground at low tide. In the March survey, a hovercraft was used to traverse the intertidal flats.

Above-ground biomass for seagrass was determined using a visual estimates of biomass technique described by Mellors (1991). This technique involves each observer ranking seagrass biomass within a 0.25 m^2 quadrat in the field. These ranks are then calibrated for each observer to produce above-ground biomass estimates in g dry weight m^{-2}.
Seagrass species were identified according to Kuo and McComb (1989). Sediment characteristics were differentiated by visual estimate of grain size: shell grit, rock, gravel (>2000 μm), coarse sand (>500 μm), sand (>250 μm), fine sand (>63 μm)

and mud (<63 μm). A global positioning system (GPS) was used to locate each survey point (latitude and longitude) and record universal time. In October 1994 a standard non-differential GPS with a ±25m error was used, while in March 1995 a post-processed differential GPS was used for position fixing with an error of ±5m.

For mapping, an aerial photograph mosaic was scanned and rectified on ArcInfo® (Geographic Information System), exported to MapInfo®, into which all survey points were imported and features were digitised. Survey points were transformed to Australian Map Grid (AMG) co-ordinates using the GPS fixes.

The boundaries of seagrass meadows were determined from aerial photographs, aerial reconnaissance observations and ground-truthing during field surveys. The position of meadow boundaries was mapped directly onto an aerial photograph from GPS coordinates and from features such as distance from shore or other landmarks. The boundary maps were used together with survey site data to produce meadow boundaries on the GIS. The error in determining the edge of seagrass meadows was set from ± 10 m to ± 20 m (depending on meadow) and was based on the availability of physical features located on the aerial photographs and survey site data. Other errors associated with mapping, such as the rectification of the photograph images, GPS error, digitising error and position of observer relative to the GPS fix, were assumed to be embedded in this range.

Where access to the lower intertidal areas of the study area was restricted by tide conditions, seagrass distribution and species composition were confirmed using low level helicopter reconnaissance to determine the edges of seagrass meadows.

2.2. Comparison of Wet and Dry Season Surveys

The initial dry-season (October) 1994 and wet-season (March) 1995 surveys were designed to provide a baseline description of seagrass distribution and abundance at Karumba. As monitoring will compare within seasons (ie summer/summer and winter/winter) the sampling regime has not been designed to allow stringent quantitative comparison between-seasons (ie summer/winter). However, semi-quantitative between season comparisons in seagrass distribution and abundance can be made from information on the number and size of meadows and data on seagrass biomass.

2.3. Macrofaunal Communities

Macrofaunal sampling was performed to produce an inventory of species and provide an indication of the importance of Karumba seagrasses for commercial faunal species. Faunal sampling is not intended as a parameter for ongoing monitoring because of unknown sampling efficiencies and the high variability of species. Monitoring changes in macrofauna would require frequent, intensive sampling which is beyond the scope of this program.

During the dry-season (October) 1994 survey, two sites were chosen for macrofaunal sampling comparison based on representative seagrass communities of the area and an additional 10 minute exploratory trawl was performed to produce a more complete species inventory (Table 1; Figure 2). During the March

1995 survey, three sites on the large Alligator Bank meadow were chosen for macrofaunal sampling (Figure 3).

Sampling was conducted at night (at high water) on 12 October 1994 and 15 March 1995. A beam trawl (1.5 m wide, 0.5 m high with a 2.0 mm mesh) was towed along 100 m transects at approximately 0.5 m s^{-1} (cf. Coles *et al.* 1993). Three replicate trawls were conducted at each site, apart from the 10 minute exploratory trawl in the October 1994 survey.

All Penaeidae (prawns) were identified to species according to Dall (1957) and Grey *et al*. (1983). Carapace length was measured (posterio-dorsal margin of the carapace to the orbit of the eye) to the nearest 0.1 mm. All fish were identified and standard length (tip of snout to last vertebra) measured to the nearest 0.1 mm.

Brachyura (crabs) were separated into families in the dry-season (October) 1994 survey, however in the wet-season (March) 1995, Brachyura were pooled with Caridea (shrimps), Isopoda, Amphipoda and other crustaceans. All crustacea were counted for each trawl. Molluscs, polychaetes and other phyla were not examined.

Abundances are presented as the number of individuals per trawl (catch rate), as beam trawl efficiencies were not determined for each taxa in this study.

For the analysis of the data obtained from both surveys, standard parametric analysis of variance (ANOVA) and T-tests were used to analyse the data (Zar 1984; Sokal and Rolf 1987). Prior to ANOVA procedures, residuals were plotted against fitted values and Bartlett's test for homogeneity of variance were carried out to check if the assumptions of the ANOVA were satisfied. Non-parametric tests (Kruskal-Wallis) were used when data was seriously unbalanced or non-normal.

↳ 3. RESULTS

3.1. Seagrass Distribution and Abundance

Two seagrass species from two families were found within the Port of Karumba survey area (Appendix 2, Plates 2 and 3).

Family Cymodoceaceae
Halophila ovalis (R. Br.) Hook.*f*. (Plate 2)

Family Hydrocharitaceae
Halodule pinifolia (Miki) den Hartog (Plate 3)

1422 ± 100 ha of seagrass in 11 meadows was mapped in the October 1994 survey and 1312 ± 53 ha of seagrass in 5 meadows was mapped in the March 1995 survey (Figures 2 and 3). In both surveys, the largest seagrass areas were on the shallow mud bank between the Norman and Bynoe Rivers (Alligator Bank) and on the sand/mud banks east of the Norman River (Elbow Bank). Seagrass cover remained consistent on the Alligator Bank meadow and patchy on Elbow Bank.

Three meadows from Elbow bank (20 ± 17 ha) and 1 meadow from Alligator bank (5 ± 3 ha), representing a total area of 25 ± 20 ha were documented in the October 1994 survey and were absent in March 1995. An additional *Halodule pinifolia* meadow (2 ± 1 ha), south of the large Elbow bank meadow, was present in the March 1995 survey but was not present during the October survey. Helicopter reconnaissance also indicated an increase of 148 ± 130 ha in seagrass area in Meadow 4 on Elbow bank (Figures 2 and 3).

In the wet-season (March) survey, there was a loss of 232 ± 31 ha of seagrass on Alligator bank and a gain of 122 ± 83 ha on Elbow bank compared with the dry season survey (October 1994). This represents a net loss for the survey region of 110 ± 52 ha in seagrass area.

Seagrass on Elbow Bank was in sand and fine sand/mud substrates. Seagrass on Alligator Bank was predominantly in mud/sand and mud/fine sand substrates (Table 2).

Seagrasses were restricted to intertidal depths, particularly in areas where water pooled at low tide. *Halodule pinifolia* was the dominant species present at 95% of sites in October 1994 and 99% of sites in March 1995. At survey sites where seagrass was present, *Halophila ovalis* was found at 77% of sites in October 1994 and 11% of sites in March 1995.

Mean above-ground biomass was highest in the Alligator Bank meadow 1 in both surveys (Figure 4, Table 2). Monitoring meadow 1 increased in above-ground seagrass biomass between the two surveys, while above-ground seagrass biomass in monitoring meadow 2 decreased over this period (Figure 4). At sites where *Halodule pinifolia* was the dominant species, above-ground biomass was highest (4.87 ± 0.18 g dw m^{-2} October 1994 and 7.10 ± 0.27 g dw m^{-2} March, 1995). Mean biomass at sites where *Halophila ovalis* dominated was lower (1.63 ± 0.33 g dw m ^{2} in October 1994; 1.17 ± 1.13 g dw m^{-2} in March 1995).

Alligator bank above-ground seagrass biomass (all sites pooled) increased from 5.02 ± 0.15 g dw m^{-2} in the dry season (October) 1994 survey to 8.29 ± 0.31g dw m^{-2} in the wet season (March) 1995 survey. There was no significant change in seagrass above ground biomass for Elbow bank over the same period.

Only 1 site was dominated by *Halophila ovalis* in the wet-season (March) 1995 survey compared with 12 sites in the dry-season (October) survey. These sites were mostly at the edge of the intertidal banks adjacent to the Norman River mouth channel, and were of low biomass. In both surveys, a higher percentage of *Halophila ovalis* was found in the fringing meadow 2, when compared with meadow 1(Figure 5).

Numerous dugong feeding trails were encountered during the surveys (particularly on Elbow bank during the March 1995 survey) and large areas of feeding trails were obvious from aerial reconnaissance (Plate 1a & b).

3.2. Penaeid Prawns

3.2.1.Dry season

During the dry-season (October) 1994 survey, 14 juvenile or sub-adult prawns from 3 species were collected (Table 3). The most common species collected was *Metapenaeus burkenroadi* (64% of total individuals), followed by *Penaeus esculentus* (brown tiger prawn), (29% of total individuals). A total of 13 prawns (9 *Metapenaeus burkenroadi* and 4 *Penaeus esculentus*) were collected at the Alligator bank site and 1 endeavour prawn (*Metapenaeus endeavouri*) represented the total penaeid catch for the Elbow Bank site. Commercially important prawn species comprised 36% of the total numbers of prawns collected (Table 3).

3.2.2. Wet season

2320 juvenile or sub-adult prawns from 9 species were collected on Alligator Bank in the wet-season (March) 1995 survey (Table 3). An unidentified prawn (*Metapenaeus* spp.) was the most commonly encountered species (96.8% of total individuals). Mean carapace length for this species was not significantly different between the three sites (Kruskal-Wallis, F=1.58, 2 x 6 df, p =0.28).

The banana prawn, *Penaeus merguiensis* (1.4% of total individuals) was the second most abundant species, although absent in site 3 trawl samples.

