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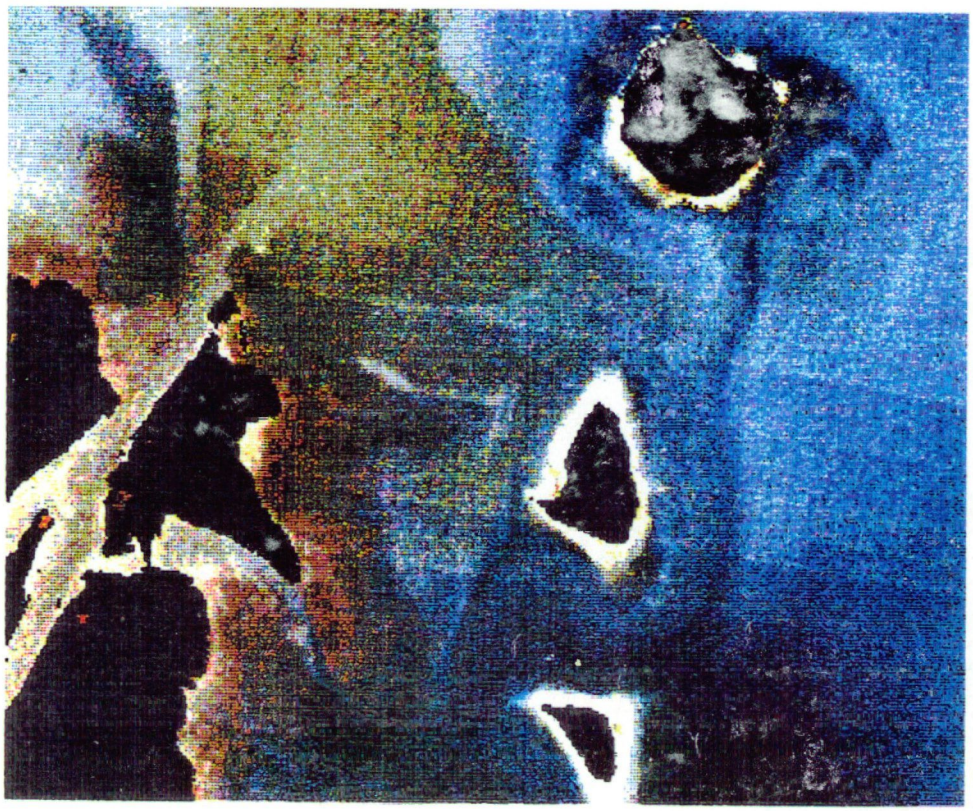
CSIRO Marine Laboratories Report

Seagrass Beds and Mangrove Forests of Fisherman Islands, Moreton Bay, Queensland

Final Report to the Port of Brisbane Authority



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EXECUTIVE SUMMARY

- Mangrove forests and seagrass beds were mapped at Fisherman Islands, Moreton Bay. There was 2.35 km^2 of mangroves in the study area. Five mangrove classes were identified: a dense high-canopy-height class (0.385 km^2); a dense mid-canopy-height class (1.248 km^2); a seedling/mangrove fringe (0.227 km^2) and a small area (0.029 km^2) comprised of a mixture of mangroves and intertidal mudflat along the seaward edge of the mangroves.

- The seagrass beds in the study area were identified from photo-interpretation of digitised aerial photographs. There was 11.90 km^2 of seagrass supporting habitat in the study area. Seven strata were identified: dense seagrass (8.078 km^2); worm digging area (0.454 km^2); patchy seagrass (1.737 km^2); very patchy seagrass (1.256 km^2); St. Helena Island seagrass bed (0.149 km^2); Oyster Point seagrass bed (0.638 km^2) and a channel strata which included all areas where the bottom structure was not discernible from the aerial photograph (26.00 km^2).

- Four seagrass species were sampled in the study area, *Zostera capricorni, Halophila ovalis, Halophila spinulosa* and *Halodule uninervis*. The dominant seagrass, in terms of biomass, was *Z. capricorni*.

- The total seagrass biomass in the study area was estimated at 4,460 t, with 17% precision where precision is the closeness of repeated measurements of the same quantity. The dense seagrass strata had high seagrass biomass (196 $g.m^{-2}$; 16% precision). The worm digging and patchy seagrass areas had moderate seagrass biomass (123 $g.m^{-2}$; 30% precision and 128 $g.m^{-2}$; 40%). The very patchy seagrass strata had low seagrass biomass (46 $g.m^{-2}$; 49% precision). The biomass at St. Helena Island was as high as the dense seagrass strata on Fisherman Islands (158 $g.m^{-2}$; 48% precision). Seagrass biomass was highest at Oyster Point (370 $g.m^{-2}$; 74% precision). The lowest biomass was found in the channel strata (31 $g.m^{-2}$; 57% precision). The relatively high overall

precision (17%) was due to the high precision (16%) of the biomass estimate for the dense seagrass strata, which comprised one third of the study area.

- Stratification substantially improved the precision (from 31% to 17%) of the estimate of total seagrass biomass compared to simple random sampling .

- The precision of the estimate of total seagrass biomass was similar, regardless of stratification technique (digitised aerial photographs, Landsat satellite mapping and depth).

- The cost of digitising existing aerial photographs and digitising depth data from nautical charts was much lower compared to the costs of obtaining and processing Landsat-TM satellite data.

- Acceptable seagrass biomass estimates can be obtained for sample processing and field sampling costs of around $14,000 (1992 dollars) for 20% precision and $20,000 for 15% precision. The cost for precisions better than 15% increases dramatically to $28,000 for 10% and $56,000 for 5%.

- The use of networked image processing, Computer Aided Drawing (CAD) , and Geographic Information System (GIS) software substantially improved productivity and accuracy in the study. It also provided a permanent, geo-coded digital database which forms the basis for future mangrove and seagrass monitoring at Fisherman Islands.

INTRODUCTION

Geographic information systems (GIS) provide managers with a tool for storing, manipulating and displaying spatial data to assist in the rational management of environmental resources. Knowing where the resources are, and in what quantities, is a prerequisite to informed and objective management.

Fisherman Islands form part of the Port of Brisbane and are managed by the Port of Brisbane Authority (PBA). The environmental resources of Fisherman Islands include mangroves and seagrass beds, both of which have been shown to be important nurseries and habitat for prawns and fish. Monitoring these resources is expensive, and it is important to compare techniques to establish the most cost-effective procedure.

The aim of the study was to compare, contrast and assess the relative merits and disadvantages of three techniques — scanned aerial photography, digitised aerial photography and Landsat-TM imagery. Comparisons were made on cost, complexity of the mapping exercise and precisions of seagrass biomass estimates obtained from stratification using the three mapping techniques. GIS software (SPANS) was used in conjunction with image processing (micro BRIAN) and CAD software (Auto CAD) to increase the productivity and accuracy, and to provide a permanent, geo-coded digital database of the mapping results.

A further objective of the project was to provide cost and precision estimates for an annual seagrass biomass monitoring program for the Fisherman Islands area.

Eleven tasks were identified to fulfil the project specifications:

- digitising the study area in Auto CAD for input into the SPANS GIS system;
- mapping the mangroves using image processing of Landsat TM satellite data;
- stratifying the study area by photo-interpretation of digitised aerial photographs;

- undertaking a pilot study to determine seagrass-biomass estimates from photo-interpretation of the digitised aerial photograph. Sample sizes for the pilot study were obtained from seagrass variance estimates from previous work by CSIRO at Victoria Point;
- stratifying the study area based on a classified Landsat TM satellite image;
- stratifying the study area using scanned aerial photographs;
- stratifying the study area by depth;
- field sampling to quantify seagrass biomass, shoot density and leaf area (allocation of samples to strata using seagrass biomass variance estimates obtained from the pilot-study);
- analysis of the relative merits and disadvantages of digitised aerial photographs, Landsat satellite mapping and scanned aerial photographs. The four techniques were compared on the basis of cost and complexity of implementing as well as the precision of the estimate of seagrass biomass;
- transfer of the GIS database to the PBA GIS.

METHODS

Landsat satellite image

A Landsat TM image of the area was obtained for 7 September, 1991. The passover time was 09:30, which corresponded to a 1.8 m tide.

Aerial photograph

Aerial photographs of the study area were taken at low tide (14:30) on 7 September, 1991 (the same day as the Landsat TM image) at 3,000 m using a Hasselblad camera with a polarising filter.

Geographic Information System

A digital map of the Fisherman Islands provided in DXF format by the Port of Brisbane Authority was input into CSIRO's SPANS GIS system. However, the map did not cover the entire study area, so the area south of Oyster Point and north to Serpentine Creek was digitised from 1:25,000 nautical and topographic charts of the area (Chart — Lower Brisbane River and Approaches 1:25,000, Qld Dept Transport, 1986; Chart — Wellington Point to the Blue Hole, 1:25,000, 1985,

Department of Harbours and Marine, Qld; Wynnum Topographic Map 1:25,000, 1984; Bishop Island Topographic Map, 1:25,000, 1971). Green Island, St. Helena Island and Mud Island were also digitised and incorporated into the map of the study area (Chart — Lower Brisbane River and Approaches 1:25,000, Qld Dept Transport, 1986; Chart — Wellington Point to the Blue Hole, 1:25,000, 1985, Department of Harbours and Marine, Qld; Wynnum; Moreton Bay Southport-Caloundra, 1:100,00, Qld Dept Transport, 1990) (Fig. 1). Depth data from nautical charts of the study area were also digitised with Auto CAD software, input into SPANS and contoured (Fig. 2). The contouring algorithm was based on interpolation of a triangulated-irregular-network.

The study area was stratified by photo-interpretation of a digitised, colour aerial photograph provided by the Port of Brisbane Authority (Fig. 3). Seven strata were identified; six seagrass strata and a subtidal channel area. The subtidal channel area was defined as all areas in the aerial photograph where bottom structure was not discernible in the photograph. The six seagrass strata were classified as intertidal high-density seagrass beds on the mudflats off Fisherman Islands, worming areas within the high-density seagrass beds, patchy seagrass areas, very patchy seagrass areas, patchy seagrass near Oyster Point, and high-density intertidal seagrass along the west side of St. Helena Island.

The aerial extent of the study area, the channel strata and the seven seagrass strata were calculated in SPANS. The total area was 41.0 km^2 of which 25.9 km^2 was subtidal channel. The most extensive seagrass strata was the intertidal high density seagrass areas on the mudflats off Fisherman Islands (8.1 km^2) which covered most of the 14.5 km^2 of intertidal mudflats. The patchy seagrass and very patchy seagrass strata were similar in size (1.737 and 1.256 km^2 respectively). The worm digging area (0.454 km^2) was about the same size as the patchy seagrass area near Oyster Point (0.638 km^2). The smallest strata was the high-density seagrass bed along the western side of St. Helena Island (0.149 km^2). Intertidal areas (14.5 km^2) covered about 30% of the study area.

MANGROVES

The mangroves were mapped from the Landsat TM image using unsupervised classification of a ratio of band 4 (near infrared) to band 3 (green), band 4 and band 3 (Fig. 4). The image was rectified and re-sampled from the original 30 x 30 m pixel size to 25 x 25 m pixels.

SEAGRASS

Study area stratified by Landsat TM satellite data

The study area was mapped into 20 classes using unsupervised classification of bands 1, 2 and 3 (blue, green and red light) (Fig. 5). The 20 classes were reduced to nine by examining a dendrogram based on euclidean distances between average spectral values for the 20 classes. The image was rectified and re-sampled from the original 30 x 30 m pixel size to 25 x 25 m pixels. The spatial pattern of Landsat classes closely paralleled depth contours, and areas deeper than 3.5 m were removed from the Landsat map in SPANS because seagrass was known to not occur deeper than 3.5 m. The area was categorised into areas that potentially could support seagrass and mangroves (Fig. 5).

Study area stratification using scanned aerial photograph

The aerial photograph of the study area was scanned in simple image format (SIF) and imported into micro BRIAN (Fig. 6). The spatial resolution of the scanned aerial photograph was in the order of 1-2 m. However, the aerial photo-montage of the study area could not be used for mapping purposes because sun flare across frames made the montage useless for scanning. Variations in brightness and colour within many photographs were non-linear and could not be corrected for (Fig. 6). To overcome this problem, the photo-montage was digitised and input into SPANS.

Field sample design-pilot study

A pilot study was undertaken to obtain seagrass biomass and density variance estimates for the strata obtained by photo-

interpretation of the digitised aerial photograph to optimise sample design (Appendix 1). An area 60 x 60 m was chosen to be the primary sample unit because the 30 m accuracy of the GPS position fixing equipment indicated that the probability of correctly locating a 60 x 60 m sample unit in the field was greater than 95%. A complete listing of all potential sample units for each strata was generated using SPANS. Seventy-eight sample sites were randomly selected from this list. Sample sites were allocated to the six seagrass strata and the channel strata in proportion to their aerial extent and estimated above-ground seagrass biomass variance estimates (Fig. 7). Above-ground seagrass biomass variance was estimated from ongoing CSIRO studies of the seagrass of Victoria Point Twenty-seven samples were allocated to the dense seagrass, 8 to the worm digging area, 8 to the patchy seagrass, 8 to the very sparse seagrass, 8 to the St. Helena seagrass, 6 to the Oyster Pt. seagrass and 5 samples to the channel strata.

Pilot study field work

Sites were located in the field using a JRC-GPS receiver. At each site, a sample of the bottom was taken using a 0.085 m^2 hand-operated seagrass grab. The sample was washed in the field using a lug-basket (10 mm holes) to remove the sediment from the seagrass rhizomes. Seagrass samples were transferred to plastic bags and stored on ice. All seagrass samples were returned to CSIRO Marine laboratories, Cleveland for processing.

Sample processing

Seagrasses were separated into species taxa. *Zostera capricorni*, *Halophila ovalis*, *Halophila spinulosa* and *Halodule uninervis*. For each species, the above-ground shoots and stems were separated from the below-ground rhizomes. The number of shoots/species in each sample were counted and for each species, the lengths and widths of ten randomly-selected shoots were measured. The above and below-ground components were dried at 60°C for 8 hours and weighed to the nearest 0.1 g. The leaf area was calculated for each species by multiplying the number of shoots in a sample by the average leaf area per shoot.

Pilot study results– optimal allocation of samples to strata

Variance estimates from the pilot study indicated that, for a sample size of 314, with Neymann allocation of samples to strata, a precision of around 15% would be obtained for seagrass biomass (Appendix 2). Because of the small sample size used in the pilot study, and hence, unreliable variance estimates, an additional 84 samples were allocated to the strata. Furthermore, at ten sites, 10 samples were taken to give a total sample size of 492. The study area was sampled again, using the same methods as the pilot-study.

RESULTS

Mangroves

There were 2.35 km^2 of mangroves in the study area. Five mangrove classes were identified; a dense/high-canopy class (0.385 km^2); a dense/mid-canopy class (1.248 km^2); a dense/low-canopy area (0.462 km^2); a seedling/mangrove fringe class (0.227 km^2) and a thin strip of mixels (mixed pixels) along the seaward edge of the mangrove forest due to mixed mangrove and mud-flat pixel reflectance values (0.029 km^2). Mangroves classes were ground-truthed by Mark Pillsworth, Ecologist with the Port of Brisbane Authority.

Seagrass species distribution and shoot density

Four seagrass species, *Zostera capricorni, Halophila ovalis , H. spinulosa* and *Halodule uninervis were* recorded in the study area (Fig. 8 a to d). The seagrass was dense on the intertidal banks but density and cover declined rapidly with increasing water depth. *Zostera capricorni* and *Halophila ovalis* were the dominant species (Fig. 12).

Z. capricorni showed a fairly uniform distribution throughout the intertidal regions adjacent the mainland, Fisherman Islands and on the mud-flats off St Helena Island. Highest values for Z. *capricorni* occurred off Oyster Point where densities of up to 136,100 shoots m^{-2} were recorded (Table 1).

Halophila ovalis also occurred extensively throughout the study area and values as high as 2,000 shoots m^{-2} were

recorded. In contrast, *H. spinulosa* showed a very clumped distribution, with most of this seagrass restricted to an area 2,000 m off the mangroves on Fisherman Islands. Densities of 75,500 shoots m^{-2} were recorded. There was a large degree of overlap between *H. spinulosa* and *Halodule uninervis* distribution. Moreover, neither seagrass was sampled closer than 800 m to the shore. *H. uninervis* shoot densities were the lowest of all the seagrasses with a maximum density of 4,100 shoots m^{-2}.

Seagrass morphometrics

The average number of leaves per shoot was 2.09 for *Halodule uninervis* and 2.64 for *Zostera capricorni*. The average shoot length was 68 and 135 mm for *H. uninervis* and *Z. capricorni* respectively. The averages for *H. spinulosa* were 54 mm for the shoot length and 25 mm for the shoot width. The average leaf length and width for *H. ovalis* was 17 and 8 mm respectively. The standard errors of all estimates were less than 0.01.

Seagrass above and below-ground biomass

The patterns of distribution of the above and below-ground biomass for all seagrasses were similar to the distribution patterns for shoot density (Fig. 9 a to d and 10 a to d). Above-ground biomass was highest for *Z. capricorni* with a maximum 2.5 $kg.m^{-2}$ recorded on the intertidal mud flats off Oyster Point and off Fisherman Islands. The maximum below-ground biomass was similar to the above-ground biomass (2.8 $kg.m^{-2}$). There was no significant difference between the above and below-ground biomass ($P>0.01$). The next largest biomasses recorded were for *H. spinulosa* at 0.2 $kg.m^{-2}$. There was no significant difference between above and below-ground biomass for this seagrass either ($P>0.01$). The maximum above-ground biomass for *H. uninervis* and *H. ovalis* was similar at 0.03 and 0.048 $kg.m^{-2}$ respectively. However, the ratio of above to below-ground biomass differed for these two species. The below-ground biomass for *H. uninervis* was significantly greater than the above-ground biomass ($P<0.01$),

whereas there was no significant difference for *H. ovalis* ($P>0.01$).

The estimate of total biomass in the study area was highest for *Zostera capricorni* with an estimated 1,876 t of above-ground and 2,212 t below-ground material (Table 2). The estimated above and below-ground biomass of *H. ovalis* was 125 t and 127 t. For *H. uninervis*, it was 14.7 t and 27.7 t, and 50 and 29 t for *H. spinulosa* (Table 2).

Seagrass leaf area

The leaf area for the four seagrasses followed the same distribution patterns as biomass and shoot density (Fig. 11 a-d). The highest leaf areas were recorded for *Z. capricorni* with 0.24 m^{-2} leaf m^{-2} (Table 1). The next largest was *H. ovalis* at 0.15 m^{-2} leaf m^{-2}. *Halophila spinulosa* (0.064 m^{-2} leaf m^{-2}) and *H. uninervis* (0.03 m^{-2} leaf m^{-2}) had relatively low leaf areas compared to the other two species.

Area covered by seagrass

The area covered by seagrass can be calculated from the results of random point sampling. It will overestimate seagrass cover since areas were sampled not points, but the bias is minimal because the grab area was small (0.085 m^{-2}) relative to the study area size. Seagrass cover for each species and all strata was calculated as the proportion of sites in a strata where seagrass was sampled (Table 3). *Zostera capricorni* seagrass cover ranged from less than 1% in the channel strata to 82% in the St. Helena strata. *Halophila ovalis* cover ranged from less than 1% in the channel strata to 64% in the worm digging area. *H. spinulosa* cover was 23% in the dense seagrass strata and was largely absent from the remaining strata. *Halodule uninervis* was absent from all strata except the dense seagrass strata (8%), the worm digging area (7%) and channel (<1%).

Stratification

There were large gains in precision for most species when the study area was stratified based on depth, digitised aerial photographs or Landsat satellite mapping, compared to precisions expected if a simple random sample was used (Table 4). Precisions ranged from 15% for *Zostera capricorni* below-ground biomass stratified by depth or Landsat mapping, to 65%

for *Halophila ovalis* shoot density from a random sample. With the exception of the random sample, which was always less precise than stratified estimates, the precisions varied depending on species and stratification method. Therefore, the best stratification method depended on the target species. For *Zostera capricorni*, the dominant seagrass in the study area, the highest precisions for above-ground biomass were obtained when stratification was based on digitised aerial photographs or Landsat satellite mapping. For below-ground biomass, the most precise estimates were obtained using either Landsat satellite data or depth and, for shoot density, the most reliable estimates were obtained when stratified by depth.

DISCUSSION

The aims of the study were to map and classify the seagrass and mangrove communities of the Fisherman Islands area using satellite imagery and aerial photography, and to compare and contrast the results. Three techniques (Landsat, digitised aerial photograph, and scanned aerial photograph) were compared for mapping and stratifying the study area.

There were 2.35 km^2 of mangroves in the study area. Five mangrove classes were identified: a dense high-canopy-height class (0.385 km^2); a dense mid-canopy-height class (1.248 km^2); a seedling/mangrove fringe (0.227 km^2) and a small area (0.029 km^2) comprised of a mixture of mangroves and intertidal mudflat along the seaward edge of the mangroves.

There were 11.90 km^2 of seagrass supporting habitat in the study area. Four seagrass species were sampled in the study area, *Zostera capricorni*, *Halophila ovalis*, *H. spinulosa* and *Halodule uninervis*. The dominant seagrass, in terms of biomass, was *Z. capricorni*. The total seagrass biomass in the study area was estimated at 4,461.4 t, with 17% precision.

Stratification was an appropriate method for estimating seagrass biomass. It substantially improved the precision (from 31% to 17%) of the estimate of total seagrass biomass compared to simple random sampling However, the precisions were relatively unaffected by stratification method

because of the significant correlation between seagrass biomass and depth. All three stratification methods resulted in strata which mirrored depth contours (Table 3).

The cost of digitising an aerial photograph was less than purchasing, image processing and rectifying Landsat satellite data, principally because of the small study area size. The cost of taking and scanning aerial photographs, for input into an image processing software system, was about the same as Landsat mapping.

It was not possible to stratify the study area using the scanned aerial photograph because sun flare across frames made the montage impossible to scan. However, image processing of a scanned colour aerial photograph could be an effective way of monitoring in small-scale studies because of the high resolution and colour contrast between features in the image. If the objective of the study included targeting small (>1 m) spatial objects, a scanned aerial photo is ideal because the image may be blocked up until the pixel reflectance variance reaches a maximum which corresponds to one half to three quarters the object size. This spatial resolution gives maximum discrimination between objects. For example, if the purpose of the study was to monitor changes in seagrass cover, due to the activities of worm diggers in the study area, then the optimal pixel size would be around 5 m. A possible monitoring strategy for such a study would be to compare variance estimates of a sequence of blocked scanned images as an indirect method of measuring changes due to worm digging. Image processing of scanned aerial photography provides one technique for such a study. Digitising the photo at this resolution would not be cost-effective and would suffer from digitising inaccuracies.

The precision of the estimate of total seagrass biomass was similar, regardless of stratification technique (digitised aerial photographs, Landsat satellite mapping and depth). However, the cost of digitising existing aerial photographs and digitising depth data from nautical charts was much lower compared to the costs of obtaining and processing Landsat-TM satellite data.

The use of networked image processing, Computer Aided Drawing (CAD) , and GIS software substantially improved productivity and accuracy in the study. It also provided a permanent, geo-coded digital database which forms the basis for future mangrove and seagrass monitoring at Fisherman Islands.

Acceptable seagrass biomass estimates can be obtained for sample processing and field sampling costs of around $14,000 (1992 dollars) for 20% precision and $20,000 for 15% precision. The cost for precisions better than 15% increases dramatically to $28,000 for 10% and $56,000 for 5%. The optimal sample strategy for monitoring seagrass on Fisherman Islands intertidal area, based on these results, is to stratify the area based on depth (0 to 3.5 m at 0.5 m intervals - 7 strata) and use field sampling to estimate seagrass biomass. An acceptable 15% precision can be obtained for around $20,000. This sample design would permit reliable (80%) detection of changes in mean seagrass biomass of 15-18% with 95% confidence.

APPENDIX 1
Equations used for variance estimates

Terms

N_h total number of sampling units in stratum h

n_h number of samples in stratum h

y_{hi} value obtained from ith unit

$W_h = \frac{N_h}{N}$ stratum weight

$f_h = \frac{n_h}{N_h}$ sampling fraction in the stratum

$\bar{y}h = \frac{\sum_{i=1}^{n_h} yhi}{nh}$ stratum mean

$\bar{y}st = \sum_{h=1}^{L} Wh\ \bar{y}h$ stratified mean

sh2 = sample estimate of stratum variance

$$v\left(\bar{y}_{st}\right) = \sum_{h=1}^{L}\left(\frac{W^2{}_h s^2{}_h}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W^2{}_h s^2{}_h}{N}\right) =$$

estimated strata variance

Estimation of sample size for fixed variance $v(\bar{y}st)$

where $n_o = \frac{N}{v\left(\bar{y}_{st}\right)} \sum_{h=1}^{L} Nhsh2$

and $n = \frac{n_o}{\left(1+\frac{n_o}{N}\right)}$

To compare the variance of a stratified sample with a random sample the following equation was used

$v_{ran} = \frac{N-n}{n(N-1)}\left(\frac{(n-1)}{n} s^2 + v\left(\bar{y}_{st}\right)\right)$ = estimated variance of the mean of a simple random sample from the same population where s^2 = estimated sample variation , N = total number of sampling units, n = number of samples.

APPENDIX 2
Pilot-Study Strata Variance estimates

Seagrass Above-Ground Biomass ($g.m^{-2}$)

Stratum	nh	$\bar{y}h$	sh2	W h	Nh	Area (km2)
1. Dense seagrass	27	50.34	1,265	0.656	2,244	8.078
2. Worming Areas	8	30.27	695	0.037	126	0.045
3. Patchy seagrass	8	68.46	14,055	0.141	483	1.737
4. Very patchy seagrass	8	4.72	178	0.101	349	1.256
5. St. Helena seagrass	8	59.33	1,741	0.012	41	0.149
6. Oyster Pt. seagrass	6	15.99	590	0.052	177	0.638
7. Channel	5	0	0	0.680	7,226	26.000

Stratified mean $\bar{y}st = 45.41\ g.m^{-2}$
Standard error = 17.4
Precision = 39% of the mean

Neymann allocation of samples to strata

Neymann allocation was used to minimise variance for fixed sample size of 314 to give expected precision of 14% of the mean. The actual number of samples taken was 388.

Strata	Neymann n_h	Actual n_h
1. Dense seagrass	164	182
2. Worming Area	7	14
3. Patchy seagrass	117	106
4. Very patchy seagrass	9	18
5. St. Helena seagrass	4	11
6. Oyster Point seagrass	4	11
7. Channel	0	46

TABLE 1

Mean and variances of above-ground biomass, below-ground biomass and shoot density of *Z. capricorni*, *H. ovalis*, *H. uninervis* and *H. spinulosa* for the seven strata (see Appendix 2) calculated using stratification by: (a) Digitised aerial photographs, (b) Landsat-TM satellite map, and (c) Depth.

Table 1 (a) — Digitised aerial photographs

Z. capricorni

Strata	*Above ground biomass* $\bar{y}_h$	*Above ground biomass* s^2_h	*Below ground biomass* $\bar{y}_h$	*Below ground biomass* s^2_h	*Shoot density* $\bar{y}_h$	*Shoot density* s^2_h
1	86.49	73,439	91.00	39,311	2,104	122,002,508
2	53.02	5,079	55.34	3,444	1,911	5,969,359
3	58.70	42,589	61.85	80,385	1,487	95,341,269
4	20.47	2,093	24.48	2,719	442	793,267
5	57.67	1,674	99.71	27,213	5,652	70,071,630
6	118.82	93,695	245.09	355,529	13,761	1,350,025,848
7	7.91	793	13.86	2,571	261	653,317

H. ovalis

Strata	*Above ground biomass* $\bar{y}_h$	*Above ground biomass* s^2_h	*Below ground biomass* $\bar{y}_h$	*Below ground biomass* s^2_h	*Shoot density* $\bar{y}_h$	*Shoot density* s^2_h
1	5.817	394.864	5.405	244.34	1114.7	23,391,277
2	4.926	65.556	7.358	180.46	1384.9	8,616,548
3	3.557	206.421	3.551	74.48	2620.8	125,233,221
4	0.281	0.739	0.237	.56	9.3	80,786
5	0.219	0.274	0.118	0.05	0.9	36,565
6	3.201	19.544	3.076	21.90	1623.9	8,491,847
7	0.916	2.894	1.225	25.40	60.5	317,689

H. uninervis

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	0.77	16.29	1.60	70.22	58.82	128,640.4
2	0.63	5.56	1.22	20.78	57.87	48,442.9
3	0.00	0.00	0.00	0.00	0.00	0.0
4	0.00	0.00	0.00	0.00	0.00	0.0
5	0.00	0.00	0.00	0.00	0.00	0.0
6	0.00	0.00	0.00	0.00	0.00	0.0
7	0.10	0.49	0.14	0.91	12.48	7,174.2

H. spinulosa

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	3.33	78.73	1.68	19.03	115.9	103499.7
2	0.00	0.00	0.00	0.00	0.0	0.0
3	0.00	0.00	0.00	0.00	0.0	0.0
4	0.00	0.00	0.00	0.00	0.0	0.0
5	0.00	0.00	0.00	0.00	0.0	0.0
6	0.00	0.00	0.00	0.00	0.0	0.0
7	0.35	2.10	0.33	1.59	20.8	6596.6

Table 1 (b) — Landsat Satellite Map

Z. capricorni

Strata	Above ground biomass $\bar{y}_h$	Above ground biomass s^2_h	Below ground biomass $\bar{y}_h$	Below ground biomass s^2_h	Shoot density $\bar{y}_h$	Shoot density s^2_h
1	10.5	833.0	14.3	1,558	260	563,239
2	80.7	77,228.5	83.9	67,943	2,583	194,096,437
3	2.3	24.9	8.4	523	147	132,671
4	30.9	9,800.1	87.5	113,395	2,639	123,204,345
5	101.1	5,339.7	121.0	12,427	2,128	77,875,422
6	23.0	1,111.8	32.4	3,045	660	906,188
7	13.5	917.5	44.2	11,214	1,020	9,711,436

H. ovalis

Strata	Above ground biomass $\bar{y}_h$	Above ground biomass s^2_h	Below ground biomass $\bar{y}_h$	Below ground biomass s^2_h	Shoot density $\bar{y}_h$	Shoot density s^2_h
1	0.83	8.42	1.12	17.36	143.7	215,922
2	5.13	310.95	4.89	205.82	1,455.8	37,269,867
3	10.20	125.06	10.99	144.85	1,245.7	1,505,080
4	0.35	2.40	0.33	1.72	76.6	62,838
5	2.55	89.25	3.52	168.59	1,979.0	77,525,643
6	0.41	1.35	0.40	1.08	160.3	158,553
7	4.75	553.25	3.54	299.43	2,887.6	202,933,271

H. uninervis

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	0.29	1.43	0.40	2.63	35.90	20,625.8
2	0.57	12.34	1.19	53.21	3.52	97,202.9
3	0.11	0.10	0.37	1.12	21.42	3,672.7
4	0.00	0.00	0.00	0.00	0.00	0.0
5	0.20	1.81	0.39	6.76	19.19	15,770.4
6	0.00	0.00	0.00	0.00	0.00	0.0
7	0.00	0.00	0.00	0.00	0.00	0.0

H. spinulosa

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	0.00	0.00	0.00	0.00	0.00	0.0
2	2.41	59.57	1.20	14.04	82.86	74993.6
3	4.06	63.75	1.99	13.53	214.16	189096.9
4	0.00	0.00	0.00	0.00	0.00	0.0
5	0.01	0.00	0.00	0.00	0.54	12.8
6	0.00	0.00	0.00	0.00	0.00	0.0
7	0.00	0.00	0.00	0.00	0.00	0.0

Table 1 (c) — Stratified by depth

Z. capricorni

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	82.99	47073.8	107.1	110999	4057	372807120
2	79.85	64667.2	95.4	29624	1241	7541423
3	86.24	90425.3	83.3	57258	1913	29204805
4	6.37	697.2	13.5	3636	1568	85504257
5	2.25	41.1	8.0	650	148	199939
6	0.00	0.0	0.0	0	0	0
7	7.32	592.5	10.0	1108	181	399057

H. ovalis

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	2.46	139.72	2.35	95.8	1,493	55,265,785
2	6.19	620.59	5.21	366.0	425	43,716,802
3	4.44	70.15	5.54	122.8	1,571	58,448,659
4	6.86	114.02	6.81	138.6	1,820	50,396,349
5	1.22	7.61	2.20	26.2	122	74,021
6	0.00	0.00	0.00	0.0	0	0
7	0.58	5.89	0.79	12.0	103	151,370

H. uninervis

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	0.067	0.59	0.12	2.2	6.2	5137
2	0.559	13.33	1.09	58.2	51.5	165755
3	1.165	22.23	2.52	94.3	74.8	79727
4	0.000	0.00	0.00	0.0	0.0	0
5	0.000	0.00	0.00	0.0	0.0	0
6	0.000	0.00	0.00	0.0	0.0	0
7	0.208	0.99	0.28	1.8	24.9	14348

H. spinulosa

Strata	*Above ground biomass* $\bar{y}_h$	s^2_h	*Below ground biomass* $\bar{y}_h$	s^2_h	*Shoot density* $\bar{y}_h$	s^2_h
1	0.004	0.00	0.00	0.00	0.17	4.1
2	1.481	36.54	0.59	6.41	60.76	67322.8
3	4.094	99.77	2.06	23.48	122.24	95105.8
4	4.119	91.60	2.33	25.98	154.56	133160.7
5	1.383	7.36	1.80	15.25	75.88	19578.5
6	0.000	0.00	0.00	0.00	0.00	0.0
7	0.000	0.00	0.00	0.00	0.00	0.0

TABLE 2. Stratified mean estimates $\bar{y}_{st}$, variance of the mean $v(\bar{y}_{st})$, upper (U95) and lower (L95) 95% confidence limits and estimated tonnes of seagrass in the study area and their 95% confidence limits for the study area stratified by A - digitised aerial photograph, L - Landsat satellite map and D - depth.

Z. capricorni

Above-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	29.69	26.61	39.80	19.58	1136	1522	749
L	48.92	70.44	65.37	32.47	1876	2507	1245
D	34.19	42.27	46.94	21.45	1298	1782	814

Below-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	37.50	41.04	50.05	24.94	1434	1914	954
L	57.68	79.60	75.16	40.19	2212	2883	1541
D	40.33	36.48	52.17	28.49	1531	1980	1081

Shoot density

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95
A	965	54893	1424	506
L	1599	179438	2429	769
D	1071	57811	1542	599

H. ovalis

Above-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	2.13	0.2217	3.05	1.21	82	117	46
L	3.26	0.3523	4.42	2.10	125	170	81
D	2.70	0.1843	3.54	1.86	103	135	71

Below-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	2.28	0.31	3.38	1.18	87	129	45
L	3.31	0.34	4.46	2.17	127	171	83
D	2.89	0.22	3.82	1.96	110	145	75

Shoot density

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95
A	509	10545	710	308
L	942	41182	1341	545
D	790	40679	1186	395

H. uninervis

Above-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	0.241	0.009	0.42	0.06	9.2	16.2	2.2
L	0.384	0.022	0.67	0.10	14.7	25.7	3.7
D	0.323	0.015	0.57	0.09	12.4	21.6	3.3

Below-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	0.45	0.025	0.76	0.14	17.2	29.0	5.3
L	0.72	0.065	1.22	0.22	27.7	46.8	8.6
D	0.63	0.048	1.06	0.20	23.8	40.1	7.5

Shoot density

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95
A	21.6	101.08	41.3	1.91
L	34.4	243.62	65.0	3.82
D	27.8	143.61	51.28	4.31

H. spinulosa

Above-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	0.94	0.039	1.33	0.56	36.0	50.7	21.2
L	1.24	0.057	1.71	0.77	47.4	65.4	29.4
D	1.32	0.062	1.81	0.83	50.2	68.8	31.6

Below-ground biomass

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95	tonnes	U95	L95
A	0.58	0.020	0.86	0.30	22.1	32.7	11.5
L	0.62	0.013	0.84	0.39	23.6	32.3	15.0
D	0.77	0.023	1.06	0.47	29.1	40.4	17.8

Shoot density

Strata	$\bar{y}_{st}$	$v(\bar{y}_{st})$	U95	L95
A	38.6	89.2	57.1	20.1
L	45.0	87.8	63.3	26.6
D	47.7	82.8	65.5	29.9

TABLE 3. Seagrass cover for each seagrass species in the seven strata identified from photo-interpretation of digitised aerial photographs. Cover for each species was calculated as the proportion of sites in a strata from which it was sampled.

Strata	*Z. capricorni*	*H. ovalis*	*H. spinulosa*	*H. uninervis*
1 Dense seagrass	60	51	23	8
2 Worming area	71	64	0	7
3 Patchy seagrass	37	34	0	0
4 Very patchy seagrass	28	11	0	0
5 St. Helena seagrass	82	36	0	0
6 Oyster Pt. seagrass	63	56	0	0
7 Channel	<1	<1	<1	<1

TABLE 4. Comparison of the precision of the estimates (standard error of the strata mean divided by the stratified mean expressed as a percent) for above and below-ground biomass, and shoot density stratified by aerial photography (Aerial), Landsat satellite data (Landsat), depth and a random design (Random) for the four species of seagrasses sampled in the study area.

Above-ground biomass

	Aerial	Landsat	Depth	Random
Zostera capricorni	17	17	19	37
Halophila ovalis	22	18	16	28
Halodule uninervis	39	39	38	55
Halophila spinulosa	21	19	19	30

Below-ground biomass

	Aerial	Landsat	Depth	Random
Zostera capricorni	17	15	15	31
Halophila ovalis	24	18	16	28
Halodule uninervis	35	35	35	64
Halophila spinulosa	24	18	20	26

Shoot density

	Aerial	Landsat	Depth	Random
Zostera capricorni	24	27	22	60
Halophila ovalis	20	22	26	65
Halodule uninervis	47	45	43	57
Halophila spinulosa	25	21	19	28