Penaeid prawn abundances per trawl and species diversity were not significantly different between sites (abundance, ANOVA F=0.8, 2 x 6 df, p = 0.5; diversity, ANOVA F=4.8, 2 x 6 df, p = 0.06).

Commercially important prawn species comprised only 1.7% of the total numbers of prawns collected (Table 3).

3.3. Fish

3.3.1. Dry season

A total of 544 individual fish were collected from beam trawl samples representing at least 17 taxa (Table 4). Catch rates were significantly higher on the Alligator Bank site than on the Elbow Bank site (Kruskal-Wallis, $F=13.5$, 1×4 df, $p<0.05$) (Table 4). Significantly more species were found at the high seagrass biomass Alligator site than at the Elbow Bank site (T-test, $t=3.18$, 4 df, $p<0.05$).

Fish collected were mostly small (mean = 16.90 ± 0.35 mm) and ranged in length from 4.7- 71.2mm (median = 14.85mm). Fish collected at Elbow Bank were significantly smaller than at Alligator Bank (T-test, $t = 2.80$, 206 df, $p<0.01$).

Lethrinidae (emperors) were the most abundant family collected (21% of total individuals). The Lethrinidae were represented by juveniles of one species. Significantly more Lethrinidae were collected at Alligator Bank than at Elbow Bank (T-test, $t = 4.71$, 2.2 df, $p<0.05$).

Platycephalidae (flatheads) were the second most abundant species (8% of total individuals). *Platycephalus arenarius* formed the dominant component of the Platycephalidae (96%). Only one individual of Platycephalidae was collected from the Elbow Bank, compared to 20 at the Alligator Bank site.

Four fish taxa collected were of commercial importance, including Carrangidae sp. (trevallies), Hemirhamphidae sp. (garfish), Lethrinidae sp. (emperors) and *Platycephalus arenarius* (flathead). Individuals of these species represented 36.2% of the total fish catch (Figure 6).

3.3.2. Wet season

A total of 592 individual fish were collected from beam trawl samples representing at least 16 taxa (Table 4). Catch rates were significantly different between all sites with the highest numbers of fish collected at site 1 and the lowest numbers occurring at site 3 (ANOVA $F=47.15$, 2×5 df, $p<0.001$).

There was no significant difference in fish species diversity between sites (ANOVA $F=0.35$, 2×5 df, $p = 0.7$). Fish collected were mostly small (mean = 19.5 ± 0.3 mm) and ranged in length from 6.6 - 129.7 mm (median = 19.4 mm). The family Engraulididae was the most abundant family collected (79% of total individuals) with *Stolephorous* sp. the most abundant species.

Commercially and recreationally important species comprised only 4.0% of the total numbers of fish collected (Figure 6). Unidentified fish species represented 6.3% of the total (Table 4).

3.4. Other crustacea

3.4.1. Dry Season

A total of 2664 individual crustacea (excluding penaeidae) were collected by beam trawl. Numbers of individual crustacea were highly variable between trawls. Higher abundances of crustacea were collected at site b (Alligator bank) than at site c (Elbow bank) (218 ± 104.18 and 78.33 ± 9.56 per trawl respectively).

Brachyurans (crabs) contributed less than 0.2% of the total number of crustacea (excluding penaeid prawns), and were represented by 2 families, Portunidae and Ocypodidae. No Brachyurans were collected on Elbow Bank.

3.4.2. Wet Season

A total of 255 individual crustacea (excluding penaeidae) were collected by beam trawl. Significantly higher abundances of crustacea were collected at site 2 (47.7 ± 10.7 per trawl) than at site 3 (14.3 ± 2.6 per trawl). Crustacean abundances at site 1 (23.0 ± 8.6) did not differ significantly from the other sites (ANOVA F=4.6, 2 x 6 df, p = 0.6). During the March 1995 survey, Brachyurans were pooled with all other crustacea (excluding penaeidae).

3.5. Future Monitoring Scheme and Sampling Design

3.5.1. General Considerations

The seagrass monitoring program was designed to ensure that any impacts and changes detected were

1. statistically significant and
2. ecologically or economically important.

For the monitoring scheme to be successful, sampling procedures were carefully selected so that changes (such as increases or decreases in seagrass biomass) will be detected. Sampling strategies were mathematically determined to predict, with a certain level of confidence, that changes of a given amount would be detected. However, these calculations depended on

1. the estimate of variance;
2. the size of the change to be detected;
3. the level of significance to be used (probability of a Type I error);
4. the assurance with which it is desired to detect the difference (probability of a Type II error).

An **estimate of variance** was obtained from the baseline data sets of the dry-season (October 1994) and the wet-season (March 1995) surveys. The **size of the change to be detected** was realistically set. This required prior estimation of the variability observed in the data and consideration of the magnitude of change that would be *biologically* and/or *economically* important (Lee Long *et al.* 1996).

The **levels of significance** and **assurance** were based on Type I and Type II errors, respectively. A Type I error is made when a difference is detected but does not really exist (i.e. the null hypothesis is rejected when it is true). The probability of such an error (α) is set prior to the experiment and is often set at 5%. A Type II error is made when a real difference exists but is not detected (i.e. the null hypothesis is accepted when it is false). The probability of a Type II error (β) depends on the choice of α and the size of the difference between the means under the null and alternate hypotheses (The *power* (*P*) of a test is related to the Type II error with $P = 1\text{-}\beta$).

In determining sampling strategies both types of error were considered. It was preferable for the probabilities of both Type I and II errors to be as small as possible. However, a reduction in the probability of a Type I error resulted in an increase in the probability of a Type II error. Therefore, we considered the seriousness of the different types of error in choosing levels of significance. In monitoring environmental factors such as seagrass abundance, a Type II error is likely to be more costly than a Type I error (Fairweather 1991; Peterman 1990) suggesting that it is better to say there is a difference when one doesn't exist (being over-cautious) than to say there is no difference when in fact a difference does exist. Hence the probability of a Type I (α) error may be sacrificed in an attempt to reduce the probability of a Type II error (β). The probability of a Type I error was therefore set at 10% (i.e. $\alpha = 0.10$) and the probability of a Type II error also at 10% (i.e. $\beta = 0.10$; Power = 90%) for the Port of Karumba monitoring program.

3.5.2. *Sampling Design for Port of Karumba*

The optimal use of available time and resources in monitoring changes in Karumba seagrasses was to consider selected meadows rather than the entire port area. A repeated measures design was considered inappropriate due to the dynamic nature of seagrass meadows and the unavailability of an accurate method for relocating sites.

The proposed monitoring scheme will survey above-ground seagrass biomass twice yearly, wet-season (high biomass) and dry-season (low biomass) for the next three years (1995/6, 1996/7, 1997/8). As growth patterns and hence variability in seagrass biomass differs markedly from winter to summer, quantitative comparisons over time will only be made within seasons (ie. dry-season with dry-season and wet-season with wet-season). Semi-quantitative comparisons between seasons (ie. dry with wet) will be made as a secondary consideration.

Within each primary meadow, seagrass biomass will be estimated at *r* randomly selected sites and *q* quadrats (replicates) within each site. The analysis of variance to compare above-ground biomass over the three years will be of the form:

ANOVA 1.

Source	df	E[MS]		F
Time(T)	2	$\sigma^2 + q\sigma_S^2 + qr\sigma_T^2$	(= TMS)	TMS/EMS
Site(S):T	$3(r-1)$	$\sigma^2 + q\sigma_S^2$	(= EMS)	
Quadrat(Q):ST	$3r(q-1)$	σ^2		

where σ^2 = variance component for Quadrat
σ_S^2 = variance component for Site
σ_T^2 = variance component for Time
TMS = treatment (Time) mean square
EMS = error mean square

The S:T term is the appropriate term for testing the effect Time (T). In practice the estimates s^2, s_S^2 and s_T^2 of σ^2, σ_S^2 and σ_T^2, respectively are used. Pairwise testing among the three times will be performed by the least significant difference (LSD) test. That is

$$LSD = t_{3(r-1)}\sqrt{\frac{2}{qr}\left(s^2 + qs_S^2 \right)} \qquad \textit{equation (1)}$$

where $t_{3(r-1)}$ is the 5% t-value with $3(r-1)$ df.

The dry-season (October 1994) and wet-season (March 1995) surveys provide information about the primary meadows being considered. For the wet-season survey the number of sites varied between meadows, although the number of quadrats/site was always 3. For illustrative purposes assume that, for a particular meadow, there were *n* sites and *m* quadrats. Then the analysis of variance table is of the form

ANOVA 2.

Source		df	MS
Site(S)	(Between)	$n-1$	$s^2 + ms_S^2$
Quadrat(Q):S	(Within)	$n(m-1)$	s^2

where s^2 = estimate of the variance component for Quadrat
s_S^2 = estimate of the variance component for Site

Assuming s^2 and s_S^2 will be satisfactory estimates of the variance components for future monitoring, these values can be substituted for σ^2 and σ_S^2, respectively, in ANOVA 1. Furthermore, from the initial surveys an estimate ($\bar{x}$) of the mean biomass for the meadow and also the range of sampled biomass were available. This was important in determining the desired limit of detection.

Equation 2 below was used to determine the number of sites (*r)* and the number of quadrats/site (*q*) such that a change in biomass of *d* would be detected at the 90% level (Type I error of 10 %) with 90% assurance of detecting a true difference of this size (Type II error of 10 %).

$$qr = \frac{2(t_0 + t_1)^2 (s^2 + q s_S^2)}{d^2} \qquad \textit{equation (2)}$$

where d = difference to detect
t_0 = the t value associated with Type I error = 10% t-value on 3(*r*-1) df.
t_1 = the t value associated with Type II error = 20% t-value on 3(*r*-1) df. (t_1 equals tabulated t for probability 2(1-*P*) where *P* is the required probability of detecting *d* if such a difference exists (Steel and Torrie 1960)
s^2 = quadrat variance component
s_S^2 = site variance component

Rearranging (2) gives

$$q = \frac{2(t_0 + t_1)^2 s^2}{d^2 r - 2(t_0 + t_1)^2 s_S^2} \qquad \textit{equation (3)}$$

Note that t_0 and t_1 depend on *r*. Given s^2 and s_S^2 and setting the number of sites (*r*) and the difference to detect (*d*) , equation (3) can be used to determine the number of quadrats required.

3.5.3. Dry-Season Sampling Design

The dry-season (October) 1994 survey identified 11 meadows on the basis of seagrass composition and biomass (Figure 2). Many of these meadows however, may be considered to be naturally ephemeral based on prior knowledge of species present and the environmental conditions under which they exist. All seagrass meadows on Elbow Bank were considered to be ephemeral or highly variable and thus unsuitable for intensive biomass monitoring. Two meadows on Alligator Bank (meadows 1 & 2) have been selected for future dry season biomass monitoring (Figure 7).

Given the quadrat and site variance components for each primary meadow, the number of sites and quadrats per site has been determined so that the least percentage change in mean biomass will be detected at the 90% level with 90% assurance of detecting a true difference (Appendix 1, Tables 5,6 and 7).

3.5.4. Wet Season Sampling Design

The wet-season (March) 1995 survey identified 5 meadows on the basis of seagrass composition and biomass (Figure 3). Similar to the dry-season (October) 1994 survey, all seagrass meadows on Elbow Bank were considered to be ephemeral or highly variable and thus unsuitable for intensive biomass monitoring. Two meadows on Alligator Bank (meadows 1 & 2) have been selected for future wet season biomass monitoring (Figure 7). The same meadows were selected for the dry season monitoring and this will allow for some interseasonal comparison of data.

Given the quadrat and site variance components for each primary meadow, the number of sites and quadrats per site has been determined so that the least percentage change in mean biomass will be detected at the 90% level with 90% assurance of detecting a true difference (Tables 8,9 and 10).

Reviewers comments following the baseline surveys suggested that monitoring temporal changes in biomass at permanently marked sites using a repeated measures approach, may be an alternative to the proposed method of monitoring the meadow as a whole. Repeated measures of permanent sites may help to separate spatial from temporal variation in the error terms for the proposed ANOVA tests.

Two techniques will be trialed:
(a) Permanent Monitoring Transects, and
(b) Permanent Sites randomly selected throughout the meadow

The original monitoring strategy and the use of repeated measures will be evaluated for differences in efficiency as tools to monitor seagrass biomass changes in the meadow.

Figure 1. Map of Queensland showing the Port of Karumba study area.

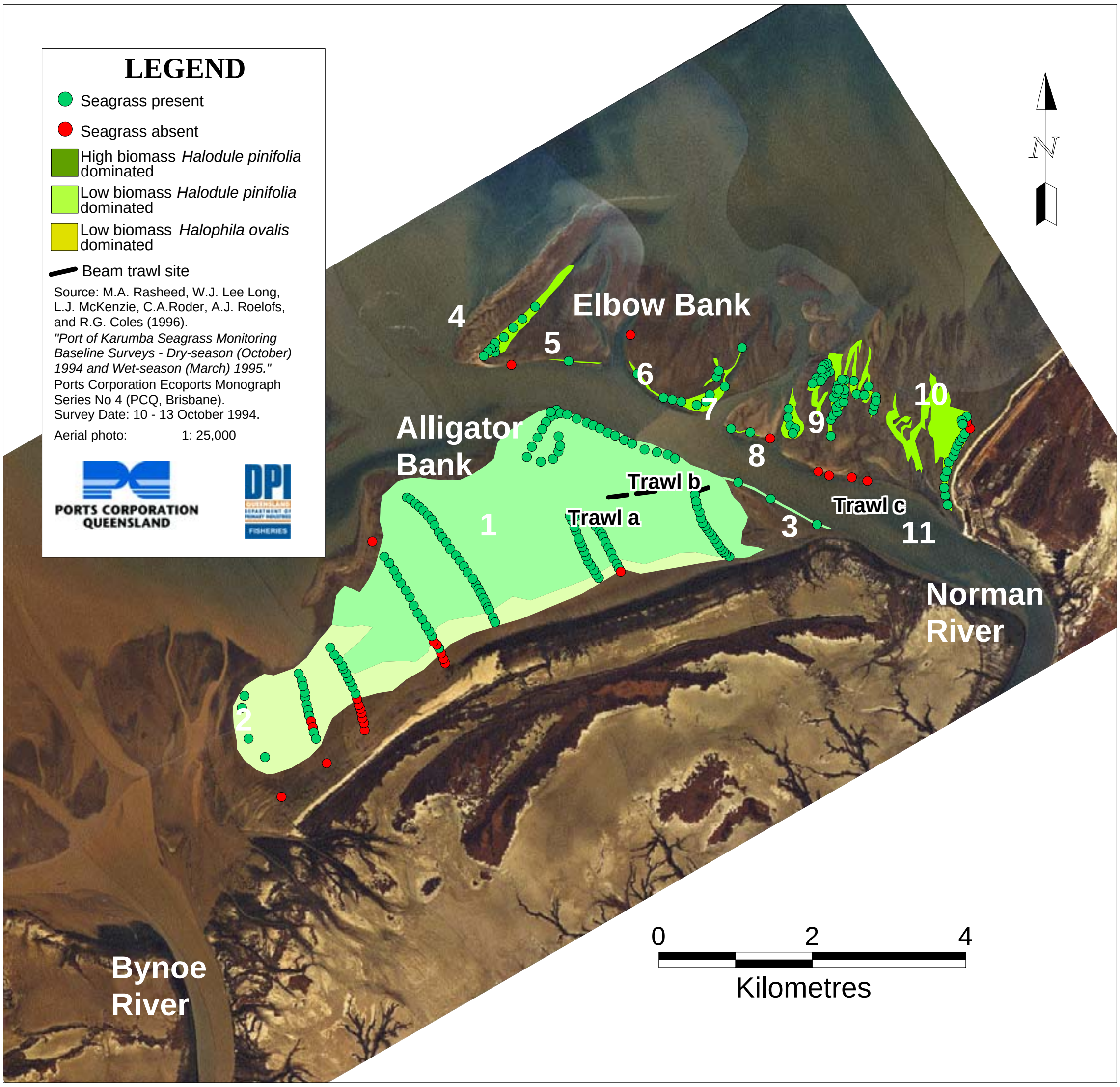


Figure 2 Location of survey sites (seagrass present & absent), seagrass meadows (1 to 11) and beam trawl sites at Port of Karumba in October 1994.

(Beam trawl codes; a. Exploratory; b. Alligator Bank; c. Elbow Bank)

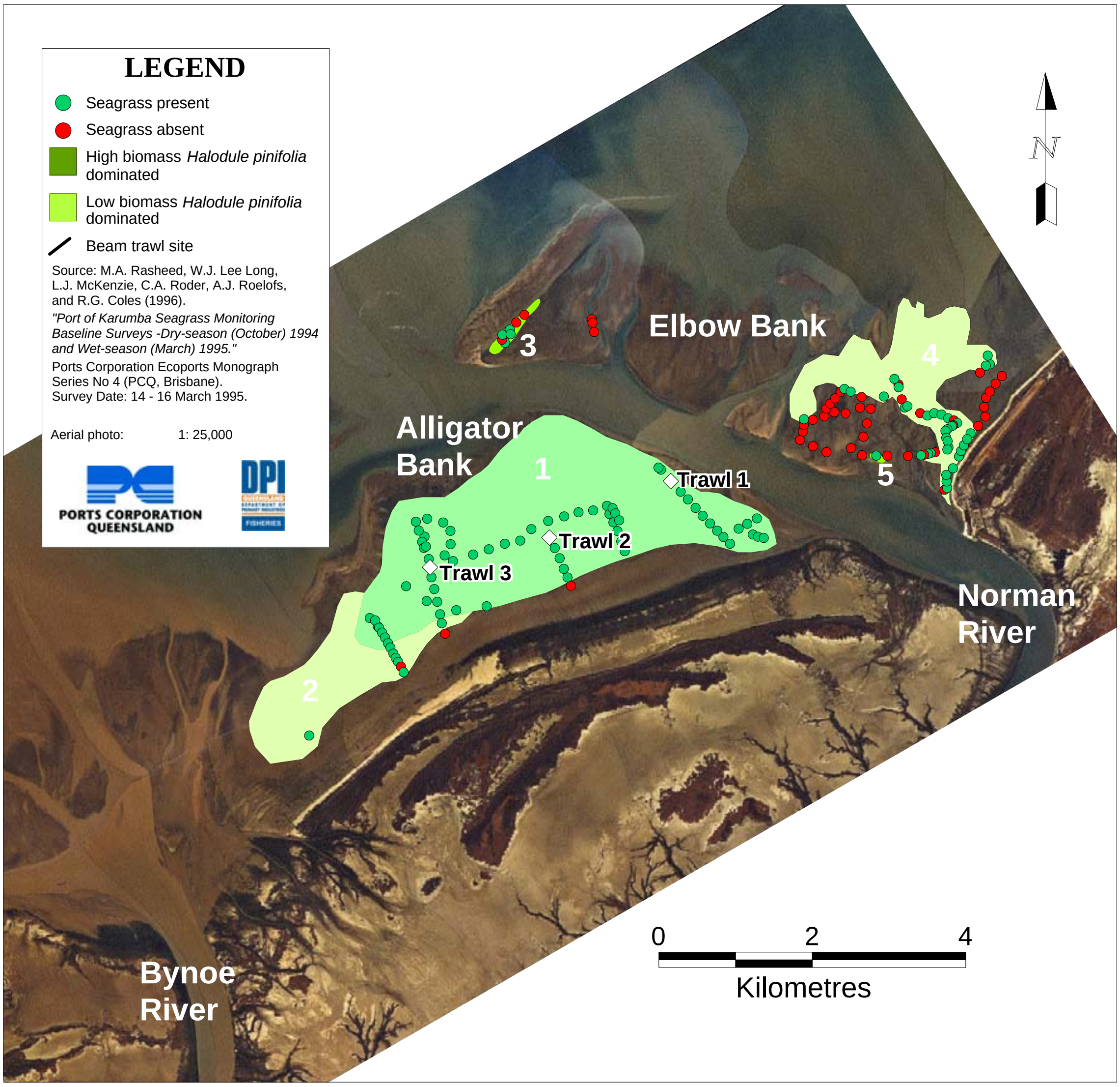


Figure 3 Location of survey sites (seagrass present & absent), seagrass meadows (1 to 5) and beam trawl sites at Port of Karumba in March 1995.