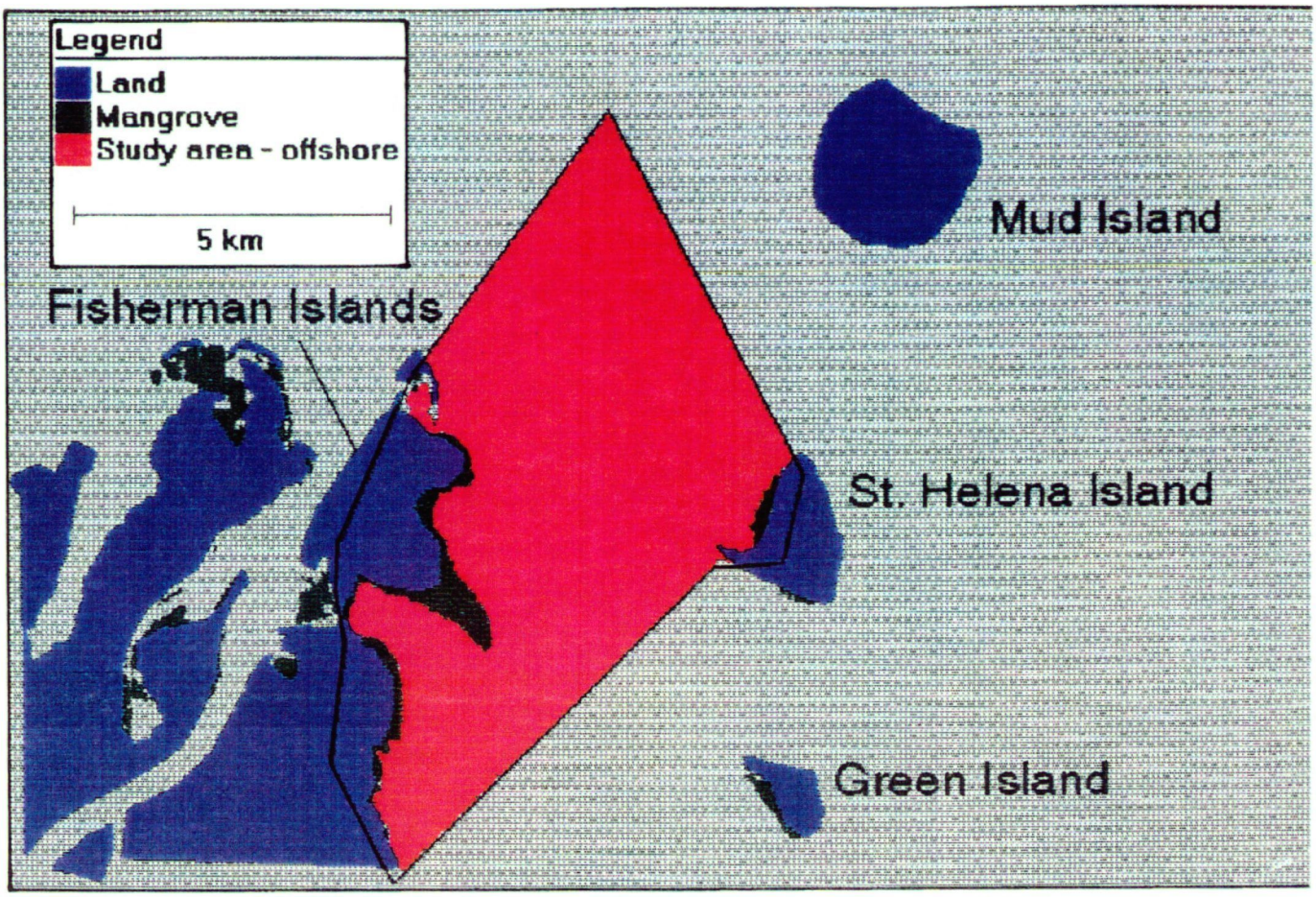

Figure 1. Fisherman Islands study area

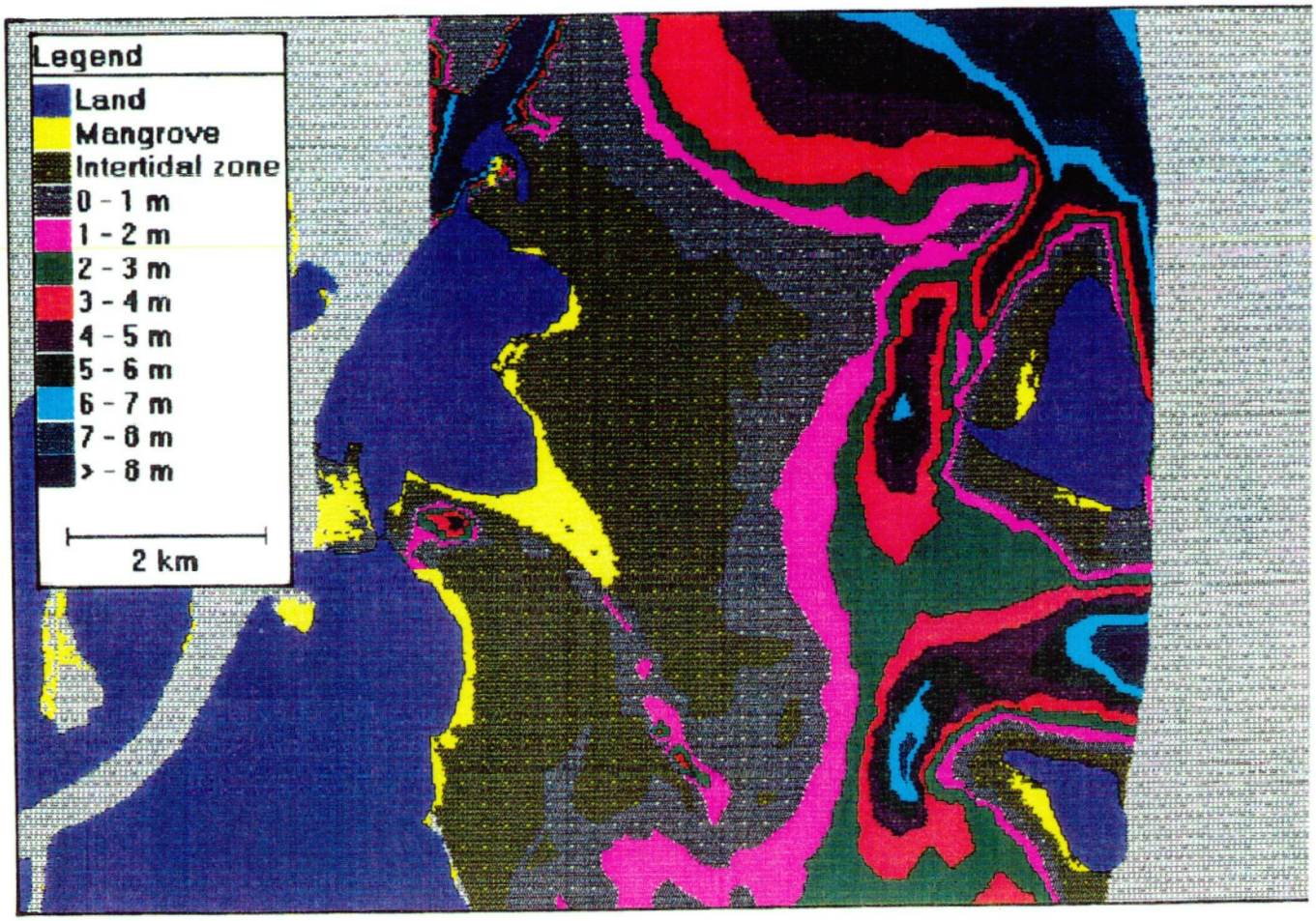

Figure 2. Depth contour plot of study area

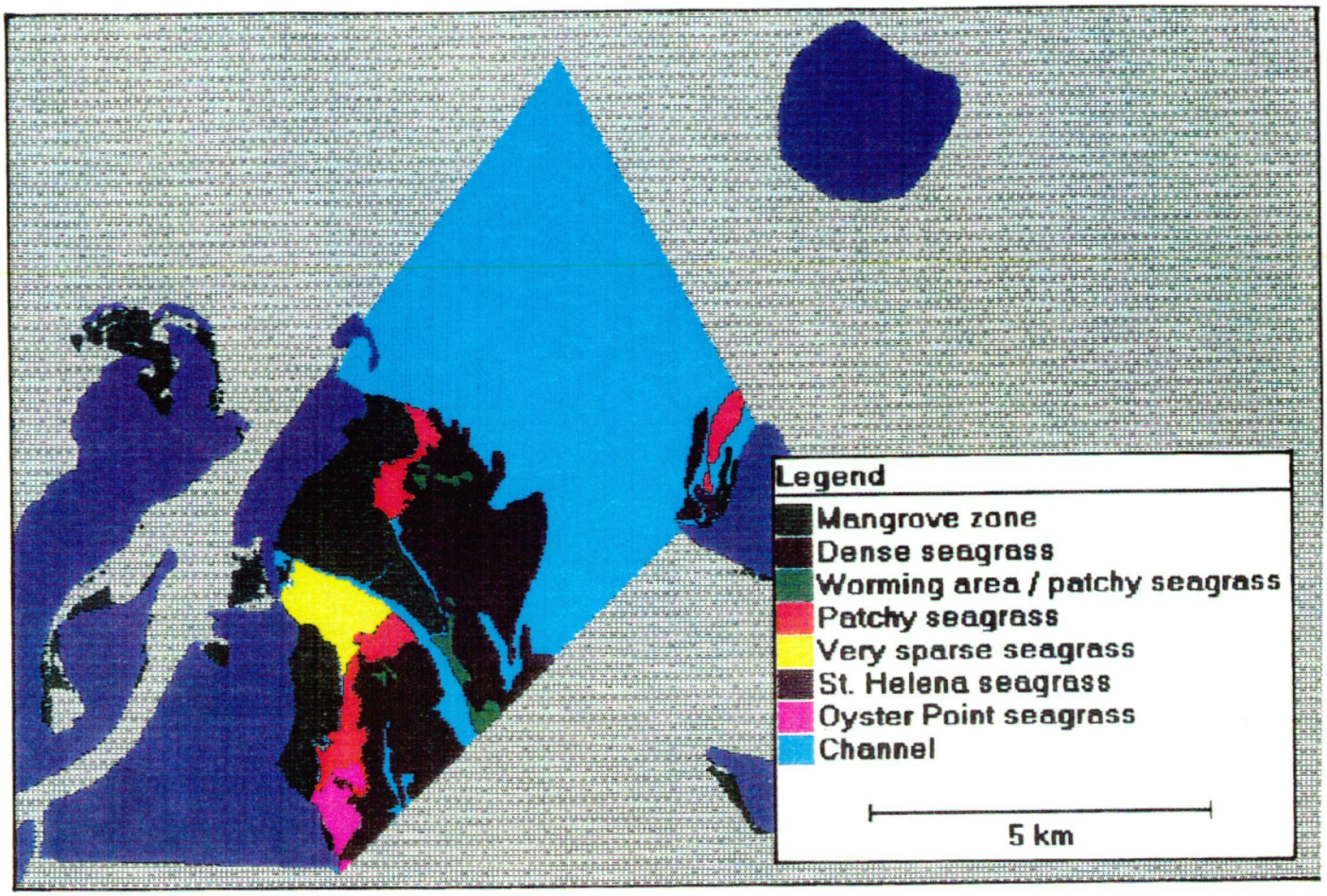

Figure 3. Study area strata from interpretation of digitised air photo

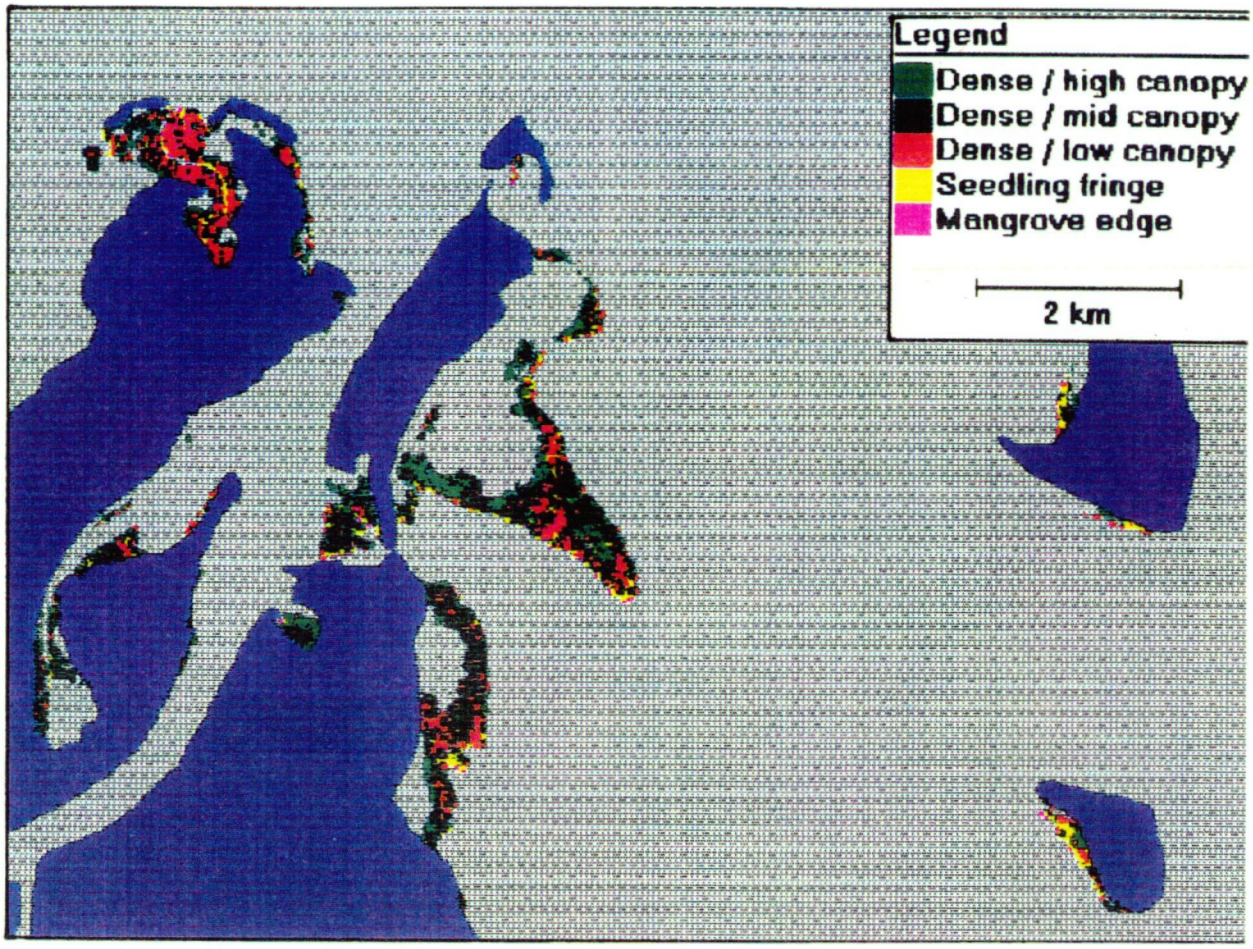

Figure 4. Mangroves of Fisherman Islands

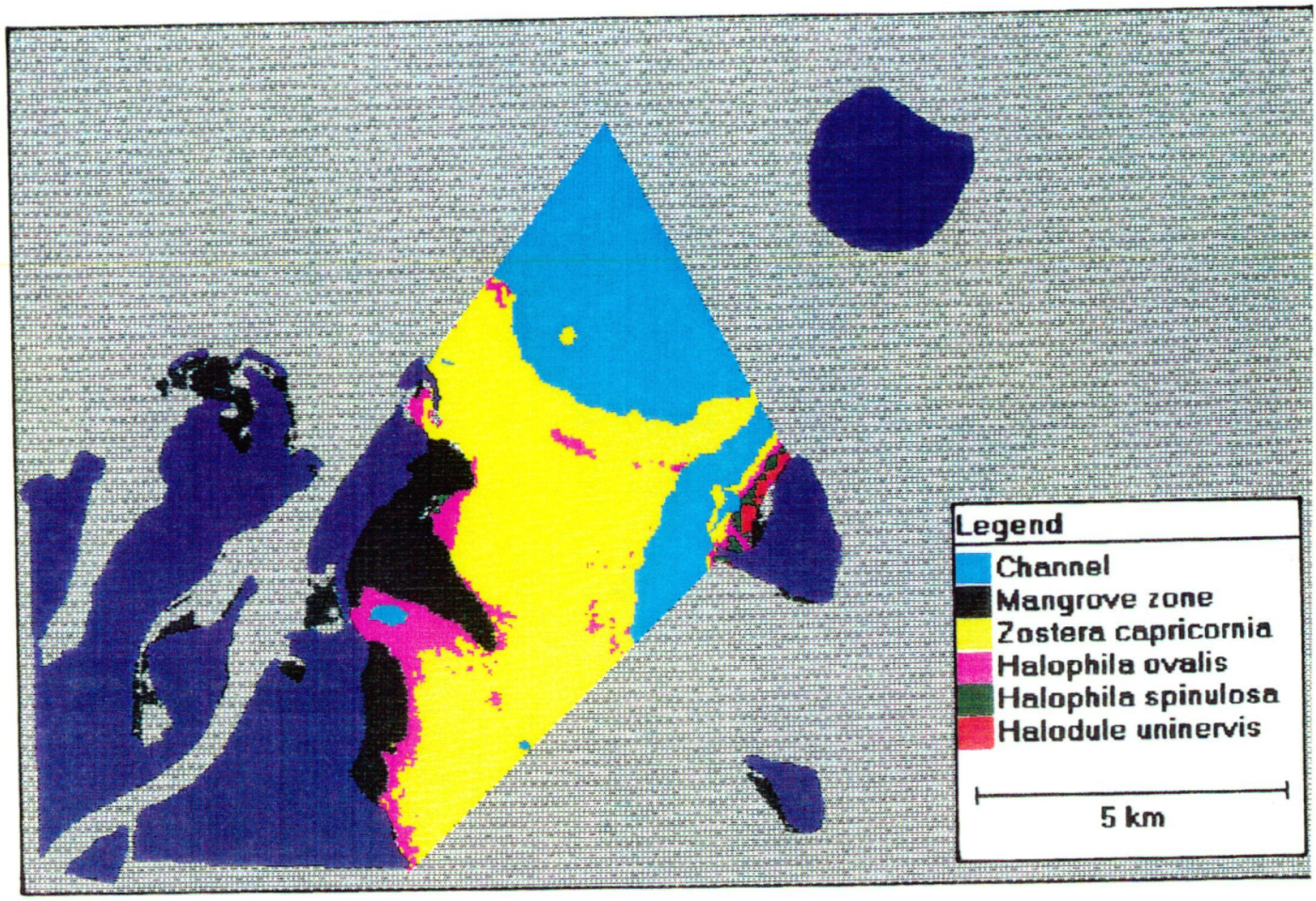

Figure 5. Landsat TM map of the study area, classified using blue, green, and red light showing mangrove zone and potential seagrass habitat. (Note – this is not a map of the actual seagrass areas).