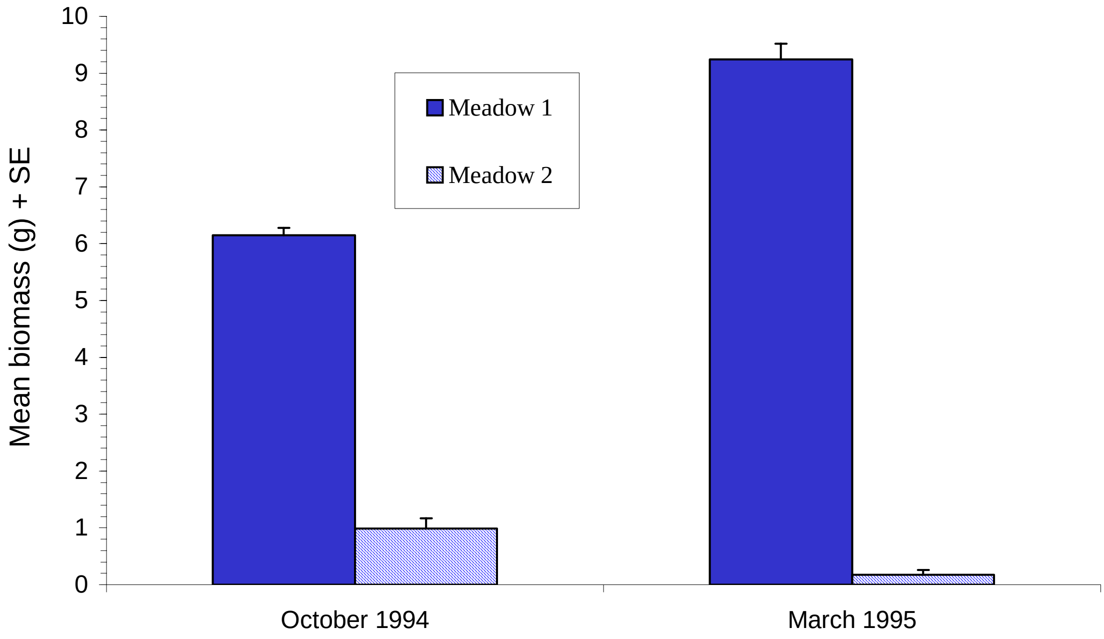


Figure 4. Comparison of seagrass biomass for the Port of Karumba monitoring meadows.

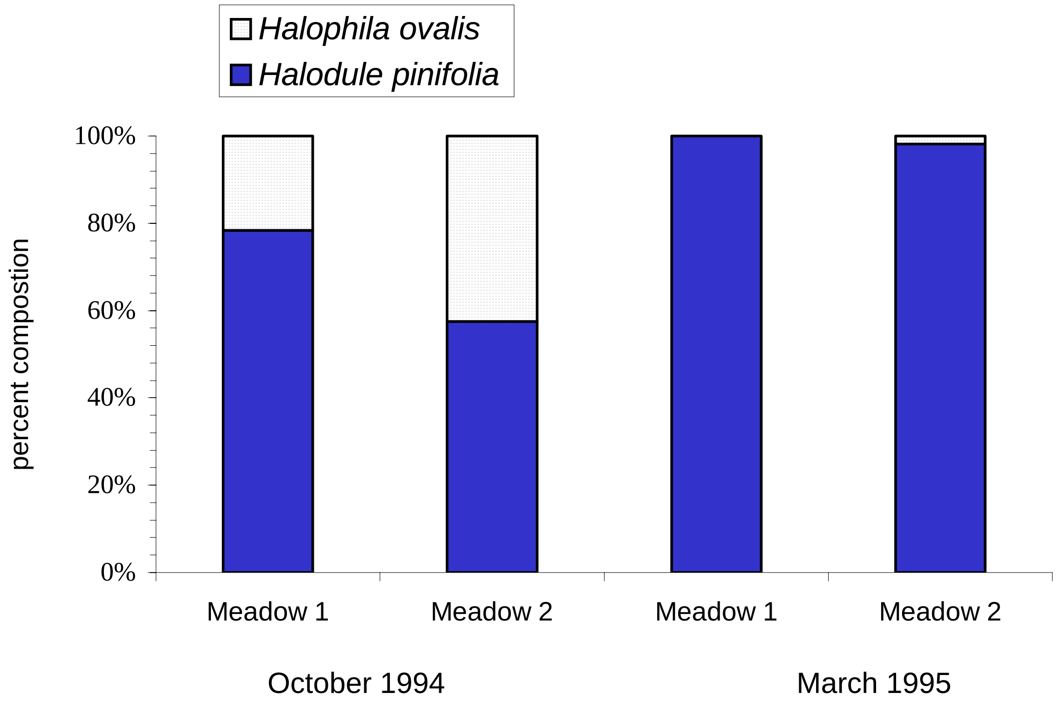
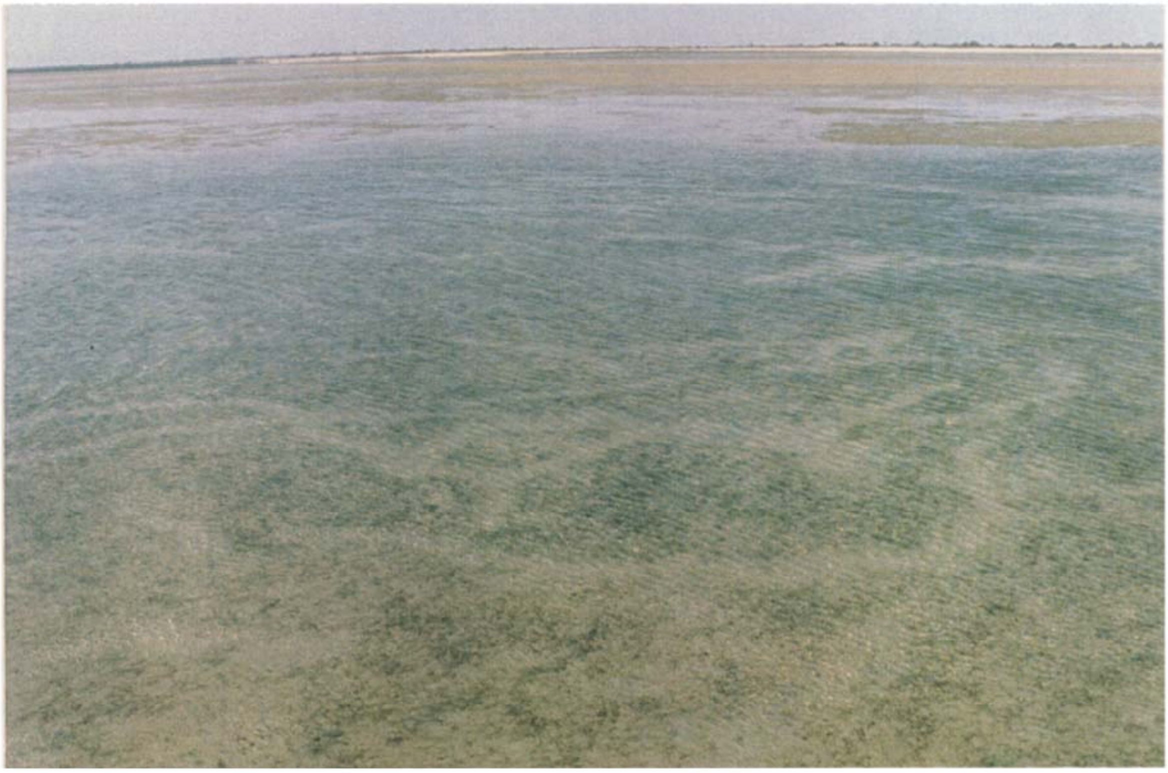


Figure 5. Seagrass species composition for the monitoring meadows in October 1994 and March 1995.

a.



b.

Plate 1. Dugong feeding trails in *Halodule pinifolia* meadows in Port of Karumba (October 1994).

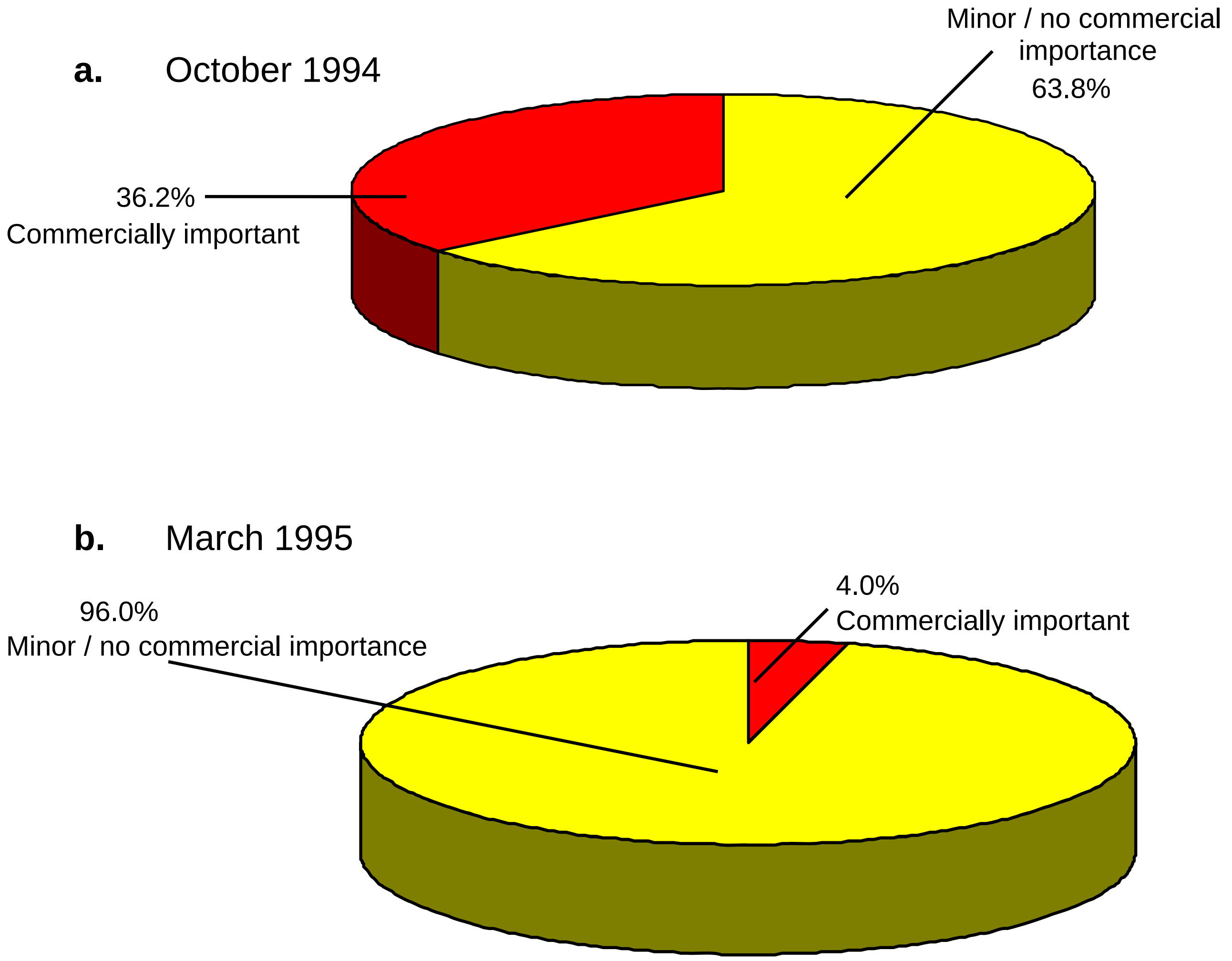


Figure 6. Comparison of commercial and non-commercial fish composition collected in Karumba beam trawls a. October 1994, and b. March 1995.

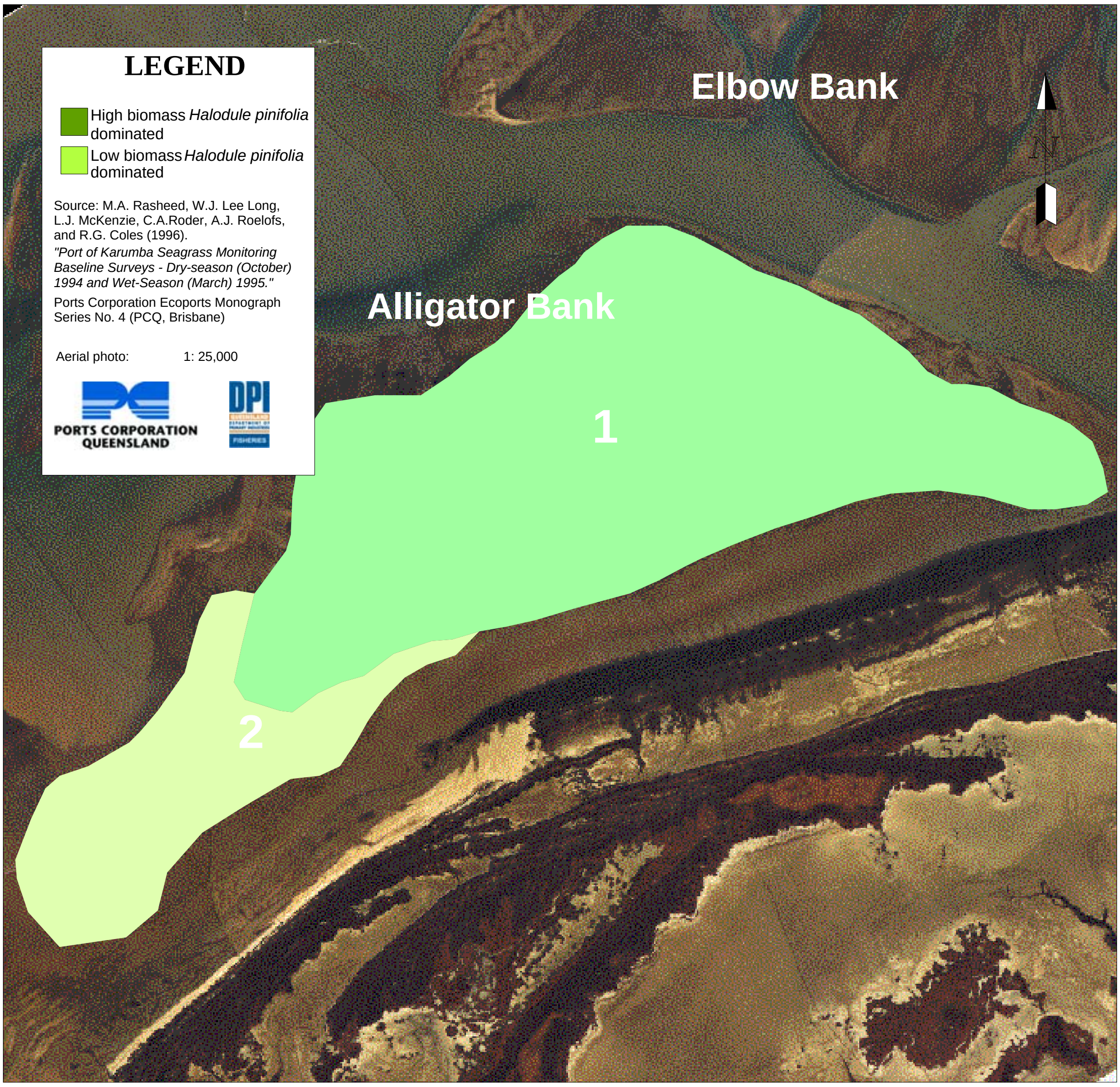


Figure 7 Location of seagrass meadows selected for monitoring in the Port of Karumba.

Table 1. **Description of beam trawl sites for the wet-season (October) 1994 and dry season (March) 1995 surveys.**

Date	Beam Trawl Site	Seagrass Species	Mean Seagrass Biomass at each site (g dw m^{-2})	Substrate	Trawl length
October 1994	Alligator	*Halodule pinifolia / Halophila ovalis*	7.27 ± 0.31	Mud / Sand	3 x100m
	Elbow	*Halodule pinifolia / Halophila ovalis*	0.79 ± 0.25	Sand / Mud	3 x 100m
	Exploratory	*Halodule pinifolia / Halophila ovalis*	6.65 ± 0.39	Mud / Sand	1 x 10 minutes
March 1995	Alligator 1	*Halodule pinifolia*	11.6 ± 0.3	Fine Sand / Mud / Shell	3 x100m
	Alligator 2	*Halodule pinifolia*	11.6 ± 0.6	Mud / Fine Sand / Shell	3 x 100m
	Alligator 3	*Halodule pinifolia*	11.7 ± 0.1	Fine Sand / Mud	3 x 100m

Table 2 Species composition, biomass and distribution of the Port of Karumba seagrass meadows.

Range calculated as per section 2.1

Meadow	**Seagrass species**	**October 1994**		**March 1995**		**Substrate**
		Biomass (g dw. m^{-2}) (ranges in brackets)	Area (ha) (*range*)	Biomass (g dw. m^{-2}) (ranges in brackets)	Area (ha) (*range*)	
Alligator 1	*Halodule pinifolia / Halophila ovalis*	6.15 ± 0.13 *(0 - 10.95)*	963 *(947 - 979)*	9.24 ± 0.28 *(0 - 15.87)*	820 *(806-834)*	Mud / Fine Sand / Shell
Alligator 2	*Halodule pinifolia / Halophila ovalis*	0.99 ± 0.18 *(0 - 8.59)*	302 *(286 - 319)*	0.17± 0.09 *(0 - 1.69)*	220 *(211-229)*	Mud / Fine Sand / Shell
Elbow Bank	*Halodule pinifolia / Halophila ovalis*	3.36 ± 0.3 *(0 - 10.97)*	152 *(087-219)*	1.43 ± 0.16 *(0 - 13.78)*	272 *(242-302)*	Sand / Fine Sand / Mud
TOTAL		4.73 ± 0.3 *(0 - 10.95)*	1422 *(1321-1526)*	6.10 ± 0.28 *(0 - 15.87)*	1312 *(1259-1365)*	

Table 3 Species, abundance, carapace lengths and fishery code for penaeid prawns caught in the Port of Karumba beam trawls, dry-season (October) 1994 and wet-season (March) 1995.