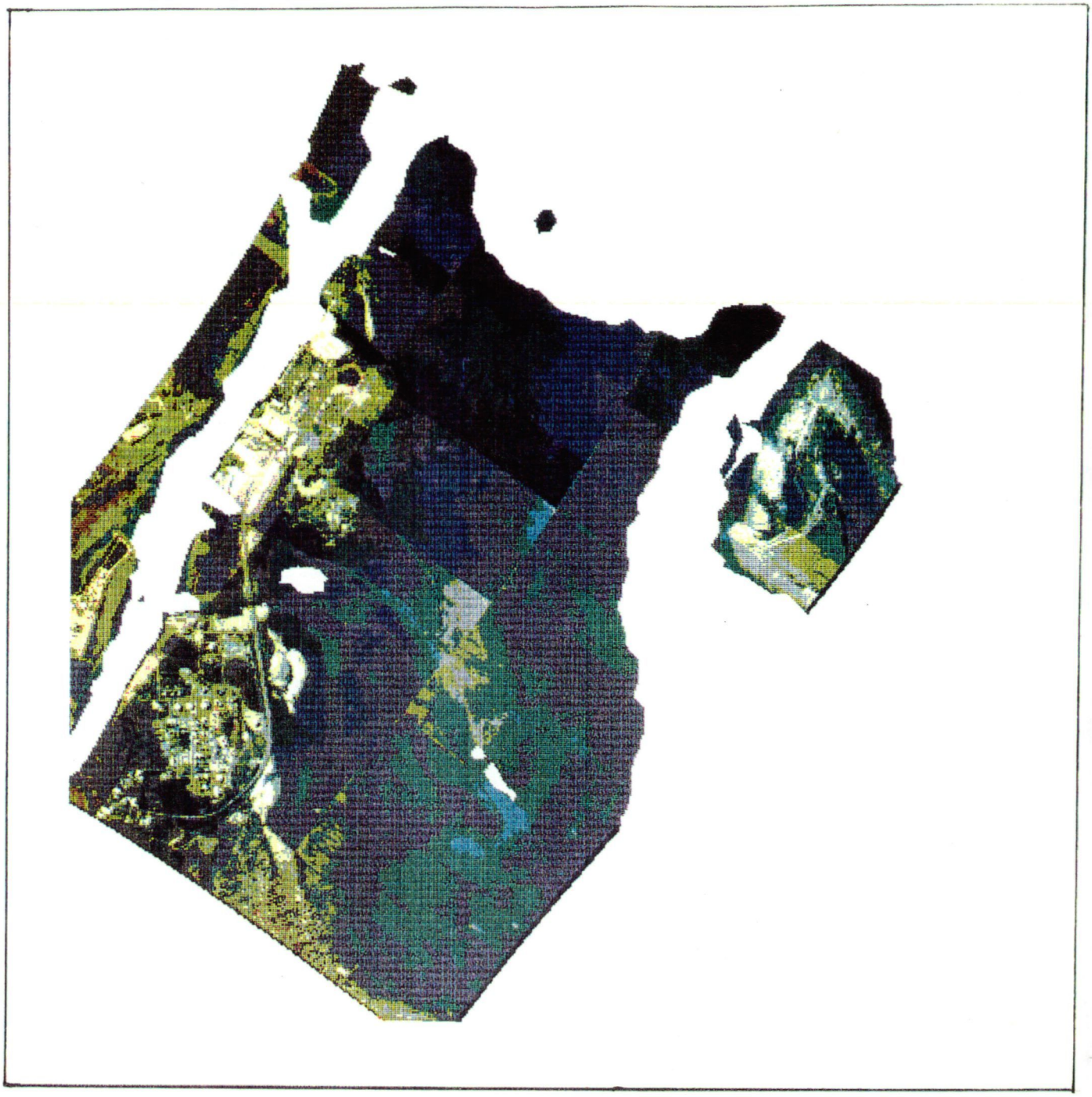

Figure 6. Scanned aerial photograph

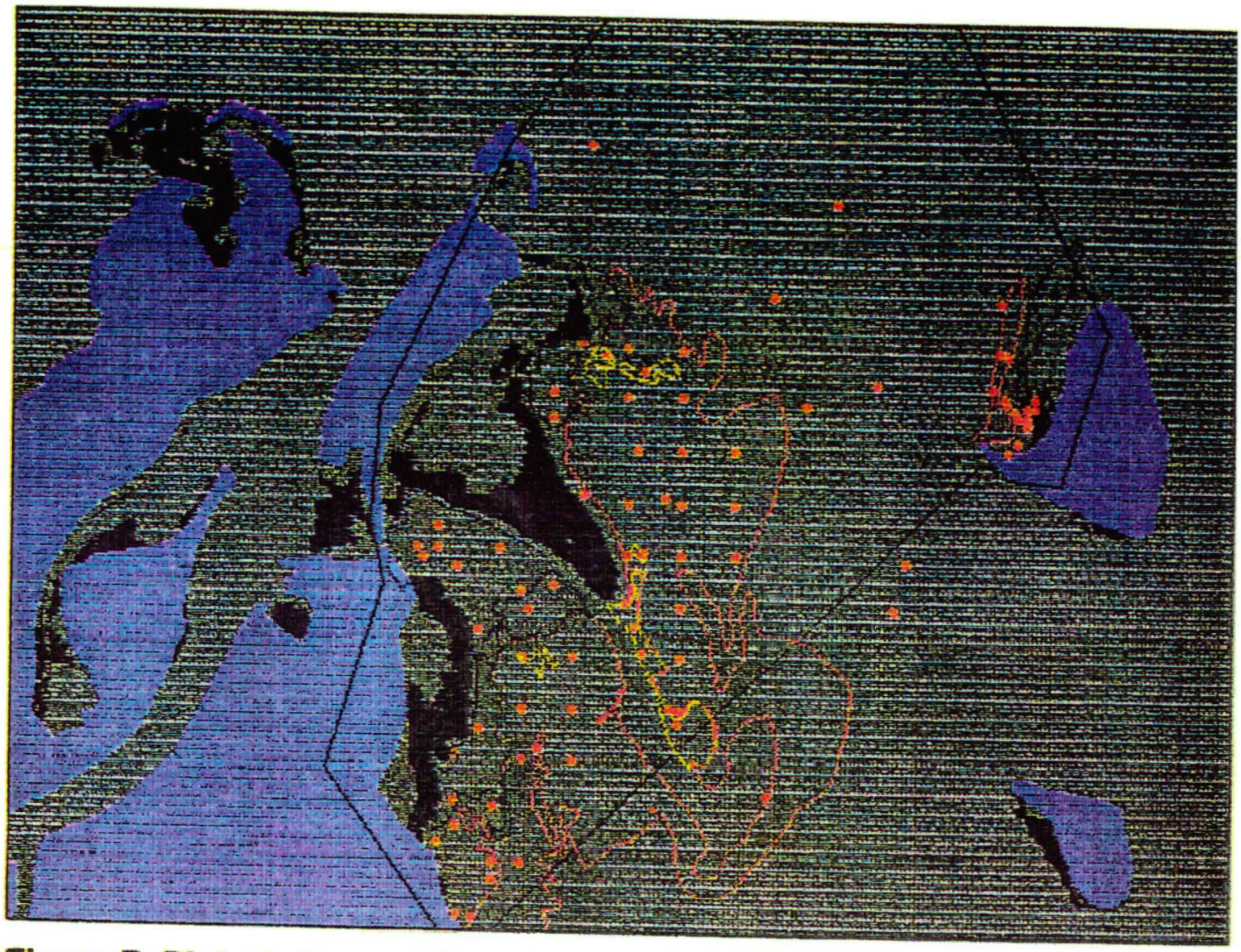

Figure 7. Plot of site positions for the pilot study

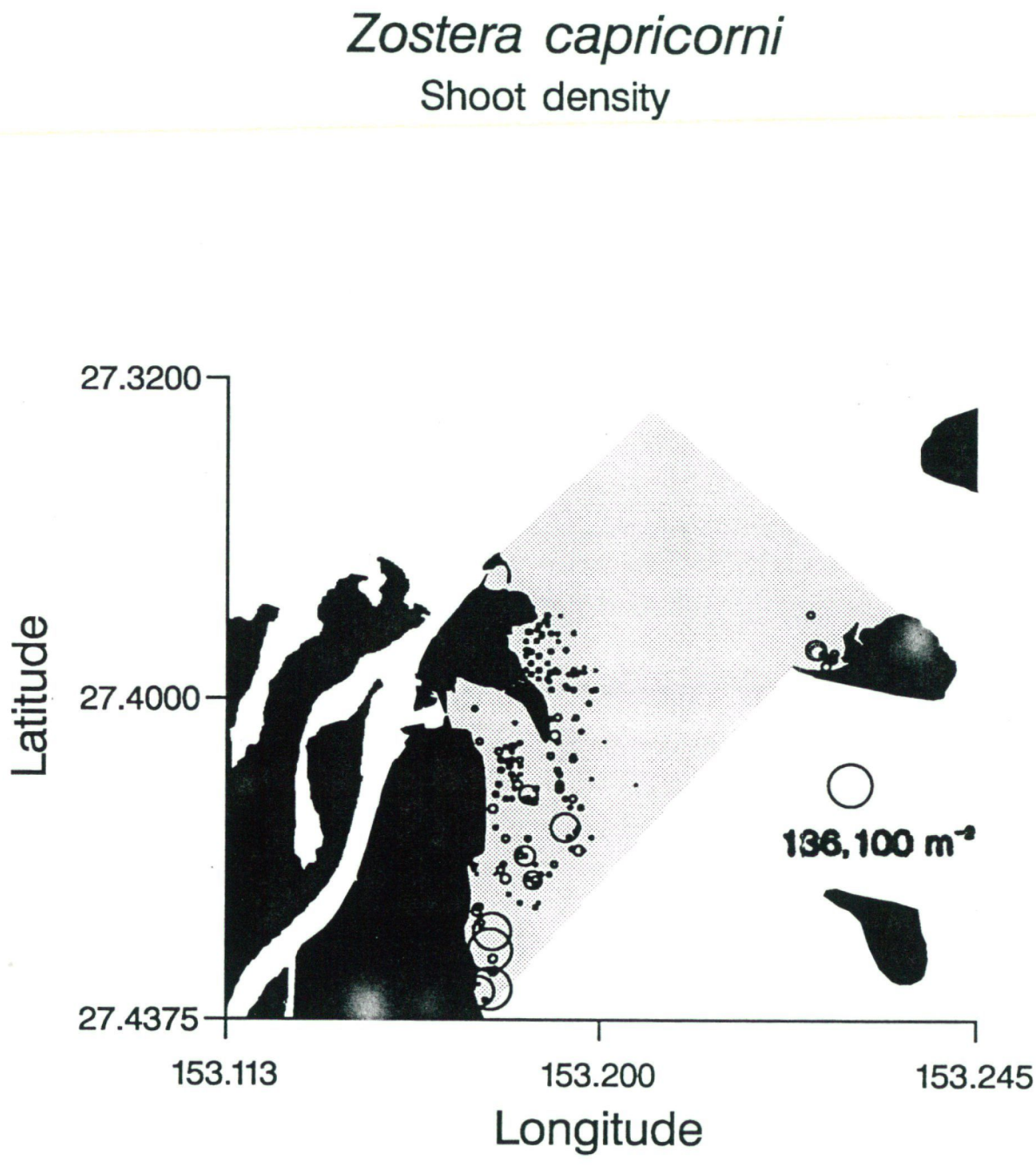

Figure 8a. Shoot density (m^2) for *Zostera capricorni*

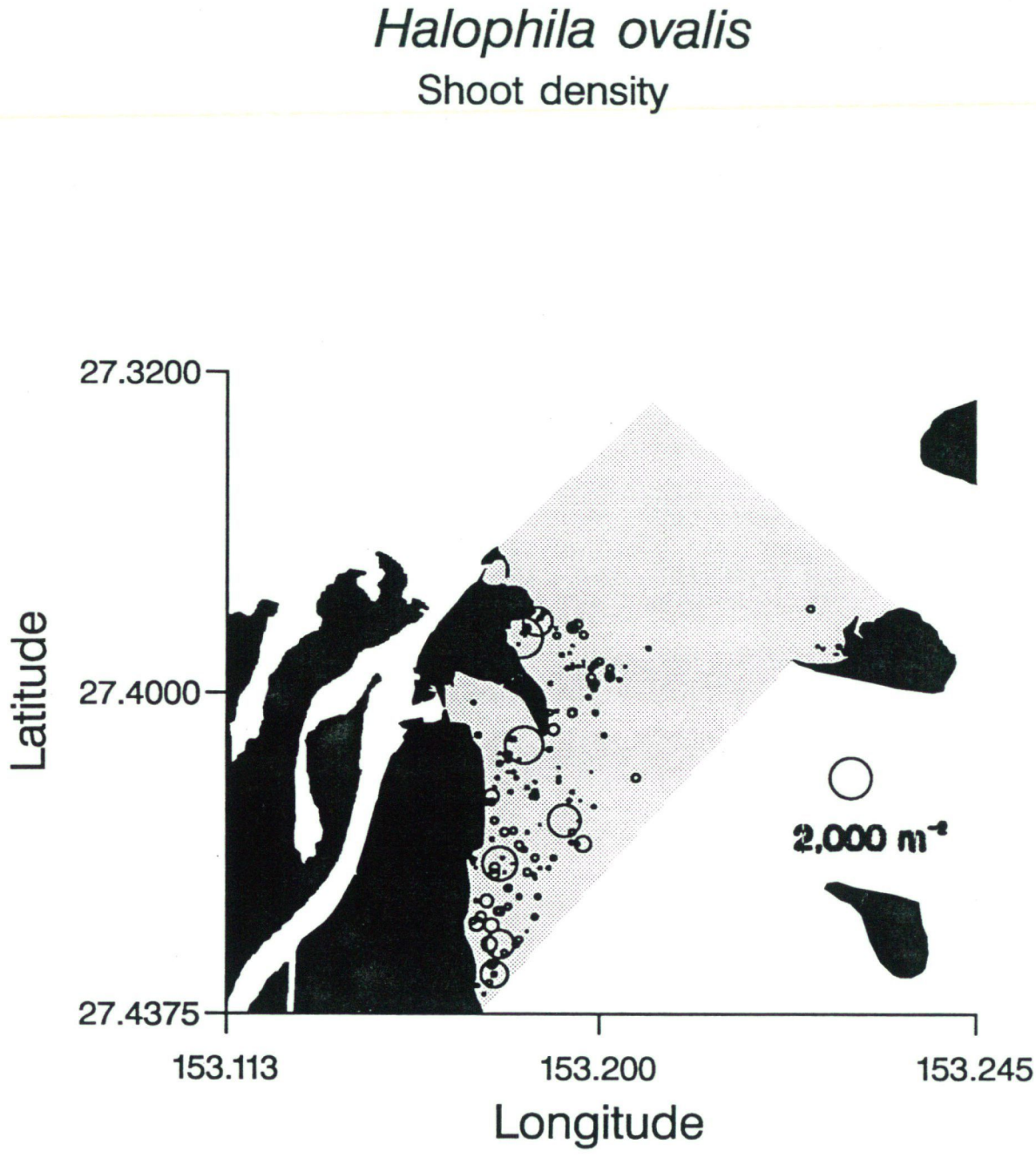

Figure 8b. Shoot density (m^2) for *Halophila ovalis*

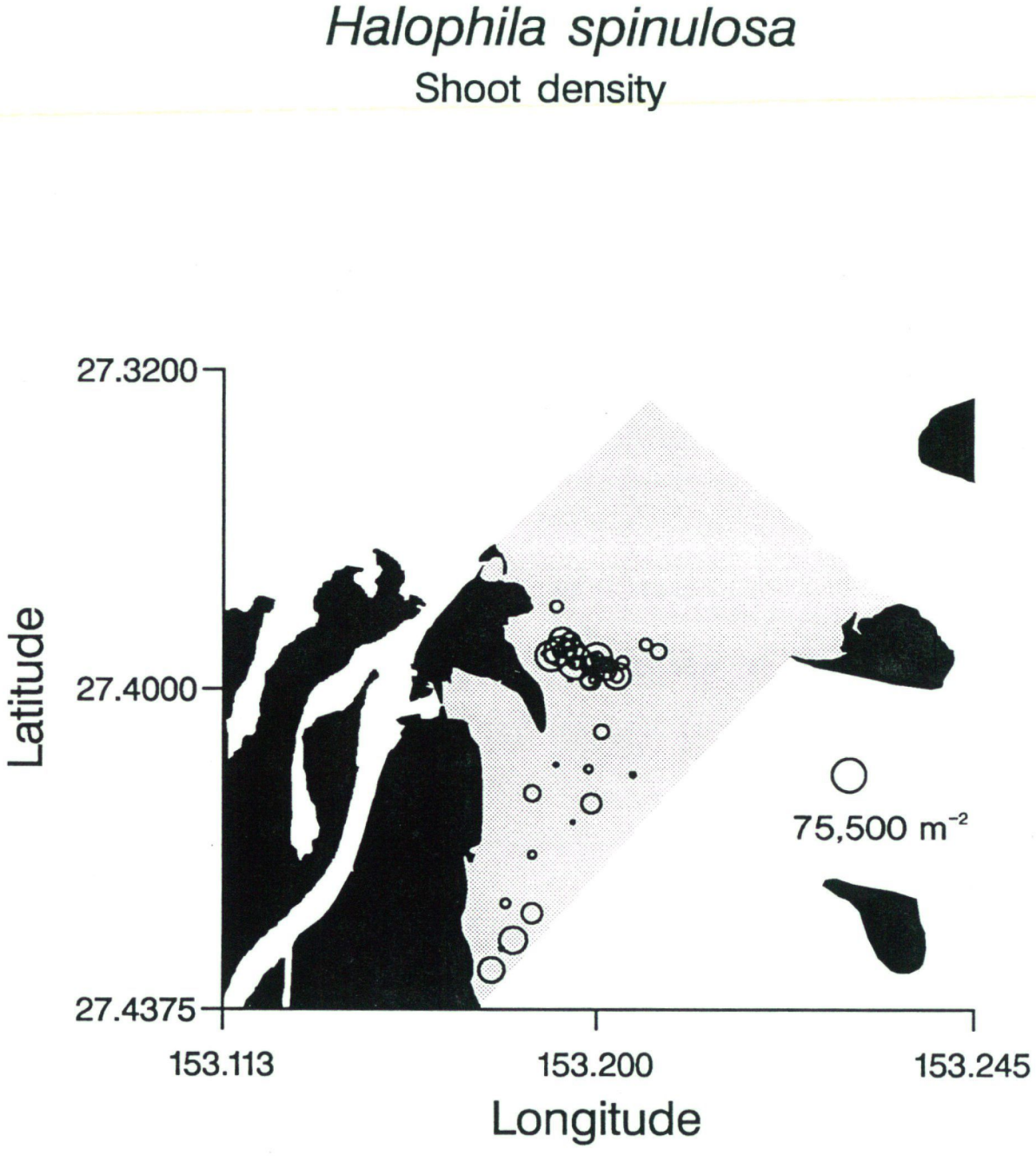

Figure 8c. Shoot density (m^2) for *Halophila spinulosa*

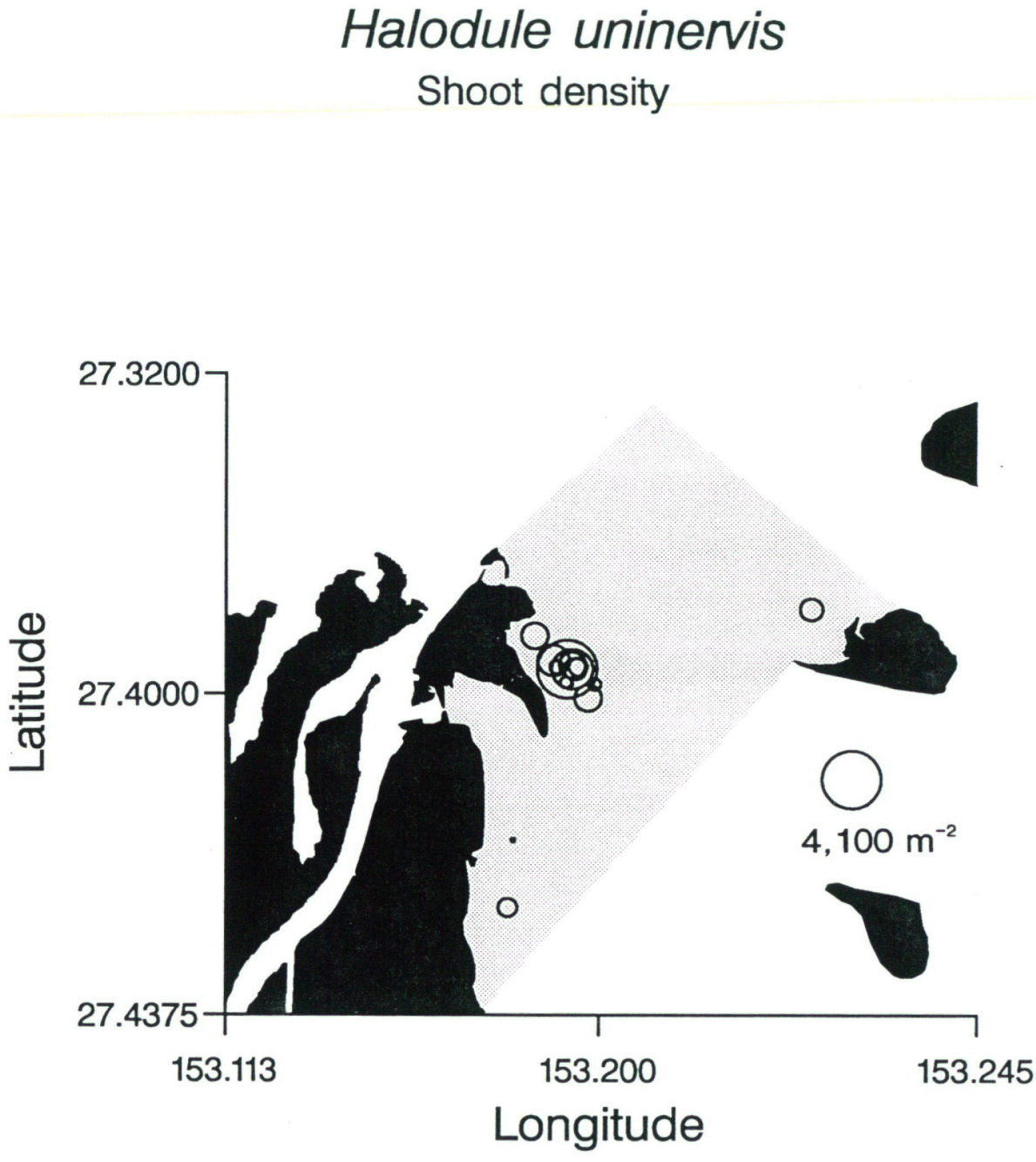

Figure 8d. Shoot density (m^2) for *Halodule uninervis*

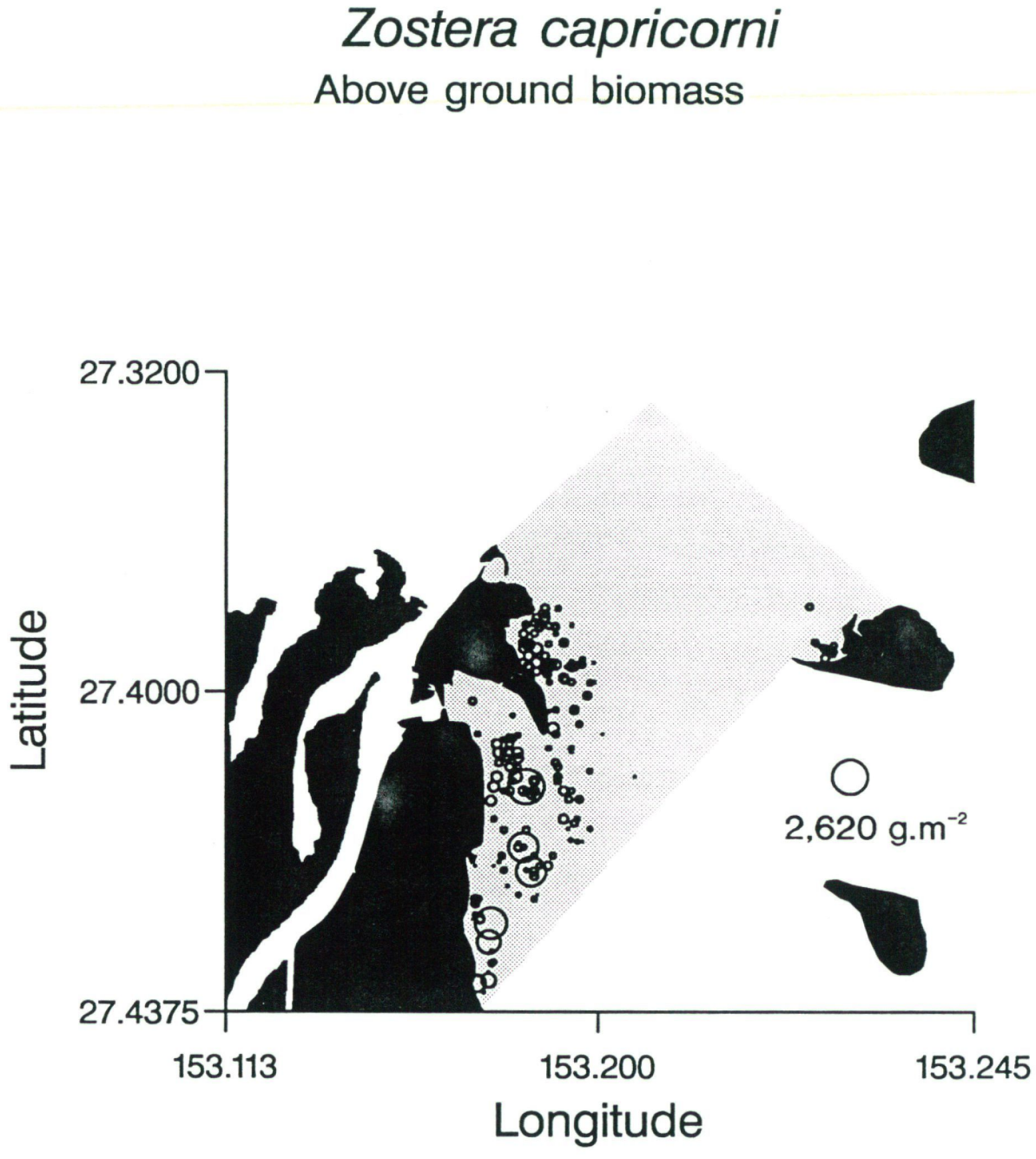

Figure 9a. Above-ground biomass ($g.m^{-2}$) for *Zostera capricorni*

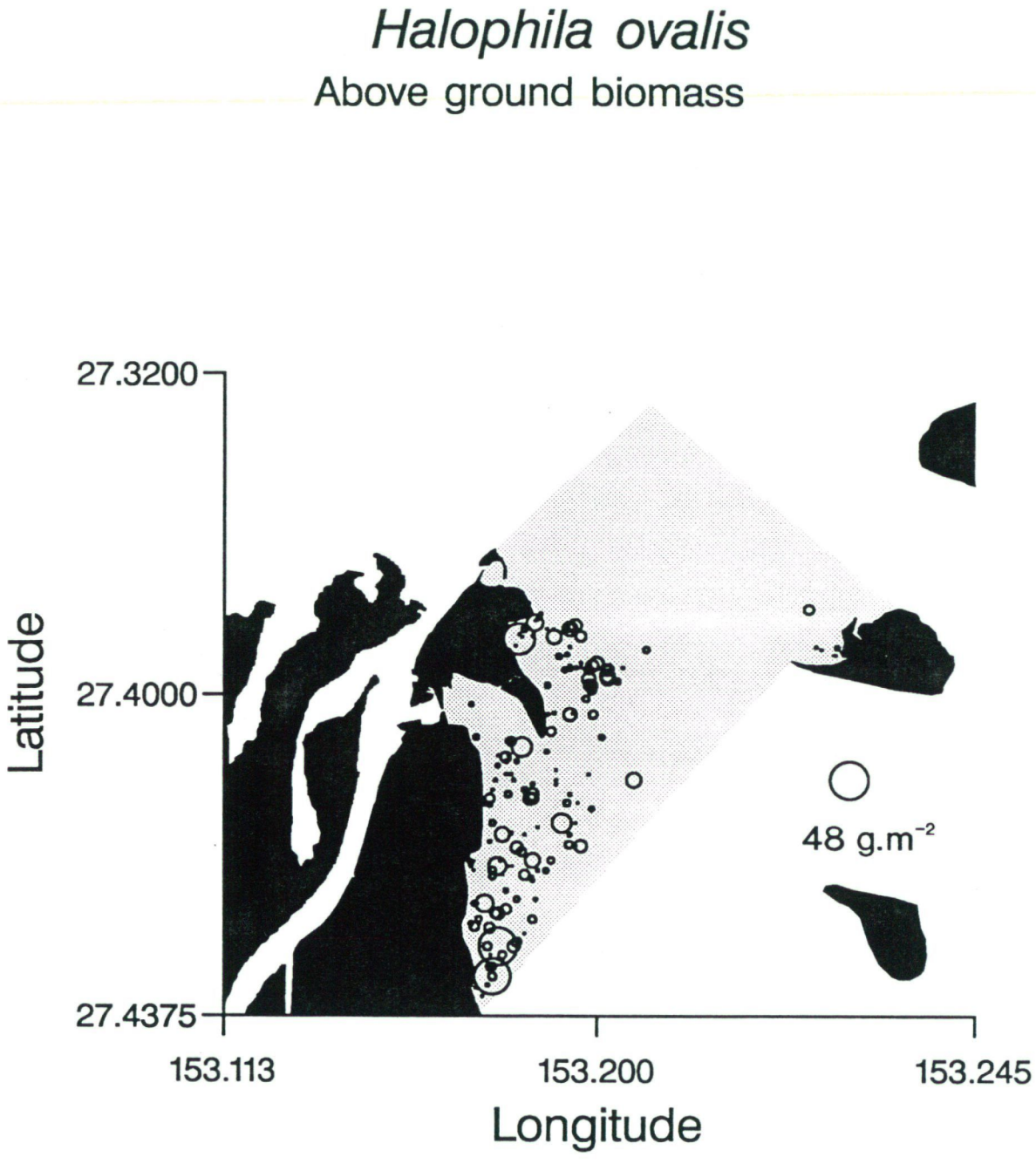

Figure 9b. Above-ground biomass ($g.m^{-2}$) for *Halophila ovalis*

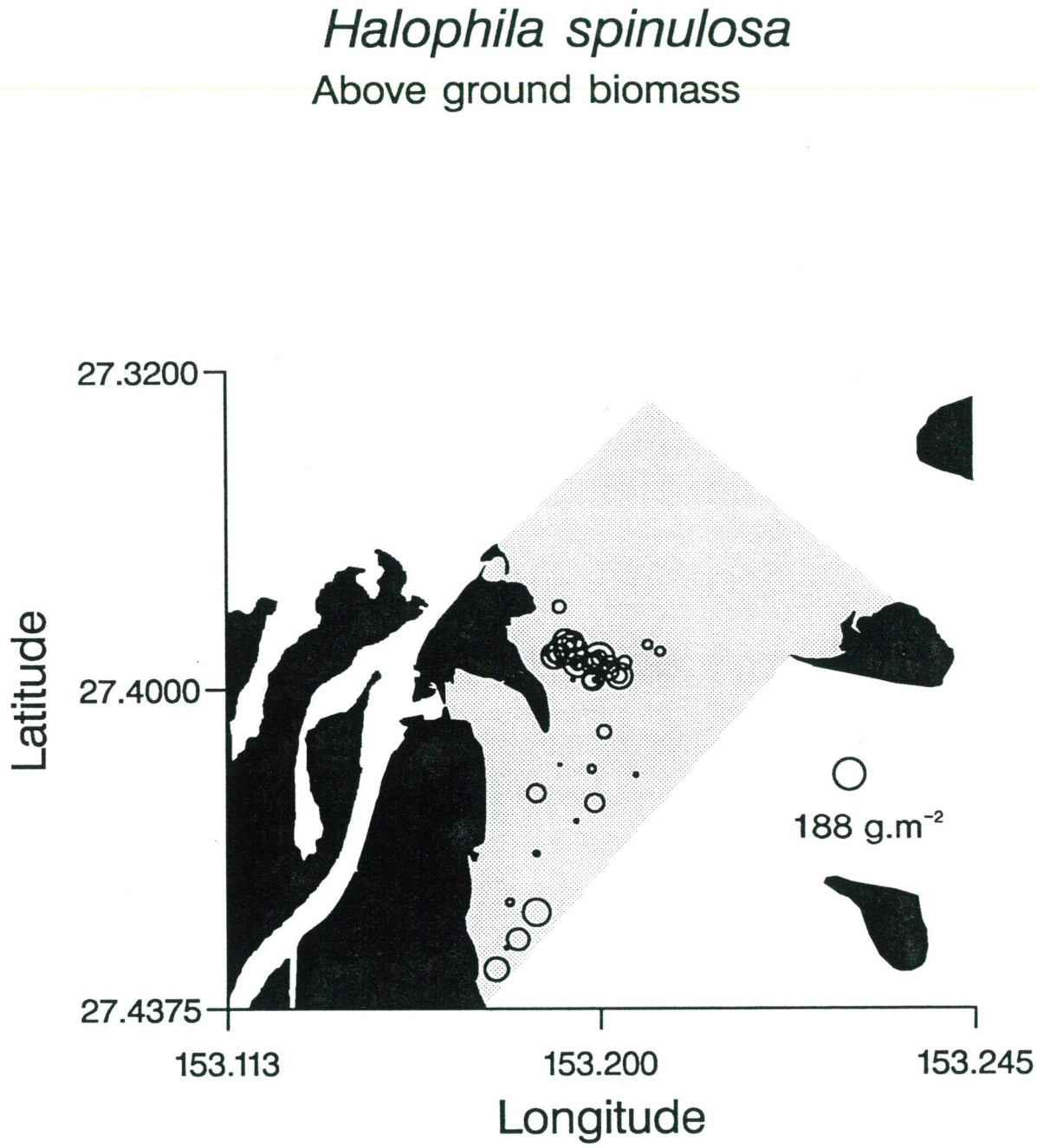

Figure 9c. Above-ground biomass ($g.m^{-2}$) for *Halophila spinulosa*

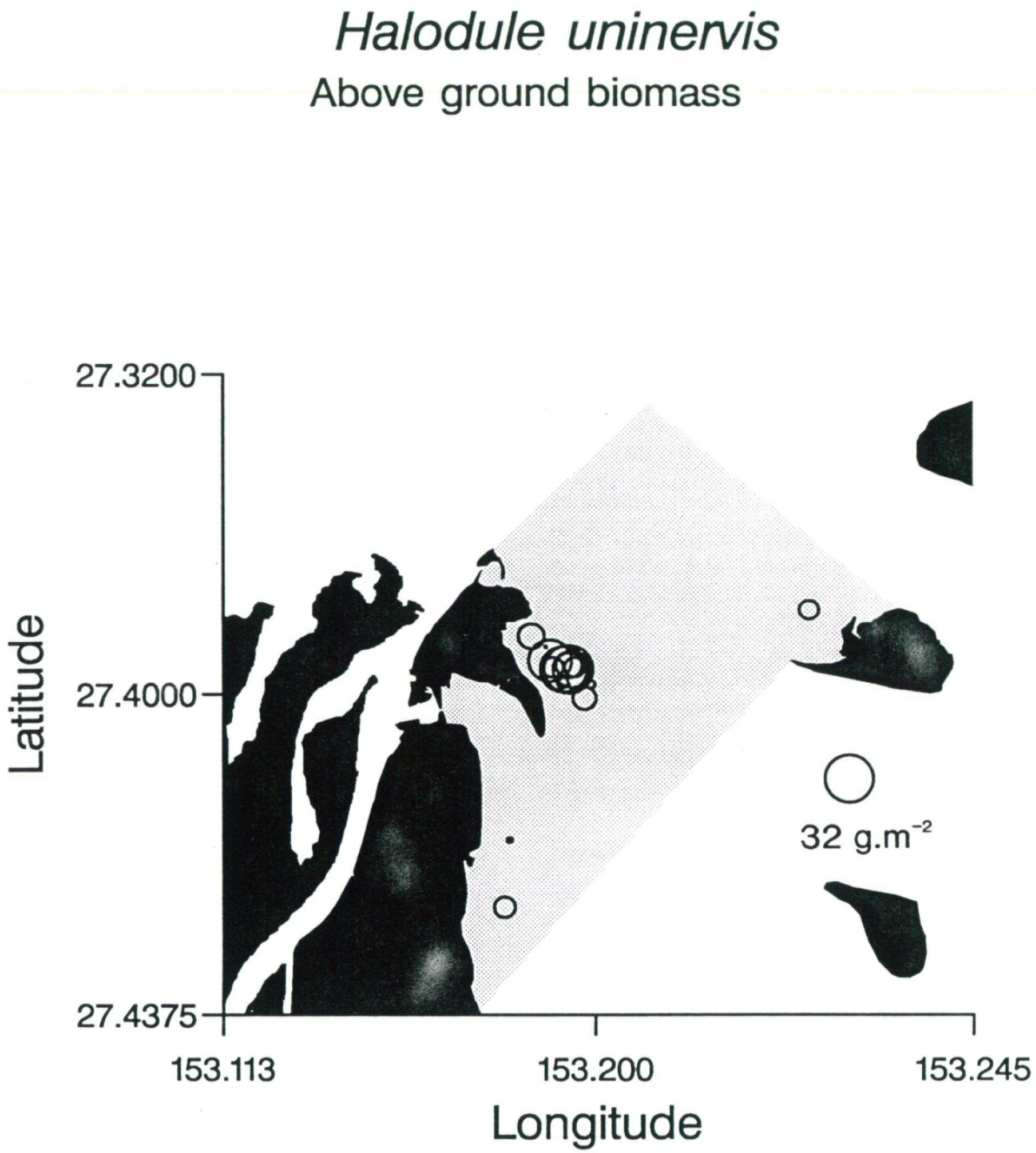

Figure 9d. Above-ground biomass ($g.m^{-2}$) for *Halodule uninervis*

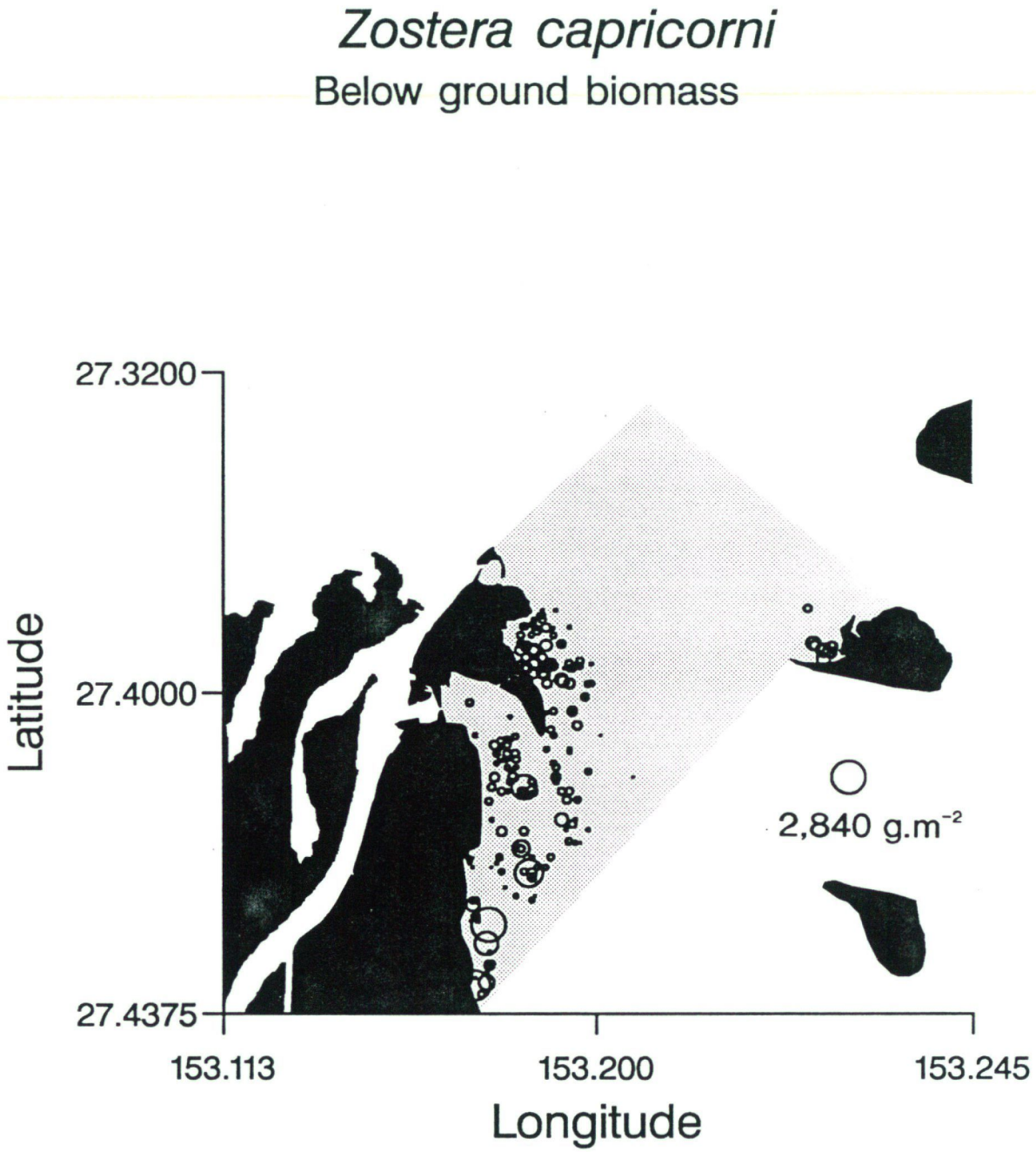

Figure 10a. Below-ground biomass ($g.m^{-2}$) for *Zostera capricorni*

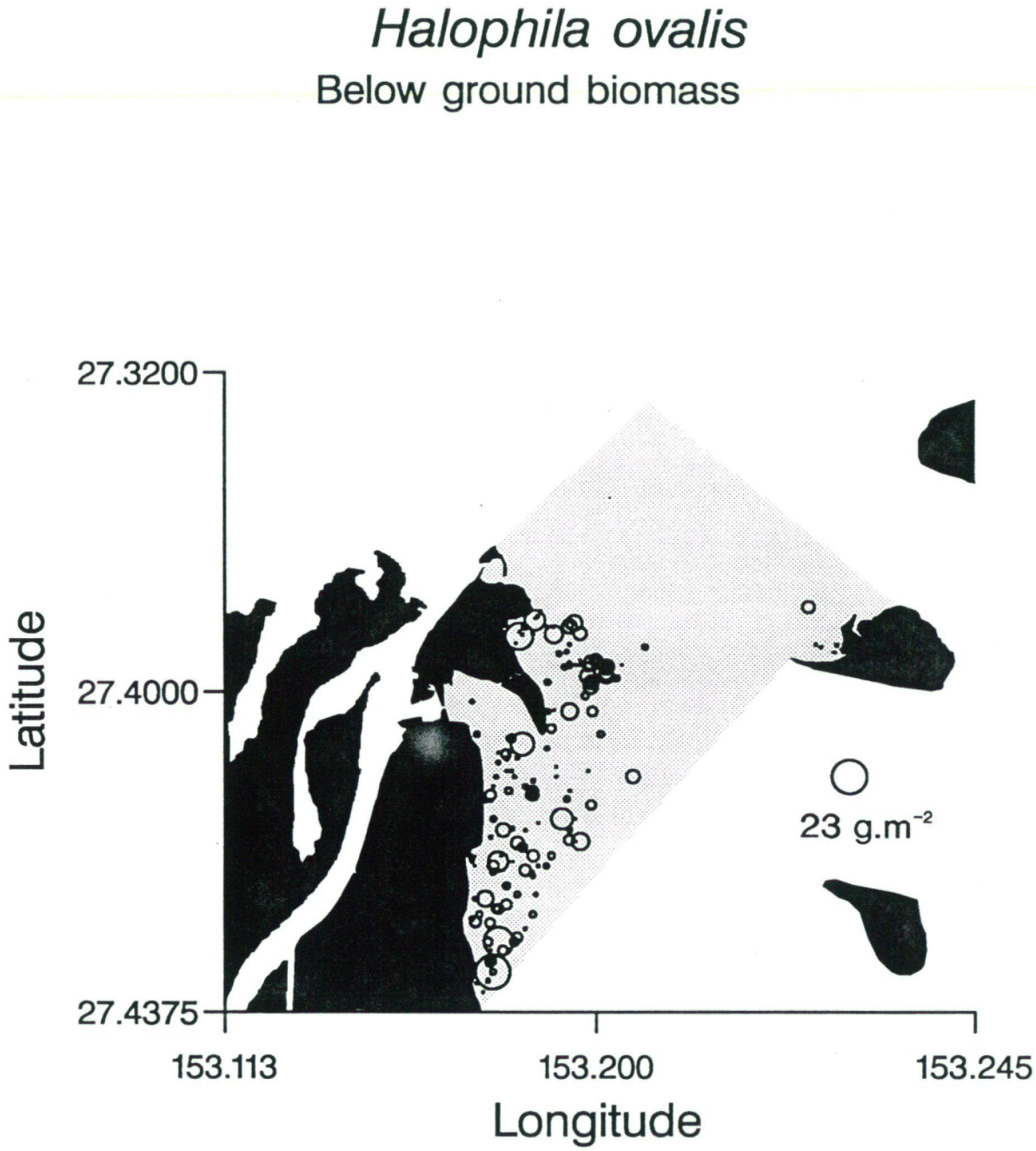

Figure 10b. Below-ground biomass (g.m^{-2}) for *Halophila ovalis*

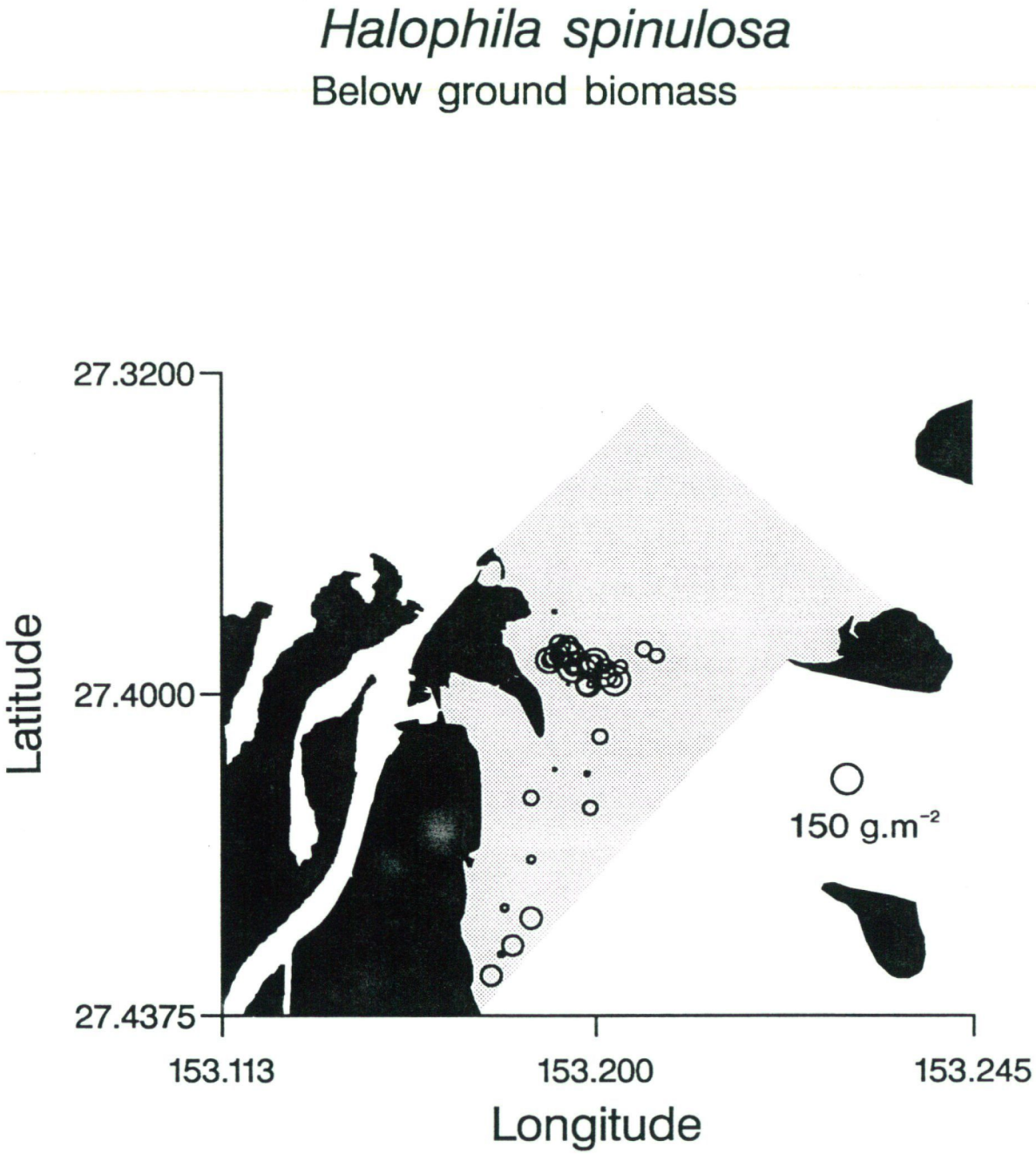

Figure 10c. Below-ground biomass (g.m^{-2}) for *Halophila spinulosa*

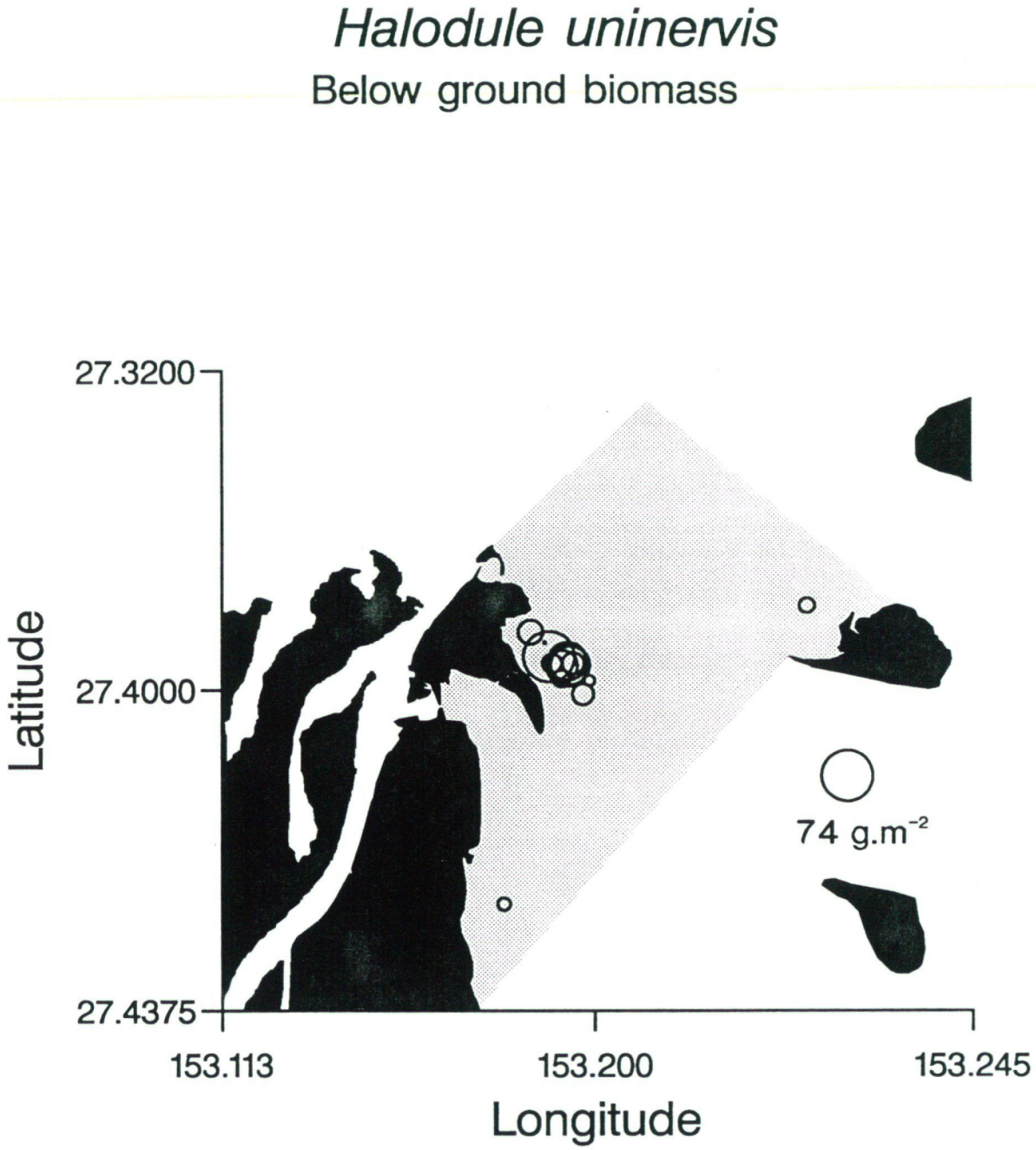

Figure 10d. Below-ground biomass ($g.m^{-2}$) for *Halodule uninervis*

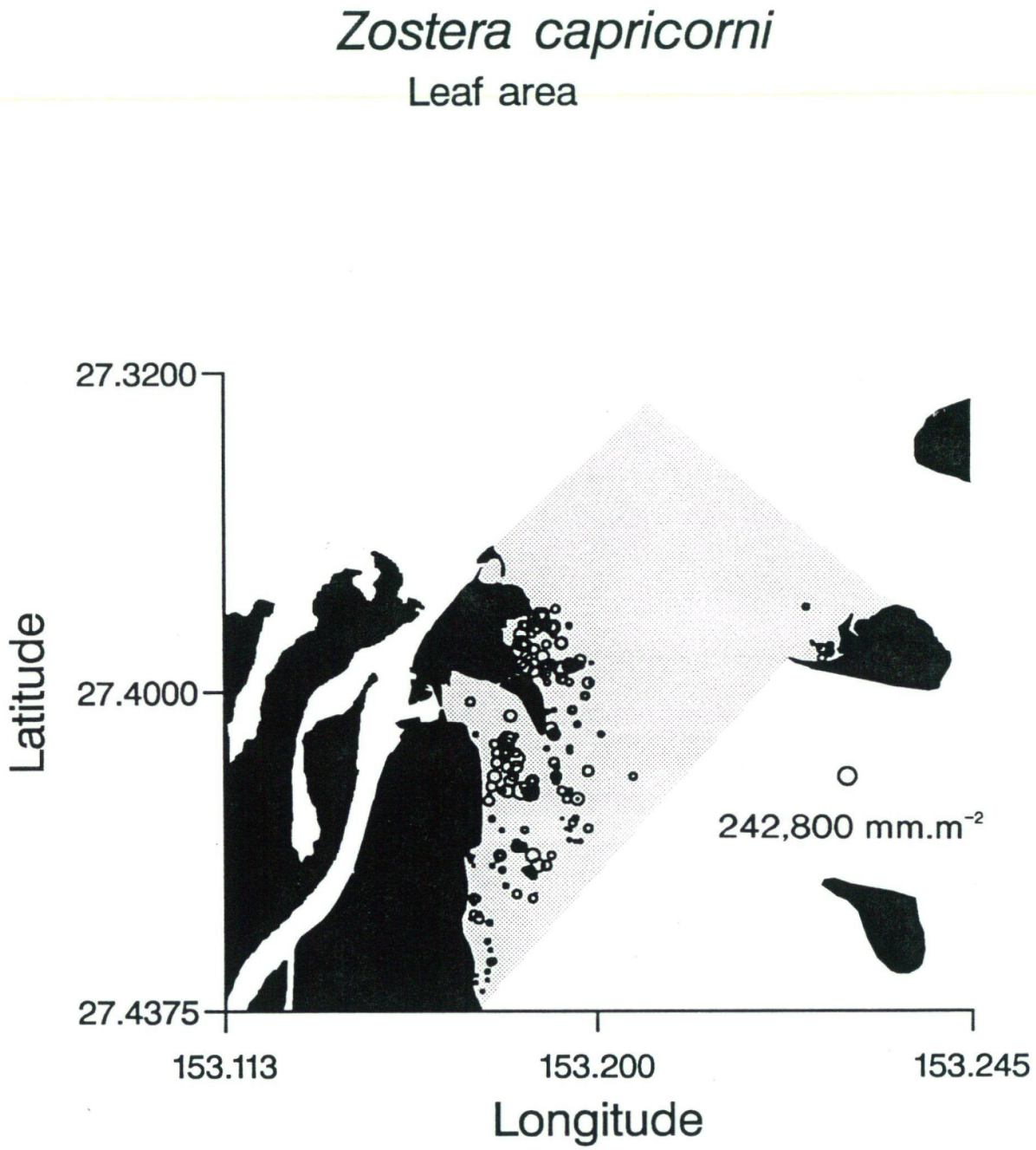

Figure 11a. Leaf area ($mm^2.m^{-2}$) for *Zostera capricorni*

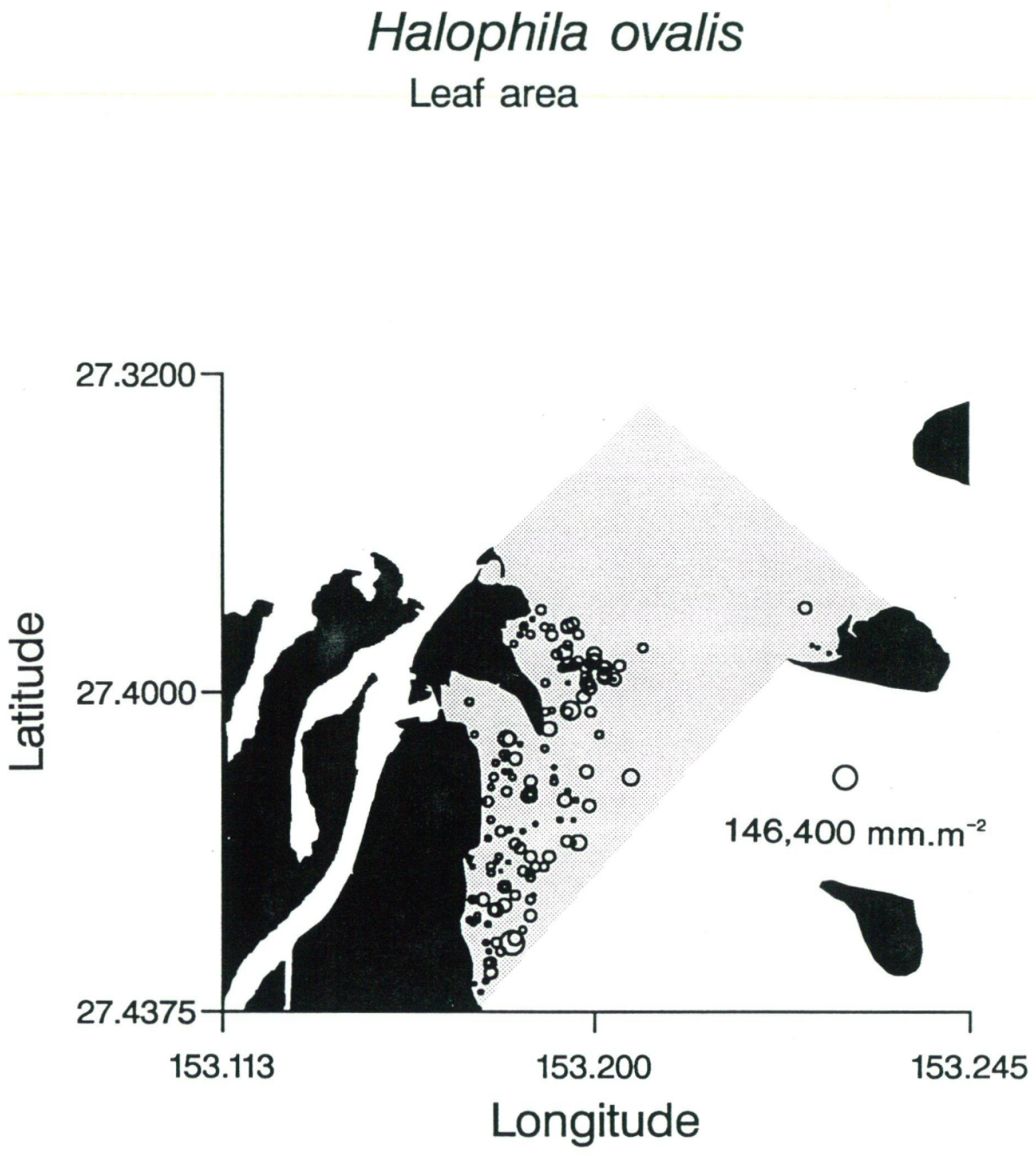

Figure 11b. Leaf area ($mm^2.m^{-2}$) for *Halophila ovalis*

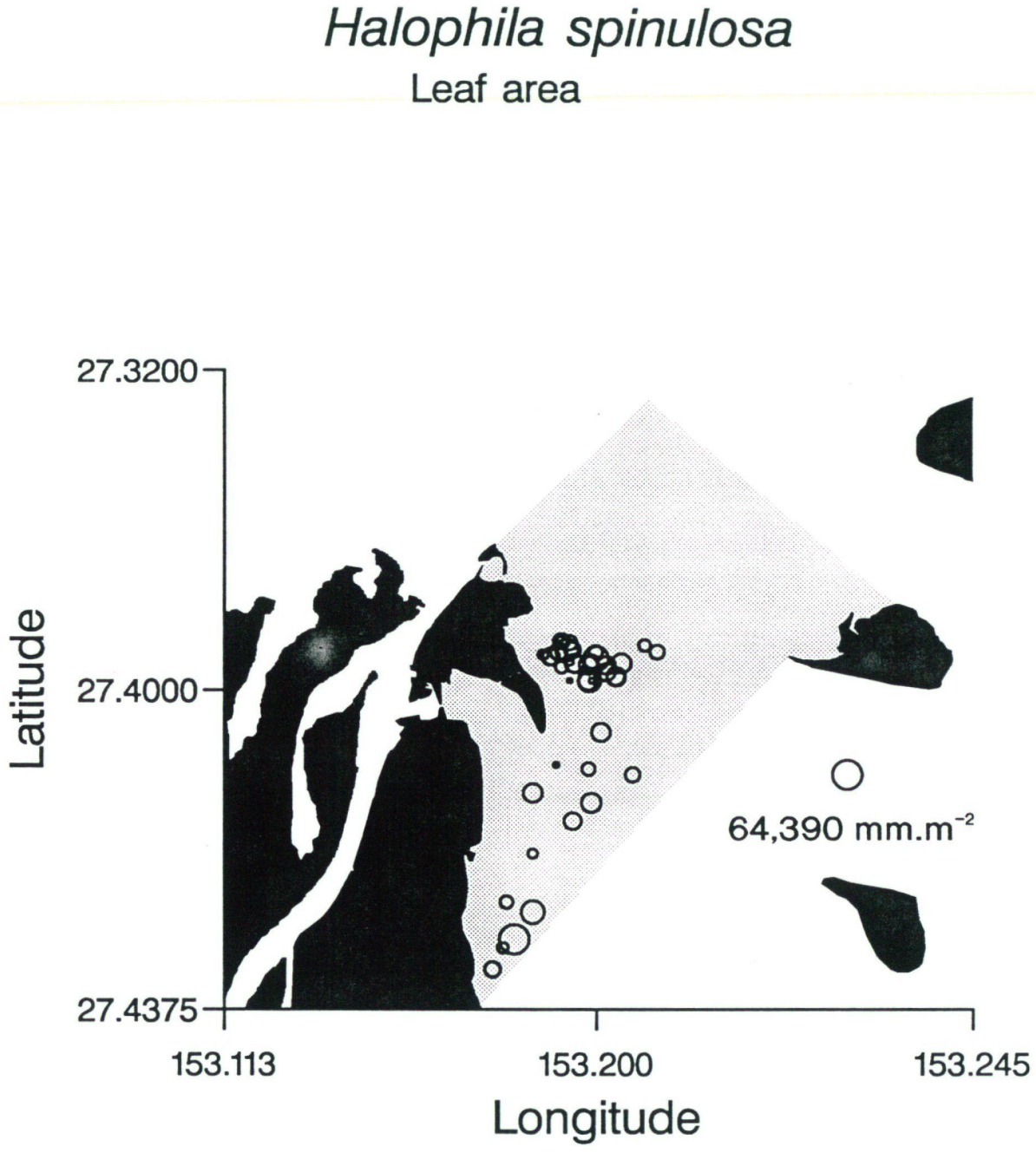

Figure 11c. Leaf area ($mm^2.m^{-2}$) for *Halophila spinulosa*

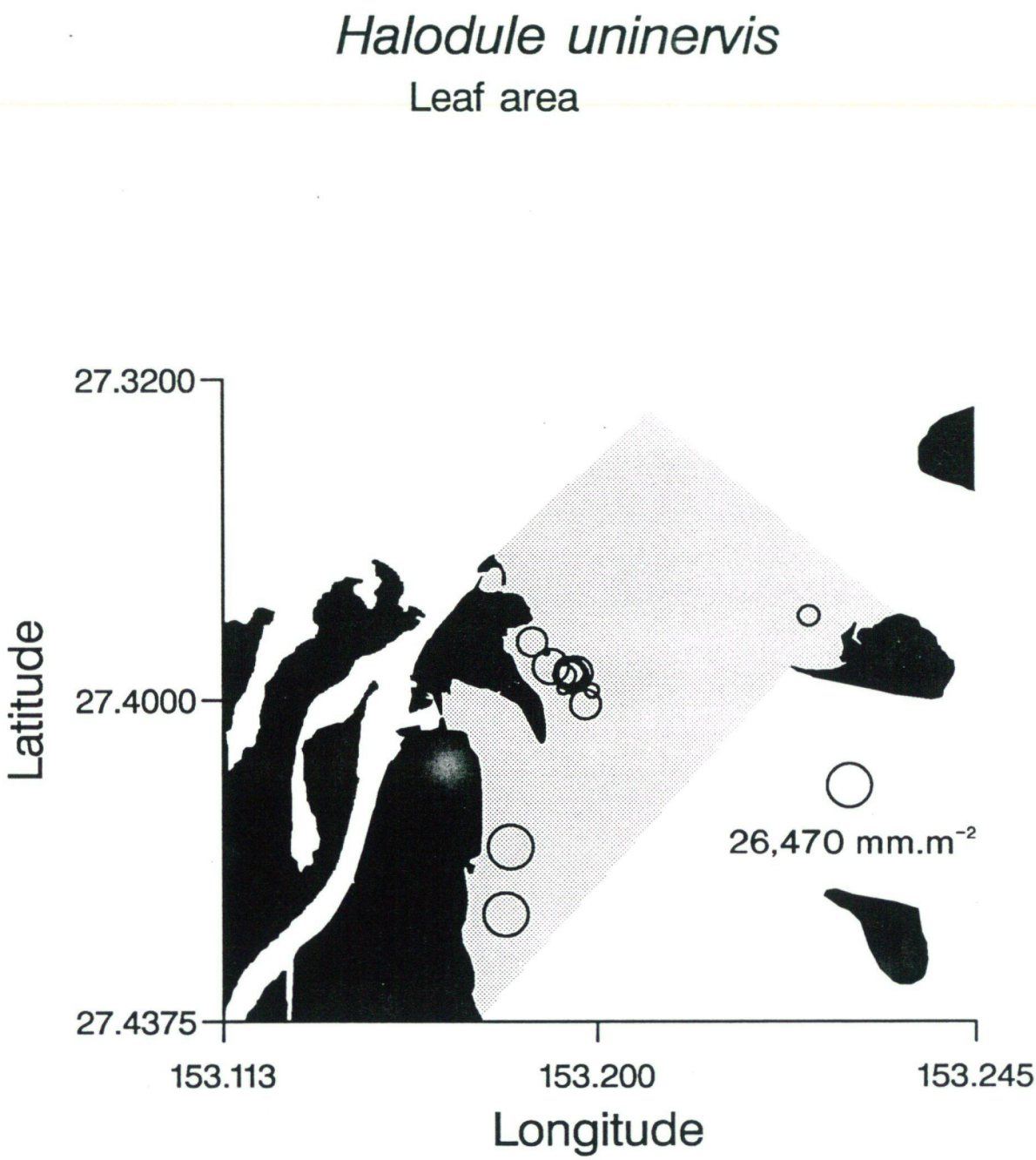

Figure 11d. Leaf area ($mm^2.m^{-2}$) for *Halodule uninervis*

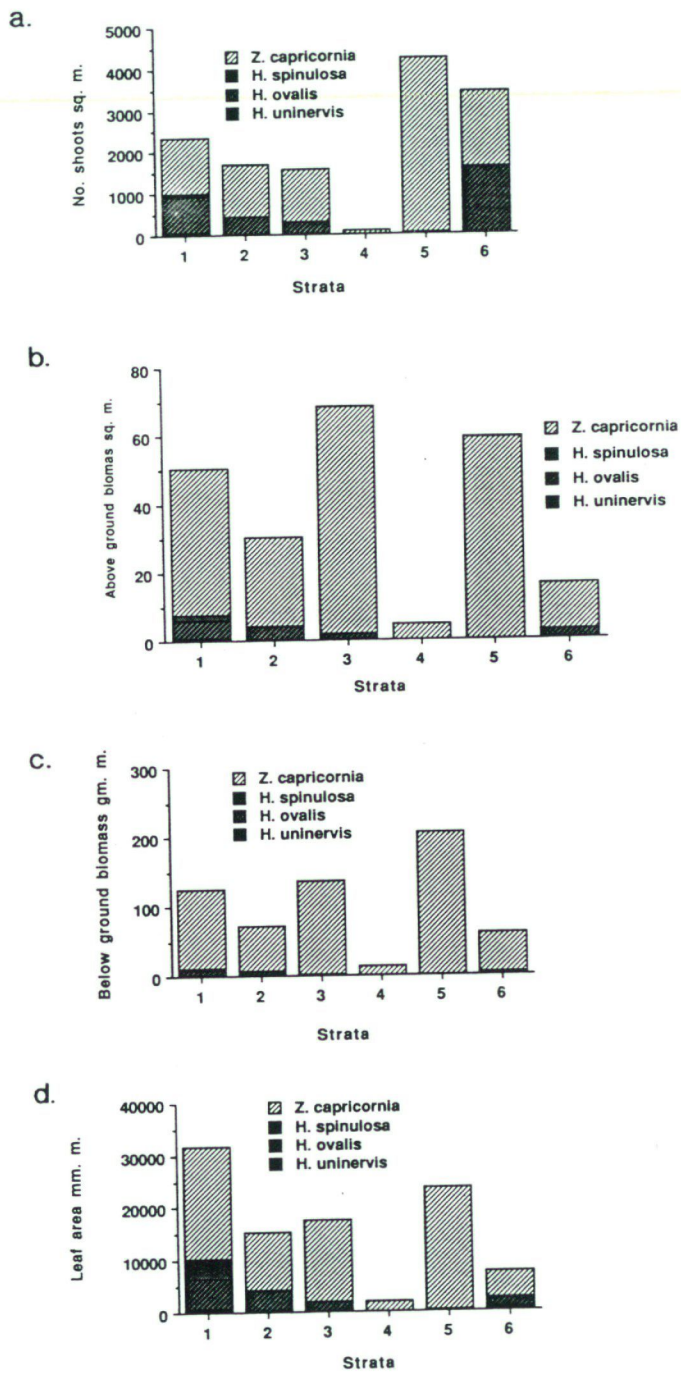

Figure 12. (a) Seagrass shoot density; (b) above-ground biomass; (c) below-ground biomass; and (d) leaf area for the four species of seagrass sampled from the six seagrass strata classified for the Fisherman Islands

CSIRO Marine Laboratories Report

Monitoring Seagrass Beds at Fisherman Islands, Moreton Bay, Queensland

Final Report to the Port of Brisbane Authority for the year 1992 – 1993

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Robert Kenyon

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July 1993

EXECUTIVE SUMMARY

- Fisherman Islands, near the mouth of the Brisbane river are managed by the Port of Brisbane Authority (PBA). This area has extensive seagrass beds and mangrove forests which have been shown to be important nursery habitat for prawns and fish, and foraging and roosting habitat for wading birds. The port authority is expanding their facilities at Fisherman Islands and they have taken steps to develop cost-effective monitoring techniques so that they can assess the effect of the development on these resources.

- CSIRO was contracted to develop the cost-effective monitoring techniques and to provide PBA with a range in cost options for obtaining seagrass biomass estimates with known reliability (Long and Poiner 1992).

- CSIRO was contracted again in 1992/93 to sample the Fisherman Islands seagrass beds. The purpose of this study was to use the cost-effective techniques developed from the 1991/92 first year study to estimate seagrass standing biomass and to compare the results of this study with those of the first year to determine if any change had taken place.

- The study area was stratified by photointerpreting colour aerial photographs. Seven strata were identified in the 1991/92 study. For this study the number of strata was reduced to six by combining the St. Helena and Oyster Pt. strata because they had similar biomass and variance. The variance estimates for seagrass biomass from the 1991/92 study were used to allocate samples to the six strata. A sample size of 340 was required, based on Neyman allocation of samples to strata, to give a precision of 17%. The seagrass beds were sampled again in January/February 1993.

- Four seagrasses were sampled in the study area, *Zostera capricorni, Halophila ovalis, Halophila spinulosa* and *Halodule uninervis*. The dominant seagrass, in terms of biomass, was *Zostera capricorni*.

- The estimated seagrass biomass for the study area was 2,527 ± 463 t (95% confidence interval). The precision for this study was 9.3% and was much better than the 17% expected from the Neyman allocation of samples to strata. The improvement in precision was attributed to a substantial reduction in the variation of *Zostera capricorni* biomass in the study area.

- There was no significant difference in seagrass biomass ($P > 0.05$) between the two years.

- The area covered by seagrass remained essentially unchanged over the two years.

INTRODUCTION

Fisherman Islands near the mouth of the Brisbane River forms part of the Port of Brisbane and is managed by the Port of Brisbane Authority (PBA) (Figure 1).

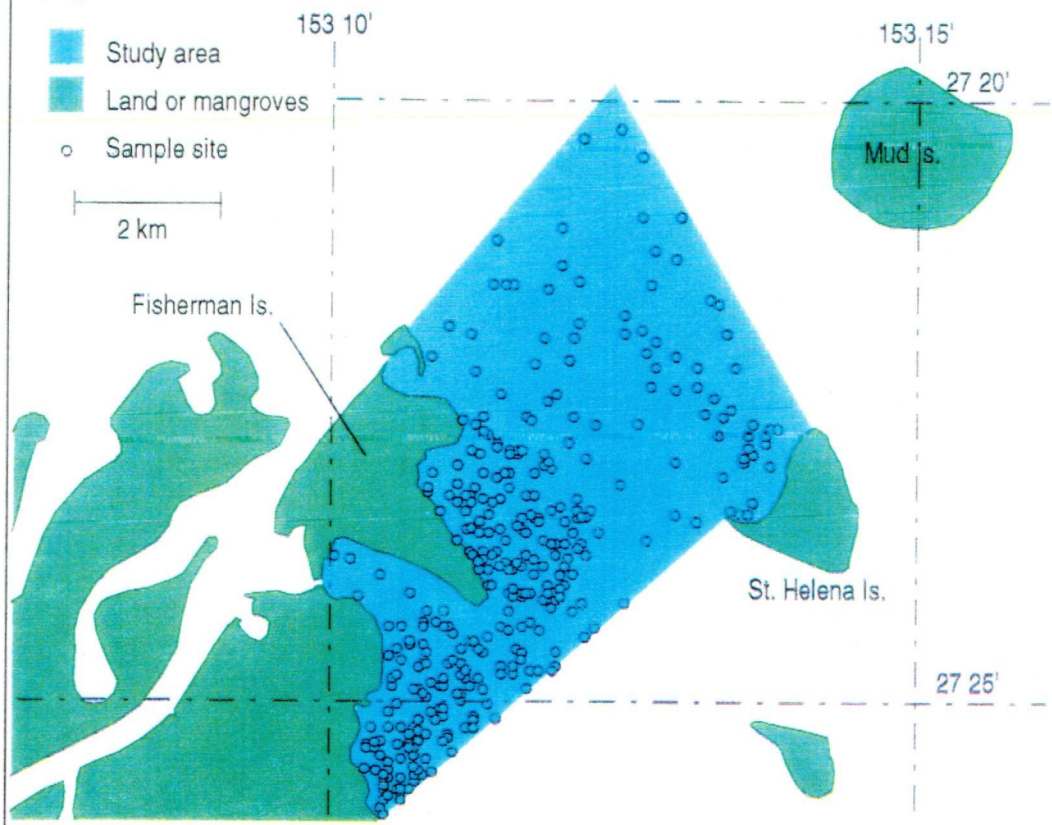

Figure 1. Fisherman Islands study area.

This area has extensive mangroves and seagrass beds that are important nurseries and habitat for prawns, fish and birds. CSIRO has mapped the mangroves and seagrass and has sampled the seagrass beds to develop techniques for cost-effective monitoring of these resources (Long and Poiner 1992). The information from this study was entered into a Geographic Information System (GIS) to provide a permanent, geo-coded database that forms the basis for future monitoring of Fisherman Islands seagrass beds and mangroves.

The purpose of this study was to apply the cost-effective monitoring techniques that CSIRO developed for the PBA, to determine whether changes had taken place over a 12 month period.

METHODS

Six tasks were identified to fulfill the project specifications:

- Neyman allocation of sampling effort to strata (Appendix 1). The strata identified from the photo-interpretation of colour aerial photographs, and the variance estimates for seagrass above ground biomass from the previous study were used in the Neyman allocation
- field sampling
- seagrass sample processing (counting, drying, weighing) in the laboratory
- estimating seagrass biomass, shoot-density and leaf area for the study area
- estimating the area covered by seagrass
- comparing the estimates from this study with the results from the previous study.