Fishery code: IV. important to the northern Australian prawn fishery; III. component of fishery; II. minor to insignificant importance; I no importance.

Species	Common name	Fishery code	Total #		Mean carapace length (mm) (ranges in brackets)		% Abundance	
			October	March	October	March	October	March
Metapenaeus burkenroadi	-	II	9	10	7.52 ± 0.93 (3.6-12.1)	6.7 ± 0.7 (3.2-9.9)	64	0.4
Metapenaeus dalli	Western School	III	*absent*	3	*absent*	6.6 ± 0.5 (5.7-7.2)	-	0.1
Metapenaeus endeavouri	True endeavour	IV	1	*absent*	9.2	*absent*	7	-
Metapenaeus spp.	-	-	*absent*	2246	*absent*	4.0 ± 0.03 (0.9-13.8)	-	96.8
Penaeus esculentus	Brown Tiger	IV	4	2	3.95 ± 0.52 (2.9-5.3)	12.2 ± 2.8 (9.4-14.9)	29	0.1
Penaeus semisulcatus	Grooved tiger	IV	*absent*	2	*absent*	10.2 ± 1.9 (8.3-12.0)	-	0.1
Penaeus merguiensis	Banana	IV	*absent*	33	*absent*	15.5 ± 0.9 (5.0-23.4)	-	1.4
Penaeus spp.	Tiger	IV	*absent*	2	*absent*	2.7 ± 0.7 (2.0-3.4)	-	0.1
Trachypenaeus curvirostrus	Southern rough	II	*absent*	15	*absent*	4.8 ± 0.2 (3.2-6.4)	-	0.6
Trachypenaeus spp.	-	-	*absent*	6	*absent*	3.4 ± 0.1 (2.8-3.7)	-	0.3
Parapenaeopsis sculptilis	Coral	I	*absent*	1	*absent*	29.3	-	>0.1
TOTAL		-	14	2320	6.9 ± 0.73 (2.9-12.1)	4.2 ± 0.04 (0.9 - 29.3)	100	100

Table 4. Taxa, abundance, size data and value codes for fish collected in Port of Karumba, dry-season (October) 1994 and wet-season (March) 1995.

Value codes (from Coles *et al*. 1993): a, incidental aquarium species; b, incidental baitfish species; c, incidental commercial species; C, targeted commercial species r, incidental recreational species.

Family	Species	Common name	Code	Average Length (mm) (ranges in brackets)		Total #	
				October1994	March 1995	October	March
Apogonidae	*Apogon* sp	Cardinal fish	a	19.6 (13.5-27.6)	13.4 (8.1-23.8)	3	8
Carangidae	sp	Trevally	c?	11.8 (9.5-16.9)	13.9	10	1
Clupeidae	sp	Herring	b?	*absent*	34.9 (29.0-43.8)	-	5
Engraulididae	*Stolephorus* sp	Anchovy	-	*absent*	19.5 (12.0-19.8)	-	463
	Thryssa sp	Anchovy	-	*absent*	18.4 (18.1-18.8)	-	2
Ephippidae	*Drepane punctata*	Sickle fish	r	*absent*	129.7	-	1
Gerreiadae	*Gerres* sp	Silver biddy	b	*absent*	13.5 (13.3-13.7)	-	2
Gobiidae	*Acentrogobius multifaciatus*	Goby	-	49.5 (28.1-71.0)	*absent*	2	-
	Glossogobius biocellatus	Goby	-	32.4 (23.8-37.0)	*absent*	4	-
	sp	Goby	-	identified to spp.	19.2 (10.8-53.6)	-	58
Hemirhamphidae	*spp*	Garfish	bC	39.6	*absent*	1	-
Leiognathidae	*Leiognathus* sp	Ponyfish	-	*absent*	16.1	-	1
Lethrinidae	sp	Emperor	c	20.1 (11.8-27.7)	14.6	112	1
Monacanthidae	sp	Leatherjacket	a	*absent*	25.7	-	1
Paralichthyidae	sp	Flounder	a	16.4 (12.4-18.6)	33.3	3	1
Platycephalidae	*Platycephalus arenarius*	Flathead	cr	29.9 (16.7-71.2)	*absent*	43	-
	spp	Flathead	cr	20.0 (16.0-23.9)	*absent*	2	-
Sciaenidae	*Johnus cf. vogleri*	Jew fish	r	*absent*	74.0	-	1
Silliganidae	*Sillago* sp	Whiting	cr	20.9	33.3	1	1
Syngnathidae	spp.	Pipefish	-	44.3 (35.1-49.8)	*absent*	9	-
Teraponidae	*Pelates quadrilineatus*	Trumpeter	-	20.23 (13.0-27.1)	*absent*	13	-
	Terapon puta	Trumpeter	-	16.1 (12.4-19.8)	*absent*	10	-
	spp	Trumpeter	-	12.6 (10.4-14.1)	*absent*	7	-
Triacanthidae	*Triacanthus angustifrons*	Tripod fish	a	10.3 (5.7-20.8)	10.2 (6.6-19.3)	25	9
Uranoscopidae	spp	Stargazer	-	31.3 (30.4-32.2)	*absent*	2	-
Unidentified			?	13 (4.7-29.9)	16.2 (8.5-22.3)	297	37
TOTAL				16.9 (4.7-71.2)	19.5 (6.6-129.7)	544	592

↳ 4. DISCUSSION

4.1. Seagrass Distribution and Abundance

The 1312 ± 53 ha of seagrass mapped in the wet-season (March) 1995 survey represented a reduction of 110 ± 52 ha since the dry season survey in October 1994, but still represents a substantial increase in area compared to previous studies (Coles *et al*. in prep.; Hilliard *et al*. 1994a, 1994b; Poiner *et al*. 1987). The present surveys represent the first intensive seagrass surveys of the area, and the increased seagrass distribution recorded may be due to the methodology used. Previous surveys relied on remote techniques such as aerial reconnaissance and photography with minimal or no ground-truthing of the area (Poiner *et al.* 1994). These methods underestimate seagrass distribution and abundance when water turbidity is high and/or seagrasses are thin bladed and low density.

Caution is required when interpreting aerial photographs, and ground-truthing is necessary to distinguish seagrass areas from algal (including filamentous algae) cover and accumulated detritus. Helicopter, hovercraft and walking surveys were used to identify the algae-covered areas north of Elbow Bank and detritus accumulations outside the Bynoe River, south of Alligator Bank.

During the wet-season (March) 1995 survey, biomass estimates could not be obtained at the seaward margins of some seagrass meadows because of unfavourable tide conditions. Seagrass distribution was mapped and species composition confirmed for these areas by low-level helicopter reconnaissance.

Patchy seagrass distribution and abundance on Elbow Bank appears to be a result of the exposure to northerly wind and wave action, and mobile sandy sediments dominate this area. Alligator Bank is more protected from wind and wave action, and sediments are muddier and less mobile than at Elbow Bank. Seagrass distribution here is more consistent and above-ground biomass is also higher.

Above-ground seagrass biomass at Alligator Bank in the wet-season (March) 1995 survey had increased since the dry-season survey. Factors which could contribute to natural seasonal change in biomass include temperature, salinity, tidal influence and exposure to air. Detailed information on these parameters is needed to help interpret the observed changes at Alligator bank.

In areas of high water turbidity, light availability is one of the primary factors controlling growth of seagrasses (Pollard and Greenway 1994). The high water turbidity in the Karumba area, and resulting low levels of light penetration, would most likely restrict the seaward seagrass distribution to the shallow intertidal areas. Seagrasses in turbid waters at Trinity Inlet, Cairns, received sufficient light for photosynthesis only at low tide (Pollard and Greenway 1994), and plants therefore grew mostly in the intertidal zone. Survival was best, however, in places where the water pooled during low tide and plants would not desiccate (Coles *et al*. 1993). On intertidal flats at Karumba, seagrasses at slightly higher elevations are also restricted to the shallow pools of water left during low tide. Seagrasses on Alligator Bank are likely to be sensitive to changes in hydrodynamics that would lead to an increase in water draining from the bank.

Halophila ovalis was much less abundant in the wet-season (March) 1995 survey than in the dry-season (October) survey. Abundance *of Halophila* species at other northern Queensland locations have been found to be seasonal and they are considered to be colonising species (Birch and Birch 1984).

Large numbers of dugong feeding trails (Plate 1) recorded during these surveys indicate that the Karumba seagrass meadows are important to dugongs. Karumba seagrasses are isolated from other seagrass areas in the Gulf (Coles *et al*. in prep), and may be the only reliable food source for dugongs in the region for 100 km to the west and 500 km to the north (Poiner *et al*. 1987). More dugong feeding trails were recorded during the survey undertaken in March 1995 than in the dry season (October) 1994 survey indicating the use of these meadows by dugong may be seasonal.

Halodule pinifolia and *Halodule uninervis* (thin-leaved) are difficult to differentiate in the field, and confusion between the two species is common. It is possible that *Halodule uninervis* (thin-leaved) was also present at Karumba although not recorded.

Temporal variation in seagrass distribution may account for some previous surveys failing to find seagrass at Karumba. Tropical seagrass abundance has been shown to be seasonal in other areas of similar latitude to Karumba (Mellors *et al.* 1993; McKenzie 1994) and Karumba seagrass abundance is also likely to vary seasonally. Seagrass distribution and abundance at Karumba may also vary significantly between years. Extended, “heavy” wet-seasons which lead to prolonged periods of low salinity may cause widespread seagrass loss. Other impacts which may cause year-to-year variation include: changes in topography, exposure and drainage patterns on the tidal flats, changes in water and sediment-nutrient concentrations and changes in sedimentation rates on the seagrass meadows.

Four narrow meadows from Elbow Bank and along the channel edges of the Norman River that were present in the dry-season (October) 1994 survey, were absent from the wet-season (March) 1995 survey (Figure 3). These areas are most vulnerable to erosive wave and current energy and therefore expected to be most ephemeral. Because of this and their small size, they are less suitable than the large Alligator Bank meadows for monitoring.

The present surveys provide a dry-season and a wet-season baseline, giving information on seagrass distribution and abundance to be used for the development of future monitoring programs. The differences in seagrass biomass and distribution between wet-season and dry-season surveys support the need to conduct both dry-season and wet-season monitoring events in Karumba. This monitoring program will help establish the level of seasonal and year to year variation in seagrass abundance at Karumba. Integrating this with other environmental and port use monitoring programs will help to identify the likely natural and anthropogenic factors which affect the health of the Karumba seagrass meadows, so that environmental management plans for the Port of Karumba can be adopted and improved.

4.2. Penaeid Prawns

Juvenile prawn numbers for Karumba were low compared with recently surveyed seagrass areas on the east coast (Coles *et al.* 1993; McKenzie *et al*., 1996). A QDPI survey of the Gulf of Carpentaria in November 1986 also found commercially important penaeid prawn abundances were low when compared with other seagrass areas of the Gulf (Coles *et al*. in prep).

The 1986 survey collected 14 prawn species, of which 4 were considered commercially important. Only one species collected in the October 1994 survey, *Penaeus esculentus* (brown tiger prawn) was collected in the 1986 survey. The trawl effort in 1986 was more intensive than the October 1994 survey and may account for the greater number of species collected. With low prawn abundances, significant differences in number of taxa collected between sampling events would be expected.

The Alligator Bank site appeared a more productive prawn nursery habitat than Elbow Bank site in the dry-season (October) 1994 survey. Seagrass biomass and abundance was higher at the Alligator site, and may have offered juvenile prawns greater shelter from predators (Zimmerman and Minello 1984; Loneragan *et al.* 1994) and more abundant food resources than the less vegetated Elbow Bank site.

The wet-season (March) 1995 survey, found that the seagrass habitat was similar at all three trawl sites on the Alligator Bank and there was little difference in both prawn abundances and species composition between trawl sites. Abundance of juvenile prawns was high compared with the dry-season survey and with recently surveyed seagrass areas on the east coast (Coles *et al*. 1993; McKenzie *et al.* 1996). Juveniles of an unidentified *Metapenaeus* species accounted for 96% of the prawns sampled, suggesting recruitment of this species to the seagrass meadows occurred around the survey period. The majority of the prawns collected in the wet-season (March) 1995 survey were too small to identify and thus pooled under *Metapenaeus* spp. Seagrass biomass was also higher for this survey and could offer juvenile prawns greater shelter from predators and a better food supply (Loneragan *et al*. 1994).

During the wet-season (March) 1995 survey, the banana prawn (*Penaeus merguiensis*) was the most common of the commercially important prawn species to be collected. Banana prawns are not normally associated with seagrass beds and were considered to be incidental in the sample. *P. merguiensis* presence on the meadows is probably associated with high rainfall and freshwater runoff immediately preceding the survey, causing prawns to be flushed out from their normal habitat in adjacent rivers and creeks (Staples & Vance 1986).

The low abundance of prawns indicate that impacts on a small area of the seagrass meadows are unlikely to have major effects on the local prawn population. Large scale loss of the Karumba seagrass meadows, however, could be detrimental, given the size of existing meadows and their isolation from other seagrass in the gulf.

Low abundances of commercially important prawns in the wet-season (March) 1995 survey and previous surveys of the area (Coles *et al*. in prep.) indicate that

Karumba seagrass meadows may only be of minor importance as a nursery ground for commercial prawn species. High numbers of small non-commercial prawns on the Alligator bank seagrass meadows may however support predatory fauna including commercially important finfish.

4.3. Fish

36.2% of the fish taxa collected in the dry-season (October) 1994 survey were of commercial or recreational importance, while only 4.0% were of importance in the wet-season (March) 1995 survey (Figure 6). A study of fishes of the Norman River estuary by CSIRO between April 1991 and February 1992 also found more than 20% of the 107 species identified were of commercial or recreational importance (Poiner *et al*. 1994). The low figure reported in the wet-season (March) 1995 study may represent seasonal variation in fish recruitment. High freshwater runoff from flooding rivers during the survey may also have led to a temporary reduction in abundance of some fish species.

The dry-season (October) 1994 survey found that fish diversity and numbers were higher for the Alligator Bank site than the less vegetated Elbow bank site. The high seagrass biomass and consistent cover on Alligator Bank may provide greater shelter and food resources for juvenile fish.

Beam trawling only captures a sub-set of the total fish community, and faster swimming large fish tend to escape capture. It is likely that Karumba seagrass meadows, with their juvenile prawn, fish and crustacea attract larger predatory fish. Several species of large predatory fish were recorded by the CSIRO study in the adjacent Norman River, including barramundi (*Lates calcarifer*), grunter (*Pomadasys kaakan*), mangrove jack (*Lutjanus argentimaculatus*) and spanish mackerel (*Scomberomorus semifasciatus*) (Poiner *et al*. 1994).

4.4. Other Crustacea

In both surveys, numbers of crustacea (excluding penaeidae) collected by beam trawls were low compared to studies in other tropical seagrass meadows (McKenzie *et al*. 1996). Low crustacean numbers may reflect the relatively low seagrass biomass for Karumba when compared to these other areas. Abundances in the wet-season (March) 1995 survey were also low compared with the dry-season survey, possibly a result of freshwater runoff in March.

4.5. Future Monitoring Strategy and Sampling Design

Seagrass meadows that are highly variable and likely to be ephemeral, such as the Elbow Bank meadows, are unsuitable for biomass monitoring. The Alligator Bank seagrass meadows are more protected and less variable than the Elbow Bank meadows and are therefore suitable for biomass monitoring.

The design of the monitoring program for Karumba ensures the finest possible changes in seagrass biomass at selected meadows can be detected, given the variability of those meadows. Utilising a design focused on meadows, that incorporates both sites and replicates within sites, enables a more efficient use of the time and resources available.

From these baseline studies involving both wet- and dry-season surveys, future monitoring will include two events per year, to obtain a quantitative measure of within-season variability as well as a semi-quantitative indication of between season variability.

Biomass results from the meadows selected for monitoring provide only part of the available information when assessing impacts on the Port of Karumba's seagrasses. Trends in biomass change observed over three consecutive surveys, even if not statistically significant, should raise a cautionary "flag" (ie., when three consecutive surveys (wet-/dry-/wet-season) biomasses are lower when compared to the previous survey of those seasons). Changes in seagrass species composition, depth distribution and areal extent of seagrass meadows can also be used to indicate impacts on the seagrasses. We would consider that a 50% change in the area of a meadow between successive surveys (of the same season) should raise concerns (Lee Long *et al.*1996). It should be emphasised that these indicators are not intended to conclusively show that seagrasses have changed beyond background variation but to raise "cautionary flags" leading to closer investigation. This information could be important to port managers as early warnings and subsequent action could prevent environmental damage.

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➭ APPENDIX 1 SAMPLING STRATEGY TABLES

Table 5. Mean, standard error, range of biomass and estimate of number of sites and quadrats per site, such that the percentage change in the mean will be detected at the 90% level with 90% assurance of detecting a true difference, for the Alligator Bank meadows, Karumba (dry-season, 1994).

Meadow ID	Biomass dry season 1994				Detectable % change	# sites	# quadrats
	mean ± SE	min	median	max			
1	6.151± 0.134	0	6.233	10.951	30	25	5
2	0.987±0.176	0	0.215	8.589	100	30	5

Table 6. Estimate of the number of quadrats per site such that, for various numbers of sites, a given percentage change in the mean will be detected at the 90% level (ie Type I error of 10%) with 90% assurance for detecting a true difference of this size (ie Type II error of 10%) for the Alligator Bank Meadow # 1 (dry-season 1994).

The mean, quadrat variance component, and site variance component for the dry season 1994 survey are 6.1561, 1.28928 and 4.5299 g dw m^2 respectively. NP = not possible to obtain a sampling procedure satisfying the given criteria.

Number of sites	df	t_0	t_1	# quads for 30% change	# quads for 50% change	# quads for 75% change	# quads for 100% change
10	27	1.703	1.314	NP	1.911	0.180	0.079
15	42	1.684	1.303	NP	0.375	0.096	0.047
20	57	1.671	1.296	NP	0.207	0.065	0.033
25	72	1.688	1.295	5.0	0.147	0.051	0.026
30	87	1.665	1.293	0.979	0.110	0.040	0.021
35	102	1.662	1.291	0.557	0.089	0.034	0.018
40	117	1.658	1.289	0.388	0.075	0.029	0.016
50	147	1.657	1.288	0.243	0.057	0.023	0.012

Table 7. Estimate of the number of quadrats per site such that, for various numbers of sites, a given percentage change in the mean will be detected at the 90% level (ie Type I error of 10%) with 90% assurance for detecting a true difference of this size (ie Type II error of 10%) for the Alligator Bank Meadow # 2 (dry-season, 1994).

The mean, quadrat variance component, and site variance component for the dry season 1994 survey are 0.9865, 2.26314 and 1.18277 g dw m^2 respectively. NP = not possible to obtain a sampling procedure satisfying the given criteria.

Number of sites	df	t_0	t_1	# quads for 30% change	# quads for 50% change	# quads for 75% change	# quads for 100% change
10	27	1.703	1.314	NP	NP	NP	NP
15	42	1.684	1.303	NP	NP	NP	NP
20	57	1.671	1.296	NP	NP	NP	NP
25	72	1.688	1.295	NP	NP	NP	12.28
30	87	1.665	1.293	NP	NP	NP	5.0
35	102	1.662	1.291	NP	NP	NP	2.94
40	117	1.658	1.289	NP	NP	NP	2.14
50	147	1.657	1.288	NP	NP	5.72	1.40

Table 8. Mean, standard error, range of biomass and estimate of number of sites and quadrats per site, such that the percentage change in the mean will be detected at the 90% level with 90% assurance of detecting a true difference, for the Alligator Bank meadows, Karumba (wet-season 1995).