Optimal allocation of samples to Strata

A sample size of 340, with Neyman allocation of samples to strata, would give a precision of around 17% for seagrass above ground biomass (Appendix 1 & 2). The study area was sampled again from 27 January 1993 to 9 February 1993 using the methods given in Long and Poiner (1992) (Figure 2). Strata 5 and 6 from the previous study (St. Helena and Oyster Pt. seagrass beds) were combined because the biomass and variance estimates, and species composition were similar for the two strata. The new stratum was called the uniform, dense seagrass stratum.

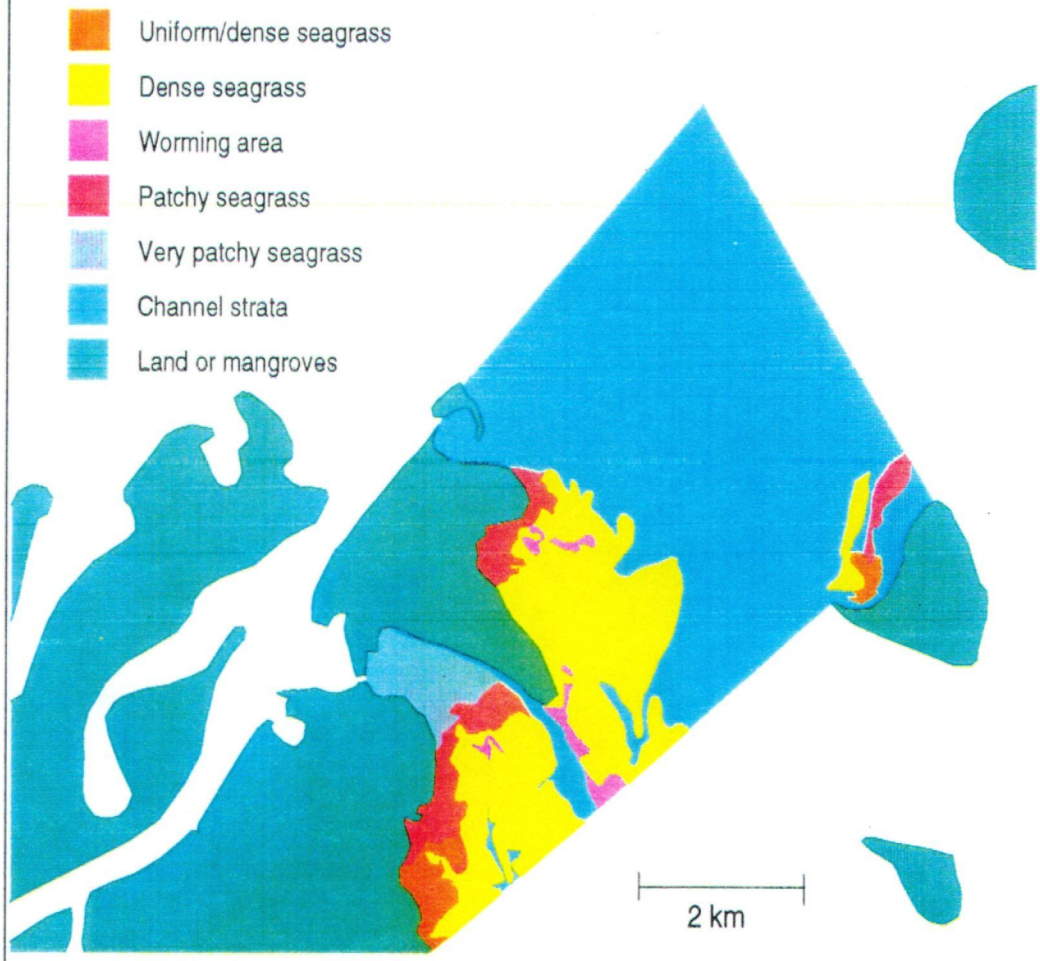

Figure 2. Fisherman Islands showing the six strata sampled for seagrass.

Species distribution

Four seagrass species, *Zostera capricorni, Halophila ovalis , Halophila spinulosa* and *Halodule uninervis* were sampled in the study area. There were large and significant correlations between the measured seagrass parameters (above and below ground biomass, shoot density and leaf area) so the patterns of above ground seagrass biomass distribution only are presented (Table 1). These patterns essentially mirror the patterns of distribution for below ground biomass, shoot density and leaf area for most species.

Table 1. Correlations between above (AGB) and below ground biomass (BGB), shoot density (ShD) and leaf area (LfA) for the seagrasses *Zostera capricorni* (n = 163) *Halophila ovalis* (n = 123), *Halodule uninervis* (n = 28), *Halophila spinulosa* (n = 41) sampled in the PBA study area. Only the correlations that were significant at $P < 0.05$ are shown.

Seagrass	AGB/BGB	AGB/ShD	AGB/LfA	BGB/ShD	BGB/LfA	LfA/ShD
Z. capricorni	0.63	0.24	0.33	0.21	0.43	.ns
H. ovalis	0.81	0.56	0.53	0.55	0.39	.ns
H. uninervis	0.99	0.93	0.51	0.93	0.49	0.48
H. spinulosa	0.85	0.88	0.54	0.90	0.61	0.54

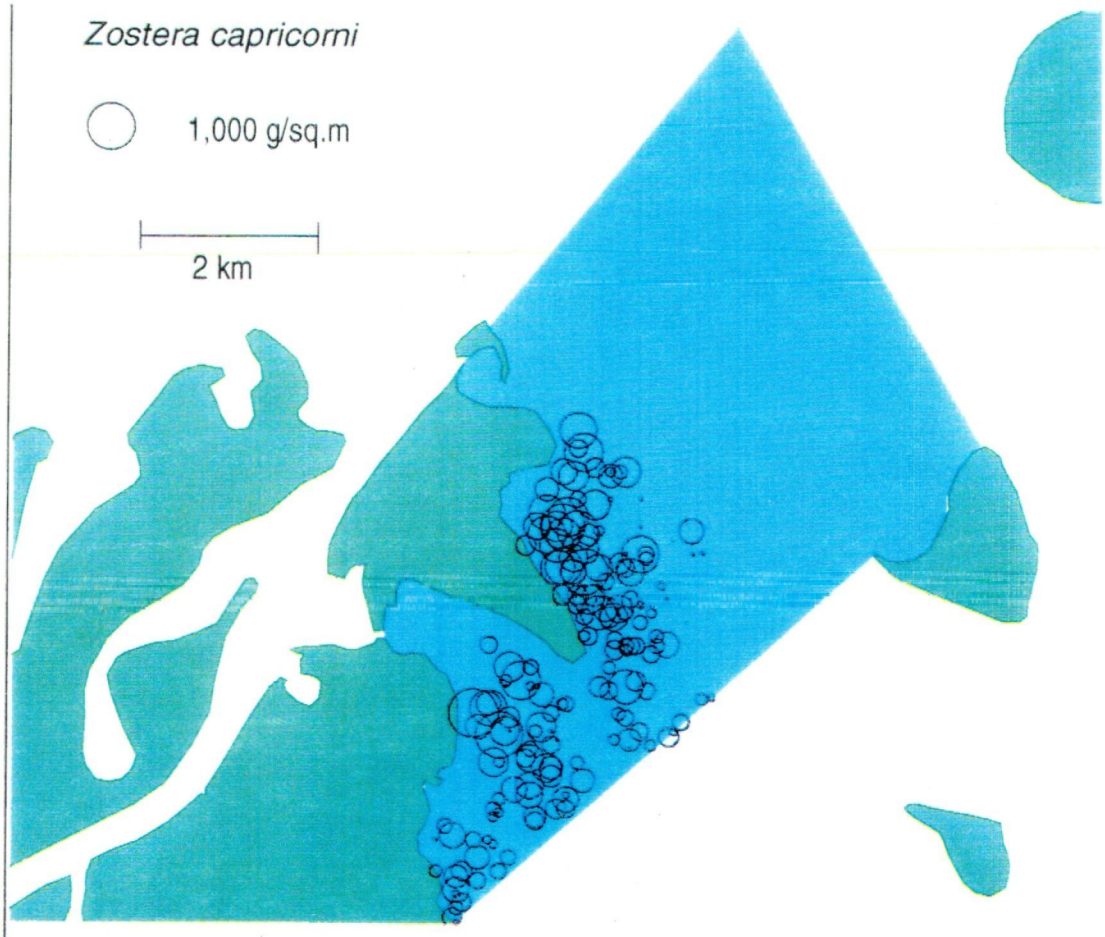

Figure 3. *Zostera capricorni* above ground biomass distribution in the Fisherman Islands study area.

Zostera capricorni and *Halophila ovalis* were the numerically dominant seagrasses in the study area. *Zostera capricorni* was uniformly distributed throughout the intertidal areas and was collected at 163 of the 340 sites (Figure 3). Above ground biomass ranged from 0 to 868g/m^2 and the average biomass disregarding strata, was 86.3g/m^2. Below ground biomass reached a maximum of 677 g/m^2 and the average was 69.0g/m^2. Shoot density peaked at 9,500 shoots/m^2 but the average density was 642 shoots/m^2. The maximum leaf area recorded was 0.614m^2/m^2 and the average was much lower at 0.02m^2/m^2.

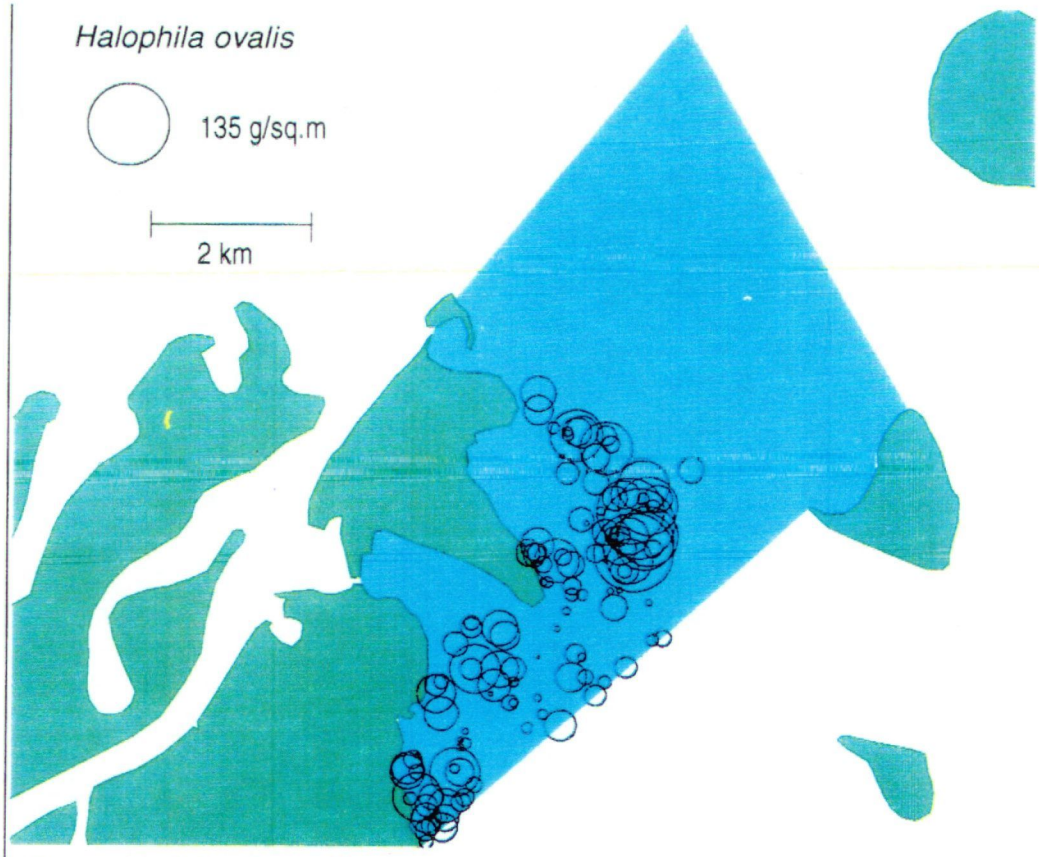

Figure 4. *Halophila ovalis* above ground biomass distribution in the Fisherman Islands study area.

Halophila ovalis also occurred extensively throughout the study area and had a maximum above ground biomass of 135g/m^2 (Figure 4). The average above ground biomass was much lower than the maximum above ground biomass (6g/m^2). This seagrass was sampled at 123 of the 340 sites. Below ground biomass showed the same pattern as above ground biomass with a maximum of 135 g/m^2 and a mean for the study area of 5.9g/m^2. The maximum shoot density was 34,750 shoots/m^2 and the average was 1,393 shoots/m^2. The maximum leaf area was 0.084 m^2/m^2 and the average was 0.0021 m^2/m^2.

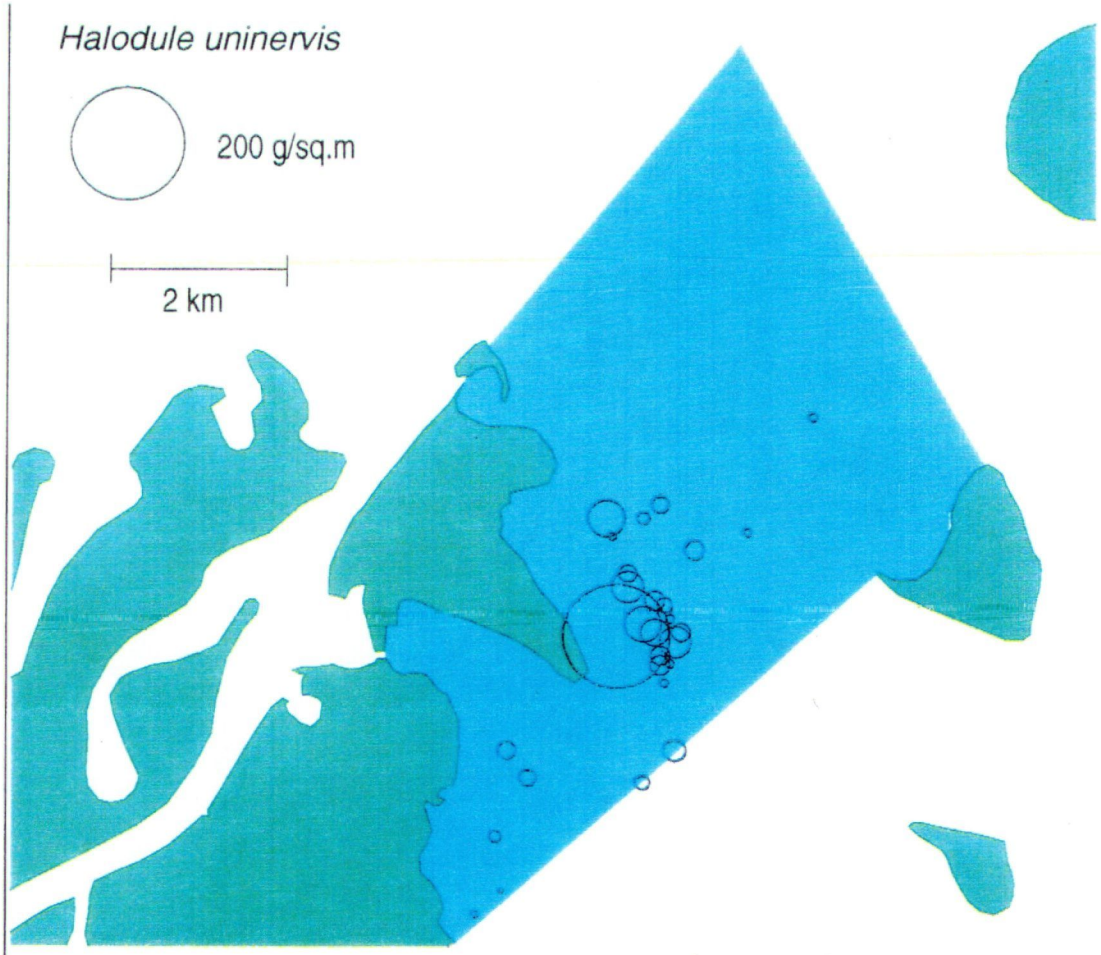

Figure 5. *Halodule uninervis* above ground biomass distribution in the Fisherman Islands study area.

The distribution of *Halodule uninervis* was much patchier than *Zostera capricorni* or *Halophila ovalis*. It was sampled at 28 of the 340 sites. It was never collected closer than 200 m off the mangroves and was concentrated along the outside edge of the intertidal areas (Figure 5). Maximum above ground biomass was 199 g/m^2 and the average was 1.2 g/m^2. Below ground biomass reached a maximum of 518.8 g/m^2 with an overall average of 2.2 g/m^2. Shoot density was the second highest of all seagrasses 11,437 shoots/m^2 and the average was 85.3 shoots/m^2. Leaf area ranged up to 0.041 m^2/m^2 but the average was only 0.0007 m^2/m^2.

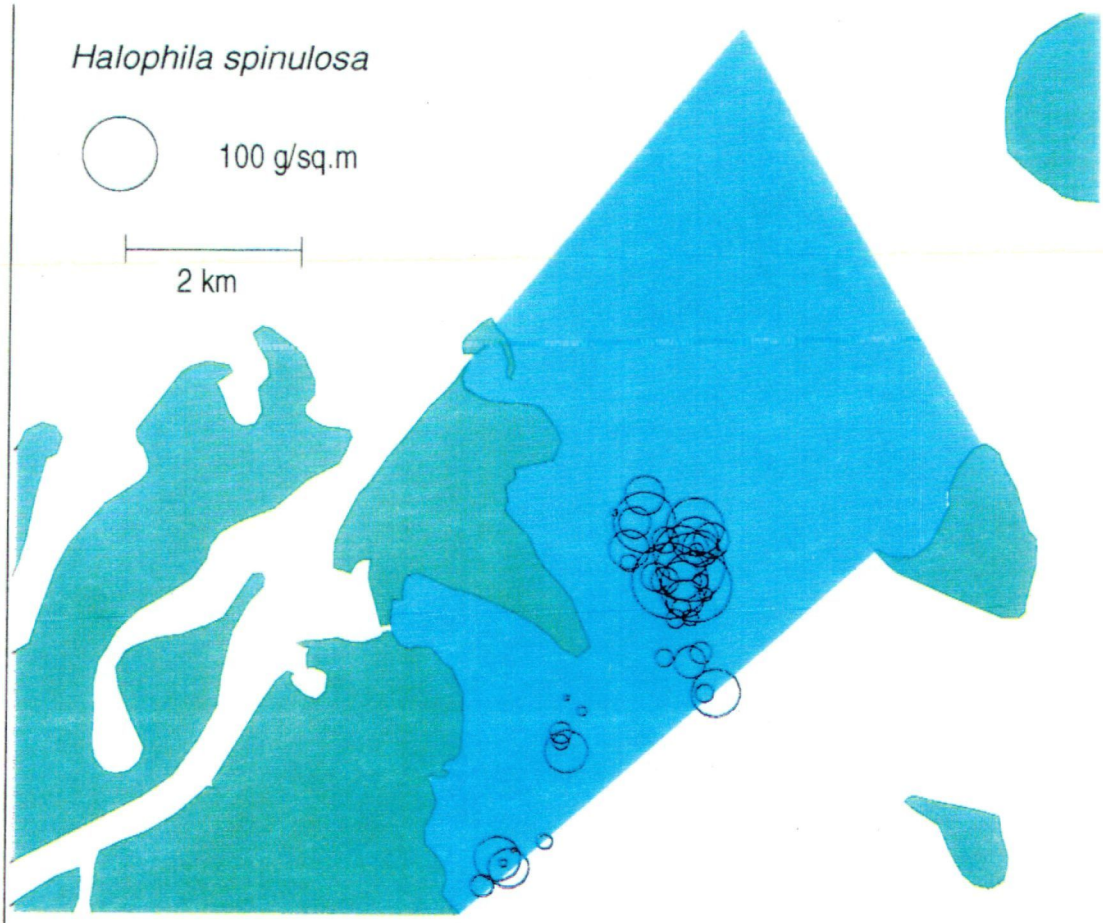

Figure 6. *Halophila spinulosa* above ground biomass distribution in the Fisherman Islands study area

The pattern of the distribution of *Halophila spinulosa* was similar to *Halodule uninervis* (Figure 6). Both species were mainly found along the outside edge of the intertidal area off Fisherman Islands. The maximum above ground biomass was 107.8g/m^2 with a mean of 3g/m^2. The maximum below ground biomass was 62.5 but the overall average was much lower (1.4 g/m^2). Shoot densities ranged up to 2,937 shoots/m^2; the average was much lower (81.0). Maximum leaf area was 0.323 m^2/m^2. The study area average was much lower 0.005 m^2/m^2.

Seagrass biomass estimates

Highest biomass estimates for *Zostera capricorni*, were in the dense seagrass beds (strata 1 mean = 207.89 g/m^2) and uniform/dense seagrass beds (strata 5 mean = 153.6 g/m^2). *Zostera capricorni* biomass was higher than the other seagrasses for all strata (Table 2).

mean = 153.6 g/m^2). *Zostera capricorni* biomass was higher than the other seagrasses for all strata (Table 2).

Table 2. Mean seagrass biomass (g/m^2), SB, and variance estimates, s^2, for Fisherman Islands seagrass in the six strata, 1 – dense seagrass, 2 – worming area, 3 – patchy seagrass, 4 – very patchy seagrass, 5 – uniform/dense seagrass, 6 – channel strata.

Strata		*Zostera capricorni*	*Halophila ovalis*	*Halodule uninervis*	*Halophila spinulosa*	All species
1	SB	207.89	15.15	5.12	6.85	235.02
	s^2	73235.15	1189.44	2495.56	489.71	75006.90
2	SB	105.60	9.17	6.25	0.0	121.02
	s^2	33455.88	252.08	117.19	0.0	29284.77
3	SB	105.69	10.63	0.0	0.0	116.32
	s^2	55553.00	455.57	0.0	0.0	53813.61
4	SB	27.76	0.0	0.0	0.0	27.76
	s^2	3854.39	0.0	0.0	0.0	3854.39
5	SB	153.56	17.75	0.0	0.0	171.31
	s^2	37855.92	650.49	0.0	0.0	35617.06
6	SB	7.36	1.109	0.25	0.19	8.91
	s^2	2361.37	39.03	2.167	2.60	2865.51

In contrast to biomass where *Zostera capricorni* dominated, *Halophila ovalis* dominated in terms of shoot-density for stratas 1, 2 and 5 (Table 3).

Table 3. Average shoot density (shoots/m^2) – ShD, and variance estimates, s^2, for Fisherman Island seagrass for the six strata, 1 – dense seagrass, 2 – worming area, 3 – patchy seagrass, 4 – very patchy seagrass, 5 – uniform/dense seagrass, 6 – channel strata.

Strata		*Zostera capricorni*	*Halophila ovalis*	*Halodule uninervis*	*Halophila spinulosa*
1	ShD	743.89	1137.76	111.77	126.66
	s^2	1355250	7039997	679438	152219
2	ShD	255.32	4166.67	1333.33	0.0
	s^2	195564	52083333	5333333	0
3	ShD	3574.47	3226.77	0.0	0.0
	s^2	587255	61084576	0	0
4	ShD	263.53	0.0	0.0	0.0
	s^2	347239	0	0	0
5	ShD	1938.57	4984.45	0.0	0.0
	s^2	5311383	69910686	0	0
6	ShD	61.87	53.80	9.82	2.48
	s^2	136590	86701	5620	432

The stratified means, area and variance were used to estimate the total standing biomass of seagrass for each species in the study area (Table 4). There was an estimated 2,527.35 tonnes of seagrass in the study area, of which 2,231.53 tonnes (88%) was contributed by *Zostera capricorni*. The precision of the estimate expressed as the standard error of the mean divided by the mean

was 9.3%. The next largest contributor was *Halophila ovalis* with 184.98 tonnes.The remaining seagrasses contributed relatively minor components to the overall seagrass biomass in the Fisherman Islands study area.

Table 4. Stratified mean ($\bar{y}_{st}$) seagrass biomass (g/m^2) and shoot density (shoots/m^2) estimates, variance of the stratified mean $v(\bar{y})_{st}$; upper (*U95*) and lower (*L95*) 95% confidence limits of the stratified mean and estimated tonnes of seagrass in the study area and their 95% confidence limits. (AGB, above ground biomass; BGB, below ground biomass; TB, total biomass; ShD, shoot density).

Species		$\bar{y}_{st}$	$v(\bar{y})_{st}$	*L95*	*U95*	tonnes	*L95*	*U95*
Zostera	AGB	34.41	18.30	26.03	42.79	1295.51	979.85	16611.17
capricorni	BGB	24.86	4.79	20.57	29.15	936.02	774.51	1097.53
	TB	59.27	36.07	47.50	71.04	2231.53	1788.33	2674.74
	ShD	263.87	1347.86	191.91	335.82			
Halophila	AGB	2.48	0.14	1.74	3.23	93.51	365.44	121.59
ovalis	BGB	2.43	0.14	1.70	3.16	91.46	64.10	118.82
	TB	4.91	0.54	3.47	6.35	184.98	130.78	239.18
	ShD	566.26	8956.64	380.77	751.76			
Halodule	AGB	0.42	0.04	0.03	0.82	15.87	1.06	30.69
uninervis	BGB	0.92	0.27	-0.10	1.94	34.70	-3.82	73.21
	TB	1.34	0.52	-0.07	2.75	50.57	-2.53	103.68
	ShD	46.74	425.14	6.33	87.15			
Halophila	AGB	1.10	0.05	0.64	1.56	41.38	24.12	58.63
spinulosa	BGB	0.50	0.01	0.28	0.72	18.89	10.69	27.09
	TB	1.60	0.11	0.94	2.26	60.26	35.27	85.26
	ShD	28.86	33.22	17.56	40.16			
All species	AGB	38.41	19.47	29.77	47.06	1446.28	1120.63	1771.92
	BGB	28.71	5.40	24.16	33.27	1081.07	909.60	1252.54
	TB	67.13	39.38	54.83	79.43	2527.35	2064.25	2990.45

Biomass estimate = 2,527.35 tonnes ± 463.10 t (18.32%, 95% confidence interval)

Potential indicator of seagrass condition

The ratio of above to below ground seagrass biomass provides a useful indicator of change in seagrass growth patterns due to physiological and other disturbances. Changes in this ratio may indicate a response to environmental impact. The variation of this ratio, standardised relative to the mean, (co-efficient of variation) may also provide an indicator of change in seagrass growth pattern. For this reason we calculated the ratio between the above and below ground biomass and tested whether or not they showed any significant differences between the 1991/92 and 1992/93 sampling periods. The ratio of above to below-ground biomass ranged from 0.58 for *Halodule uninervis* to 2.93 for *Halophila spinulosa* (Table 5).

Table 5. Contrast of the ratio of above-to below ground biomass, $\frac{AGB}{BGB}$, coefficient of variation, c.v. and sample size, *n* for the seagrasses sampled at Fisherman Islands for 1991/92 and 1992/93 for (a) *Zostera capricorni*, (b) *Halophila ovalis*, (c) *Halodule uninervis* and (d) *Halophila spinulosa*.

	$\frac{AGB}{BGB}$	c.v.	*n*
(a) *Zostera capricorni*			
1991/92	1.07	94.0	189
1992/93	1.66	87.1	168
(b) *Halophila ovalis*			
1991/92	1.20	67.4	120
1992/93	1.36	65.0	157
(c) *Halodule uninervis*			
1991/92	0.58	56.6	15
1992/93	1.11	129.3	28
(d) *Halophila spinulosa*			
1991/92	2.93	67.4	42
1992/93	2.32	65.0	38

There was no significant difference between the 1991/92 and 1992/93 ratio of above to below ground biomass for all seagrasses ($P > 0.05$) except *Zostera capricorni*. This ratio was significantly higher in 1992/93 than 1991/92. Thus more Z. *capricorni* was sampled above ground compared to below ground in 1992/93 compared to 1991/92. In contrast, there was no significant difference

for the coefficient of variation for *Zostera capricorni* above to below ground biomass ratio for the 1991/92 and 1992/93 sampling periods ($P > 0.05$). This indicated that even though the ratio of above to below ground biomass differed significantly between years, the variability of the ratio was the same for both years. Therefore the shift in partitioning of seagrass biomass into above and below ground components was not accompanied by an increase or decrease in the variation of this partitioning.

Comparison with the 1992 seagrass biomass estimate

The seagrass biomass estimate for 1993 was 2,527 ± 463 t (95% confidence interval) compared with 2,144 ± 568 t (95% confidence interval) for 1992, a difference of 383 t. The 95% confidence interval for the difference between the 1992 and 1993 biomass estimate included no difference. We therefore concluded that there was no change in seagrass biomass in the study area over the two year study period ($P > 0.05$) (Figure 7).

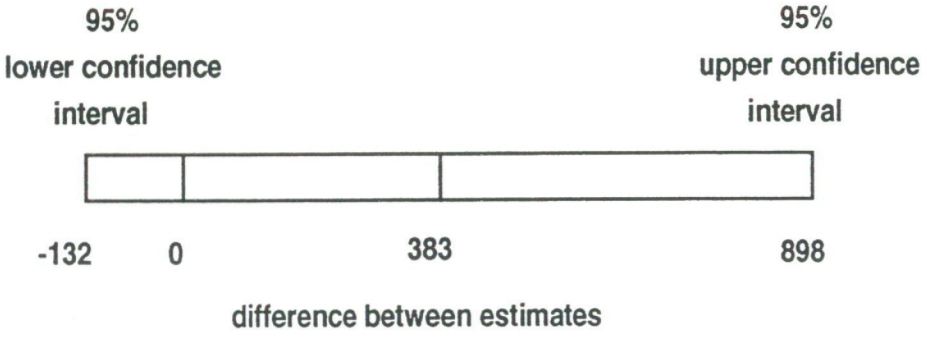

Figure 7. Ninety-five percent confidence interval for the difference between seagrass biomass estimates from the 1991/92 and 1992/93 field sampling.

Area covered by seagrass

The area covered by seagrass (%) was calculated as the proportion of samples where seagrass was present (Table 6). Highest covers were in the dense seagrass strata and strata 5. The two dominant seagrasses largely determined the covers for the 6 strata. *Zostera capricorni* seagrass cover ranged from less than 3% in the channel strata to 64.6% in the dense seagrass strata 1. In the very patchy seagrass strata 3, and the very dense seagrass strata 5. *Halophila ovalis* cover was the same as *Z. capricorni* (~ 35 and 58% respectively). The seagrass cover estimates for this year correspond closely with those from 1991/92 except for strata 2. The discreprancy in strata 2 was probably due to the small sample size, and therefore the seagrass cover estimates there were unreliable. The strata with large sample sizes correspond closely between the two years of sampling and there is no obvious evidence that seagrass cover has declined in the study area.

Table 6. Area covered by seagrass in 1992/93 for the six strata sampled in the Fisherman Islands study area. 1991/92 estimates in brackets. Strata 1 – dense seagrass, 2 – worming area, 3 – patchy seagrass, 4 – very patchy seagrass, 5 – uniform/dense seagrass, 6 – channel strata.

Strata	*Zostera capricorni*	*Halophila ovalis*	*Halodule uninervis*	*Halophila spinulosa*
1.	64.6 (60)	45.9 (51)	11.9 (8)	19.1 (8)
2.	33.3 (71)	33.3 (64)	33.3 (7)	0.0 (7)
3.	38.2 (37)	32.4 (34)	0.0 (0)	0.0 (0)
4.	20.0 (28)	0.0 (11)	0.0 (0)	0.0 (0)
5.	57.9 (73)	57.9 (46)	0.0 (0)	0.0 (0)
6.	2.9 (< 1)	5.7 (< 1)	2.9 (< 1)	1.4 (< 1)

Sediment type distribution

The sediment texture at each site was categorised as either mud, sandy mud, muddy sand or sand, input into SPANS and a Voroni map of sediment classes produced (Figure 8).

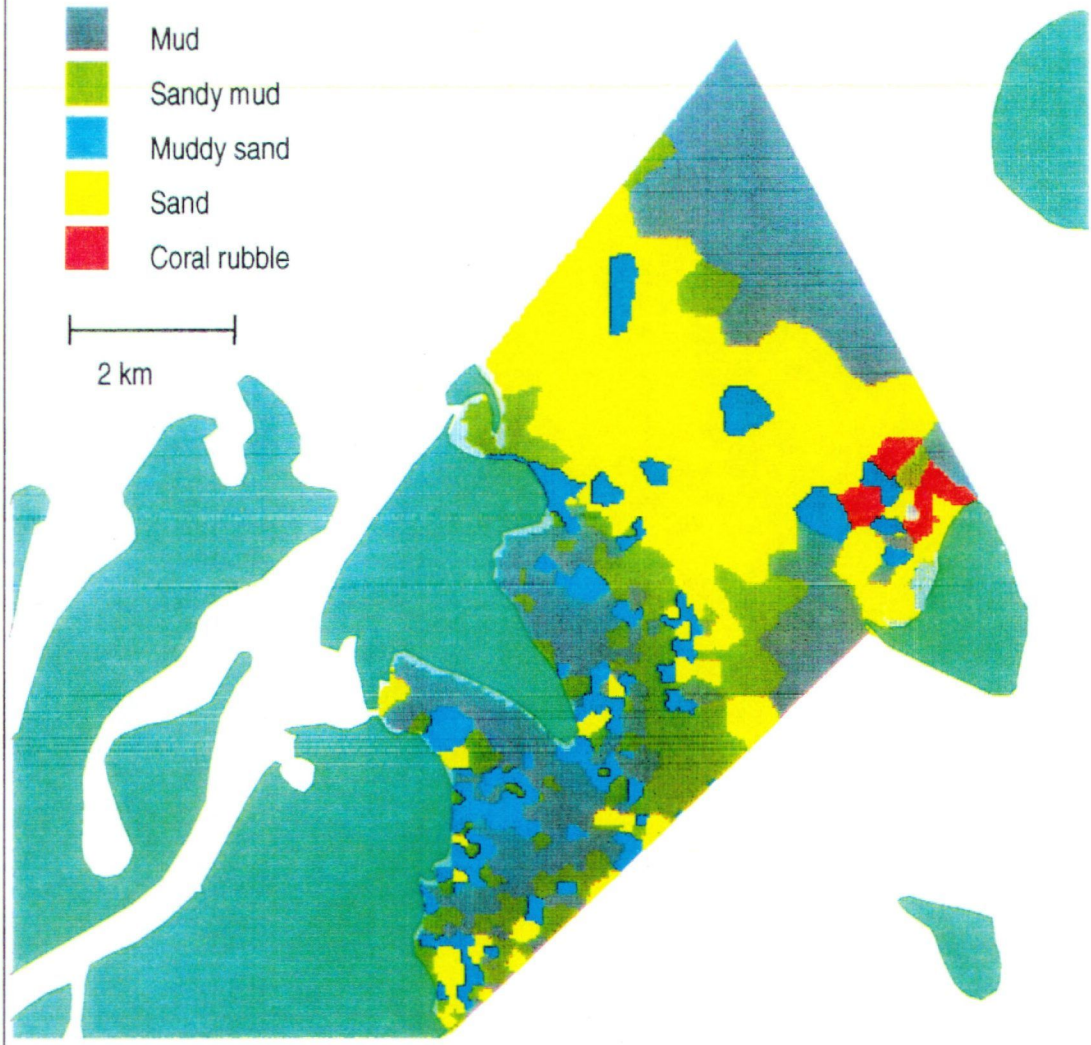

Figure 8. Sediment type map for the Fisherman Islands study area.

The sediments ranged from muds, sandy muds and muddy sands through to sands. Sand was found throughout the study area but formed larger patches subtidally between the intertidal areas and the muds found in the deeper water in the northern section of the study area. The sand found in the intertidal areas and the southern end of the study area was patchy with no obvious pattern. Sandy mud and muddy sand was found throughout the study area but formed largest contiguous patches near the seaward edge of the intertidal area. There were small areas of coral rubble off the western coast

of St. Helena Island.

Changes over time

The seagrass biomass from this study was 2,527.35 ± 463.1 t (18.32%; 95% confidence interval) compared with 2,144 ± 568.22 t (26.51%; 95% confidence interval). This represents a substantial improvement in the reliability of the estimate (from 26.51 to 18.32%) which was due to a more even distribution of *Zostera capricorni* throughout the intertidal study area.

Power curves

For monitoring purposes, it is important to decide how large the change in seagrass biomass is that one wishes to detect. The magnitude of the change is called the effect size (see Cohen 1977 for more details). The sensitivity of the test to detect this change is measured by the power of the test. The sample size required for powers ranging from < 10 to > 90% was calculated for *Zostera capricorni* in strata 1 as a function of effect size. The effect size was defined as percentage change in mean *Zostera capricorni* biomass (Figure 9). The power curves were constructed for *Zostera capricorni* in strata 1 because *Z capricorni* was the numerically dominant seagrass and strata 1 was the largest strata with dense seagrass.

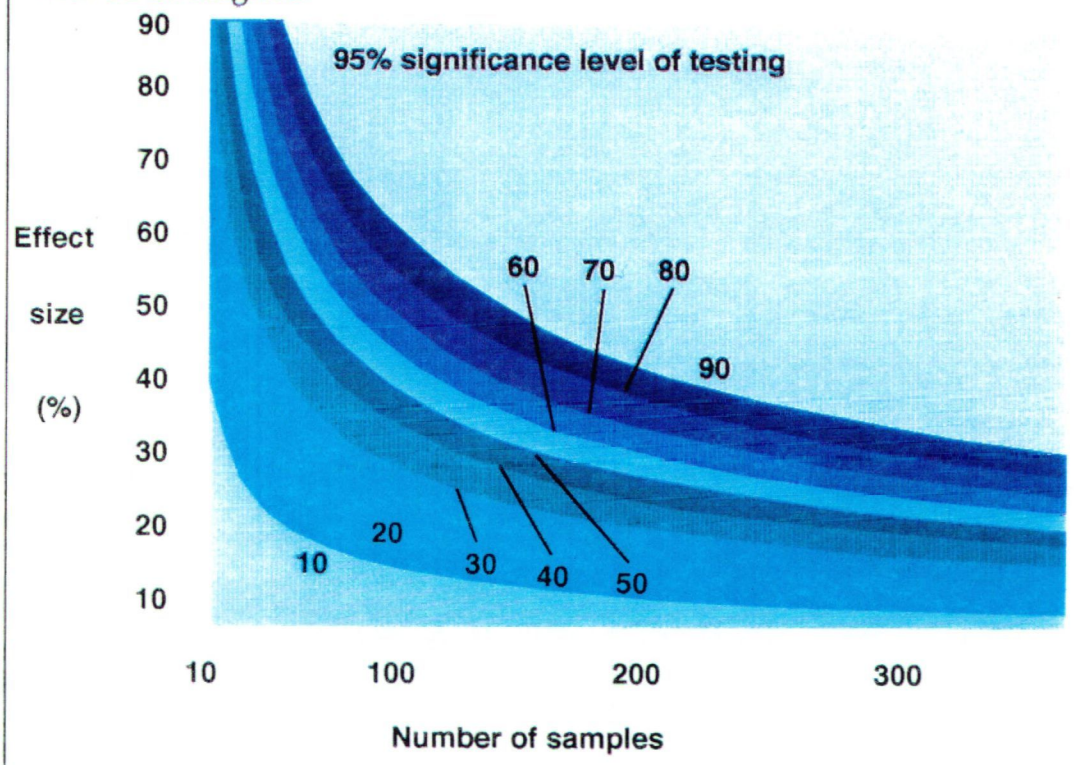

Figure 9. Power curves for *Zostera capricorni* as a function of effect size (% change of the mean) and sample size. The significance level was $\alpha = 0.05$.

The power curves indicated, for example, that a sample size of 300 was required to detect a 35% change in mean *Zostera capricorni* biomass with 80% power in strata 1. Thus with the present sampling design, we can expect to be able to detect about a one third increase or decrease in *Z. capricorni* seagrass biomass with 80% power at the 95% significance level.

DISCUSSION

The main purpose of this study was to apply the monitoring techniques developed from the previous year to estimate seagrass standing biomass one year later. *Zostera capricorni* was still the dominant seagrass (biomass) in the study area and both *Z. capricorni* and *Halophila ovalis* were widely distributed throughout the intertidal areas as before. The precisions obtained in this study were much better than expected, based on the variance estimates from the previous year. This was due to a more even distribution of *Z. capricorni* in the intertidal areas, shown by the reduced variance estimates and the bubble plots of *Z. capricorni*. There was also some evidence that more growth was being diverted into the above rather than below ground plant components, shown by the significant 1.5 times increase in the ratio of above to below ground biomass for *Z. capricorni*.

There was no evidence that there had been changes in seagrass biomass in the study area over the last year. The large sample size used for this study and the dense spatial arrangement of the samples, provide the reliable biomass estimates necessary for such monitoring.

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APPENDIX 1
Equations used for stratified sampling

Terms:

N	total number of possible sampling units in the study area
N_h	total number of possible sampling units in stratum h
n_h	actual number of samples taken in stratum h
y_{hi}	value obtained from ith unit in stratum h
$W_h = \frac{N_h}{N}$	stratum h weight
$f_h = \frac{n_h}{N_h}$	sampling fraction in stratum h
$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$	stratum h mean
$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$	stratified mean over all strata
s_h^2	sample estimate of stratum variance

$$v(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{W^2_h s^2_h}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W^2_h s^2_h}{N}\right)$$

= estimated strata variance

Estimation of sample size for fixed variance $v(\bar{y}_{st})$

$$n = \frac{n_o}{\left(1+\frac{n_o}{N}\right)}$$

where $$n_o = \frac{N}{v(\bar{y}_{st})} \sum_{h=1}^{L} N_h s_h^2$$

APPENDIX 2

Neyman allocation of samples to strata

The optimal allocation of samples, n_h, to strata based on the 1991/92 seagrass above ground biomass (g/m^2) strata means, $\bar{y}_h$, variances, s_h^2, strata weights, W_h, possible number of samples, N_h, and strata area at Fisherman Islands.

Strata	n_h	$\bar{y}_h$	s_h^2	W_h	N_h	Area (km^2)
1. Dense seagrass	209	86.49	73,439	0.211	2,145	8.077
2. Worming Areas	3	53.02	5,079	0.012	118	0.454
3. Patchy seagrass	34	58.70	42,589	0.045	453	1.723
4. Very patchy seagrass	5	20.47	2,093	0.032	326	1.172
5. Very dense seagrass	19	118.82	93,695	0.017	194	0.662
6. Channel	70	7.91	793	0.680	6,875	25.560

Stratified mean, $\bar{y}_{st}$ = 29.69 g/m^2

Stratified variance $v(\bar{y}_{st})$ = 26.61

CSIRO Marine Laboratories Report

Rehabilitation and creation of seagrass meadows — methods of germinating, handling and storing *Zostera capricorni* seeds

Final Report

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EXECUTIVE SUMMARY

- The loss of some seagrass beds in Australia has been well documented, particularly around the temperate and sub-tropical coastlines.
- Recolonisation by seagrass can be hastened by the planting out of propagules.
- Rehabilitating or creating new beds using seeds or seedlings may be relatively inexpensive, and does not destroy existing beds.
- Before seagrass restoration field trials can be undertaken, the physiological and environmental controls of seed dormancy need to be understood so that methods to induce and control germination can be developed. In addition, seed viability testing and seed storage techniques need to be developed.
- In this study, methods were developed for testing the viability and storage of *Z. capricorni* seeds. These methods are cheap and easy to perform, and are consequently suitable for large scale applications.
- A method has also been developed to germinate seeds: incising the seed coat and incubating in low salinity seawater (1-10‰) at a low temperature (15°C). However, this method is labour intensive and consequently expensive and not suitable for large applications.
- Further research is required to develop a more cost effective method of germinating seeds.

BACKGROUND

Developments associated with the expansion of the Port of Brisbane will create areas where seagrass meadows can be promoted. Currently, it is not possible to successfully plant seagrasses. The first step in developing a restoration technique is to select an appropriate planting unit. Studies by CSIRO have shown seeds are the appropriate planting unit for most

tropical and sub-tropical seagrasses, including *Zostera capricorni,* which is the most important seagrass species in central and southern Queensland, including the Fisherman Islands area (2,527 tonnes of biomass) (Long et al., 1993). Furthermore, we know how to collect the large numbers of seeds of this species required for germination and storage trials – 20,000 seeds. However, before seagrass restoration field trials can be undertaken, the physiological and environmental controls of seed dormancy need to be understood so that methods to induce and control germination can be developed. In addition, appropriate seed storage techniques and seed viability tests have to be developed.

OBJECTIVES

- Determine the physiological (developmental) and environmental controls of seed dormancy in the seagrass *Zostera capricorni.*
- Develop methods to induce and control seed germination in *Z. capricorni.*
- Develop a simple, fast and cost-effective seed viability test for *Z. capricorni.*
- Determine appropriate storage techniques for seeds of *Z. capricorni.*

INTRODUCTION

Zostera capricorni the most common seagrass in south east Australia, is predominantly found in sheltered bays, estuaries and coastal lagoons, and in salinities ranging from 3-37‰ (den Hartog, 1970; Harris et al., 1980; West, 1983; Hyland et al., 1989). Its distribution is being adversely affected by human activities (Shepherd et al., 1989) so it is crucial that we learn to maintain the seagrass beds, manage natural recolonisation, and possibly recreate seagrass beds artificially. Development such as at the Port of Brisbane at the river mouth provides a special management area where there will be the opportunity to trial techniques for planting seagrass. An understanding of the germination of *Z. capricorni* is an essential first step.