Meadow ID	Biomass wet season 1995				Detectable % change	# sites	# quadrats
	mean ± SE	min	median	max			
1	9.24± 0.28	0	10.41	15.87	30	35	3
2	0.17± 0.09	0	0.04	1.69	50	15	3

Table 9. Estimate of the number of quadrats per site such that, for various numbers of sites, a given percentage change in the mean will be detected at the 90% level (ie Type I error of 10%) with 90% assurance for detecting a true difference of this size (ie Type II error of 10%) for the Alligator Bank Meadow # 1 (wet-season 1995).

The mean, quadrat variance component, and site variance component for the wet season 1995 survey are 9.24, 2.536 and 14.307 g dw m^2 respectively. NP = not possible to obtain a sampling procedure satisfying the given criteria.

Number of sites	df	t_0	t_1	# quads for 30% change	# quads for 50% change	# quads for 75% change	# quads for 100% change
10	27	1.703	1.314	NP	NP	0.210	0.078
15	42	1.684	1.303	NP	0.698	0.097	0.044
20	57	1.671	1.296	NP	0.255	0.063	0.031
25	72	1.688	1.295	NP	0.158	0.047	0.024
30	87	1.665	1.293	NP	0.114	0.037	0.019
35	102	1.662	1.291	2.324	0.089	0.031	0.016
40	117	1.658	1.289	0.754	0.073	0.026	0.014
50	147	1.657	1.288	0.325	0.054	0.020	0.011

Table 10. Estimate of the number of quadrats per site such that, for various numbers of sites, a given percentage change in the mean will be detected at the 90% level (ie Type I error of 10%) with 90% assurance for detecting a true difference of this size (ie Type II error of 10%) for the Alligator Bank Meadow # 2 (wet-season 1995).

The mean, quadrat variance component, and site variance component for the wet season 1995 survey are 0.17, 0.1565 and 0.0315 g dw m^2 respectively. NP = not possible to obtain a sampling procedure satisfying the given criteria.

Number of sites	df	t_0	t_1	# quads for 30% change	# quads for 50% change	# quads for 75% change	# quads for 100% change
10	27	1.703	1.314	NP	4.378	NP	NP
15	42	1.684	1.303	NP	2.191	NP	NP
20	57	1.671	1.296	NP	1.454	NP	121.38
25	72	1.688	1.295	NP	1.095	NP	16.289
30	87	1.665	1.293	NP	0.877	NP	8.692
35	102	1.662	1.291	NP	0.730	144.43	5.915
40	117	1.658	1.289	NP	0.625	26.543	4.470
50	147	1.657	1.288	NP	0.487	10.216	3.023

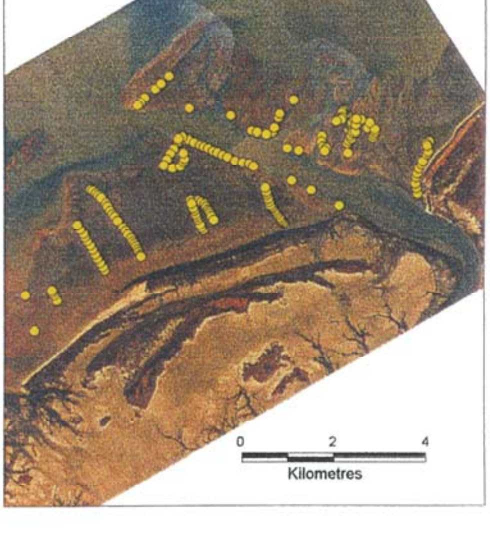
⇘ APPENDIX 2 - SEAGRASSES

Plates 2 - 3

The following plant specimens are typical of seagrass species collected from sites in the Port of Karumba

Plate 2. *Halophila ovalis*

Halophila ovalis



Source: M.A. Rasheed, W.J. Lee Long, L.J. McKenzie, C.A. Roder, A.J. Roelofs, and R.G. Coles (1996) *"Port of Karumba Seagrass Monitoring Baseline Surveys - Dry-season (October) 1994 and Wet-season (March) 1995".* Ports Corporation Ecoports Monograph Series No. 4 (PCQ, Brisbane).

Survey Date: 10-13 October 1994 & 14-16 March 1995

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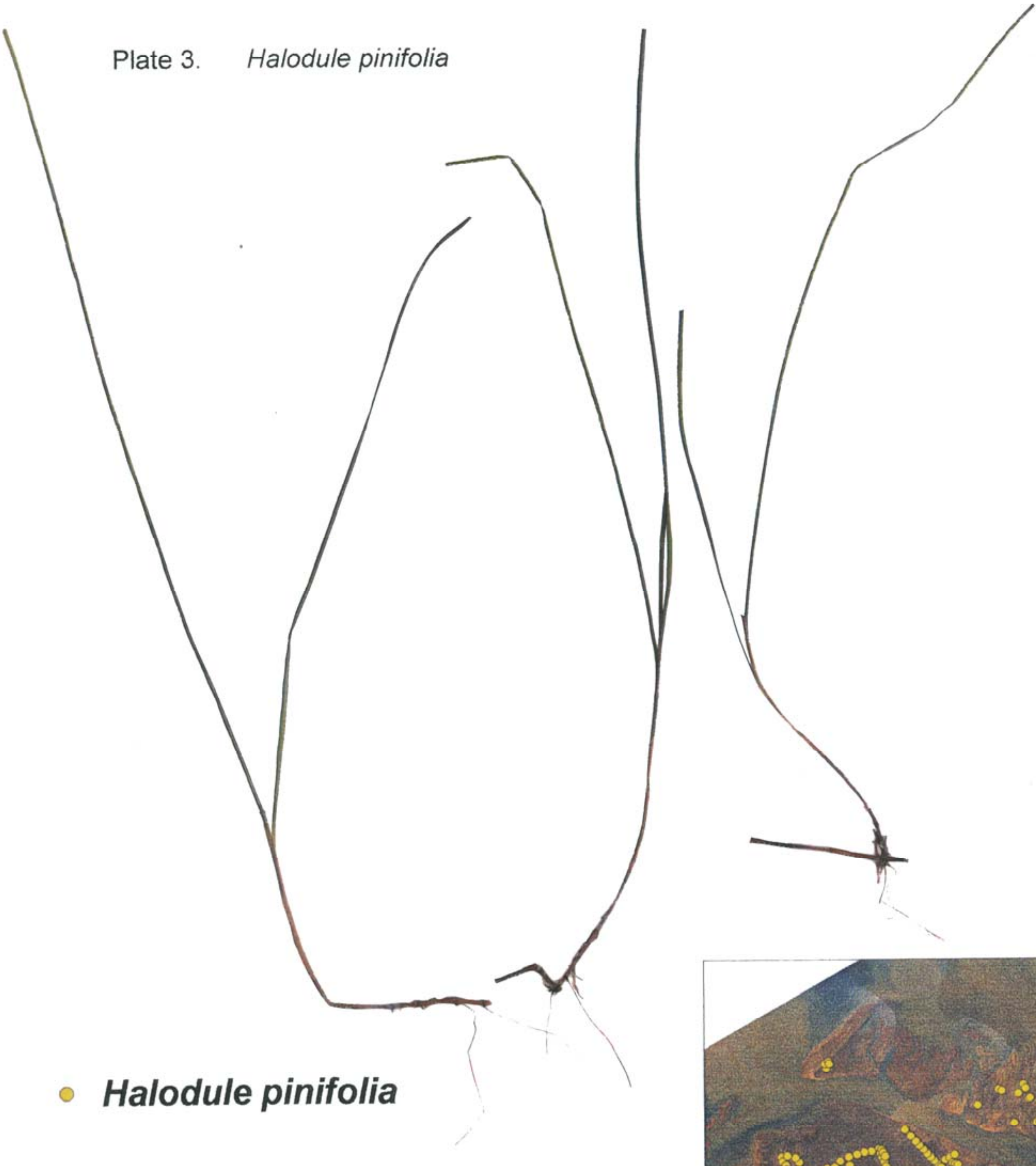
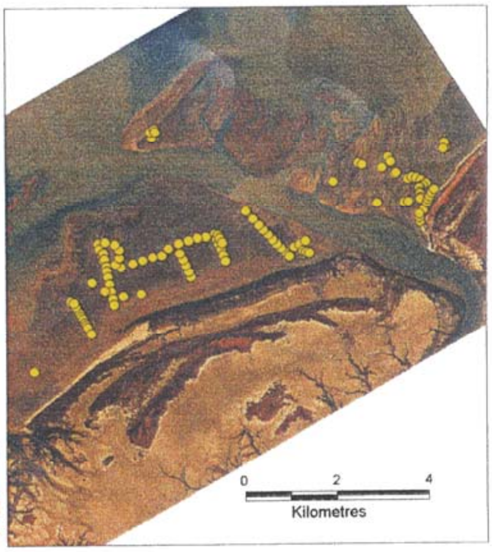
Plate 3. *Halodule pinifolia*



● ***Halodule pinifolia***



Source: M.A. Rasheed, W.J. Lee Long, L.J. McKenzie, C.A. Roder, A.J. Roelofs, and R.G. Coles (1996) *"Port of Karumba Seagrass Monitoring Baseline Surveys - Dry-season (October) 1994 and Wet-season (March) 1995".* Ports Corporation Ecoports Monograph Series No. 4 (PCQ, Brisbane).

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