Rehabilitation and creation of seagrass beds

The loss of some seagrass beds in Australia have been well documented, particularly around the temperate and sub-tropical coastlines (Shepherd et al., 1989). In tropical Australia, seagrass beds have been destroyed by natural causes such as cyclones (Birch and Birch, 1984; Poiner et al., 1989) and movement of sediment (Kirkman, 1978). They have also been removed by the creation of canal estates and marinas and other foreshore modifications (Hyland et al., 1989). It can be demonstrated that seagrass beds may also have been lost as a result of increased turbidity, siltation and nutrients in the bays and rivers, a consequence of rural and urban development (Shepherd et al., 1989).

Rehabilitation and creation of new seagrass beds has received much attention (for a review see Larkum and West, 1983). Recolonisation by seagrass can be hastened by the planting out of propagules. Plugs of *Z. capricorni* and sediment (100-200 cm^2) have been successfully transplanted, and over three years grown to ten times their original size (Harris et al., 1980). Individual shoots of *Z. capricorni* anchored with wire have also been transplanted, and survived for 4 months, before being destroyed by a storm (West et al., 1990). 4-5 m^2 plots of *Z. capricorni* and sediment have also been successfully transplanted using a 20 tonne amphibious excavator (pers obs). However, any form of transplantation, whether by hand or machine, is expensive and requires the destruction, or partial destruction of an existing bed. In contrast, rehabilitating or creating new beds using seeds or seedlings may be relatively inexpensive, and does not destroy existing beds.

Viability trials

If seeds are to be used in rehabilitation or creation of *Z. capricorni* beds it is important that they are viable, that is capable of germination. Germination tests take many weeks to complete, and are inconclusive if the seeds are dormant. Consequently it is important to have a seed viability test that does not rely on germination.

The tetrazolium test is an internationally accepted biochemical test which gives a reliable estimation of the viability of a seed sample. Tetrazolium chloride or bromide is used as an indicator to reveal normal cellular metabolism. The solution is imbibed by the seed, and reacts with hydrogen atoms which are released by the dehydrogenase enzymes during cellular respiration (ie there is a redox reaction). The triphenyl formazan which is released is a stable, non-diffusible red substance, and the presence of this substance makes it easy to distinguish the red-coloured living parts of seeds from the unstained dead ones.

The conditioning, preparation for staining, and staining in a tetrazolium test vary according to the type of seed being tested. As the tetrazolium test had not previously been used on *Zostera capricorni*, appropriate conditioning, preparation and staining techniques needed to be developed.

Germination trials

Before seagrass restoration trials can be undertaken, the physiological and environmental controls of seed dormancy need to be understood so that methods to induce and control germination can be developed.

The germination of *Z. capricorni* has not been studied in either the field or laboratory. However, germination of *Zostera marina* and *Zostera noltii* have been studied. In summary, laboratory and field experiments indicate that low temperature, low salinity and low oxygen potential may all increase germination rates of *Z. marina* (Taylor, 1957; McMillan, 1983; Orth and Moore, 1983; Phillips et al., 1983; Moore et al., 1993), and low salinities increase germination rates for *Z. noltii* (Loques et al., 1990). Germination rates of *Z. noltii* are also much higher for incised than for unincised seeds (Loques et al., 1990).

Storage trials

The seeds of *Z. capricorni* are only available for collection for approximately one month after they have been produced, that is they are not stored in the sediment from one flowering season to the next (Conacher et al., in press). This may not

coincide with the most appropriate time to artificially establish a seagrass bed. Consequently, the use of seeds in the creation and rehabilitation of seagrass beds will be enhanced by the development of storage techniques.

The aims of this study were; to develop a method for determining the viability of seeds; to investigate methods of inducing germination of seeds; and to investigate methods of storing seeds of the seagrass *Z. capricorni* .

METHODS

The study area

Moreton Bay (27° 25′ S 153° 20′ E) is a large semi-enclosed bay in subtropical southern Queensland. In Moreton Bay, *Z. capricorni* flowers between September and April (Young and Kirkman, 1975; Conacher et al., in press). Seeds are mainly found at the time of flowering and a large bank of seeds in the sediment does not develop (Conacher et al., in press). Whilst flowering in *Z. capricorni* is extensive, propagation appears to be almost entirely vegetative, and seedlings are only rarely found (Ferguson Wood, 1959; Harris et al., 1980).

The salinity range in western Moreton Bay is from 22-36‰, with lower salinities following heavy rainfall. The mean winter water temperature is approximately 16°C, with a minimum of 12°C, and the mean summer water temperature is 28°C, with a maximum of 30°C (O'Brien, 1992).

Seed collection

The proposed germination and storage trials, and the viability testing, required large numbers of seeds (20,000 to 40,000/species) so as to have statistically valid sample sizes and levels of replication. Seeds of the sub-tropical seagrass *Zostera capricorni* were collected from Moreton Bay where CSIRO has monitored seagrass for the past 5 years and hence has detailed knowledge of the spatial and temporal variability of seed production, and the fate of seeds. Seeds were collected from an intertidal sandbank covered with the short-leafed form of *Z. capricorni* in the Rous Channel, Moreton Bay (27°25'S 153°22'). The top 3 cm of sediment was collected using a shovel, and immediately sieved through 0.5 mm mesh, which

retained the seed. The seagrass was gently rinsed in seawater to dislodge mature seeds, and these were added to the seeds and sediment. The resulting mixture was stored in seawater, aerated, and transported to a nearby laboratory, where it was re-sieved and individual seeds were picked out and stored in aerated seawater. Seeds were collected in January, at the peak of the flowering season. All experimental trials began within 48 hours of collecting the seeds.

Viability trials

In the viability trials two tetrazolium concentrations (0.5 and 1.0%) at two staining temperatures (20 and 25°C) were studied. The seed coat was removed from the seeds to allow the tetrazolium solution to come into contact with the embryo. For each treatment 2 replicate groups of approximately 25 seeds were incubated. The colour of the radicle and of the hypocotyl (red, brown or unstained) were recorded for each seed after 2, 4, 20, 24, 48 and 72 hours. The results of the treatments were then compared to the results from the most successful germination trials.

Germination trials

The germination trials were divided into two experiments. In experiment 1 we investigated the effects of a variety of chemical and physical treatments on germination (Table 1). In the second experiment we studied the effects and interactions of temperature (15, 20, 25, 30, 20/30°C), salinity (1, 5, 10, 20, 30 and 40‰) and incising the seed coat on germination. For each treatment in both experiments, 25 seeds were put in each of two glass Petrie dishes and irrigated with the treatment medium. The seeds were then covered with the top of the Petrie dish, and placed in growth cabinets, with 12 hours of light and 12 hours of darkness, and irrigated with the treatment medium as necessary to prevent dehydration. In the control treatment the seeds were kept at 25°C and irrigated with artificial seawater ('Instant Ocean') at 35‰. These were the standard conditions used and, unless otherwise stated, all seeds in the trials were treated this way. The number of germinated seeds in each treatment was recorded approximately every 5 days for 28 days.

Storage trials

Seeds were stored in aerated sea water at room temperature (22-24°C), in aerated, chilled sea water (5-10°C), and in anaerobic sediment at room temperature (22-24°C), all in the dark. The viability of seeds from the aerobic treatments was tested after 0, 10, 14, 21, 50, 91, 183, 316 and 534 days using tetrazolium, and the viability of seeds in the anaerobic treatment was tested after 0, 91 and 316 days. In each test 3 samples of 30 seeds from each treatment were soaked in 0.5% tetrazolium for 24 hours at 25°C.

DATA ANALYSIS

Germination trials

Data from the first experiment, in which a variety of physical and chemical treatments were used, were analysed by a one way analysis of variance (ANOVA).

Data from the second experiment were analysed by a three way, nested, analyses of variance. Temperature (T), salinity (S) and incision (I) were treated as fixed, orthogonal factors. Because the effect of incising the seeds was so marked the data for incised and unincised seeds were also analysed separately in two way analyses of variance in which temperature (T) and salinity (S) were treated as fixed, orthogonal factors.

The data used in these analyses was the number of seeds that had germinated after 28 days. The data from both experiments were homoscedastic (Cochrane's $C \propto = 0.05$) so no transformations were necessary. Where ANOVA indicated significant differences among means, the Student-Newman-Keuls (SNK) and examination of plots of the variables were used to distinguish among them.

Storage trials

Linear regressions for seed viability for each storage treatment were calculated so that viability after a given period could be calculated.

RESULTS

Viability trials

Soaking the seeds in 0.5% Tetrazolium at 25°C for 18-24 hours, gave the most consistent staining pattern. With this treatment, the hypocotyl of viable seeds stained red and the radicle either red or brown. With the other treatments, there was either understaining or overstaining. 100% positive staining corresponded with 100% germination in the germination trials.

Germination trials

Experiment 1

Analysis of variance confirmed that there were marked differences in the number of seeds that had germinated between the treatments (Table 2). After 28 days the treatments that promoted the highest germination were: pretreating the seeds by soaking them for 4 days in fresh water (26% germinated s.e. 2.0); soaking the seeds in 0.2‰ KNO_3 (24% s.e. 8.0); soaking the seeds in 50 ppm Thiourea (20% s.e. 0.0); and removing the seed coat and using a 20/30°C day/night cycle (18% s.e. 2.0). Some seeds also germinated when the seeds were incubated on agar (10% s.e. 10.0) and when the seed coat was removed and the seeds were kept at a constant 25°C (2% s.e. 2.0) . No seeds germinated in the control, cold night (15/25°C), warm day (20/30°C), floating, chill, dark, GA_3 500 ppm and Thiourea 500 ppm treatments (Fig 1).

Experiment 2

Analysis of variance confirmed that incising the seed coat had a significant effect on germination (Table 3). 49% (s.e. 4.8) of the incised seeds had germinated after 28 days while only 8% (s.e. 1.1) of the unincised seeds had.

Salinity had a significant affect on germination of both incised and unincised seeds (Tables 4 and 5). Germination was highest at 1, 5 and 10‰ for both the incised and unincised seeds. 93% (s.e. 1.0) of the incised seeds germinated at these salinities, whereas only 13% (s.e. 7.1) germinated at 20‰, 2.33% (s.e. 7.1) germinated at 30‰ (s.e. 2.5) and .0.3% germinated at 40‰ (Fig 2).

Temperature and the interaction between temperature and salinity also had significant effects on germination of the incised seeds. The seeds in 20, 30 and 40‰ only germinated at 15°C. Germination of seeds in 1, 5 and 10‰ was slightly higher at the lower temperatures (Fig 3). In the unincised seeds, temperature and the interaction between temperature and salinity were not significant.

Storage trials

Seeds stored aerobically at 5-10°C retained their viability for longest. After 50 days 79% (s.e. 1.5) of these seeds were still viable. However there was a rapid decrease in viability after 50 days, with only 19% (s.e. 10.4) viable at 91 days, and none viable after 18 months (Fig 4). 38% (s.e. 2.7) of the seeds stored aerobically at 22-24°C were viable after 21 days, whilst none were viable after 50 days. 14% of the seeds stored anaerobically at 22-24°C were viable after 91 days, and none after 316 days (Fig 4).

The regression for the percentage of viable seeds for the aerobic treatment at 22-24°C is:
$y = 72 - 1.6x \quad r^2 = 0.60$

for the aerobic treatment at 5-10°C is:
$y = 64.4 - 0.16x \quad r^2 = 0.71$

and for the anaerobic treatment at 22-24°C is:
$y = 98 - 1.68x \quad r^2 = 0.99$

where y = % viable seeds and x = the number of days .

CONCLUSIONS

A quick and effective means of determining the viability of *Z. capricorni* seeds was developed. This method can now be used to ensure that seeds are viable before they are used in rehabilitation projects or in further studies of the germination and growth of seedlings.

Making an incision in the seed coat promoted rapid and almost complete germination. The seed coat of *Z. capricorni* may be a relatively impermeable barrier, which prevents ingress of water, and reduces gas exchange between the embryo

and its surroundings, as Loques et al. (1990) suggested for *Z. noltii*. The seed may be unable to germinate unless this barrier is broken in some way. In intertidal and subtidal areas the seed coat may be broken by gentle abrasion of the seed coat against grains of sediment.

Like *Z. noltii* and *Z. marina* low salinities (1-10‰) promoted higher germination rates of incised and unincised seeds. At low salinities the seeds may absorb water, bursting their teguments, or low salinities may act directly on embryo development by promoting hydration of the tissues and respiration (Loques et al., 1990). Seeds in salinities of 20, 30 and 40‰ only germinated at low temperatures (15°C). In Moreton Bay salinities are rarely as low as 1-10‰ (Patterson and Witt, 1992), consequently *Z. capricorn*i is most likely to germinate in winter. Paradoxically, *Z. capricorn*i seeds are produced in spring and summer and very few can be found in winter (Conacher et al., in press). This suggests that another physical factor, perhaps low oxygen potential in the sediment (Moore et al., 1993), may also promote germination.

Weak solutions (50 ppm) of Thiourea, GA_3 and a 0.2‰ solution of KNO_3 also promoted germination. Thiourea is used to break dormancy in many seeds, stimulating germination, while the internal concentration of Thiourea in the seed is comparatively low. However, it is also known to inhibit growth so it is probably not suitable for the mass production of *Z. capricorni* seedlings. Both GA_3 and KNO_3 have been used to promote germination in other seeds; however, the exact mechanism of their actions are unknown (Mayer and Poljakoff-Mayber, 1975).

The best method for storing seeds is keeping them in aerated water at 5-10°C. Under this regime there is a gradual decline in seed viability from 100% when first collected to 19% after 13 weeks. That is in a rehabilitation project, it would be wise to use the seeds as soon as possible, and certainly within 13 weeks of collection.

Both germination rates and storage life of *Z. capricorni* seeds were highest at low temperatures. This may be an indication

that *Z. capricorni* is better adapted to temperate rather than tropical and subtropical climates. *Z. capricorni* is found along the east coast of Australia from Mallacoota (37° 33′ S 149° 45' E) in the south (Jacobs and Williams, 1978) to approximately 16° S (Lee Long et al., 1993). An isolated patch has also been recorded at Prince of Wales Island (10° 37' S 142° 10' E), in the Torres Strait (Long pers. com., 1990). That is whilst Moreton Bay is approximately the midpoint of the latitudinal range of *Z. capricorni* , it does not correspond with ideal conditions for germination and storage of seeds. In south eastern Australia (37-27° S) *Z. capricorni* is the most common species and is found in salinities ranging from 1-35%, whereas in north eastern Australia (27-16° S) it is restricted to areas of low salinity and is not one of the most common species (Lee Long et al., 1993). It would be interesting to compare growth rates of *Z. capricorni* at different latitudes, and at different salinities and temperatures, to see if these were also higher at low temperatures and salinities.

In summary, methods have been developed for testing the viability and storage of *Z. capricorni* seeds. These methods are cheap and easy to perform, and are consequently suitable for large scale applications. A method has also been developed to germinate seeds: incising the seed coat and incubating in low salinity seawater (1-10‰) at a low temperature (15°C). However, this method is labour intensive and consequently expensive and not suitable for large applications. Further research is required to develop a more cost effective method of germinating seeds.

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Table 1: Chemical and physical treatments used in Experiment 1

Treatment	Description
Control	12 hours light, 12 dark. 25°C, 35‰ salinity
Cold night	25/15°C day/night cycle
Warm day	30/25°C day/night cycle
Agar	agar substrate (35‰ salinity)
Floating	seeds floating (35‰ salinity)
Fresh	96 hour pretreatment in fresh water (0‰)
Chill	96 hour pretreatment at 10°C
Dark	no light
GA_3 50 ppm	GA_3 50 ppm (35‰ salinity)
GA_3 500 ppm	GA_3 500 ppm (35‰ salinity)
Thiourea 50 ppm	Thiourea 50 ppm (35‰ salinity)
Thiourea 500 ppm	Thiourea 500 ppm (35‰ salinity)
KNO_3	0.2‰ KNO_3 (35‰ salinity)
Coat removed	Seed coat removed
Coat removed 2	Seed coat removed, 30-20°C day night cycle

Table 2: Analysis of variance of the number of germinated seeds (Germination Experiment 1)

Source	df	MS	F	Test df	Sig.
Between	14	13.0	7.5	14, 15	p= 0.0002
Within	15	1.8			

Table 3: Analysis of variance of the number of germinated seeds (Germination Experiment 2). I = incision, T = temperature, S = salinity.

Source	df	MS	F	Test df	Sig.
I	1	2920	986	1, 120	p= 0.0001
T	4	7	2	4, 120	p= 0.0723
S	5	912	308	5, 120	p= 0.0001
I x T	4	14	5	4, 120	p= 0.0120
I x S	5	474	160	5, 120	p= 0.0001
T x S	20	12	4	20, 120	p= 0.0001
I x T x S	20	9	3	20, 120	p= 0.0001
Residual	120	3			

Table 4: Incised seeds: analysis of variance of the number of germinated seeds (Germination Experiment 2). T = temperature, S = salinity

Source	df	MS	F	Test df	Sig.
T	4	18	4	4, 60	p= 0.0080
S	5	1333	285	5, 60	p= 0.0001
T x S	20	21	4	20, 60	p= 0.0001
Residual	60	5			

Table 5: Unincised seeds: analysis of variance of the number of germinated seeds (Germination Experiment 2). T = temperature, S = salinity

Source	df	MS	F	Test df	Sig.
T	4	12	3	4, 60	p= 0.05780
S	5	263	53	5, 60	p= 0.0010
T x S	20	29	1	20, 60	p= 0.3241
Residual	60	75	1		

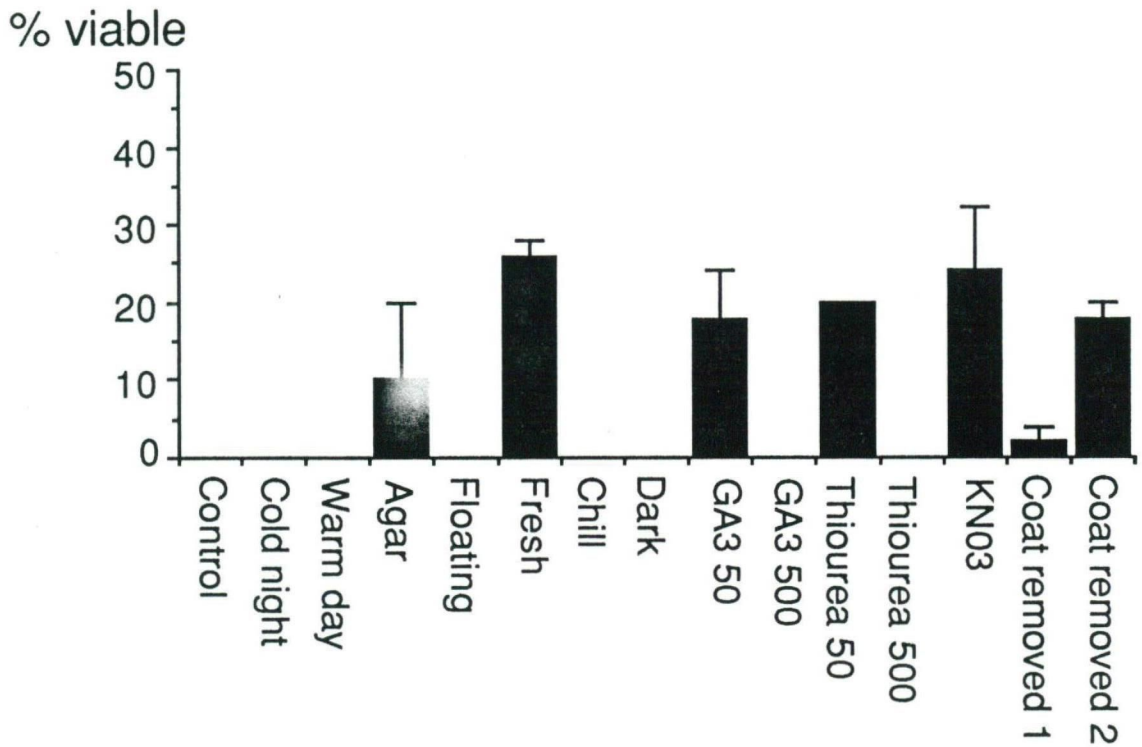

Figure 1: The percentage of seeds that germinated per treatment in Experiment 1 (± 1 s.e.).

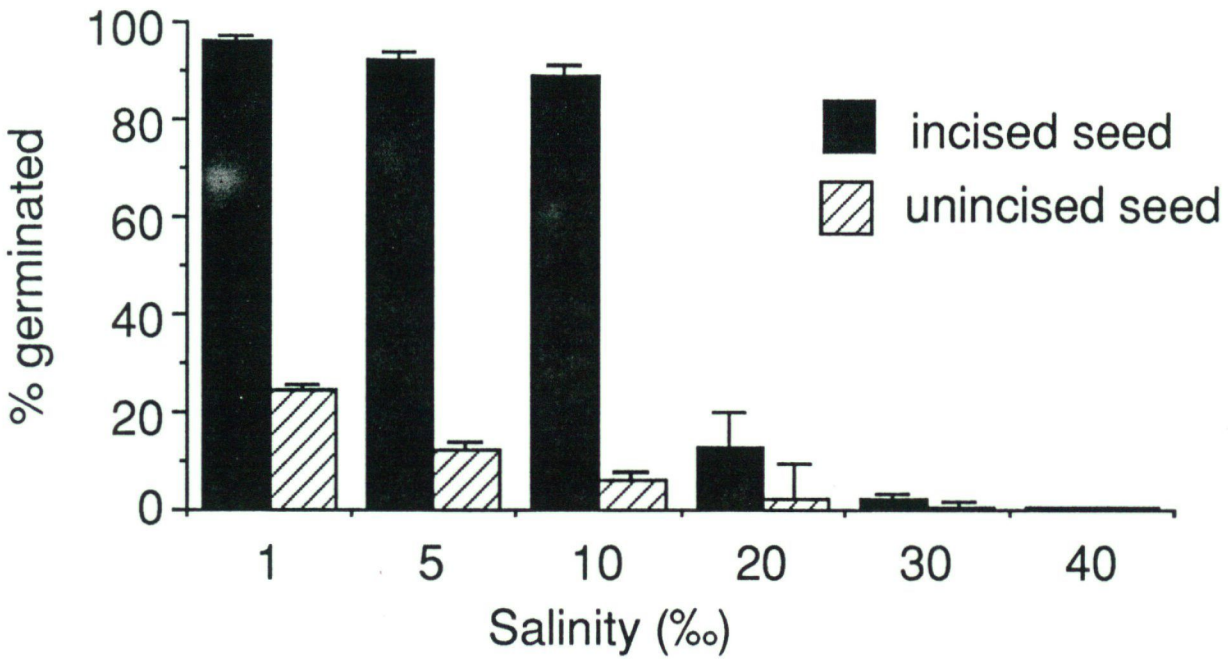

Figure 2: The percentage of seeds that germinated in each salinity in Experiment 2 (±1 s.e.)

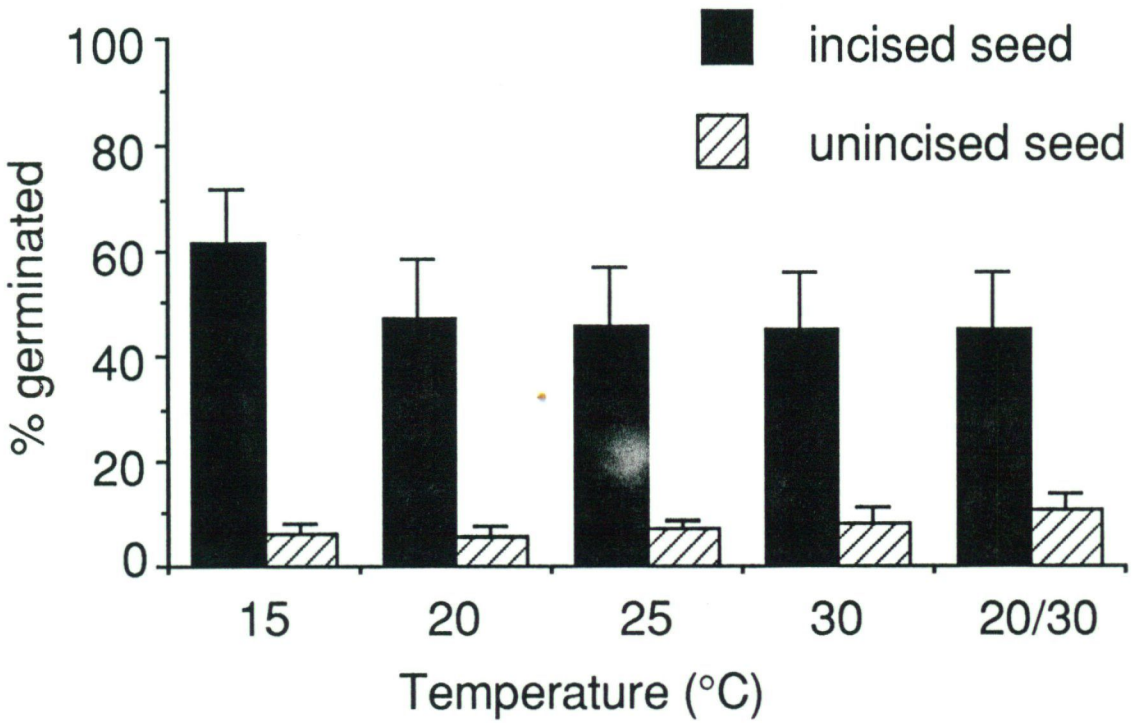

Figure 3: Th e percentage of seeds that germinated in each temperature in Experiment 2 (± 1 s.e.)

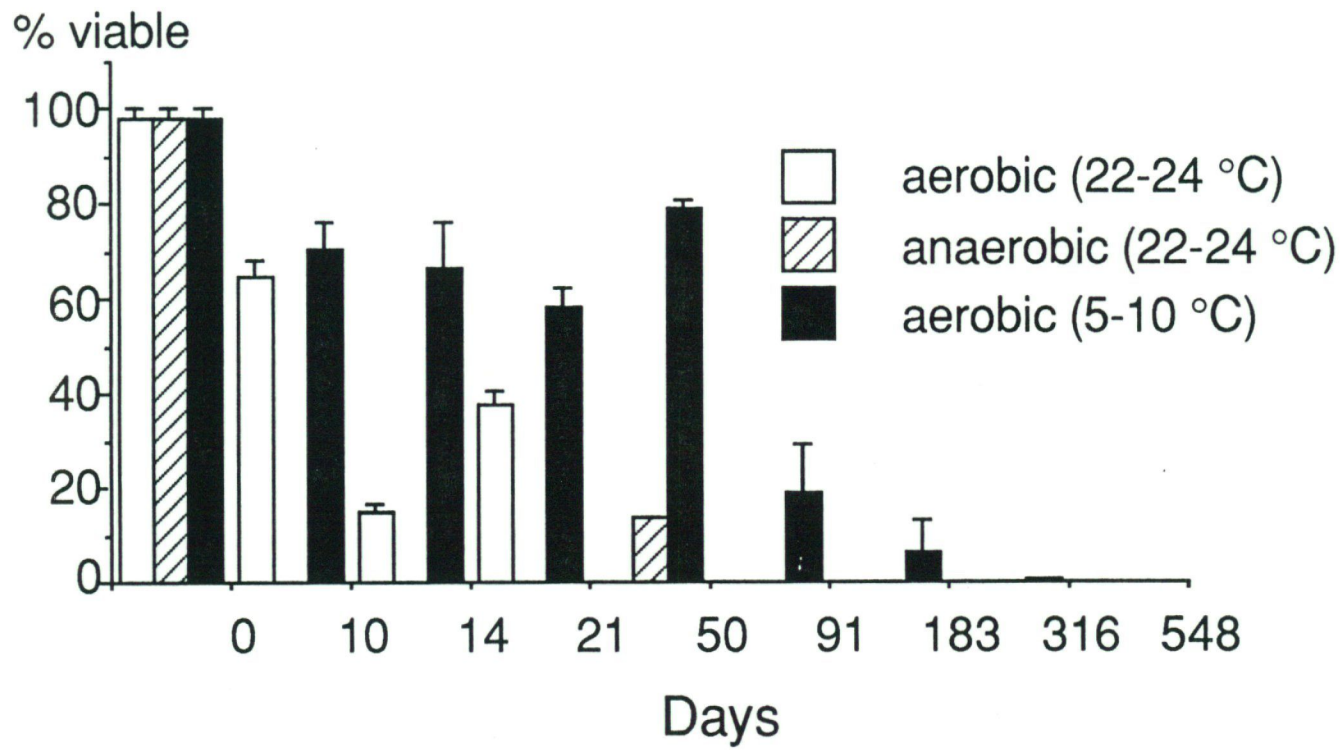

Figure 4: The percentage of viable seeds after storage in: aerobic seawater at 22-24 °C; anaerobic storage at 22-24 °C; and aerobic storage at 5-10 °C.

CSIRO Division of Fisheries
Final Report

Monitoring Seagrass Beds at Fisherman Islands, Moreton Bay, Queensland

Final Report to the Port of Brisbane Corporation for the year 1993 – 1994

Brian Long
Robert Kenyon
Ian Poiner
Neil Loneragan



July 1994

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This report summarises three years (1991–1994) of research by the CSIRO Division of Fisheries to monitor the seagrass beds of Fisherman Islands for the Port of Brisbane Corporation. Techniques were developed in 1991/92 for cost-effective, efficient and reliable seagrass biomass estimation, and these were applied in 1992/93 and 1993/94 to monitor changes in seagrass biomass.

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Executive Summary

- Fisherman Islands, near the mouth of the Brisbane river are managed by the Port of Brisbane Corporation (PBC). This area has extensive seagrass beds and mangal forests which have been shown to be important nursery habitat for prawns and fish, and foraging and roosting habitat for wading birds. The Port of Brisbane Corporation is expanding its facilities at Fisherman Islands and needed to develop cost-effective monitoring techniques to assess the effect of the development on these resources.
- CSIRO was contracted to develop the monitoring techniques and to provide PBC with a range of cost options for obtaining seagrass biomass estimates with known reliability (Long and Poiner 1992). These methods were used in 1991/92 and 1992/93 to provide seagrass biomass estimates for the Fisherman Islands study area (Long and Poiner 1992; Long *et al.* 1993; Long *et al.* 1994).
- CSIRO was contracted in 1993/94 (this study) to continue to monitor the seagrass beds and to report on any changes in the study area over the last three years. The seagrass beds were sampled from 20 December 1993 to 6 January 1994. A sample size of 340 was required, based on Neyman allocation of samples to strata, to give a precision of around 15%.
- Four seagrasses were sampled in the study area, *Zostera capricorni, Halophila ovalis, Halophila spinulosa* and *Halodule uninervis*. The dominant seagrass, in terms of biomass, was *Zostera capricorni*.
- The estimated seagrass biomass for the study area was 2355 ± 273 t (95% confidence interval; precision = 5.9%) for the 1993/94 study period. The estimate for 1992/93 was 2678 ± 491 t (95% confidence interval; precision = 9.4%) and 2180 ± 547 t (95% confidence interval; precision = 12.8%) for 1991/92. The precision, defined as the mean divided by the standard error of the mean and expressed as a percentage, has improved over the three year study period because the dominant seagrass, *Zostera capricorni,* has become more uniformly distributed in the intertidal areas over the three year study period.
- There was no significant difference in seagrass biomass ($P > 0.05$) between the three years.
- The area covered by seagrass has remained essentially unchanged over the previous two years. This was shown in the Dense seagrass stratum 1, where the area covered by seagrass has changed less than 2% over the last two years (82.5% in 1992/93 and 83.9% in 1993/94). In contrast the area covered by seagrass has increased from 55% in 1991/92 to greater than 80% in 1992/93 and 1993/94.

Introduction

Fisherman Islands near the mouth of the Brisbane River forms part of the Port of Brisbane and is managed by the Port of Brisbane Corporation (PBC) (Fig. 1). The PBC carried out a base-line resource inventory of the Port area in 1991/92 to assess and minimise any environmental impacts of future Port development (PBA 1994). The PBC is expanding its facilities by reclaiming land off the north-eastern end of Fisherman Islands along the existing quay-line. The areas adjacent to the development have extensive mangroves and seagrass beds that are important nurseries and habitat for prawns, fish and birds. In 1991/92 the CSIRO Division of Fisheries mapped the mangroves and seagrass as part of a project to develop techniques for cost-effective monitoring of these resources (Long and Poiner 1992; Long *et al.* 1993; Long *et al.* 1994). The seagrass beds were monitored in 1992/93 and 1993/94 to detect any changes in seagrass biomass over time

This report presents the results of the 1993/94 seagrass monitoring and the results of the analysis of the three years data to quantify any changes in seagrass distribution and abundance in the Fisherman Islands study area over the three year study period.

The data and results from this, and the previous studies was entered into a Geographic Information System (GIS) to provide a permanent, geo-coded database. This will form the basis of future monitoring of Fisherman Islands seagrass beds and mangal forests by the PBC.

Methods

Geographic Information System

A digital map of Fisherman Islands in DXF format (Autocad ® digital exchange format) provided by the Port of Brisbane Corporation was input into a SPANS® GIS. This map did not cover the entire study area (Fig. 1). The coastline west of Fisherman Islands was digitised from topographic charts of the area (Wynnum Topographic Map 1:25000, 1984; Bishop Island Topographic Map 1: 25000, 1971).

Study area stratification 1991-1994

The study area was stratified by hand-digitising seven ground-cover types identified from colour aerial photographs provided by the Port of Brisbane Corporation. The photographs were taken at low tide (0.2 m) at 14:30 on 7 September 1991 at an altitude of 3000 m. The Hasselblad camera was fitted with a blue polarising filter to reduce sun glare and highlight areas of seagrass.

Initially, six seagrass and one channel stratum were identified (Fig. 2). The channel stratum was defined as all areas in the aerial photograph where we could not discern the seabed. The six seagrass strata were classified as: (1) intertidal, Dense seagrass beds on the mudflats off Fisherman Islands; (2) Worm digging areas (where professional bait fishermen dig for nereid worms) in dense seagrass beds; (3) Patchy seagrass areas; (4) Very patchy seagrass areas; (5) seagrass beds near Oyster Point; (6) Dense seagrass along the west side of St. Helena Island. However, stratum 5 and 6 were combined into one (Uniform/dense seagrass) stratum after the initial sampling because the strata had similar variance estimates (Long *et al.* 1993).

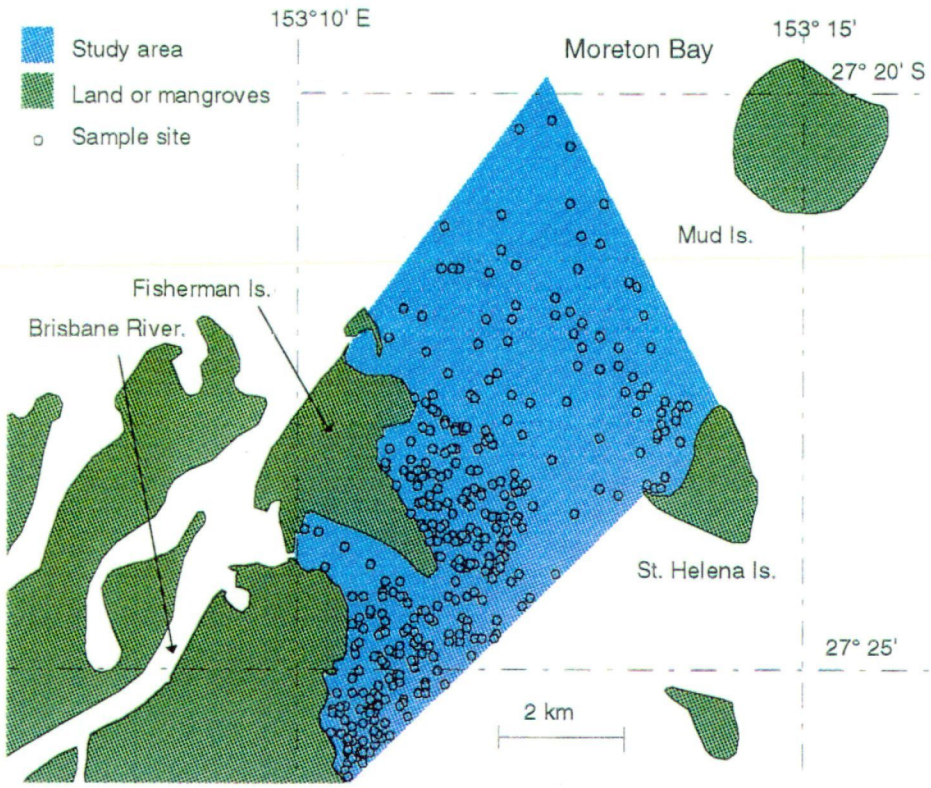

Figure 1. Fisherman Islands study area showing the sites sampled for seagrass and sediment.

The study area was divided up into 60 m × 60 m squares, the smallest area that could reliably be located in the field using the Global Positioning System (GPS) with one receiver. A complete list of all potential sample sites for each stratum was generated by the GIS, put into a database and a random subset was selected for sampling.

Sample design 1993/94

Neyman allocation was used to minimise the variance for a fixed sample size (eq. 1) and each stratum was allocated sampling effort according to above-ground seagrass biomass variance estimates from the 1991/92 study and the area of the stratum (Cochran 1977). Thus a larger sample was taken if the stratum was larger or the stratum is more variable internally (eq. 2).

$$v_{\min}(\bar{y}_{st}) = \frac{(\sum W_h S_h)^2}{n} - \frac{\sum W_h S_h^2}{N} \qquad \text{eq. 1}$$

$$n_h = n \frac{N_h S_h}{\sum N_h S_h} \qquad \text{eq. 2}$$

where $\bar{y}_{st}$ is the stratified mean, N is the total number of sample units, N_h is the potential number of sample units in stratum h, W_h is the stratum weight, $\frac{N_h}{N}$, n_h is the number of samples taken in stratum h, n is the number of samples taken, and S_h^2 is the stratum variance.

The variance estimates from the 1991/92 sampling period indicated that a sample size of 340, with Neyman allocation of samples to strata, was needed to give a precision of around 15% of the mean for seagrass above-ground biomass (Appendix 1). The study area was sampled from 20 December 1993 to 5 January 1994 (Fig. 2). There were 211 samples taken in the Dense seagrass stratum 1, 4 samples taken in the Worm digging areas (stratum 2), 34 samples taken in the Patchy seagrass areas (stratum 33), 6 samples taken in the Very patchy seagrass areas (stratum 4), 17 samples taken in the Uniform/dense seagrass areas near Oyster Pt and St. Helena Island (stratum 5) and 68 samples taken in the Channel (stratum 7).

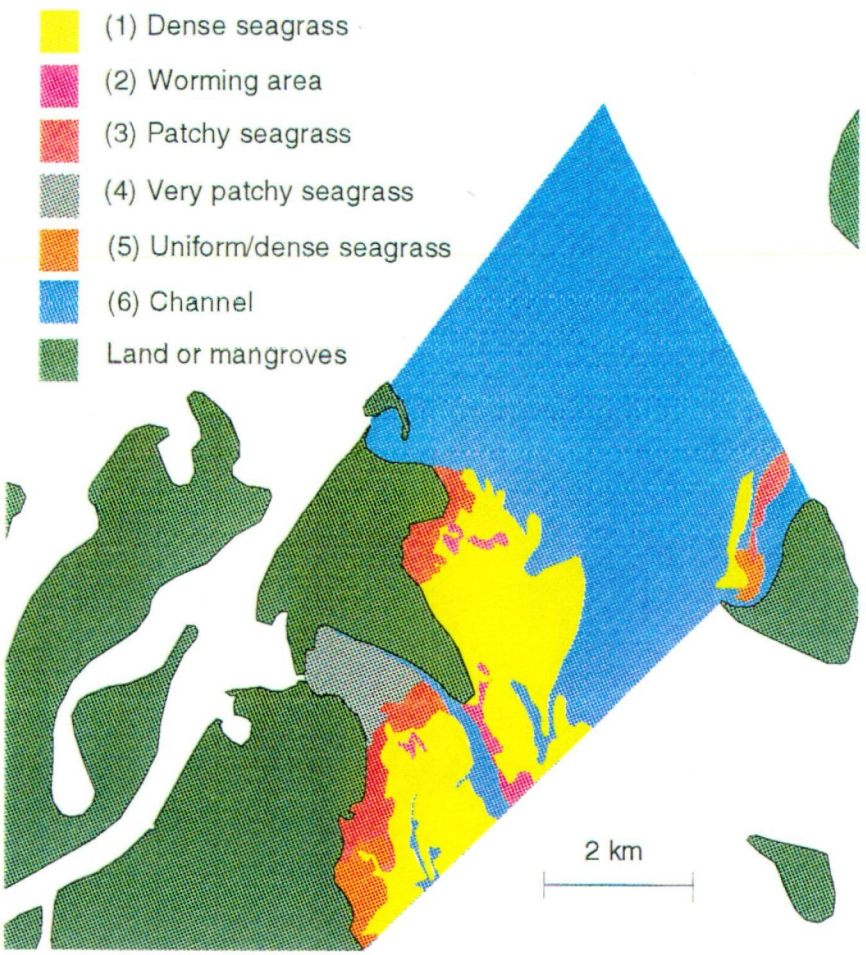

Figure 2. Fisherman Islands study area showing the six strata identified from colour aerial photographs.

Field work

Sites were located in the field with a GPS receiver. At each site, a sample of the bottom was taken with a hand-operated seagrass grab (Long *et al.* 1994). A 4.5 m dinghy was used for transport to sample sites and as a platform to operate the grab.

Sample processing

The seagrass samples were sorted into species and the number of shoots per species counted. For each species the above-ground shoots and stems were separated from the below-ground rhizomes, dried at 60° for 48 h and weighed to the nearest 0.1 g.

Species distribution

Bubble plots of seagrass above-ground biomass were produced to illustrate spatial patterns in seagrass distribution in the Fisherman Islands study area.

The area of the bubble was proportional to the seagrass above-ground biomass to give a true representation between bubble area and seagrass biomass values.

Area covered by seagrass

The area covered by seagrass (%) was calculated as the proportion of samples where seagrass was present.

Seagrass biomass estimates

The mean values for seagrass biomass and shoot-density for the six strata were estimated using the formulae given in Appendix 1. The six strata means and strata variances were combined using the formulae in Appendix 1 to obtain the stratified mean and variance of the stratified mean. The stratified mean and variance of the stratified mean were used to estimate the total seagrass biomass and the upper and lower 95% confidence interval for the biomass estimate in the study area.

Ratio of above- to below-ground biomass

The ratio of above- to below-ground biomass was calculated for each sample by dividing the above-ground biomass by the below-ground biomass. The ratio of above to below-ground seagrass biomass provides a useful indicator of change in seagrass growth patterns due to physiological and other disturbances. Changes in this ratio may indicate a response to environmental impact. The variation of this ratio, standardised relative to the mean, (coefficient of variation) may also provide an indicator of change in seagrass growth pattern. A *t*-test was used to compare differences in the ratios of above- and below-ground biomass.

Sediment texture analysis

Qualitative measurements of sediment texture were taken by squeezing a small handful of sediment taken from a grab sample and classifying the sediment as either mud, sandy mud, muddy sand, sand or rubble. A sediment-texture map was produced for the study area by creating a mosaic of irregular shaped polygons that were centred on the sample locations and by classifying each polygon according to sediment type. The technique used to produce a mosaic of classified polygons is shown in Figure 3.

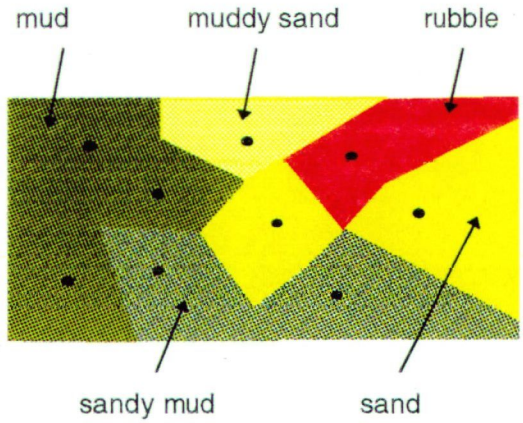

Figure 3. Technique used to produce a sediment map by classifying polygons according to sediment type recorded at each point.

Results

Species distribution

Four seagrass species were collected from the study area during the December 1993/ January 1994 sampling period. Ranked by biomass they were *Zostera capricorni, Halophila ovalis, Halophila spinulosa* and *Halodule uninervis*. Above- and below-ground seagrass biomass and shoot-density were significantly correlated ($P < 0.05$), so only bubble plots of above-ground biomass are presented (Table 1).

Table 1. Correlation coefficients, *r*, and significance levels for the relationship between above (AGB) and below-ground biomass (BGB), shoot density (ShD) and leaf area (LfA) for the December 1993/January 1994 sampling period in the Fisherman Islands study area, for *Zostera capricorni* (*n* = 166) *Halophila ovalis* (*n* = 100), *Halodule uninervis* (*n* = 12), *Halophila spinulosa* (*n* = 35). ** $P < 0.01$.

Species	AGB / BGB	AGB / ShD	AGB / LfA	BGB / ShD	BGB / LfA	LfA / ShD
Z. capricorni	0.57**	0.11**	0.72**	0.11	0.23**	-0.03
H. ovalis	0.88**	0.63**	0.61**	0.53**	0.52**	0.24**
H. uninervis	0.77**	0.82**	0.67**	0.74**	0.96**	0.59*
H. spinulosa	0.95**	0.94**	0.67**	0.92**	0.71**	0.66**

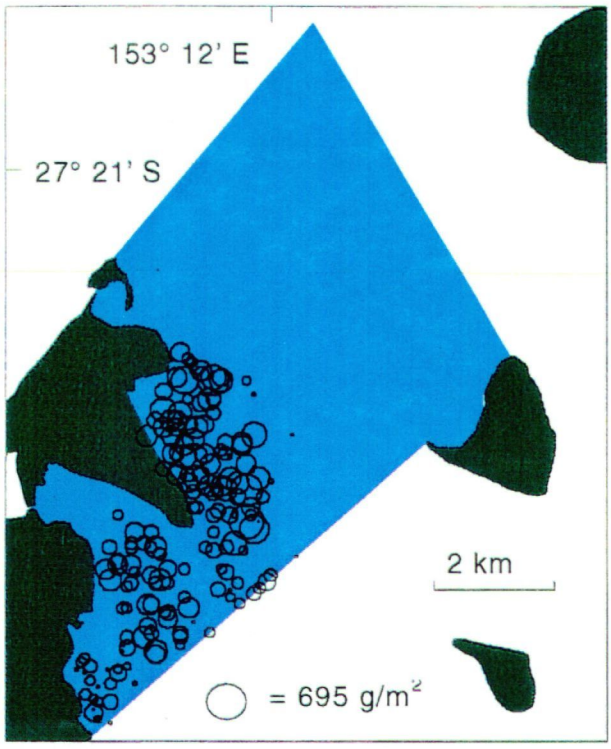

Figure 4. *Zostera capricorni*, above-ground biomass distribution in the Fisherman Islands study area in the December 1993/January 1994 sampling period.

Zostera capricorni and *Halophila ovalis* were the dominant seagrasses in the study area in terms of biomass. *Zostera capricorni* was uniformly distributed throughout the intertidal areas and was collected at 167 of the 340 sites (Fig. 4). Above ground biomass ranged up to 695g/m^2. The stratified mean, $\bar{y}_{st}$, was 28.1 g/m^2 and the estimate of the variance of $\bar{y}_{st}$, $v(\bar{y}_{st})$, was 4.16. Below ground biomass reached a maximum of 625 g/m^2, with a stratified mean of 26.4 g/m^2 and $v(\bar{y}_{st})$ of 3.92. Shoot density peaked at 26500 shoots/m^2. The stratified mean was 254.3 shoots/m^2 and $v(\bar{y}_{st})$ was 1098. The maximum leaf area recorded was 0.78 m^2/m^2.

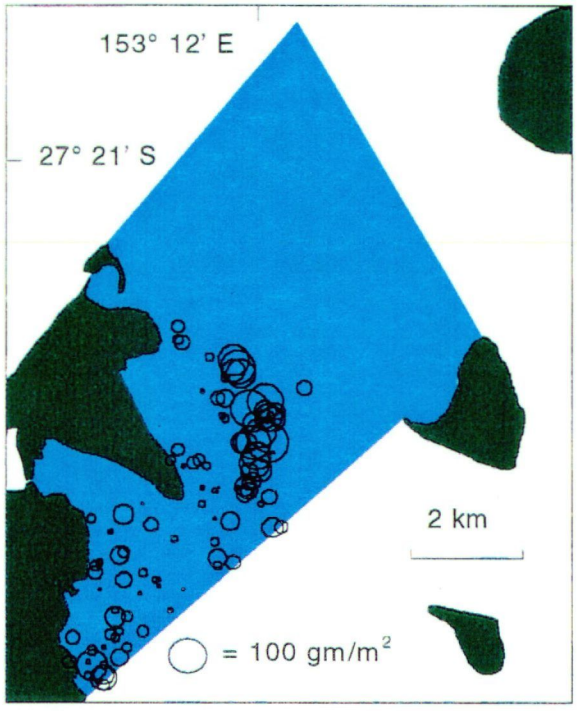

Figure 5. *Halophila ovalis,* above-ground biomass distribution in the Fisherman Islands study area in the December 1993/ January 1994 sampling period.

Halophila ovalis also occurred extensively throughout the study area and was sampled at 100 of the 340 sites (Fig. 5). The maximum above-ground biomass was 103 g/m^2. The stratified mean, $\overline{y}_{st}$, was 2.19 g/m^2 and the estimate of the variance of $\overline{y}_{st}$, $v(\overline{y}_{st})$, was 0.11. Below-ground biomass reached a maximum of 163 g/m^2, with a stratified mean of 2.57 g/m^2 and $v(\overline{y}_{st})$ was 0.18. The maximum shoot density was 20750 shoots/m^2. The stratified mean was 415 shoots/m^2 and $v(\overline{y}_{st})$ was 6527. The maximum leaf area was 0.081 m^2/m^2.

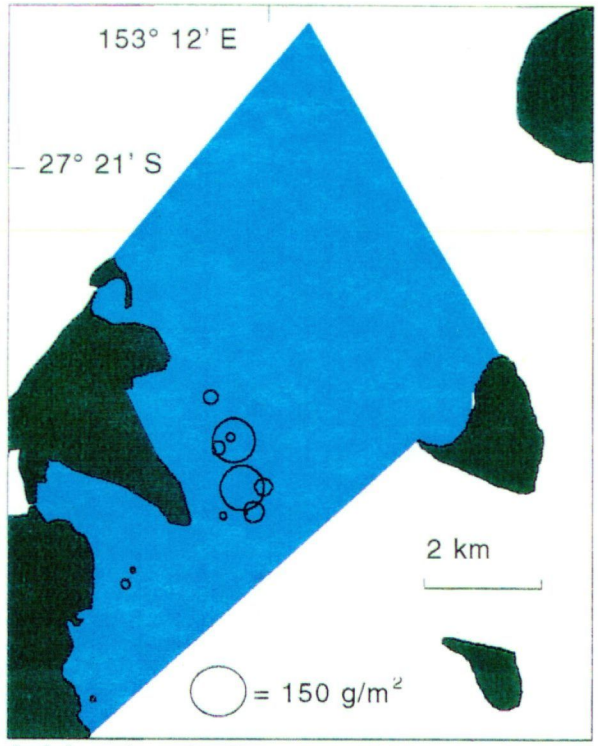

Figure 6. *Halodule uninervis,* above-ground biomass distribution in the Fisherman Islands study area in the December 1993/January 1994 sampling period.

The distribution of *Halodule uninervis* was more restricted than either *Zostera capricorni* or *Halophila ovalis*. It was sampled at only 12 of the 340 sites. It was never collected closer than 200 m to the mangroves and was mainly found on the seaward side of the intertidal areas (Fig. 6). Maximum above-ground biomass was 58.8 g/m^2. The stratified mean, $\overline{y}_{st}$, was 0.17 g/m^2 and the estimate of the variance of $\overline{y}_{st}$, $v(\overline{y}_{st})$, was 0.01. Below-ground biomass reached a maximum of 154 g/m^2 with a stratified mean of 0.29 g/m^2 and $v(\overline{y}_{st})$ of 0.01. Shoot density was the third highest of the seagrasses at 3000 shoots/m^2, $\overline{y}_{st}$ was 11.9 and $v(\overline{y}_{st})$ was 24. *Halodule uninervis* leaf area ranged up to 0.162 m^2/m^2.

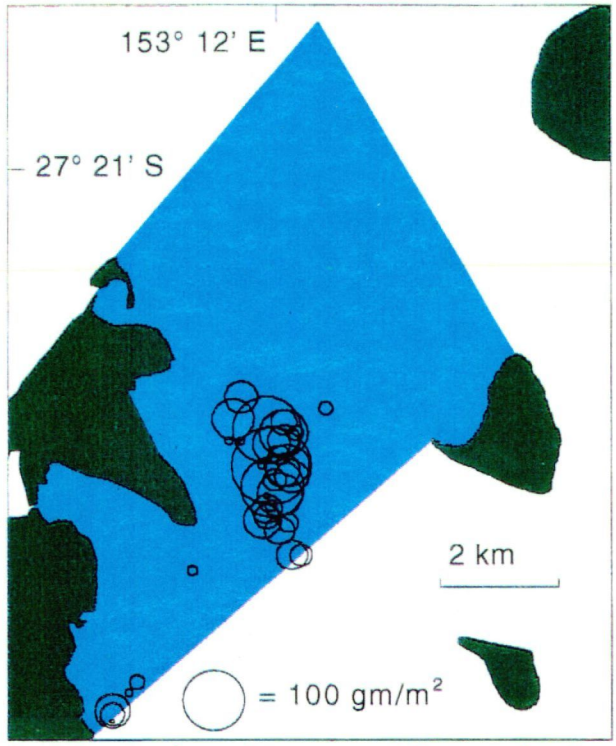

Figure 7. *Halophila spinulosa,* above-ground biomass distribution in the Fisherman Islands study area during the December, 1993/ January, 1994 sampling period.

The pattern of the distribution of *Halophila spinulosa* was similar to *Halodule uninervis* (Fig. 7). Both species were mainly found along the outside margins of the intertidal area off Fisherman Islands. The maximum above-ground biomass was 174.4 g/m^2 with a stratified mean, $\bar{y}_{st}$, of 1.27 g/m^2 and the estimate of the variance of $\bar{y}_{st}$, $v(\bar{y}_{st})$, was 0.09. The maximum below-ground biomass was 97.5 g/m^2 but the stratified mean, 0.98 g/m^2 was much lower ($v(\bar{y}_{st})$ = 0.06). Shoot densities ranged up to 5750 shoots/m^2; but the stratified mean was much lower (45.2 shoots/m^2; $v(\bar{y}_{st})$ = 124.8). Maximum leaf area was 0.232 m^2/m^2.

Area covered by seagrass

Seagrass cover was high in the Dense seagrass stratum 1, and the Uniform/dense seagrass stratum 5 (84% and 71% respectively) (Table 2). The two dominant seagrasses, *Zostera capricorni* and *Halophila ovalis*, largely determined the covers for the six strata. *Zostera capricorni* was absent in the Channel stratum and reached a maximum cover (75%) in the

Worm digging area stratum 2. However, as only four samples were taken in this stratum based on the optimal allocation of sampling effort to strata, this estimate may not be representative of the stratum as a whole. *Halophila ovalis* was absent from the Worm digging areas stratum 2 and reached a maximum in the Dense seagrass stratum 1. Only two seagrasses, *Halophila ovalis* and *Halophila spinulosa*, were collected in the Channel stratum 6.

Table 2. Area (%) covered by seagrass in the six strata sampled in the December 1993/ January 1994 sampling period in the Fisherman Islands study area.

	Strata					
Species	1	2	3	4	5	6
Z. capricorni	64	75	50	17	65	0
H. ovalis	39	0	21	17	35	4
H. uninervis	5	25	0	0	6	0
H. spinulosa	16	0	0	0	0	3
All species	84	75	62	33	71	4

Seagrass biomass estimates

The strata means and variances for the four seagrasses in the December 1993/January 1994 sampling period (Table 3) were combined to estimate the stratified means and variances and hence to estimate the total seagrass biomass for the Fisherman Islands study area (Table 4). The stratified mean for total seagrass biomass (i.e. above- + below-ground biomass) was 61.93 g/m^2 and the estimate of the variance of the mean was 13.45. The precision of this estimate, expressed as the standard error of the mean divided by the mean, was 6.6%. There was an estimated 2355 tonnes of seagrass in the study area, of which 2017 tonnes (86%) was *Zostera capricorni*, *Halophila ovalis* was 181 tonnes (7.6%) and the remaining two seagrasses *Halodule uninervis* and *Halophila spinulosa* contributed 157 tonnes (6.4%) (Table 4).

Table 3. Strata means, $\bar{y}_h$, and strata variance, s_h^2, for above-ground biomass (AGB; g/m^2), below-ground biomass (BGB; g/m^2), seagrass biomass (AGB+BGB; g/m^2), shoot density/m^2 for the six strata (1: Dense Seagrass, 2: Worm Digging Areas, 3: Patchy Seagrass, 4: Very Patchy Seagrass, 5: Uniform/dense seagrass, 6: Channel) in the Fisherman Islands study area.

		AGB		**BGB**		**TB**		**ShD**	
Strata	Species	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2
1	*Z. capricorni*	103	15596	101	16268	205	54725	780	1599715
	H. ovalis	7.33	275	8.49	460	15	1387	1155	8434866
	H. uninervis	0.72	32.4	1.26	121	1.9	257	51	108361
	H. spinulosa	4.98	364	3.25	143	8.2	951	171	471798
	All species	116	14471	114	15496	231	50917		
2	*Z. capricorni*	74.2	5047	59.0	2568	133	8333	584	233097
	H. ovalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H. uninervis	0.18	0.12	0.21	0.17	0.38	0.59	11.7	553
	H. spinulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All species	74.3	5042	59.3	2596	133	8372		
3	*Z. capricorni*	67.6	7733	41.0	2985	108	18553	486	410843
	H. ovalis	1.59	22.9	1.14	10.6	2.73	63.8	462	1926724
	H. uninervis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H. spinulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All species	69.2	7678	42.23	2927	111	18310		
4	*Z. capricorni*	8.80	465	3.59	77.2	12.3	921	84.3	42652
	H. ovalis	0.77	3.59	1.55	14.3	2.32	32.2	386	896170
	H. uninervis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H. spinulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All species	9.58	452.31	5.13	78.2	14.7	884		

Table 3. (continued).

Strata	Species	AGB		BGB		TB		ShD	
		$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2
5	*Z. capricorni*	32.8	2553	36.2	3189	69.0	11184	2531	39178645
	H. ovalis	4.36	204	4.56	169	8.91	742	1067	5232222
	H. uninervis	0.04	0.02	0.04	0.02	0.07	0.09	7.35	919
	H. spinulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All species	37.2	2978	40.8	3463	78.0	12543		
6	*Z. capricorni*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H. ovalis	0.54	6.55	0.70	11.2	1.24	34.8	152	665252
	H. uninervis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	H. spinulosa	0.22	1.82	0.36	4.86	0.58	12.6	9.58	3147
	All species	0.76	14.0	1.06	29.3	1.82	83.8		

Table 4. Estimated seagrass above-ground biomass (AGB), below-ground biomass (BGB) and total biomass (TB=AGB+BGB) and associated lower 95% confidence interval (L95) and upper 95% confidence interval (U95) for the Fisherman Islands study area for the December 1993/January 1994 sampling period. The stratified shoot-density mean/m^2, $\bar{y}_{st}$, (ShD) and associated lower 95% confidence interval (L95) and upper 95% confidence interval (U95) are also shown.

	AGB			BGB			TB			ShD/m^2		
Species	**tonnes**	**L95**	**U95**	**tonnes**	**L95**	**U95**	**tonnes**	**L95**	**U95**	$\bar{y}_{st}$	**L95**	**U95**
Z. capricorni	1069	917	1221	1003	855	1150	2017	1795	2348	254	189	319
H. ovalis	83	59	108	98	66	129	181	126	237	415	257	574
H. uninervis	6	0	13	11	0	23	17	0	35	12	2	22
H. spinulosa	48	26	71	37	18	56	86	45	126	45	23	67
All species	1207	1058	1356	1149	1005	1296	2355	2082	2629			

Sediment type distribution

The sediments in the study area ranged from mud, sandy mud and muddy sands through to sands and rubble (Fig. 8). There was 14.4 km^2 of sediment classed as mud, 2.7 km^2 of sandy mud, 3.5 km^2 of muddy sand, 15.3 km^2 of sand and 1.8 km^2 of rubble. Sand formed large contiguous areas in the subtidal regions in the northern section of the study area. The distribution of sediment type was more complex in the intertidal regions off Fisherman Islands. There were small areas of coral rubble off the west side of St. Helena Island and off the northern edge of Fisherman Islands.

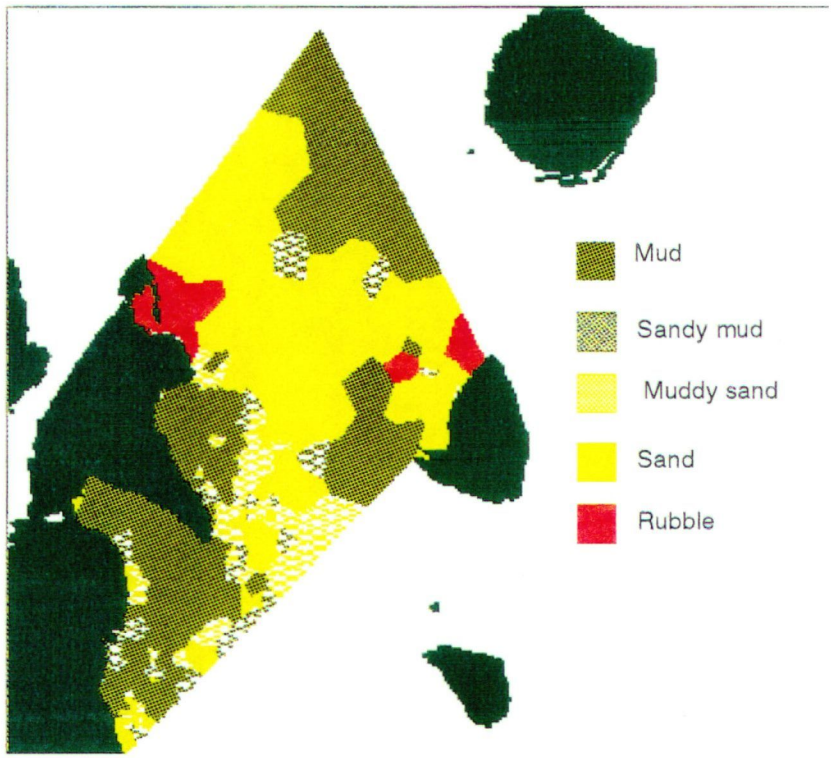

Figure 8. Sediment-type distribution in the December 1993/January 1994 sampling period in the Fisherman Islands study area.

Changes over time

Species distribution

The distribution of *Zostera capricorni*, *Halophila ovalis* and *Halophila spinulosa* has not changed over the three year study period (Fig. 9, 10 & 12). In contrast there has apparently been a reduction in *Halodule uninervis* distribution in the southern part of the study area (Fig. 11).

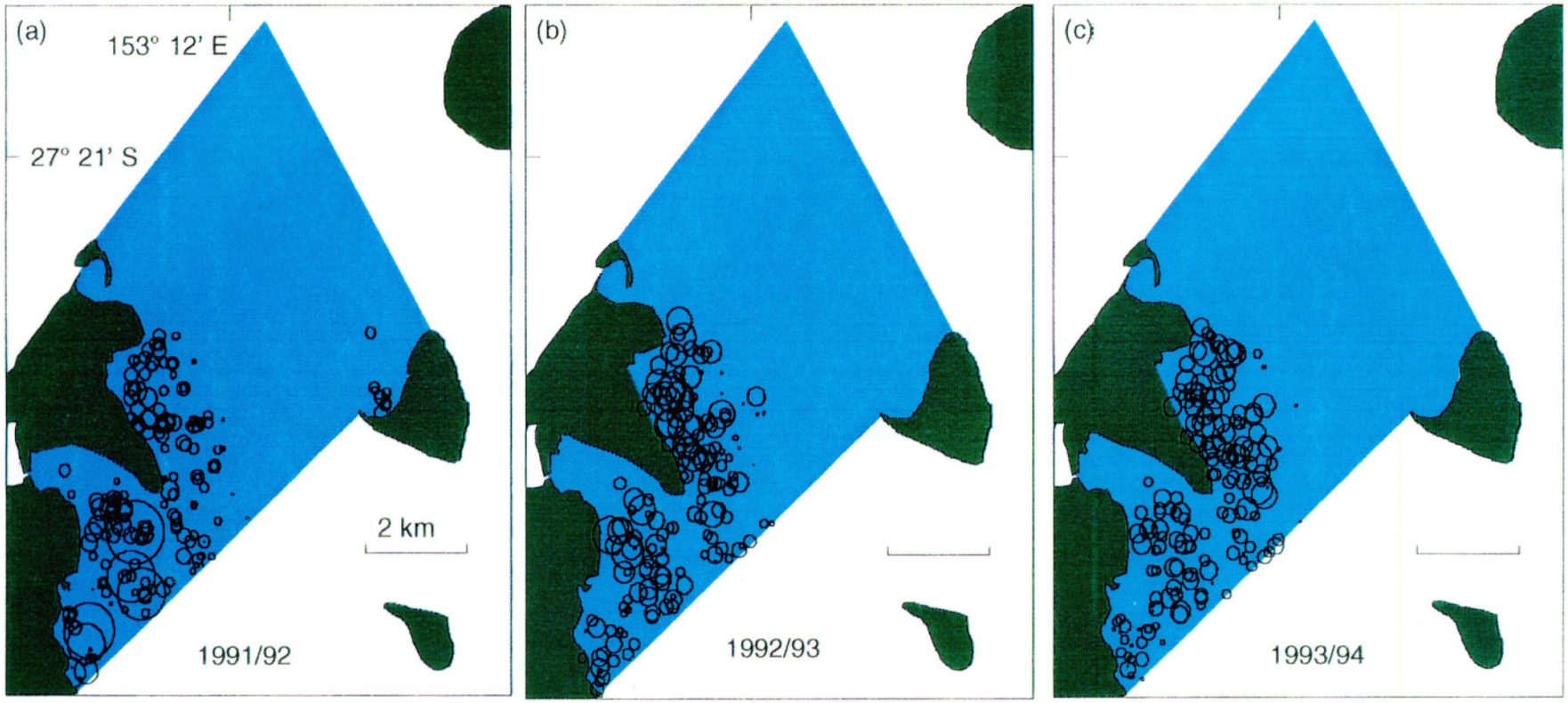

Figure 9. *Zostera capricorni* above-ground biomass distribution in the Fisherman Islands study area for the (a). 1991/92, (b). 1992/93 and (c). 1993/94 sampling period.

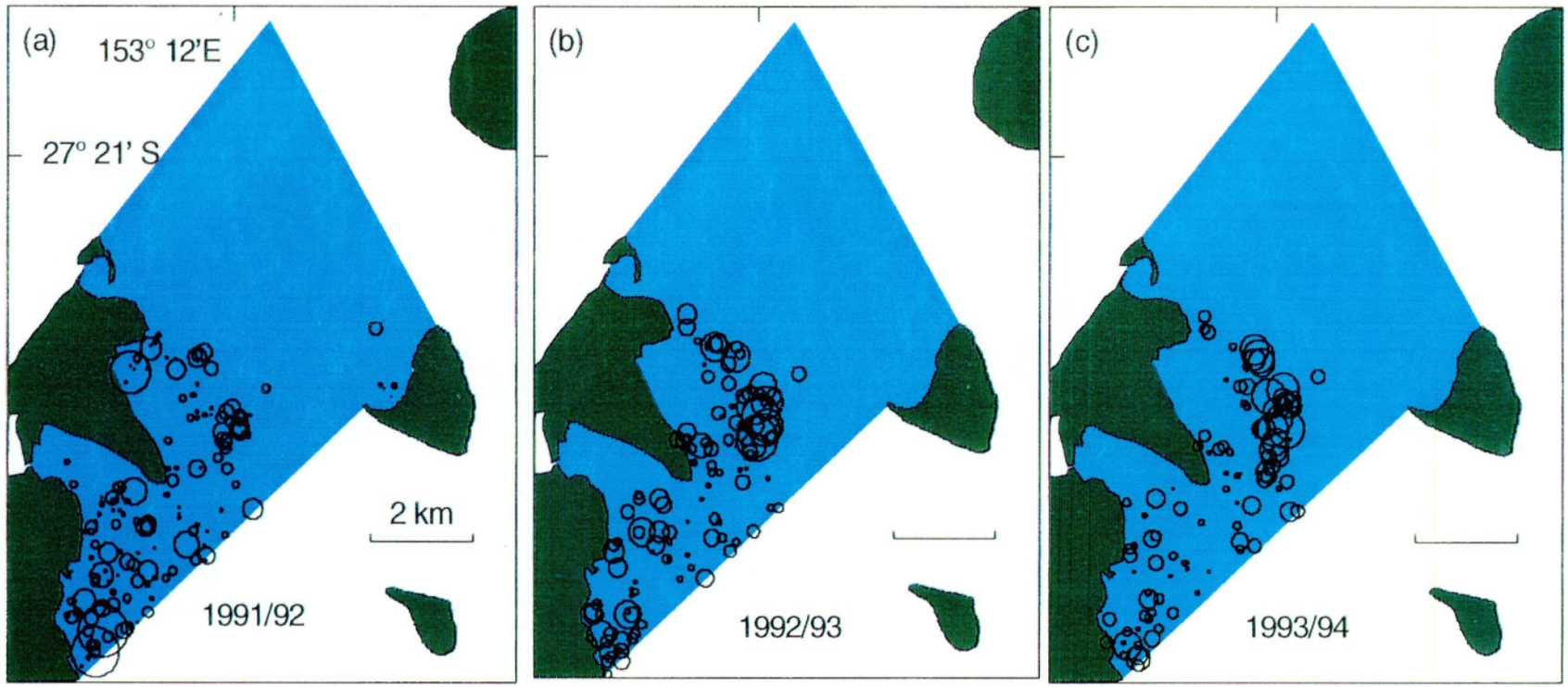

Figure 10. *Halophila ovalis* above-ground biomass distribution in the Fisherman Islands study area for the (a). 1991/92, (b). 1992/93 and (c). 1993/94 sampling period.

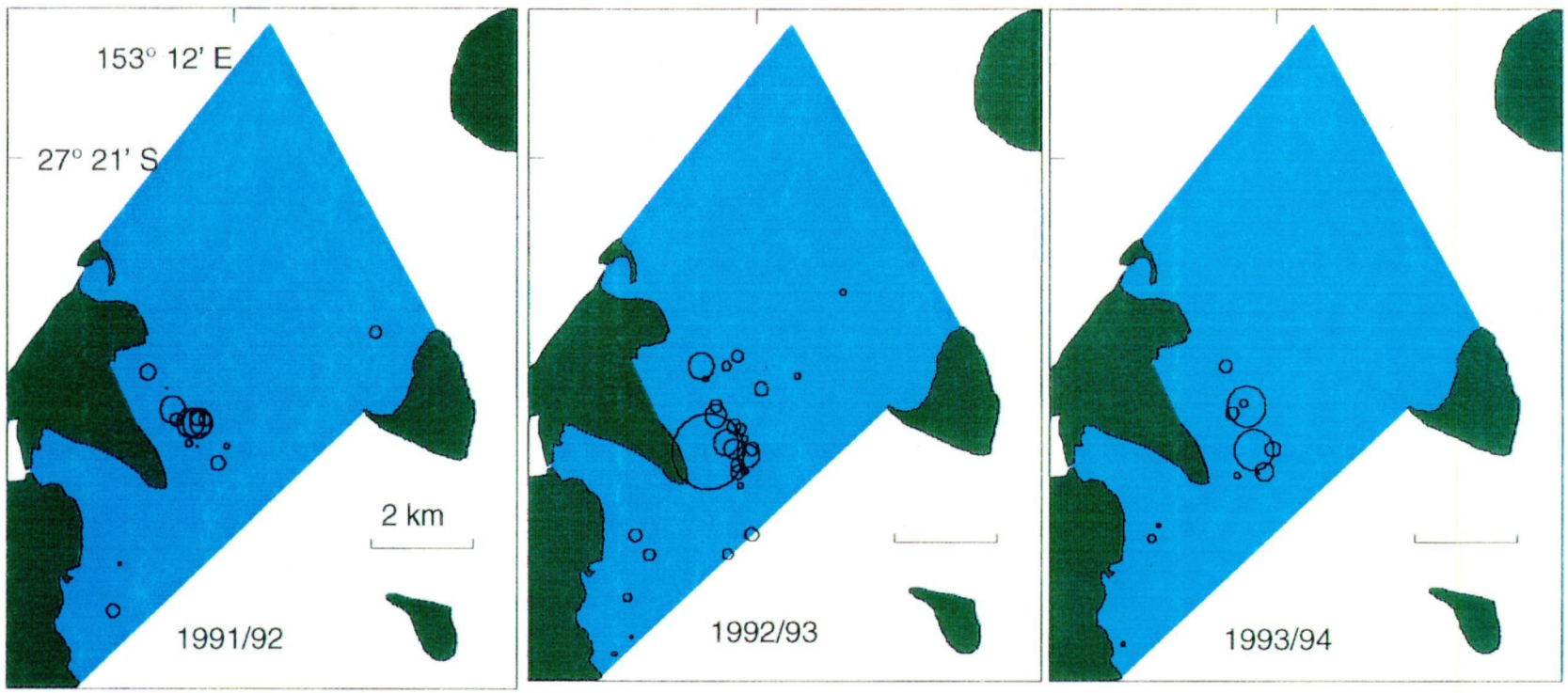

Figure 11. *Halodule uninervis* above-ground biomass distribution in the Fisherman Islands study area for the (a) 1991/92, (b). 1992/93 and (c). 1993/94 sampling period.

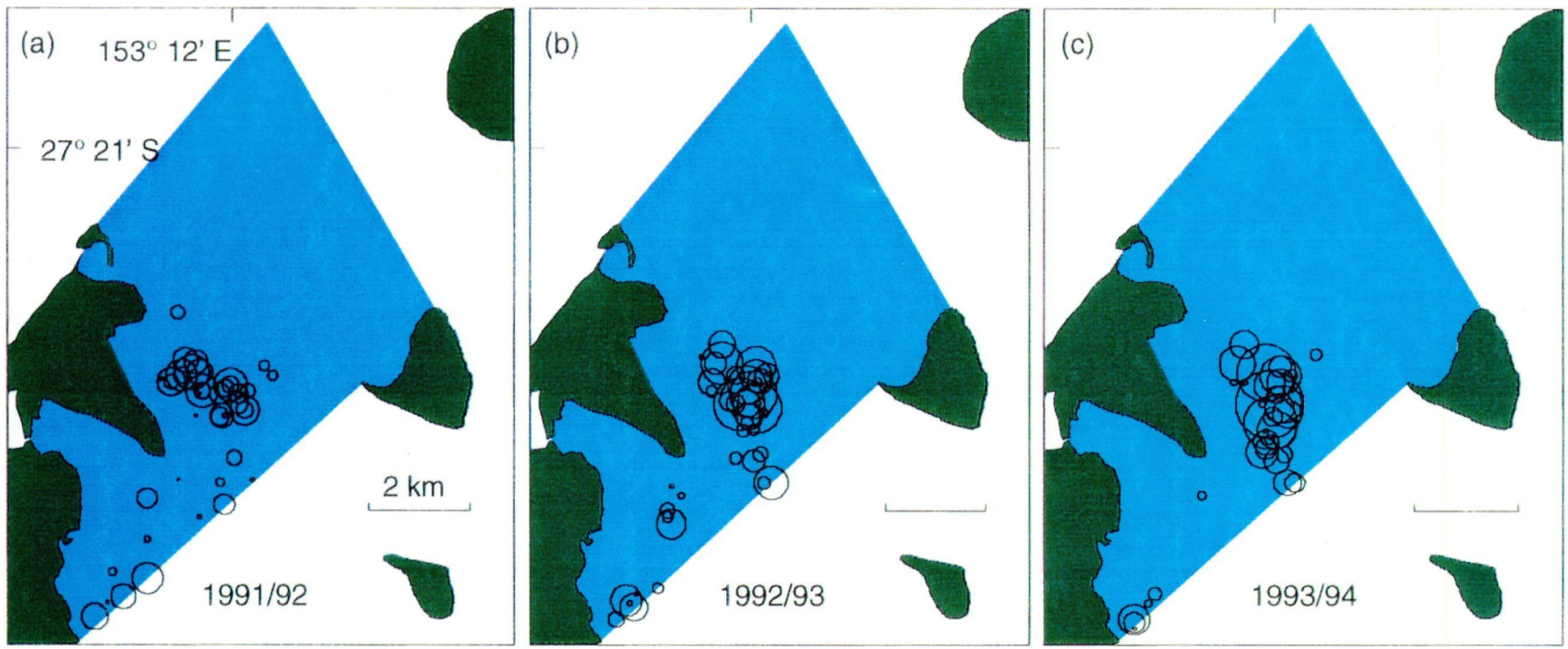

Figure 12. *Halophila spinulosa* above-ground biomass distribution in the Fisherman Islands study area for the (a). 1991/92, (b). 1992/93 and (c). 1993/94 sampling period.

Area covered by seagrass

The seagrass cover estimates for the December 1993/January 1994 sampling period corresponds closely with those from 1991/92 and 1992/93 sampling period for most strata (Table 5). In the Dense seagrass (stratum 1), and the Worm digging areas (stratum 2), the estimates of seagrass cover differed by less than 2% for the last two years. The biggest change was in the Very patchy seagrass (stratum 4) where seagrass cover has doubled from 16 to 34%. However, there were only six samples taken in this stratum and the cover estimates were thus unreliable. For the two dominant seagrasses, *Zostera capricorni* and *Halophila ovalis*, there has been little change in seagrass cover over the three year study period.

Table 5. Area (%) covered by seagrass in the Fisherman Islands study area from 1991 to 1994 for the six strata (1: Dense seagrass; 2: Worm digging areas; 3: Patchy seagrass, 4: Very patchy seagrass, 5: Uniform/dense seagrass; 6: Channel).

		Strata					
Species	**Year**	**1**	**2**	**3**	**4**	**5**	**6**
Zostera capricorni	1991/92	60.0	71.0	37.0	28.0	73.0	<1.0
	1992/93	64.6	33.3	38.2	20.0	57.9	2.9
	1993/94	64.0	75.0	50.0	16.7	64.7	0.0
Halophila ovalis	1991/92	51.0	64.0	34.0	11.0	46.0	<1.0
	1992/93	45.9	33.3	32.4	0.0	57.9	5.7
	1993/94	39.3	0.0	20.6	16.7	35.3	4.4
Halodule uninervis	1991/92	8.0	7.0	0.0	0.0	0.0	<1
	1992/93	11.9	33.3	0.0	0.0	0.0	2.9
	1993/94	4.7	25.0	0.0	0.0	5.8	0.0
Halophila spinulosa	1991/92	8.0	7.0	0.0	0.0	0.0	<1
	1992/93	19.1	0.0	0.0	0.0	0.0	1.4
	1993/94	15.6	0.0	0.0	0.0	0.0	2.9
All species	1991/92	55.0	71.4	41.2	27.8	77.8	8.7
	1992/93	82.5	75.0	57.1	16.7	76.5	7.6
	1993/94	83.9	75.0	61.7	33.3	70.6	4.4

Seagrass biomass

The strata means for above- and below ground biomass for the six strata did not differ significantly over the three year study period (Table 6). There has, however, been a significant reduction in *Zostera capricorni* shoot-density between the 1991/92 sampling period and the 1992/93 and 1993/94 sampling period in all strata, and is shown in the significant difference between these stratified means (Table 7).

The mean seagrass biomass (95% confidence interval) estimate for all species for 1993/94 was 2355 ± 273 t compared with 2678 ± 481 t for 1992/93, and 2180 ± 548 t for 1991/92 (Table 7). The 95% confidence intervals for all three years overlap and we concluded that there has been no change in seagrass biomass in the study area over the three year study period ($P > 0.05$) (Fig. 13).

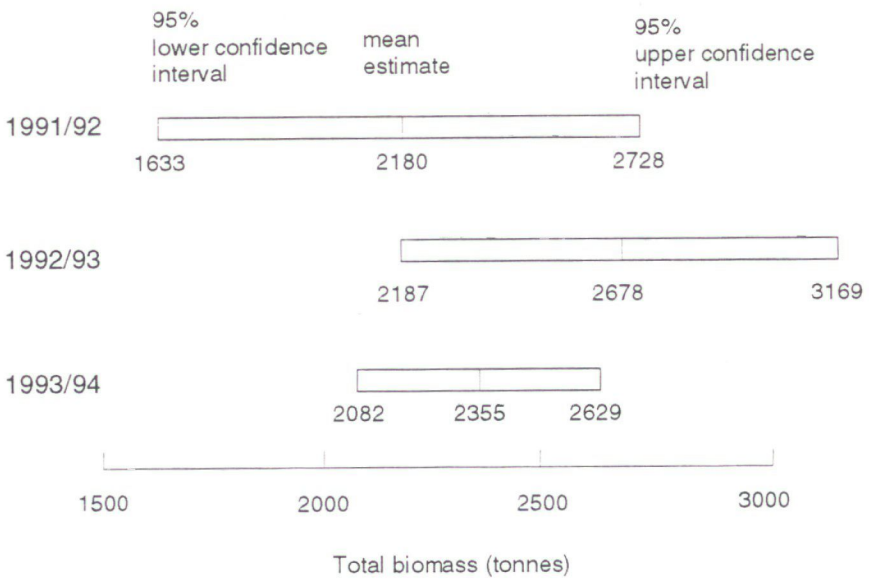

Figure 13. Stratified mean and 95% confidence interval for the estimates of total seagrass biomass for the Fisherman Islands study area for the three year sampling period (1991/92, 1992/93 and 1993/94).

Table 6. Strata means, $\bar{y}_h$, and variance, s_h^2, for above-ground biomass (AGB; g/m^2), below-ground biomass (BGB; g/m^2), seagrass biomass (AGB+BGB; g/m^2), shoot density/m^2 for the six strata (1: Dense Seagrass, 2: Worm Digging areas, 3: Patchy seagrass, 4: Very patchy seagrass, 5: Uniform/dense seagrass, 6: Channel strata) in the Fisherman Islands study area over the three year study period.

			AGB		**BGB**		**TB**		**ShD**	
Strata	Species	year	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2
1	*Zostera*	1991/92	82.6	67886	87.6	36746	170	192838	2006	112320356
	capricorni	1992/93	111	24761	90.8	16506	202	72113	731	1349197
		1993/94	103	15596	101	16268	205	54725	780	1599715
	Halophila	1991/92	5.51	366	5.17	229	10	1146	1063	21584278
	ovalis	1992/93	7.72	345	7.52	297	15	1184	1193	7769005
		1993/94	7.33	275	8.49	460	15	1387	1155	8434866
	Halodule	1991/92	0.73	15.0	1.50	64	2.2	135	56	119802
	uninervis	1992/93	1.77	197	3.30	1281	5.0	2471	110	673084
		1993/94	0.72	32.4	1.26	121	1.9	257	51	108361
	Halophila	1991/92	3.08	73.3	1.50	17.0	4.5	158	106	96267
	spinulosa	1992/93	4.68	235	2.11	51.3	6.7	485	125	150921
		1993/94	4.98	364	3.25	143	8.2	951	171	471798
	All species	1991/92	92.0	67323	95.8	36312	187	190653		
		1992/93	126	24212	103	18367	229	74057		
		1993/94	116	14471	114	15496	231	50917		
2	*Zostera*	1991/92	53.0	5079	55.3	3444	108	12431	1911	5969359
	capricorni	1992/93	122	24329	124	26663	246	101840	485	342505
		1993/94	74.2	5047	59.0	2568	133	8333	584	233097

Table 6. (continued).

Strata	Species	year	AGB		BGB		TB		ShD	
			$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2
	Halophila	1991/92	4.93	65.56	7.36	180	12.2	458	1384	8616548
	ovalis	1992/93	2.50	25.00	4.38	76.5	6.88	189	3125	39062500
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Halodule	1991/92	0.63	5.56	1.22	20.7	1.85	47.8	58.8	48442
	uninervis	1992/93	0.94	3.52	3.75	56.2	4.69	87.8	1000	4000000
		1993/94	0.18	0.12	0.21	0.17	0.38	0.59	11.7	553
	Halophila	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	spinulosa	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All	1991/92	58.5	5299	63.9	3606	122	13040		
	species	1992/93	125	23255	132	24235	258	94771		
		1993/94	74.3	5042	59.3	2596	133	8372		
3	*Zostera*	1991/92	50.0	38176	53.8	71940	103	213099	1304	85082472
	capricorni	1992/93	76.8	33124	29.4	3043	106	53931	408	625914
		1993/94	67.6	7733	41.0	2985	108	18553	486	410843
	Halophila	1991/92	3.16	184	3.16	156	6.32	667	2326	112141434
	ovalis	1992/93	5.67	142	4.69	98.4	10.3	444	3143	59529959
		1993/94	1.59	22.9	1.14	10.6	2.73	63.8	462	1926724
3	*Halodule*	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	uninervis	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Halophila	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	spinulosa	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. (continued).

Strata	Species	year	AGB $\bar{y}_h$	AGB s_h^2	BGB $\bar{y}_h$	BGB s_h^2	TB $\bar{y}_h$	TB s_h^2	ShD $\bar{y}_h$	ShD s_h^2
	All	1991/92	53.1	38628	56.9	72383	110	214912		
	species	1992/93	82.5	32404	34.13	2882	116	52234		
		1993/94	69.2	7678	42.23	2927	111	18310		
4	*Zostera*	1991/92	20.4	2093	24.48	2719	44.9	9393	442	793267
	capricorni	1992/93	17.2	1786	5.88	207	23.1	3211	219	289365
		1993/94	8.80	465	3.59	77.2	12.3	921	84.3	42652
	Halophila	1991/92	0.28	0.74	0.24	0.56	0.52	2.58	89.3	80786
	ovalis	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.77	3.59	1.55	14.3	2.32	32.2	386	896170
	Halodule	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	uninervis	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Halophila	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	spinulosa	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All	1991/92	20.7	2116.37	24.72	2735	45.4	9471		
	species	1992/93	17.2	1786.38	5.88	207	23.1	3211		
		1993/94	9.58	452.31	5.13	78.2	14.7	884		
5	*Zostera*	1991/92	93.9	55636	226	216172	320	455062	10457	822298650
	capricorni	1992/93	65.1	6065	101	21336	166	40705	2135	5573571
		1993/94	32.8	2553	36.2	3189	69.0	11184	2531	39178645
	Halophila	1991/92	1.92	13.7	1.84	14.9	3.77	54.7	971	5542728
	ovalis	1992/93	8.79	187	7.47	150	16.2	666	4635	72780155

Table 6. (continued).

Strata	Species	year	AGB		BGB		TB		ShD	
			$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2	$\bar{y}_h$	s_h^2
5		1993/94	4.36	204	4.56	169	8.91	742	1067	5232222
	Halodule	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	uninervis	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.04	0.02	0.04	0.02	0.07	0.09	7.35	919
	Halophila	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	spinulosa	1992/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	All	1991/92	95.8	56082	228	216325	324	456285		
	species	1992/93	73.9	5846	108	20595	182	38716		
		1993/94	37.2	2978	40.8	3463	78.0	12543		
6	*Zostera*	1991/92	0.11	0.52	0.16	1.22	0.27	3.33	4.86	1087
	capricorni	1992/93	5.78	1645	1.49	77.5	7.27	2393	46.7	102992
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Halophila	1991/92	0.26	1.54	0.38	4.40	0.64	10.87	29.1	17902
	ovalis	1992/93	0.62	10.3	0.73	11.4	1.34	43.1	80.3	139979
		1993/94	0.54	6.55	0.70	11.2	1.24	34.8	152	665252
	Halodule	1991/92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	uninervis	1992/93	0.04	0.05	0.23	1.69	0.27	2.30	10.42	5959
		1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Halophila	1991/92	0.26	1.03	0.50	4.64	0.76	9.70	18.95	5521
	spinulosa	1992/93	0.13	1.18	0.07	0.33	0.20	2.75	2.64	458
		1993/94	0.22	1.82	0.36	4.86	0.58	12.6	9.58	3147
	All	1991/92	0.63	7.59	1.04	27.4	1.67	63.0		
	species	1992/93	6.57	1874	2.51	139	9.09	2958		
		1993/94	0.76	14.0	1.06	29.3	1.82	83.8		

Table 7. Estimated seagrass above-ground biomass (AGB), below-ground biomass (BGB) and total biomass (TB=AGB+BGB) in tonnes and associated lower 95% confidence interval (L95) and upper 95% confidence interval (U95) for the Fisherman Islands study area for the December 1993/January 1994 sampling period. The stratified shoot-density mean/m^2, $\bar{y}_{st}$, (ShD) and associated lower 95% confidence interval (L95) and upper 95% confidence interval (U95) are also shown.

		AGB			BGB			TB			ShD/m^2		
Species	Year	tonnes	L95	U95	tonnes	L95	U95	tonnes	L95	U95	$\bar{y}_{st}$	L95	U95
Zostera	1991/92	915	602	1223	1061	802	1321	1974	1427	2521	744	369	1119
capricorni	1992/93	1361	1032	1690	1004	826	1181	2365	1896	2833	267	199	334
	1993/94	1069	917	1221	1003	855	1150	2017	1795	2348	254	189	319
Halophila	1991/92	63	39	87	64	41	88	128	81	174	400.88	238.9	563
ovalis	1992/93	99	69	129	98	69	128	197	140	255	586	406	766
	1993/94	83	59	108	98	66	129	181	126	237	415	257	574
Halodule	1991/92	7	2	11	14	4	23	20	7	34	14	3	24
uninervis	1992/93	17	1	32	36	0	77	53	0	109	44	9	79
	1993/94	6	0	13	11	0	23	17	0	35	12	2	22
Halophila	1991/92	33	21	46	26	9	42	59	32	86	37	20	54
spinulosa	1992/93	44	25	62	20	11	29	64	37	90	30	18	42
	1993/94	48	26	71.08	37.09	18.32	55.85	85.52	45.21	126	45	23	67
All species	1991/92	1016	706	1325	1164	904	1426	2180	1633	2728			
	1992/93	1520	1180	1860	1158	969	1346	2678	2187	3169			
	1993/94	1207	1058	1356	1149	1001	1296	2355	2082	2629			

Ratio of above- to below-ground seagrass biomass

There was no significant difference between the 1991/92, 1992/93 and 1993/94 ratio of above to below-ground biomass for all seagrasses except *Zostera capricorni* (Table 8). The ratio of above- to below-ground biomass for *Z. capricorni* was significantly higher in 1992/93 than 1991/92 . More *Z. capricorni* was sampled above-ground compared to below-ground in 1992/93 compared to 1991/92. In contrast, there was no significant difference for the coefficient of variation (*c.v.*) for *Zostera capricorni* above- to below-ground biomass ratio for the 1991/92 and 1992/93 sampling periods ($P > 0.05$). This indicated that even though the ratio of above to below-ground biomass differed significantly between these years, the variability of the ratio was the same for both years. Therefore the shift in partitioning of seagrass biomass into above and below-ground components was not accompanied by an increase or decrease in the variation of this partitioning. In contrast, although there was no significant difference in ratios between 1993/94 and 1992/93 for *Z. capricorni*, the ratio was significantly more variable in 1993/94 (*c.v.* = 136.1) compared to 1992/93 (*c.v.* = 87.1) and 1991/92 (*c.v.* = 92.7).

Table 8. Ratio of above- to below-ground biomass, $\frac{AGB}{BGB}$, coefficient of variation, *c.v.*, and sample size, *n*, for the three year study period (1991/92 to 1993/94) in the Fisherman Islands study for *Zostera capricorni*, *Halophila ovalis*, *Halodule uninervis* and *Halophila spinulosa*.

Species	Year	$\frac{AGB}{BGB}$	*c.v.*	*n*
Zostera capricorni	1991/92	1.28	92.7	145
	1992/93	1.66	87.1	168
	1993/94	1.56	136.1	166
Halophila ovalis	1991/92	1.25	64.7	122
	1992/93	1.37	64.1	119
	1993/94	1.31	75.4	100
Halodule uninervis	1991/92	0.64	49.8	10
	1992/93	1.11	129.3	28
	1993/94	0.86	78.3	12
Halophila spinulosa	1991/92	3.07	183.5	33
	1992/93	2.32	63.1	38
	1993/94	1.67	56.6	35

Sediment-type distribution

There has been no change in area described as mud or rubble in the Fisherman Islands study area over the three year study period (Fig. 14; Table 9). There was 12 to 14 km^2 of mud in the study area over the three year sampling period. In contrast the area of sediment described as sandy mud decreased from 8 km^2 in 1991/92 to 2.7 km^2 in 1993/94. Similarly the areas described as muddy sand decreased from 7 km^2 down to 3 km^2 in 1993/94. These decreases were compensated by increases in areas described as sand and muddy sand (Table 10).

Table 9. Area (km^2) estimates of sediment type from the samples taken in the Fisherman Islands study area over the three year study period.

Sediment type	Year	Area (km^2)
Mud	1991	12.0054
	1992	12.6532
	1993	14.3554
Sandy mud	1991	8.8356
	1992	4.2229
	1993	2.7203
Muddy sand	1991	7.1393
	1992	2.3076
	1993	3.5378
Sand	1991	7.7622
	1992	17.5453
	1993	15.2734
Rubble	1991	1.9417
	1992	0.9718
	1993	1.8139

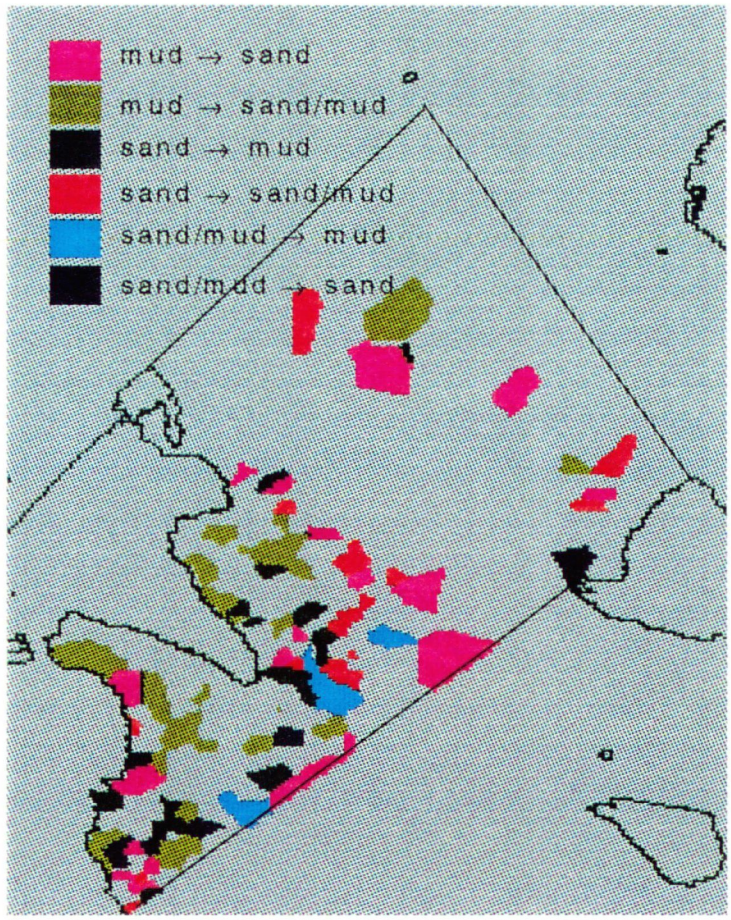

Figure 14. Change in sediment-type from the 1992/93 to the 1993/94 sampling periods.

Over 2 km^2 that was described as mud in the 1991/92 sampling period was described as sand in the 1992/93 sampling period (Table 10). In contrast, only 0.59 km^2 described in the 1992/93 sampling period as mud was described as sand in the 1993/94 sampling period. Similarly there was over 2 km^2 of sediment described as mud in the 1991/92 sampling period that was described as either sandy mud or muddy sand in the 1992/93 sampling period. In contrast, less than 1 km^2 of sediment that was described as mud in the 1992/93 sampling period was described as either sandy mud or muddy sand in the 1993/94 sampling period. Only small areas changed from sand to mud over the three year sampling period (1991/92 to 1992/93: 0.27 km^2, and 1992/93 to 1993/94: 0.64 km^2)

Table 10. Change in sediment type over the three year sampling period. 1 to 2: change from 1991/92 to 1992/93; 1 to 3: change from 1991/92 to 1993/94; 2 to 3: change from 1992/93 to 1993/94.

Time interval	change in sediment	Area (km^2)
1991/92 to 1992/93	mud→ sand	2.2814
1992/93 to 1993/94	mud→ sand	0.59439
1991/92 to 1992/93	mud→ sand/mud	2.4809
1992/93 to 1993/94	mud→ sand/mud	0.90689
1991/92 to 1992/93	sand→mud	0.2763
1992/93 to 1993/94	sand→mud	0.64737
1991/92 to 1992/93	sand→sand/mud	0.2919
1992/93 to 1993/94	sand→sand/mud	2.47238
1991/92 to 1992/93	sand/mud→mud	4.6683
1992/93 to 1993/94	sand/mud→mud	2.55609
1991/92 to 1992/93	sand/mud→sand	7.3010
1992/93 to 1993/94	sand/mud→sand	1.09556

Discussion

The purpose of this study was to apply the monitoring techniques previously developed (Long and Poiner 1992) to quantify changes in seagrass distribution and abundance over the three year study period. *Zostera capricorni* was the dominant seagrass in terms of biomass, and both *Z. capricorni* and *Halophila ovalis* were widely distributed throughout the intertidal areas as before. There were no major shifts in the distribution of any of the four seagrasses in the study area. The area covered by *Zostera capricorni* in the dense seagrass stratum 1 has been remarkably constant with less than a 5% change (60% in 1991/92, 64.6% in 1992/93 and 64% in 1993/94) over the three year study period. The precision of the seagrass biomass estimate for this study were much better than expected, based on the variance estimates from the previous year, and this was due to a more even distribution of *Z. capricorni* in the intertidal areas (shown by the lower variance estimates and the bubble plots of *Z. capricorni*). There is statistical evidence that more growth was being diverted into the above- rather than below-ground plant components in 1993/94 and 1992/93 than in 1991/92. The ratio is, however, significantly more variable this year (*c.v.* = 136.1) compared to the previous years (92.7 in 1991/92 and 87.1 in 1992/93). The reason for the changes in the ratio of above- to below-ground biomass for *Z. capricorni* has yet to be determined.

Power to detect change

The sample size required for powers ranging from < 10 to > 90% were calculated for *Zostera capricorni* in stratum 1 as a function of effect size. The effect size was defined as percentage change in mean *Zostera capricorni* biomass (Figure 14a,b & c). The power curves were constructed for *Zostera capricorni* in stratum 1 because *Z capricorni* was the numerically dominant seagrass and stratum 1 was the largest strata with dense seagrass.

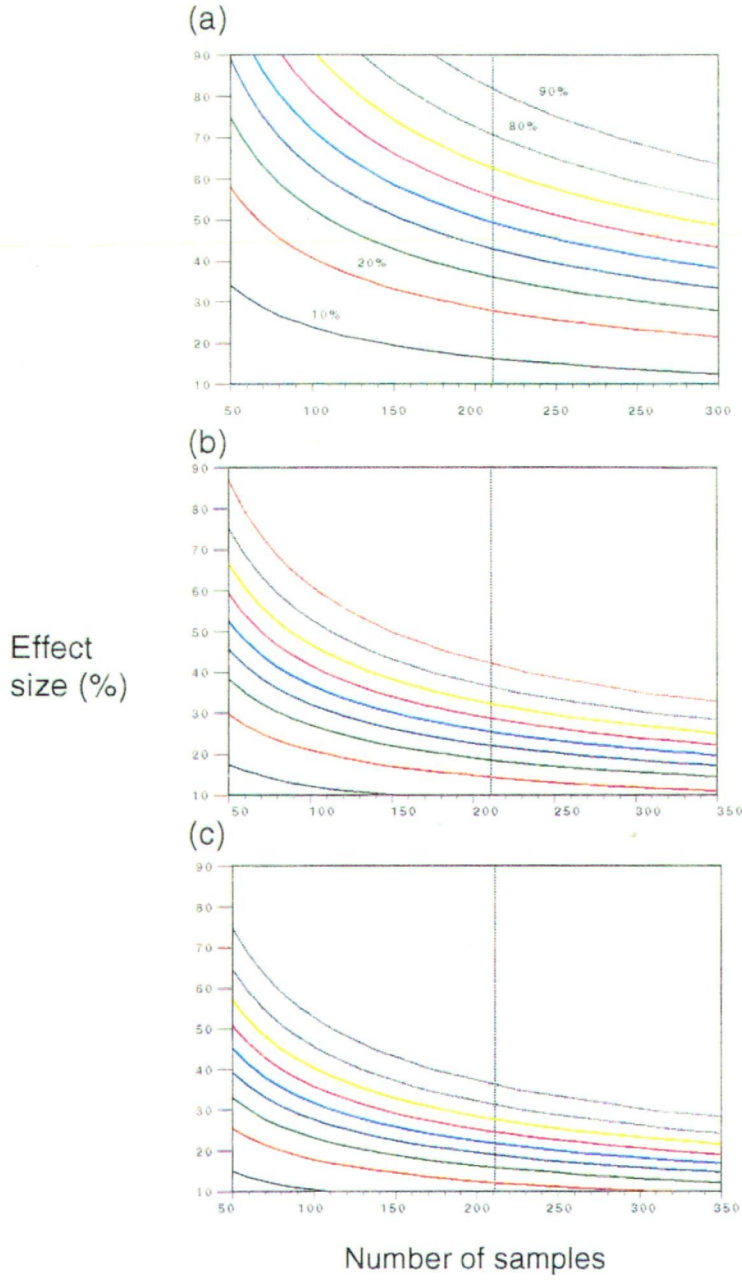

Figure 15. Power curves for *Zostera capricorni* biomass as a function of effect size (% change of the mean) and sample size based on the (a). 1991/92 sample ($\bar{y}_h$=170g/m^2; s_h^2= 192838), (b). 1992/93 sample ($\bar{y}_h$= 202 g/m^2 ; s_h^2= 72113) and (c) 1993/94 sample ($\bar{y}_h$=205; s_h^2= 54725). The vertical reference line shows the sample size (n=211) taken in stratum 1. The significance level was $\alpha = 0.05$.

The power curves indicated, that with a sample size of 211 in the Dense seagrass stratum 1, it was possible to detect a 75%, 45% and 37% change in *Zostera capricorni* biomass with 80% power at the 95% significance level for the 1991/92, 1992/93 and 1993/94 sampling periods respectively.

The power to detect change has substantially improved in 1992/93 and 1993/94 sampling periods compared to the 1991/92 sampling period because of the reduced variation in *Z. capricorni* biomass from 192838 in the 1991/92 sampling period to 72113 in the 1992/93 and 54725 in the 1993/94 sampling period.

In conclusion there was no evidence that there has been changes in seagrass biomass in the study area over the last three years. In contrast the seagrass beds in the Fisherman Islands study area as a whole have been remarkably stable. For monitoring changes in seagrass biomass in a large area such as the Fisherman Islands study area, a large sample size (300+) is required to detect changes in the order of 35–45% of the mean with high power (80%). The large sample size required is due to the complex spatial heterogeneity of seagrass.

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Appendix 1

Stratified sampling - terms

In stratified sampling the population of N units is divided into subpopulations of N_1, N_2, N_3,... N_L units respectively. If each stratum is homogenous in that the measurements vary little from one unit to another, a precise estimate of any stratum mean can be obtained in that stratum. These estimates can then be combined into a precise estimate for the whole population. The notation of terms used for stratified sampling follows below:

N	total number of possible sampling units in the study area
N_h	total number of possible sampling units in stratum h
n_h	actual number of samples taken in stratum h
y_{hi}	value obtained from ith unit in stratum h
$W_h = \frac{N_h}{N}$	stratum h weight
$f_h = \frac{n_h}{N_h}$	sampling fraction in stratum h
$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$	stratum h mean
$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$	stratified mean over all strata
s_h^2	sample estimate of stratum variance

$$v(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{W_h^2 s_h^2}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W_h^2 s_h^2}{N}\right)$$

= estimated strata variance

Estimation of sample size for fixed variance $v(\bar{y}_{st})$

$$n = \frac{n_o}{\left(1+\frac{n_o}{N}\right)}$$

where $$n_o = \frac{N}{v(\bar{y}_{st})} \sum_{h=1}^{L} N_h s_h^2$$

Neyman allocation of samples to strata

The optimal allocation of samples, n_h, to strata based on the 1991/92 seagrass above-ground biomass (g/m^2) strata means, $\bar{y}_h$, variances, s_h^2, strata weights, W_h, possible number of samples, N_h, and strata area at Fisherman Islands.

Strata	n_h	$\bar{y}_h$	s_h^2	W_h	N_h	Area (km^2)
1: Dense seagrass	209	86.49	73,439	0.211	2,145	8.077
2: Worming Areas	3	53.02	5,079	0.012	118	0.454
3: Patchy seagrass	34	58.70	42,589	0.045	453	1.723
4: Very patchy seagrass	5	20.47	2,093	0.032	326	1.172
5: Very dense seagrass	19	118.82	93,695	0.017	194	0.662
6: Channel	70	7.91	793	0.680	6,875	25.560

Stratified mean, $\bar{y}_{st}$ = 29.69 g/m^2

Stratified variance $v(\bar{y}_{st})$ = 26.61

MANGROVE MONITORING
FISHERMAN ISLANDS 1991-94

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Synopsis:

An account of a long-term (September 1991 - May 1994) monitoring study in the mangroves of the Fisherman Islands

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EXECUTIVE SUMMARY

Fisherman and Whyte Islands, at the Brisbane River mouth, are being developed as a major port facility by the Port of Brisbane Authority (PBA). The expansion of port capacity has necessitated disturbance of intertidal and subtidal lands of the Fisherman Islands, some of which are vegetated by mangroves.

Mangrove communities within Moreton Bay are highly productive and structurally complex. They provide large amounts of plant litter, an important primary food source for aquatic organisms inhabiting mangrove-dominated estuaries. Mangroves are also important nursery and feeding grounds for many fishes and crustaceans, most of which are of direct importance to commercial and recreational fisheries.

Mangroves within the Fisherman Islands study area cover approximately 200 ha. In a regional context, this represents $<2\%$ of the 13900 ha of mangroves in Moreton Bay (Hyland and Butler, 1988).

This document presents the results of a study of the structure and productivity of mangroves in the Fisherman Islands region, commissioned by the PBA and conducted by WBM Oceanics Australia. The study was initiated in September 1991. Final measurements were taken in May 1994. Results presented in earlier progress reports (WBM Oceanics Australia 1992, 1993) are incorporated into this final report.

The data from this study has allowed detailed comparisons of productivity (as measured by litterfall) to be drawn between mangrove monitoring sites and between years, prior to and during reclamation works. Key findings of the studies are:

- the mangroves at the monitoring sites are typical in structure and composition to mangrove communities elsewhere in Moreton Bay

- the mangroves are healthy and not subject to on-going adverse impacts

- annual total litterfall ranged from 5.83 to 8.37 t/ha in 1992/3 and 7.14 to 10.62 t/ha in 1993/4. These values are in the lower half of the range in values reported from temperate to tropical mangrove communities around the world

- stem growth (increase in girth) over the duration of the study was very small and highly variable

- no major structural changes in mangrove communities at the sites were observed over the monitoring period

One mangrove reproductive cycle, in 1993, was recorded during the study. Evidently fruit production by mangroves at Fisherman Islands does not occur every year. This information on the season and frequency of fruiting will be vital to the Port Authority if it plans seed collections for mangrove regeneration projects.

Leaf litterfall production peaked during the growing season of spring through to early autumn. This corresponds with periods of greatest leaf production and shoot growth, as documented in other mangrove studies in Moreton Bay.

No comparable data for stem girth measurements on mangroves in Moreton Bay or in southeast Queensland were found with which to compare the results of this study. However, the small changes in stem girth are thought to indicate that the mangroves are in a mature to over-mature (senescent) stage in their development and thus experiencing slow rates of stem growth.

The monitoring programme has provided one of the longest running data sets on litterfall production for mangroves in Moreton Bay, and possibly the only data on stem girth changes. The data has a wide range of applications, including:

- as detailed baseline data for future mangrove monitoring studies
- effective management of the mangrove resources
- timing of seed collections for mangrove rehabilitation works.

1.0 INTRODUCTION

The Fisherman Islands at the mouth of the Brisbane River are being developed as a major port facility by the Port of Brisbane Authority (PBA). Tidal wetlands (saltmarsh, seagrass and mangroves) occur on and adjacent to the islands.

The PBA has recognised the need to expand the port's capacity to accommodate increases in port usage (PBA 1992). The Moreton Bay Strategic Plan (DEH 1992), designed to ensure appropriate land use within Moreton Bay, designates lands at the Fisherman Islands for port-related activities.

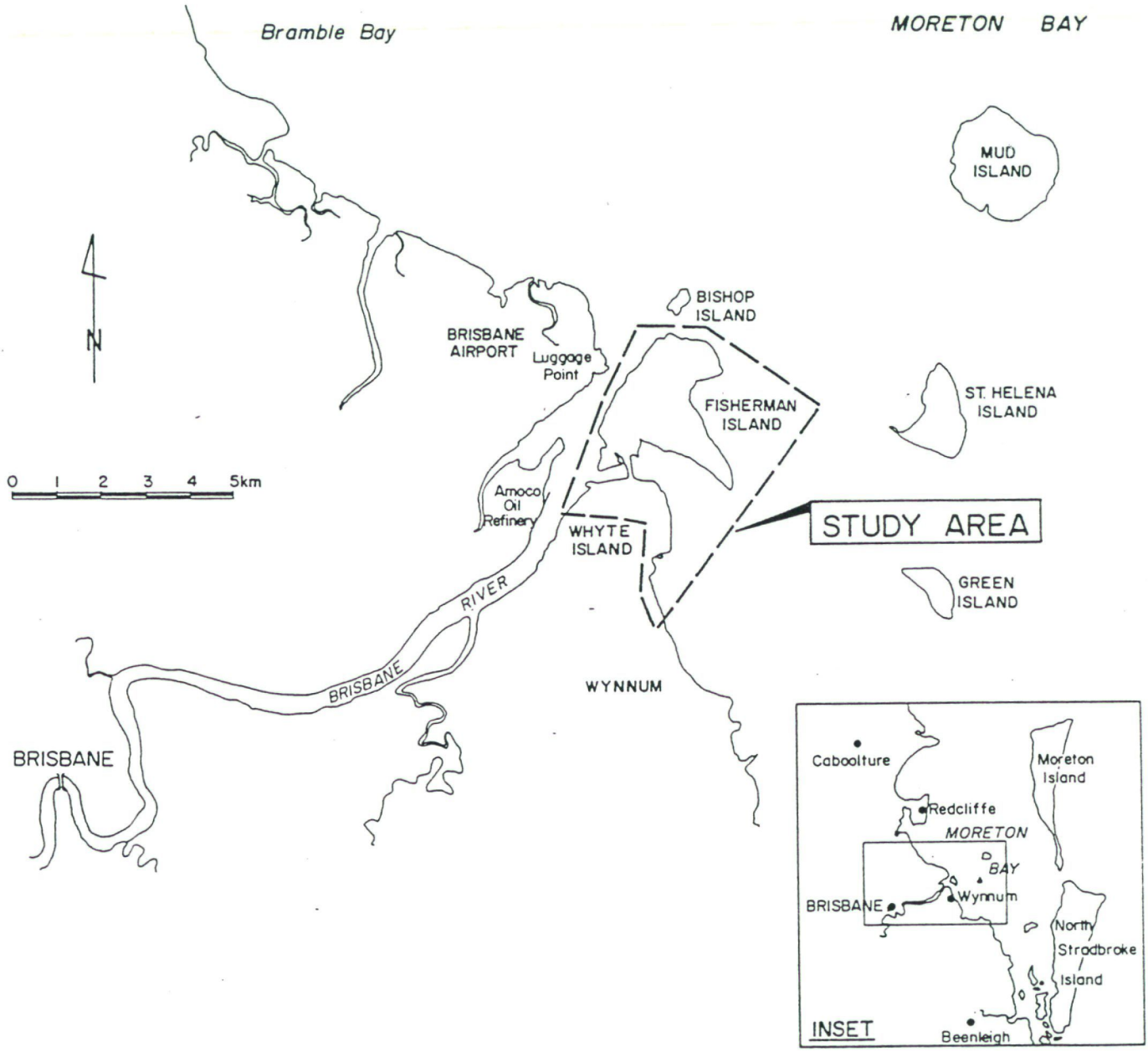
Expansion of the port on the southern side of the Brisbane River mouth will necessitate disturbance of intertidal and subtidal lands at the Fisherman Islands, some areas of which support mangroves.

The PBA commissioned WBM Oceanics Australia to undertake studies of tidal wetlands occurring on and adjacent to the Fisherman Islands, Whyte Island and the Wynnum foreshores. Figure 1.1 shows the extent of the study area.

The present studies are the continuation of mangrove productivity monitoring initiated in September 1991 and reported earlier (WBM Oceanics Australia 1992, 1993).

The results of the present study are combined and compared with previous data to provide the PBA with one of the longest running mangrove monitoring studies ever conducted in Moreton Bay. This will provide a baseline data set against which future monitoring can be compared and contrasted.

This document reports the results of monitoring conducted from September 1991 to May 1994, with reference to the results of previous reports (WBM Oceanics Australia 1992, 1993) to elucidate long term trends.



FIGURE

STUDY AREA

1.1

2.0 REVIEW OF PREVIOUS REPORTS

Study Initiation 1991

The results of initial monitoring were reported in detail in WBM Oceanics Australia (1992).

Initiation of the study in September 1991 involved the selection of six monitoring sites in the Fisherman Islands area by the PBA in consultation with WBM Oceanics Australia. The following structural parameters of the mangrove community at each site were measured:

- projective foliage cover (PFC%)
- canopy height (m)
- stand density (no. of trees/ha)
- stand basal area (tree cross-sectional area at 1.3m above ground level [breast height], m^2/ha)

Mangrove productivity was monitored through collection of litterfall and measurement of changes in stem girth.

Litterfall catchers were installed at four of the six sites to collect plant litterfall. Dendrometers were installed on ten trees at each of the six sites to measure changes in stem girth.

The areas of each tidal community present in the Fisherman Islands region (saltmarsh, mangroves, seagrass) were measured and comparisons made with their regional (Moreton Bay) distribution. The ecological importance of tidal communities was discussed.

Key findings of the study were:

- mangrove communities at the monitoring sites were similar in structure and composition to mangrove communities elsewhere in Moreton Bay.

- the two litterfall collections made over the study duration (17 weeks) were insufficient to reveal any seasonal patterns or trends. However, the average litterfall production from these two collections, when extrapolated to an annual figure, agreed closely with estimates of annual litterfall production from other mangrove communities in Moreton Bay.

- Minimal change in stem girth was recorded over the study's duration. This may have reflected the maturity of the individual trees measured at each site.

- No major structural changes were observed in the mangrove communities at the monitoring sites over the study duration.

It was concluded that longer term monitoring would be necessary to detect any seasonal patterns in litterfall production or larger stem girth changes.

Mangrove productivity monitoring 1992/1993

The second report (WBM Oceanics Australia 1993) provided the results of mangrove productivity monitoring up to May 1993, including and expanding upon the results of earlier monitoring (reported in WBM Oceanics Australia 1992).

Litterfall and stem girth increment were the two aspects of productivity that were monitored.

Key findings of the study were:

- The mangroves were in a healthy condition.

- Sufficient data was collected to calculate a figure for annual litterfall. The range in this figure across the four sites monitored agreed closely with annual litterfall estimates made for mangroves elsewhere in Moreton Bay.

- Larger changes in stem girth were recorded compared with earlier monitoring. However, changes in stem girth were not always positive and were highly variable within sites, despite the uniformity in size of tree stems measured.

- The first fruit production event since monitoring commenced was recorded in autumn 1993. Fruit production in the mangroves of the Fisherman Islands region evidently does not occur every year.

It was concluded that:

- Litterfall monitoring conducted for a further 1 to 2 years would reveal the extent of inter-annual variability in seasonal patterns and total production.

- Initial expectations of stem girth monitoring had not been realised, but with the equipment (dendrometers) already installed, little additional time or expense was required to take further readings.

3.0 MONITORING PROGRAMME METHODOLOGY

The present monitoring programme is a continuation of the mangrove productivity studies initiated in September 1991 and reported on previously (WBM Oceanics Australia 1992, 1993). It was implemented to provide quantitative data on mangrove communities adjacent to the Fisherman Islands prior to, and during, further reclamation works for the Port of Brisbane.

The results of monitoring for the entire study duration (September 1991 to May 1994) are documented in this report.

Monitoring methods were described in detail previously (WBM Oceanics Australia 1992, 1993) and only a brief outline is provided in this report.

A summary of monitoring frequency for each parameter measured is provided below.

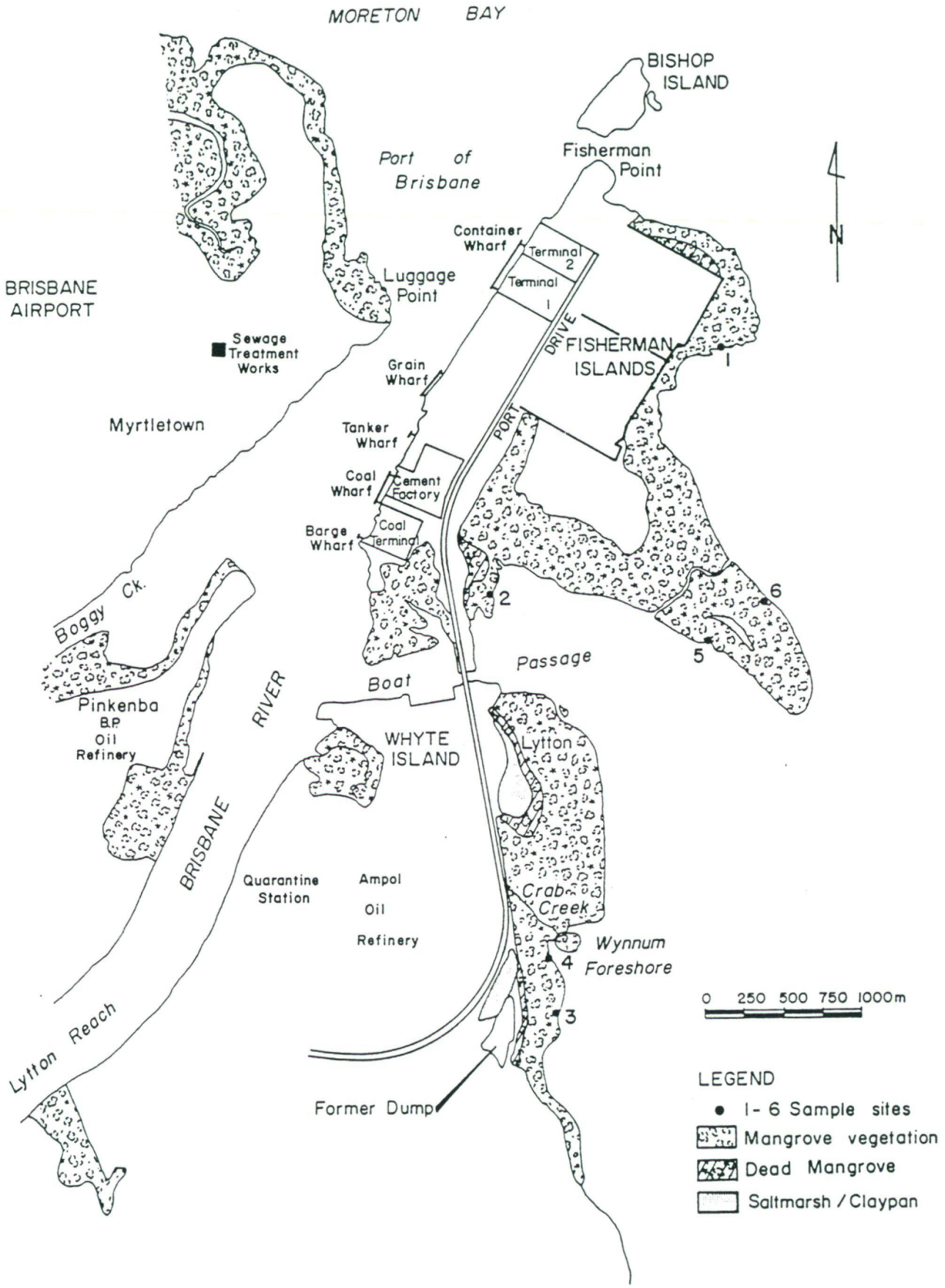
Litterfall

Seasonality (trend over time) and rate (production per unit time) of litter production was studied at four sites in the mangroves of the Fisherman Islands region (sites 1, 4, 5 and 6; Figure 3.1). Three mangrove communities were represented at these four sites - low open, low closed and open *Avicennia marina* (grey mangrove) forest. Structural features of these sites are outlined in Table 3.1. In September 1991, fourteen randomly located litter catchers were suspended from canopy branches at sites 1, 4, 5 and 6 to keep them clear of high tides. At each site, litter was collected approximately every two months for 32 months as detailed in Table 3.2.

TABLE 3.1: STRUCTURAL FEATURES OF FISHERMAN ISLANDS AND WYNNUM FORESHORES MANGROVE MONITORING SITES (September 1991)

	Site					
	1	2	3	4	5	6
Vegetation structural form	Open forest	Open forest	Low open forest	Low open forest	Low closed forest	Open forest
Dominant species	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*
Projective foliage cover (%)	62	67	62	62	72	61
Canopy height (m)	10 - 13	10 - 13	8 - 10	8 - 10	8 - 10	10 - 13
Stand density (stems per ha)	334	462	830	876	893	380
Stand basal area (m^2/ha)	24.0	23.1	24.1	28.9	24.1	24.3
Stem girth (cm)*	87.0 ± 4.4 (n=72)	73.5 ± 3.5 (n=68)	56.9 ± 2.5 (n=60)	59.7 ± 3.1 (n=60)	55.9 ± 2.2 (n=60)	86.1 ± 3.5 (n=60)
General description	Tall trees, large girths single-stemmed, widely spaced	Tall trees, moderate to large girths, single or double-stemmed, well spaced	Low trees, small girths, one to a few stems, closely spaced	Low trees, small girths, one to a few stems, closely spaced	Low trees, small girths, one to a few stems, closely spaced	Tall trees, large girths, single-stemmed, widely spaced

* mean ± standard error



MANGROVE VEGETATION, FISHERMAN ISLAND 1991

FIGURE 3.1

WBM OCEANICS AUSTRALIA

TABLE 3.2: TIMING OF LITTERFALL COLLECTIONS FISHERMAN ISLANDS (1991 - 1994)

Collection Period	Collection Number	Month
1991/92	Installation of litterfall traps	September 1991
	1st	December 1991
	2nd	February 1992
	3rd	May 1992
1992/93	4th	July 1992
	5th	September 1992
	6th	November 1992
	7th	January 1993
	8th	March 1993
	9th	May 1993
1993/94	10th	July 1993
	11th	September 1993
	12th	November 1993
	13th	January 1994
	14th	March 1994
	15th	May 1994

Following collection, the plant litter was sorted into leaf, stem and fruit (including all stages from bud to fully developed propagule) material, oven dried at 80°C, then weighed ($\pm$ 0.01 g).

Comparison of litterfall between the 1992/3 and 1993/4 collection periods was based on the breakup of collections as shown in Table 3.2. Annual litterfall was expressed in tonnes/ha.

Seasonality and rate of litterfall production was expressed in units of grams per square metre per day. This allowed direct comparison of litterfall rates between collection dates, when collections could not be made at exactly two monthly intervals.

Stem girth

Change in stem girth was monitored by dendrometers installed on 10 trees at each of the six sites (Figure 3.1). A detailed description of the construction and installation of the dendrometers is provided in WBM Oceanics Australia (1992).

Following installation of dendrometers on the 25th October 1991, readings were taken on the following dates:

- 1st Reading February 1992
- 2nd Reading September 1992
- 3rd Reading March 1993
- 4th Reading September 1993
- 5th Reading January 1994

All the dendrometers on the trees at Site 2 were removed by persons unknown some time before the fourth reading. They were not replaced, as it was considered highly probable that they would be removed again. By the fifth reading in January 1994, the markings on the remaining dendrometers had become heavily weathered and no further readings could reliably be taken after this time.

Canopy Height

Canopy height and projective foliage cover were measured at each site. These two parameters are measured to classify vegetation structural type according to the widely used scheme of Specht (1970).

Canopy height was indirectly determined by heighting several trees in the overstorey at each site with a Suunto clinometer and was expressed as a range (m).

Projective Foliage Cover

Projective foliage cover estimates the horizontal cover of a site by the overstorey canopy and provides a measure of a plant community's potential productivity. At each site, projective foliage cover was determined from 50 random point quadrant sitings and was expressed as a percentage.

Photographic record

A photographic record of the mangrove community at each site was made by taking a photo facing each major cardinal point from a fixed reference point.

Photos were taken at the following dates:

- September 1991
- February 1992
- September 1992
- March 1993
- November 1993
- May 1994

These photographs were taken to note any marked changes in seedling populations and general structure of the mangrove community. The photographic record has been provided to PBA separately of this report.

Statistical Analysis

Statistical analysis was carried out using the computer software SPSSPC (SPSS 1988). Mangrove litterfall was compared between sites within each year using a one-way ANOVA in conjunction with the Duncan test with a significance level of 0.05. Mangrove litterfall was compared between years for each site using a t-test for independent samples and Levene's Test for equality of variances.

4.0 RESULTS

4.1 LITTERFALL

The following aspects of litterfall production are examined:

- annual production
- site differences
- seasonal patterns

4.1.1 Annual Production

Total litterfall (leaf, stem and fruit) and leaf litterfall (leaf only) at each site for 1992/3 and 1993/4 is presented in Table 4.1. Data is illustrated as a bar graph in Figure 4.1.

No significant differences in total or leaf litterfall occurred between 1992/3 and 1993/4 at any of the sites except site 4, where leaf litterfall was significantly greater in 1993/4 than 1992/3.

4.1.2 Site differences

Annual leaf and total litterfall was compared between sites for each year, 1992/3 and 1993/4.

Leaf Litterfall

In the collection period 1992/3, leaf litterfall was significantly greater in the low closed forest (site 5), than in the taller, open forests (sites 1 and 6).

TABLE 4.1: ANNUAL TOTAL AND LEAF LITTERFALL PRODUCTION FOR 1992/93 AND 1993/94

Site	Community Structural Type	Litterfall Component			
		Total (t/ha)		Leaf (t/ha)	
		1992/3	1993/4	1992/3	1993/4
1	*Avicennia marina* open forest	6.36	7.14	3.85	4.02
4	*A. marina* low open forest	8.37	10.62	4.65	5.40
5	*A. marina* low closed forest	7.87	7.86	4.87	4.58
6	*A. marina* open forest	5.83	8.11	3.78	4.56

In the collection period 1993/4, leaf litterfall was significantly greater in the low open forest (site 4) than in the open forest of Site 1 (Table 4.1, Figure 4.1).

Total Litterfall

Since leaf litterfall contributed at least 50% to the total litterfall, between site differences in total litterfall were similar to those seen in leaf litterfall.

Total litterfall in 1992/3 was significantly greater in the low open and low closed forests (sites 4 and 5, respectively) than in the open forests (sites 1 and 6).

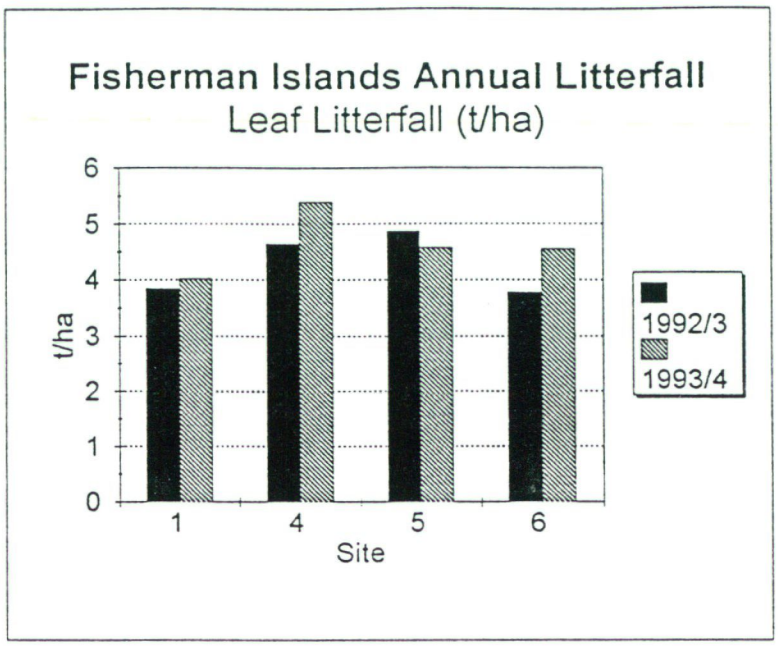
In 1993/4, total litterfall was significantly greater in the low open forest (site 4) than in all other sites (Table 4.1, Figure 4.1).

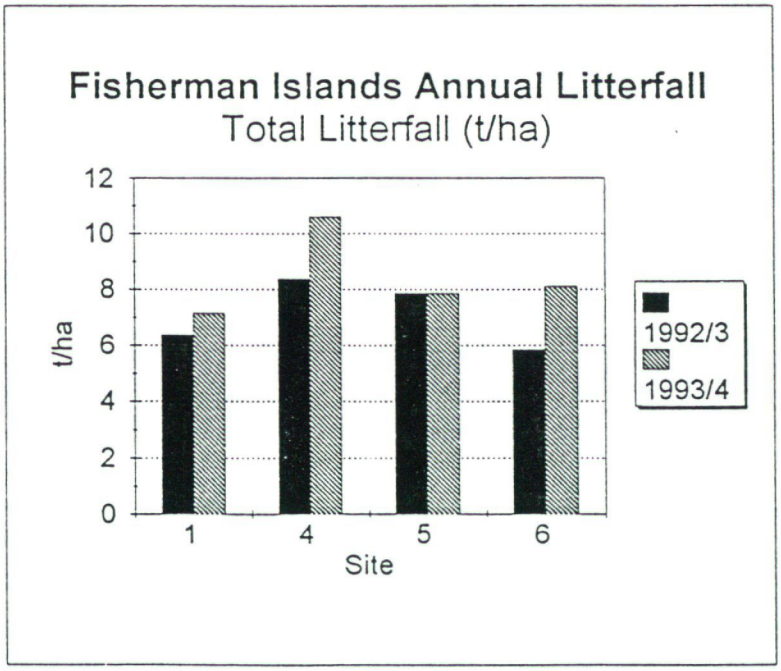
4.1.3 Seasonal Patterns

Seasonal patterns of litterfall production are examined by components - leaf, fruit, total and stem.

Leaf Litterfall

Three peaks in leaf litterfall were identified over the study duration. These occurred during spring, summer and early autumn months at all sites. The seasonal pattern of leaf litterfall at Site 1 is illustrated in Figure 4.2. Appendix A provides illustrations of seasonal leaf litterfall at sites 4, 5 and 6.





FIGURE

Annual Total and Leaf Litterfall, All Sites 4.1

Peaks in leaf litterfall occurred in:

- February (site 4) and May 1992 (all other sites; late autumn)
- November 1992 (late spring)
- January 1994 (mid summer)

Fruit Litterfall

Fruit litterfall production peaked in March 1993 and September 1993 at all sites, and was generally insignificant at all other times (Figure 4.2).

The first peak in March 1993 comprised flowers and immature fruit, whilst the second peak in September 1993 was of mature fruit.

Total Litterfall

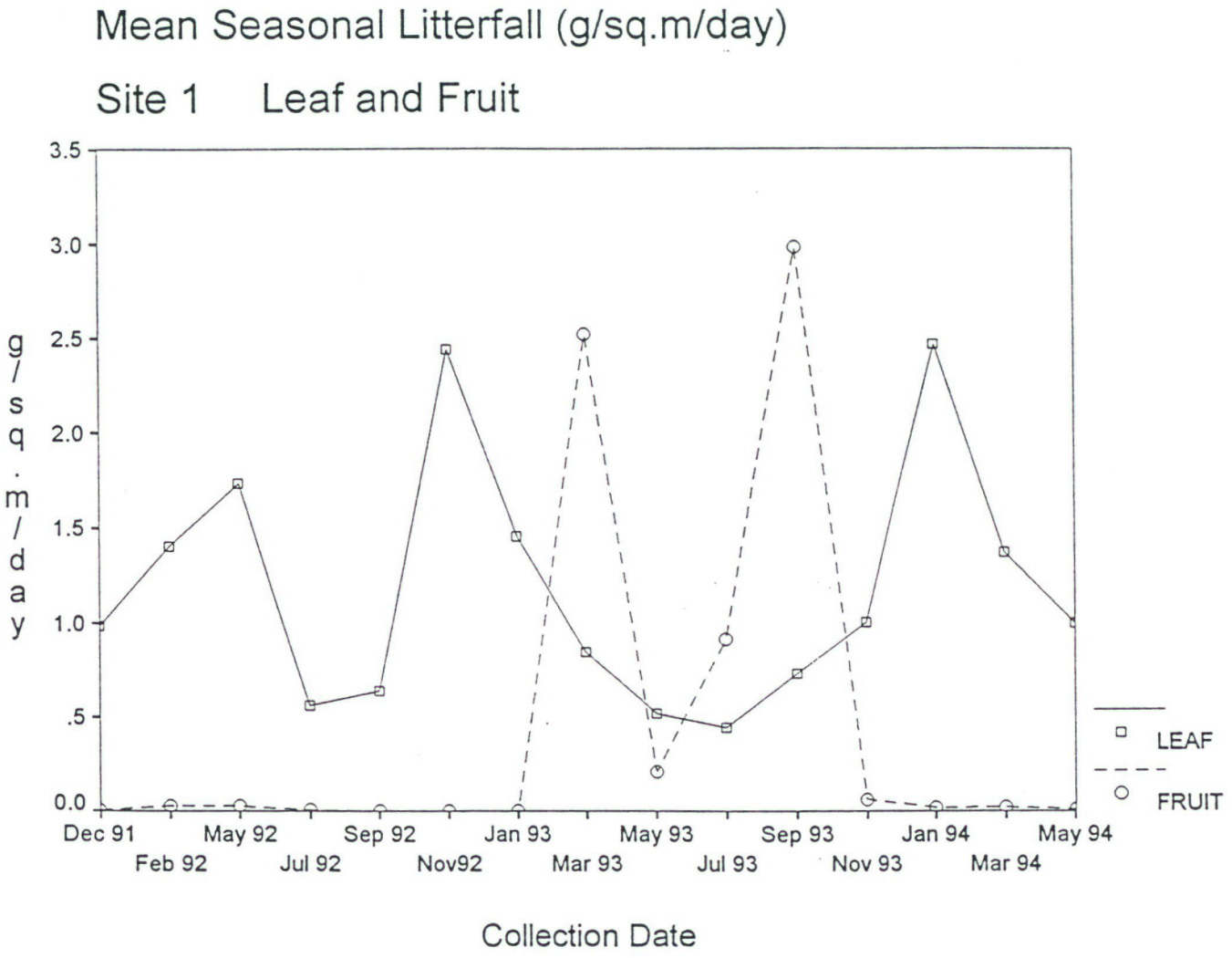
Seasonal patterns in total litterfall production at all four sites are illustrated in Figure 4.3. Patterns in production were generally similar across all sites with least litter being produced in the winter months.

Peaks in total litterfall occurred in:

- late summer-autumn 1992
- late spring 1992
- early autumn 1993
- early spring 1993
- summer 1994

Stem Litterfall

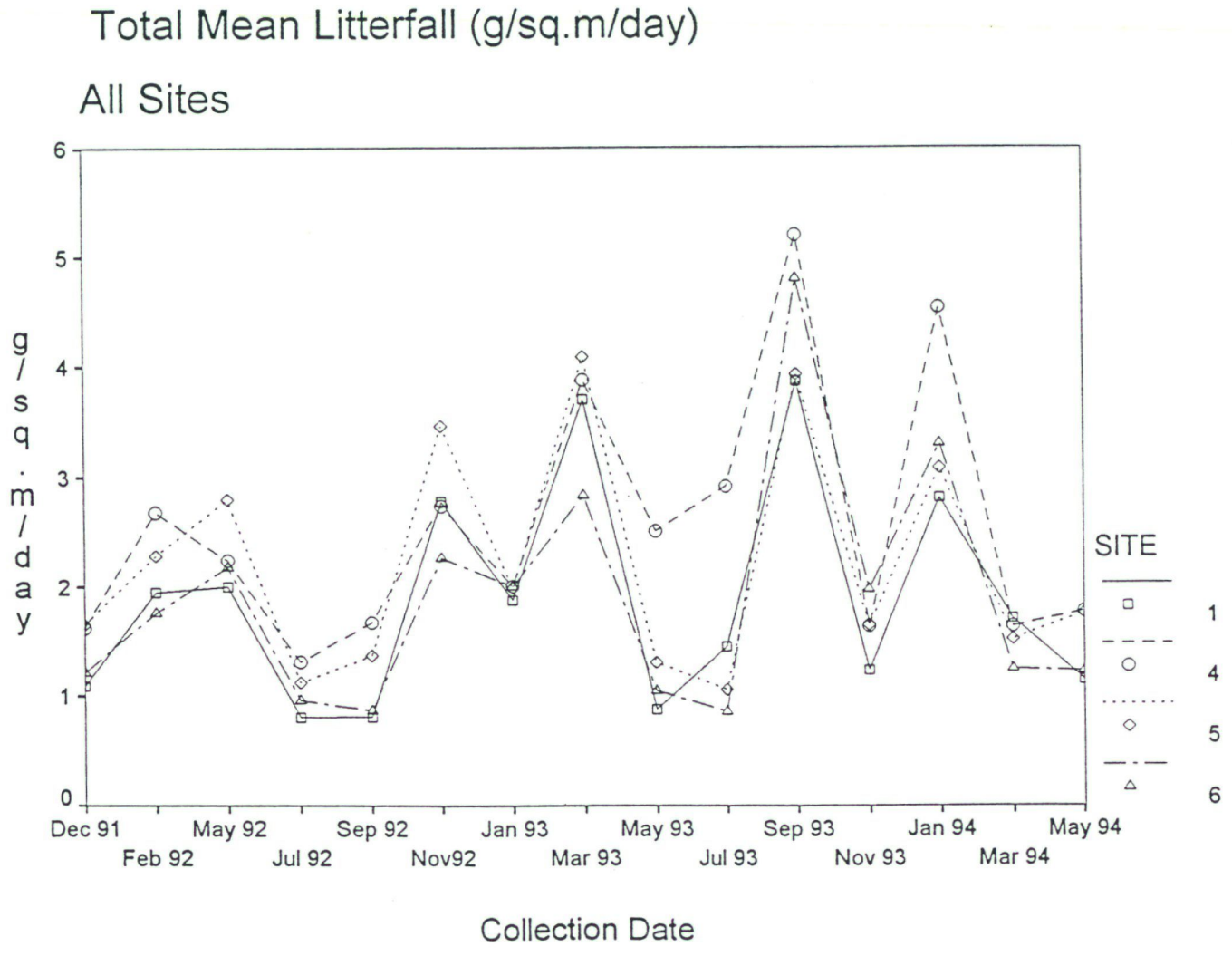
No seasonal pattern in stem litterfall was observed (Figure 4.4). The high variability in stem litterfall within sites is probably due to the less predictable nature of its fall (related to storm and wind events) and high variability in stem size (from twigs to branch sections).



Seasonal Pattern of Leaf and Fruit Litterfall Site 1*

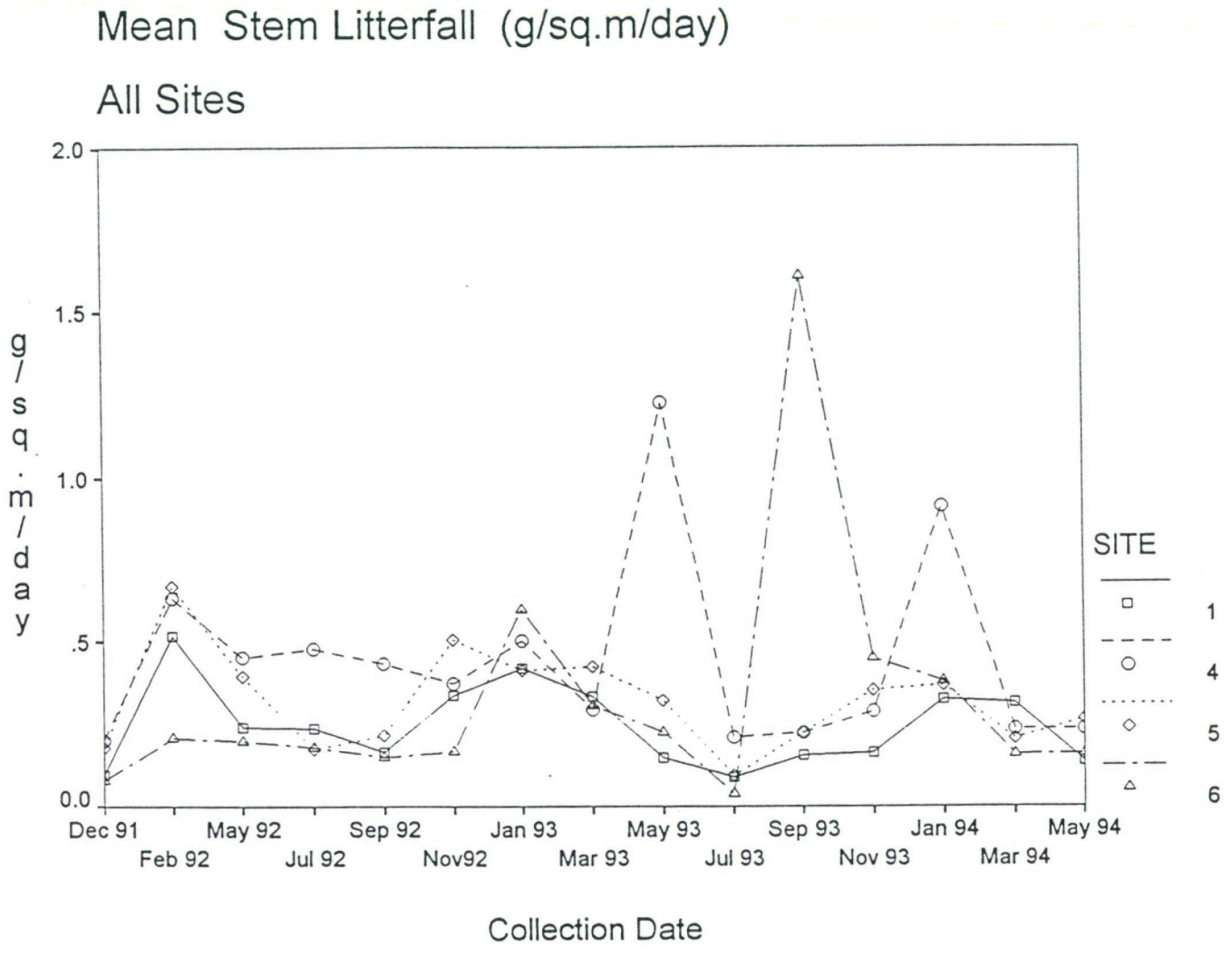
FIGURE 4.2

* N.B. Data for other sites is presented in Appendix A



FIGURE

Seasonal Pattern of Total Litterfall, All Sites 4.3



FIGURE

Seasonal Pattern of Stem Litterfall, All Sites

4.4

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4.2 STEM GIRTH

Changes in stem girth for the ten trees monitored at each of the six sites (Figure 3.1) are summarised in Table 4.2.

By the last measurement in January 1994 (over 26 months since commencement of measurement in October 1991) at least half of the trees at each site had increased in girth.

The largest increases occurred on trees at Sites 3 and 4 (with maximum increases of 17.3 mm and 14.7 mm respectively). Sites 3 and 4 also supported the most number of trees showing girth increases (8 trees at each).

The largest decreases in stem girth and the most trees showing decreases occurred at Site 6, where five trees decreased in girth since the start of measurement, with a maximum decrease of 4.3 mm.

Detailed analysis of average stem increment for each site was not made because of the high within-site variability (standard error of average stem girth change generally >30%). This occurred even though average tree girth at the commencement of measurements was low (<10% standard error).

TABLE 4.2: SUMMARY OF CHANGES IN STEM GIRTH (mm) FOR THE PERIOD 25/10/91 - 14/1/94

Ten trees were monitored for changes in stem girth at each site.

		SITE					
		1	**2**	**3**	**4**	**5**	**6**
Average Initial Girth		753 (± 54.6)	754 (± 48.2)	636 (± 32.6)	600 (± 26.8)	773 (± 55.7)	952 (± 62.7)
Average Final Girth		755 (± 55.0)	755 (± 48.2)	643 (± 32.1)	606 (± 27.0)	776 (± 56.0)	952 (± 62.3)
Measurement number	Date	Stem girth change (mm)					
1	7/2/92	-0.8 to 1.8	-2.5 to 0.5	-2.5 to 0.5	-1.0 to 1.3	-2.3 to 1.8	-4.1 to 0.0
2	18/9/92	-1.0 to 2.3	-2.5 to 3.1	-1.0 to 8.6	-0.1 to 5.6	-2.5 to 4.8	-3.6 to 1.3
3	12/3/93	-3.8 to 3.3	-2.5 to 4.3	-0.3 to 4.3	-0.5 to 12.5	-2.5 to 7.1	-3.8 to 3.3
4	8/9/93	-0.5 to 5.8	*	0 to 14.0	-0.25 to 13.0	-2.5 to 8.6	-3.8 to 2.5
5	14/1/94	0 to 5.6	*	0 to 17.3	0 to 14.7	-2.8 to 9.1	-4.3 to 4.1
No. trees increasing in girth size since start		6	5	8	8	7	5
No. trees decreasing in girth size since start		0	2	0	0	3	5

* dendrometers were removed from trees at site 2 sometime after the 3rd measurement by persons unknown.

4.3 PROJECTIVE FOLIAGE COVER, CANOPY HEIGHT AND VEGETATION STRUCTURAL TYPE

Table 4.3 compares the canopy heights and projective foliage cover (PFC) values from their recording in September 1991 to that in January 1994. Together, PFC and canopy height determine the vegetation structural type according to the classification scheme of Specht (1970).

TABLE 4.3: PROJECTIVE FOLIAGE COVER (PFC), CANOPY HEIGHT AND VEGETATION STRUCTURAL TYPE, AT THE START (SEPTEMBER 1991) AND END (MAY 1994) OF THE MONITORING PROGRAMME.

		Site					
Date	**Attribute**	**1**	**2**	**3**	**4**	**5**	**6**
25/9/91	PFC%	62	67	62	62	72	61
	Canopy height (m)	10-13	10-13	8-10	8-10	8-10	10-13
	Vegetation structural type *	open forest	open forest	low open forest	low open forest	low closed forest	open forest
12/5/94	PFC %	64	60	66	69	70	68
	Canopy height range	10-13	10-13	8-10	8-10	8-10	10-13
	Vegetation structural type *	open forest	open forest	low open forest	low open forest	low closed forest	open forest

*after Specht (1970)

Minor variations in PFC were recorded between the first and the final measurements. The range in canopy heights did not markedly change from the first to the final reading.

4.4 PHOTOGRAPHIC RECORD

The photographic record documents general mangrove community structure at the monitoring sites over the study duration.

The photographic record did not reveal any gross changes in the structure of the mangrove communities at the monitoring sites since the first photos taken in September 1991 until the final photos of May 1994.

5.0 DISCUSSION

This mangrove monitoring programme is the longest conducted in Moreton Bay.

Litterfall production over two complete years was measured and changes in stem girth were monitored over 26 months.

This study provides the Port of Brisbane Authority with:

- baseline data, including photos, against which future comparisons can be made
- an understanding of the natural seasonal and annual variability in litterfall of the mangroves adjacent to the port
- information on periods of fruit production, essential if seed collections for mangrove rehabilitation are planned

5.1 LITTERFALL

Litterfall is commonly used as an indirect measure of primary productivity in mangrove studies as it is more readily obtained than direct measures of primary productivity.

Litterfall was measured in this study to allow comparisons to be made with litterfall estimates derived from other mangrove studies. This will provide the Port of Brisbane Authority with information on the relative productivity of the mangroves adjacent to the port, compared to mangroves from other regions.

Annual Production

Studies of litterfall production in mangrove communities from around the world reveal a wide range in litter production, from 0.8 t/ha/year in a temperate/subtropical mangrove forest in southern Florida, to 28.1 t/ha/year in a mixed species tropical mangrove forest in North Queensland (Hutchings and Saenger 1987). The annual litterfall values from this study fall in the lower half of the range referred to by Hutchings and Saenger (1987). This is to be expected, given the location of the Fisherman Islands in the more temperate parts of the subtropics.

The range in annual total litterfall values (from 5.83 to 10.62 t/ha/year) between the sites of this study illustrates the variation that can occur in the same locality between mangrove communities differing slightly in structure.

Variation in litterfall production between mangrove communities of differing structure was also identified in the study by Davie (1984) on Mud Island, where annual litterfall ranged from 1.94 to 6.42 t/ha/year.

Significantly greater annual total and leaf litterfall was recorded in the low open and/or low closed mangrove forests (sites 4 and 5 respectively) than in taller, open mangrove forests (sites 1 and 6). The greater number of trees in the low open and low closed mangrove forests (higher stem densities) than in the taller, open mangrove forests, would contribute to this difference.

Whilst differences in annual litterfall were evident between sites, few differences emerged between the two complete years of litterfall measurement at individual sites. The only exception was site 4, where leaf litterfall was greater in the second year of measurement (1993/4).

Seasonal Patterns

Leaf Litterfall

Peaks in leaf litterfall have been related to periods of new leaf production and/or shoot growth (Davie 1984). The timing of peaks in leaf litterfall in this study are similar to those recorded for mangroves at the nearby Mud Island. Both this study and that of Davie (1984) recorded strong peaks in spring months (September 1979 and October 1980 by Davie (1984) and November 1992 this study). The absence of a peak in leaf litterfall in the spring of 1993 for this study is thought to be related to a flower and fruit production cycle during this time. A peak in leaf litterfall occurred in January 1994 in this study, following the completion of fruit fall. Davie (1984) also recorded a January peak in litterfall (in 1980), however this was related to increased storm activity.

In both this study and the Mud Island study (Davie 1984) minimums in leaf litterfall occurred during winter months. At the Fisherman Islands, a more pronounced winter minimum in leaf litterfall was recorded for 1993 than for 1992, apparently due to a period of flowering and fruiting. Saenger and Moverley (1985), in a productivity study of mangroves in central Queensland, also recorded a marked depression in leaf production during flowering and fruiting. Similarly, leaf litterfall was at a minimum during a period of high fruit litterfall in the mangroves of Mud Island (Davie 1984).

The seasonal pattern of leaf litterfall for subtropical mangroves in eastern Australia appears to peak in spring months and is at a minimum during winter. When a flowering or fruiting event occurs, the period of minimum leaf litterfall may be prolonged.

Fruit Litterfall

Only one full reproductive cycle was recorded over the study duration. This was displayed as two peaks in the collection periods:

- March 1993 - flowers and immature fruit
- September 1993 - mature fruit

The results of this study indicate that the grey mangroves of the Fisherman Islands region, (and probably the rest of Moreton Bay) do not fruit annually. A similar finding was made in a study of grey mangroves in Westernport Bay where fruit were produced only every second or third year (Clough and Attiwill 1982). The 17 month study of mangroves at Mud Island (Davie 1984) recorded only one major peak in fruit production.

In tropical areas, fruit production is an annual event (Hutchings and Saenger 1987), indicating that the tropical environment is more favourable to frequent mangrove fruit production than the sub-tropical environment of Moreton Bay.

A knowledge of when and how often the mangroves of the Fisherman Islands fruit will be vital to the Port of Brisbane Authority, if it plans to conduct any mangrove regeneration projects requiring seeds in the port's vicinity.

5.2 STEM GIRTH

The small changes in stem girth over the study duration of approximately 26 months (max. increment = 3.9%), indicate that the mangroves in the Fisherman Islands region may be mature and progressing into over-maturity or senescence. During these stages, growth rates decline. The stem girth data of this study support this.

The paucity of studies of changes in stem girth on mangroves elsewhere in Australia prevents a comparison and assessment of the significance of the changes in stem girth recorded in this study. However, the largest changes in girth increments recorded in this study do not appear to be very large for a measurement period of approximately 26 months.

5.3 PROJECTIVE FOLIAGE COVER (PFC), CANOPY HEIGHT AND VEGETATION STRUCTURE

Slight differences in PFC were recorded in the final measurement of this parameter, compared with the measurements taken at the initiation of the study.

However, the mangrove communities had not perceptibly altered in structure since the initial measurements. The change in PFC values could be the result of measurement error, actual increases in foliage cover (which probably does fluctuate through different seasons of the year) or a combination of both.

The range in canopy heights recorded at the end of the study were consistent with those recorded at the study initiation.

6.0 OVERVIEW AND RECOMMENDATIONS

The study provides the Port of Brisbane Authority with a baseline data set on mangrove productivity that is one of the longest running data sets on litterfall production for mangroves in Moreton Bay.

It provides information on the quantity, rate and seasonality of mangrove litterfall. This will be useful for:

- comparison with future mangrove productivity monitoring studies
- comparing the productivity of mangrove communities at the study site to communities elsewhere
- providing input for nutrient budget studies on mangrove ecosystems
- examining long-term responses to changing conditions in the surrounding environment
- timing of seed collections for mangrove rehabilitation works

It is recommended that future monitoring be instigated after the port expansion is completed. Monitoring could include:

- litterfall collections (for 1 year, every 4 to 5 years)
- aerial photography (annually to monitor the health of the canopy, and changes in the mangrove community boundary)

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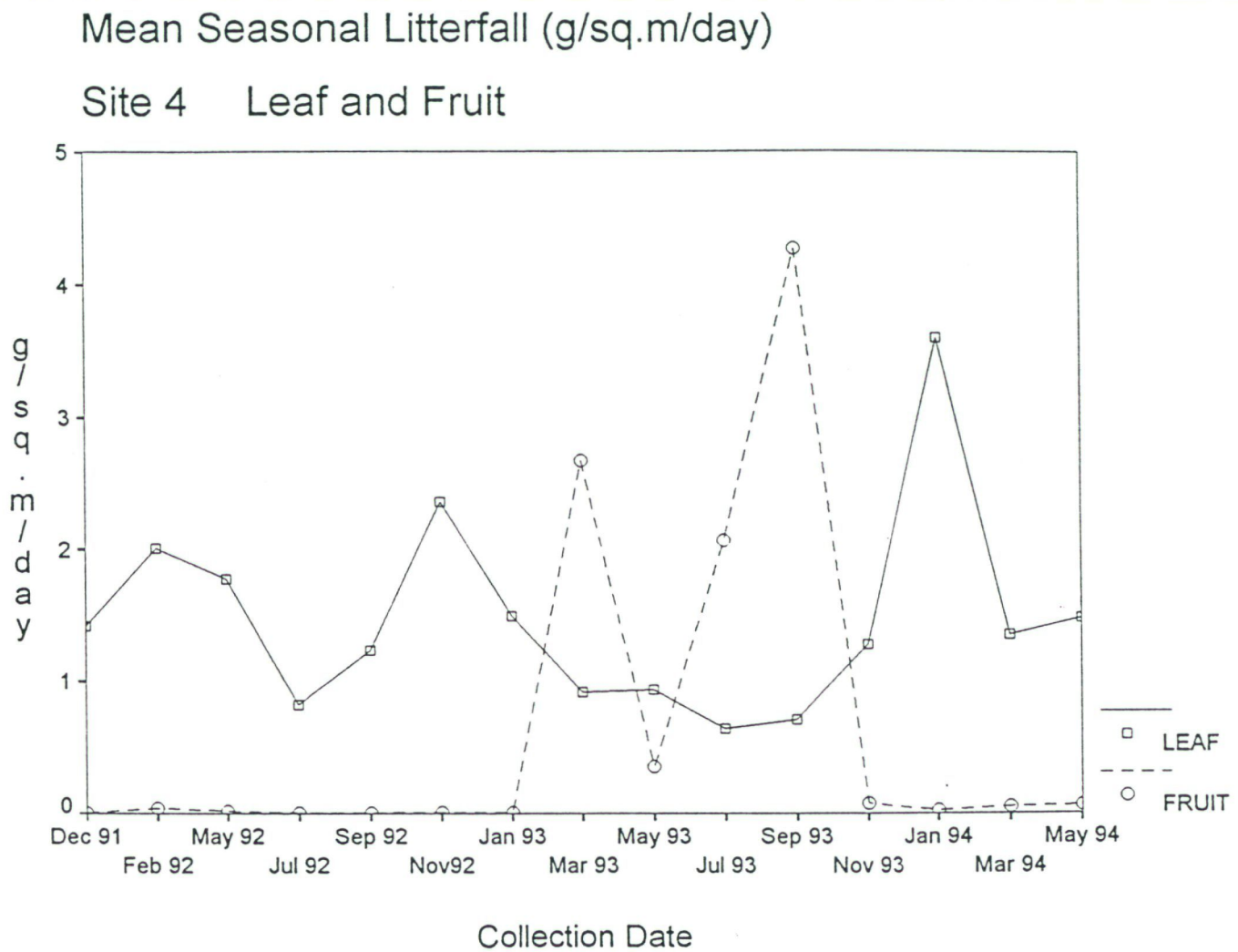
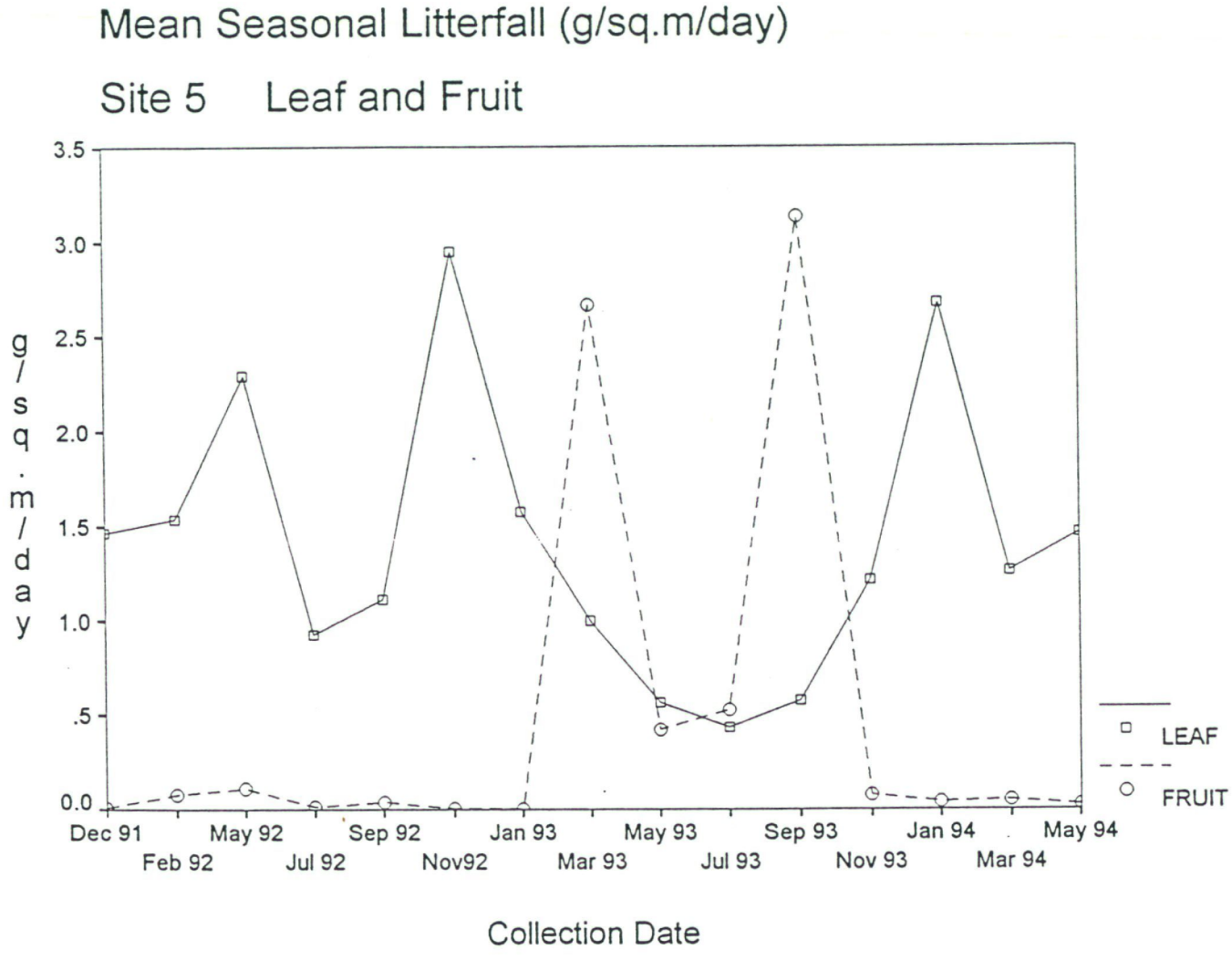
APPENDIX A

Seasonal Leaf Litterfall Graphs
For Sites 4, 5 and 6



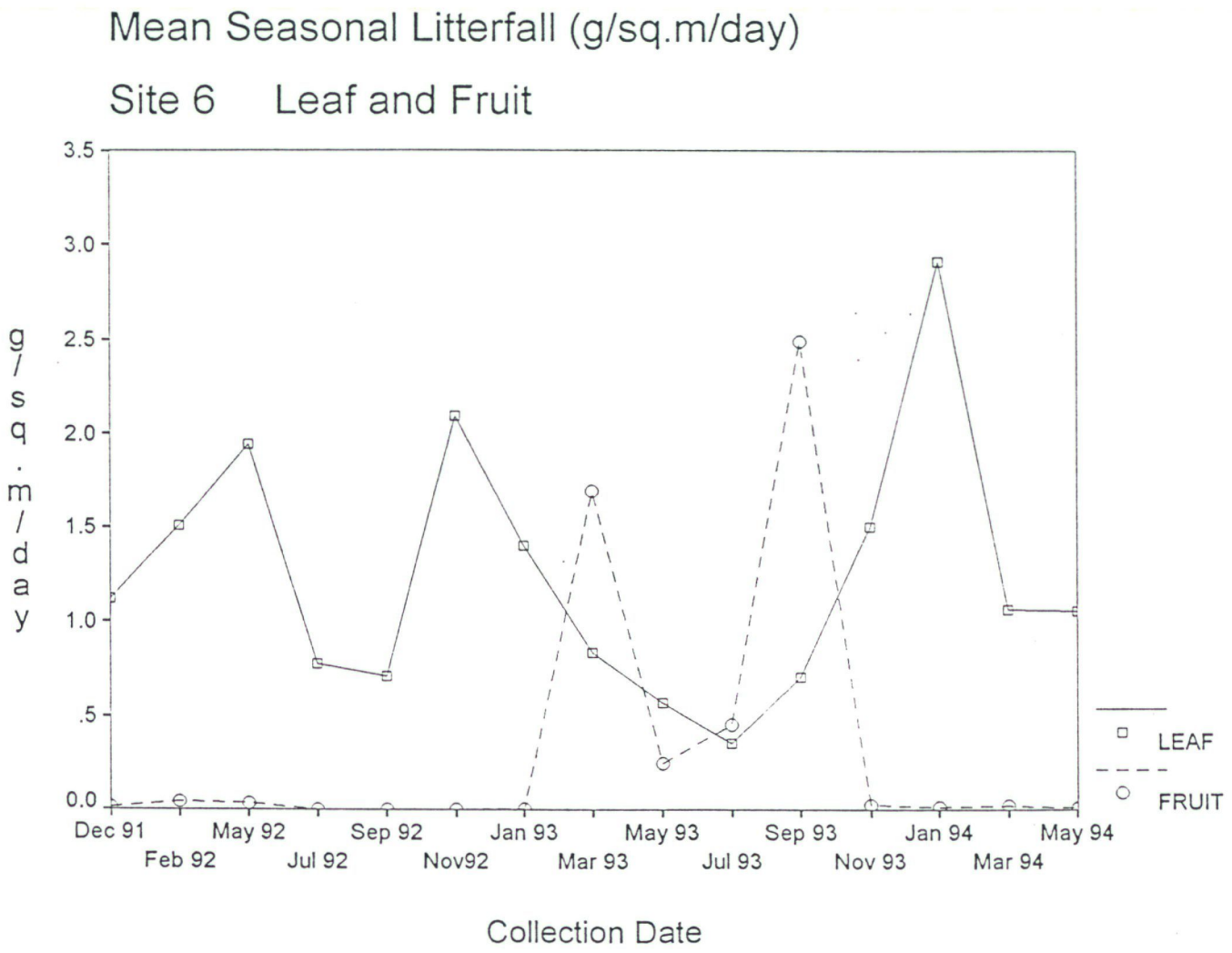
FIGURE

Seasonal Pattern of Leaf and Fruit Litterfall, Site 4 A.1



FIGURE

Seasonal Pattern of Leaf and Fruit Litterfall, Site 5 A.2



FIGURE

Seasonal Pattern of Leaf and Fruit Litterfall, Site 6 A.3

MANGROVE PRODUCTIVITY MONITORING STUDY

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Client: **PORT OF BRISBANE AUTHORITY**

Client Contact: **MARK PILLSWORTH**

Client Reference:

Synopsis:

This report relates to the monitoring of mangrove productivity in the Fisherman Islands mangroves for the years 1992/93. Mangrove productivity attributes monitored included litterfall and stem girth increment.

REVISION/CHECKING HISTORY

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EXECUTIVE SUMMARY

Fisherman and Whyte Islands have been developed as a major port facility at the Brisbane River mouth by the Port of Brisbane Authority (PBA). The PBA foresees the need to expand port capacity which will involve disturbance of intertidal and subtidal lands of the Fisherman Islands, some of which are vegetated by mangroves.

Mangrove areas cover approximately 220 ha. Mangrove communities of Moreton Bay are highly productive and structurally complex. They provide large amounts of plant litter, an important primary food source for aquatic organisms of mangrove-dominated estuaries. Mangroves are also important nursery and feeding grounds for many fishes and crustaceans, most of which are of direct importance to commercial and recreational fisheries.

In a regional context, the mangroves of the study area on Fisherman Islands represent 1.7% of the 13900 ha of mangroves in Moreton Bay.

This document provides the 1992/93 results of a mangrove productivity monitoring study in the Fishermen Islands region, commissioned by the PBA and it is the second report of a three year survey. It expands on the results of earlier mangrove monitoring initiated in September 1991. The earlier study (WBM Oceanics Australia 1992) described the structure of the mangrove communities at which monitoring studies were conducted, and the results of initial monitoring (up to February 1992).

The study has gathered data on the productivity of mangrove communities at four sites in the study area from September 1991 to May 1993. Litterfall and stem girth increment were the two aspects of mangrove productivity monitored. The data from this study will enable detailed comparisons to be drawn between mangrove communities prior, during and following reclamation works. Key findings of the studies are:

- The mangroves at the monitoring sites are typical in structure and composition to mangrove communities elsewhere in Moreton Bay

- The mangroves are healthy and not subject to on-going adverse impacts

- Annual total litterfall ranged from 4.86 to 6.96 t/ha/yr, agreeing closely with other litterfall studies conducted in Moreton Bay and indicating that port-related activities have not adversely affected productivity of adjacent mangroves

- Litterfall estimates displayed low within-site variability, indicating that the spatial arrangement of litterfall catchers sampled areas of mangrove forest that were structurally homogeneous

- Stem growth over the duration of the study was very small and highly variable

- No major structural changes in the mangrove communities at the sites were observed over the monitoring period (September 1991 to May 1993) although changes may occur over a longer term

Seasonal patterns in litterfall are emerging from the study results. The first major fruit litterfall has been recorded since the study was initiated (September 1991), indicating that fruit production is not always annual. Continued monitoring will allow verification of the periodicity of fruit production in the *Avicennia marina* - dominated mangrove communities adjacent to the Port of Brisbane. This information will be vital to the Port Authority if it plans seed collections for mangrove regeneration projects.

Litterfall monitoring is proceeding without major technical problems and is probably the longest of such studies to be conducted in Moreton Bay. Results to date have been very reliable.

Litterfall monitoring extended over the next 1-2 years would provide data encompassing a broad range of seasonal and annual variation in productivity. Litterfall should continue to be collected at intervals of no more than two months; longer intervals allow trapped litter to decompose and result in underestimation of litterfall production.

Stem girth increments were very small, in many cases negative (decrements) and highly variable, despite the relatively uniform size of the tree stems measured. The initial expectations of the stem girth increment data have not been realised. However, with the monitoring equipment already installed, it is relatively inexpensive to take further readings. Over a longer measurement period (up to five years) changes in stem girth increment may be larger and more readily interpreted.

Monitoring to date has provided a full year baseline data set and should be continued in order to elucidate seasonal and annual trends in mangrove productivity during and following reclamation activities.

The on-going mangrove monitoring program provides a means by which any adverse effects to mangrove communities neighbouring the port development area can be assessed.

1.0 INTRODUCTION

The Port of Brisbane Authority (PBA) has developed Fisherman and Whyte Islands as a major port facility at the mouth of the Brisbane River. Tidal wetlands (saltmarsh, mangroves and seagrass) occur on and adjacent to the islands.

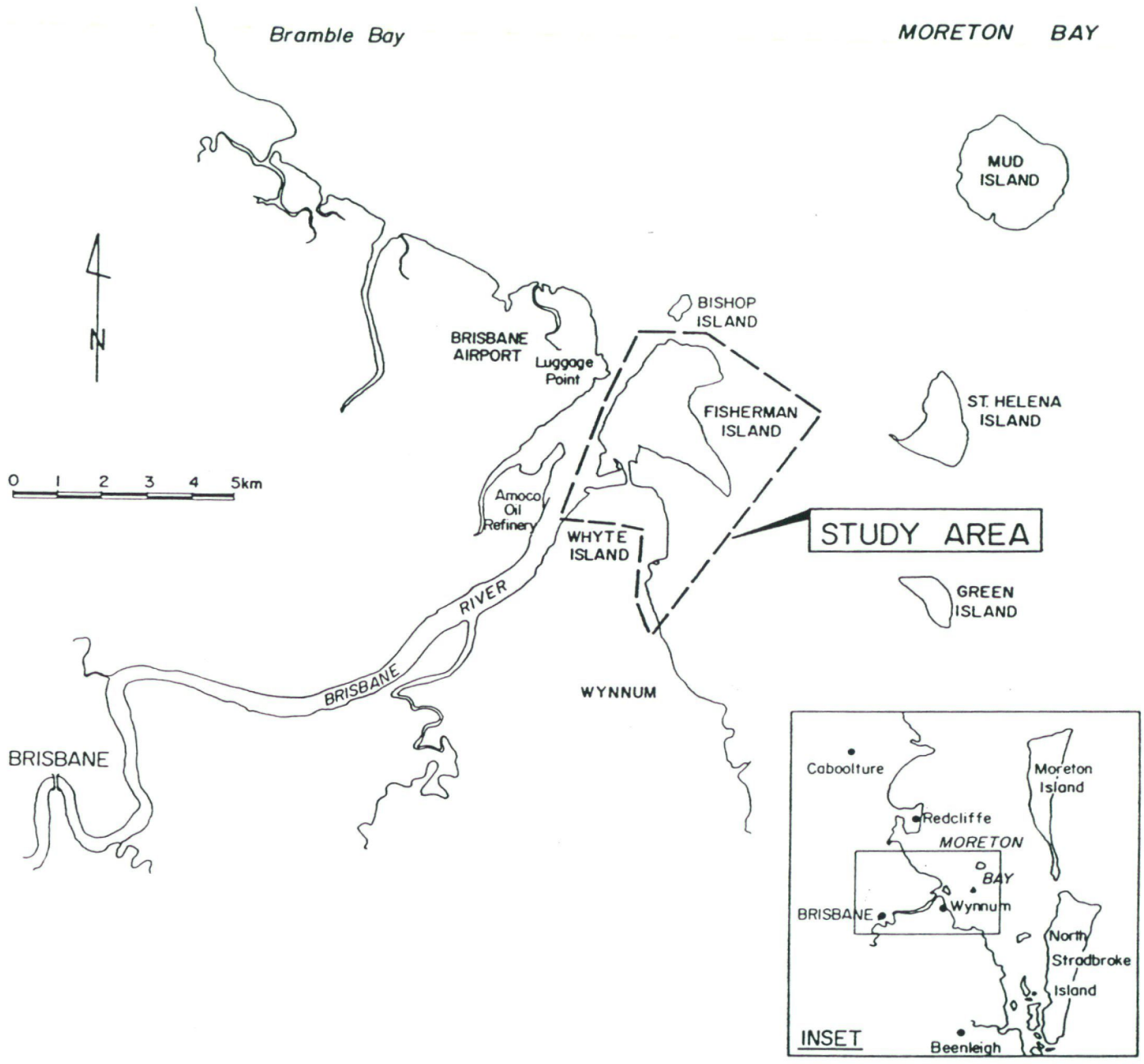
The PBA has identified a long term need to expand the capacity of the port to accommodate a future expansion in port usage (PBA 1992). The Moreton Bay Strategic Plan (DEH 1992), designed to ensure appropriate land use within Moreton Bay, accommodates lands at the Fisherman Islands for port-related activities.

Further expansion of port-related facilities on the southern side of the mouth of the Brisbane River, as described in the PBA strategic plan, will require disturbance of intertidal and subtidal lands at the Fisherman Islands, some areas of which support mangroves.

WBM Oceanics Australia was commissioned by the PBA to undertake studies of tidal wetlands occurring on and adjacent to Whyte and Fisherman Islands and the Wynnum foreshores. The study area is shown diagrammatically in Figure 1.1, and in aerial photography (1991) in Figure 1.2.

The present studies are the continuation of mangrove productivity monitoring, initiated in September 1991 and reported earlier (WBM Oceanics Australia 1992).

The results of the present study will provide the PBA with background information for port environmental management and possible opportunities to accommodate development strategies which enhance, rehabilitate, restore and even create mangrove habitat areas. Section 8.0 provides a glossary of terms used in this report.



STUDY AREA

FIGURE 1.1

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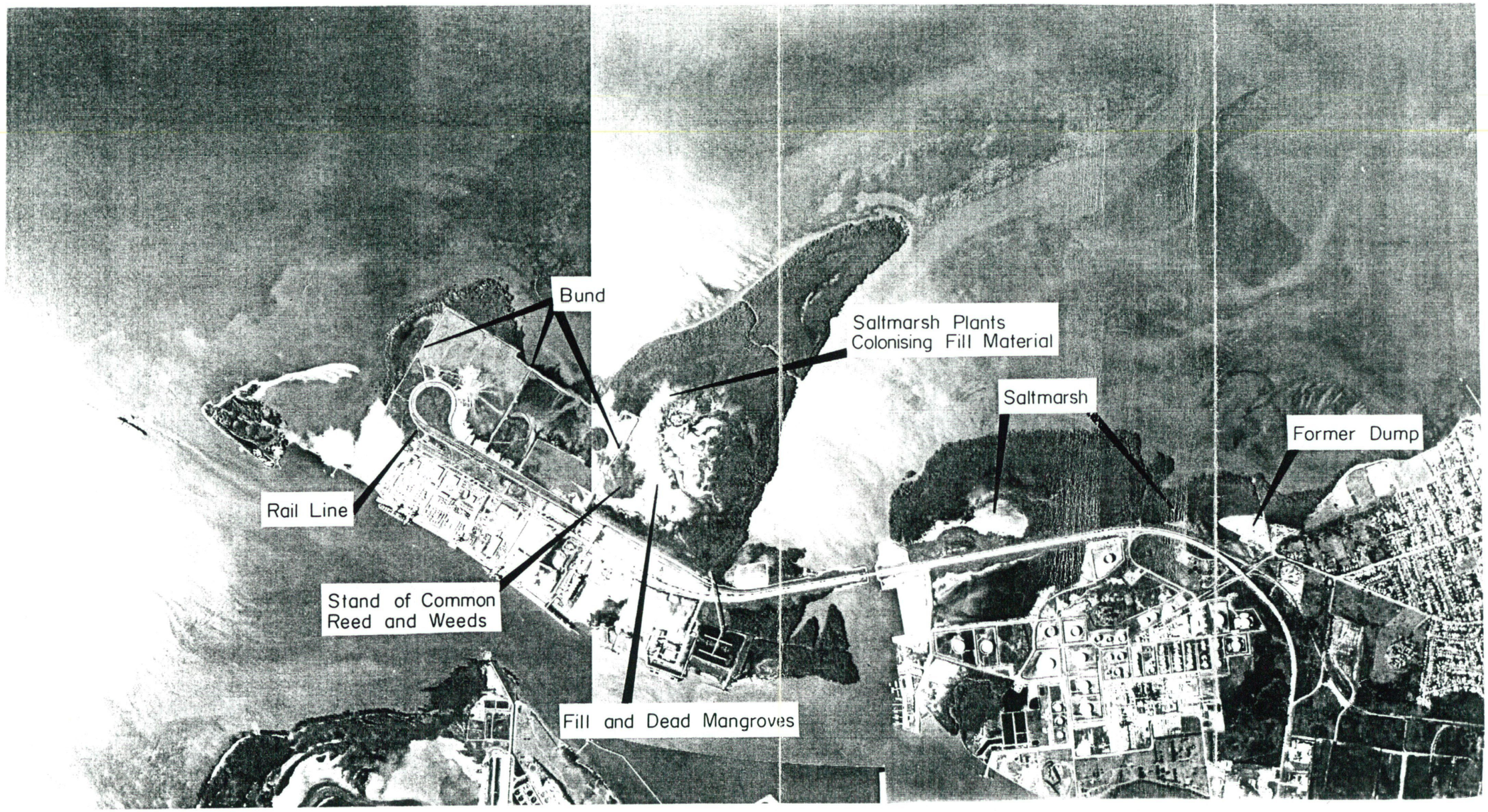


N

0 250 500 750 1000m

FIGURE

1991 AERIAL PHOTOGRAPHY OF STUDY AREA 1.2

WBM OCEANICS AUSTRALIA

2.0 MANGROVE VEGETATION IN THE STUDY AREA

A detailed description of the extent of various wetland types (mangroves, saltmarsh, seagrass) that occur in the study area is provided in the preceding report (WBM Oceanics Australia 1992).

2.1 SPECIES COMPOSITION

Mangroves are the most conspicuous component of tidal wetlands in the Fisherman Islands region and occur from the mean tide level to extreme high water spring level. Seven mangrove species (Table 2.1) occur in Moreton Bay (Hyland and Butler, 1988), five of which were observed during the present field surveys on Fisherman and Whyte Islands and the adjacent Wynnum foreshores.

Hutchings and Saenger (1987) noted that in terms of the number of species and structural complexity of forests, the Moreton Region has one of the most highly developed mangrove areas along the east coast of Australia.

2.2 REGIONAL SIGNIFICANCE

WBM Oceanics Australia (1992) provided an accurate assessment of mangrove areas near the Fisherman and Whyte Islands. In contrast to previous studies, the assessment was undertaken using a combination of aerial photography and detailed ground surveys (truthing).

Other studies on mangrove communities near the Fisherman Islands is provided in WBM Oceanics Australia (1992) and any inaccuracies in these studies is discussed.

The area of mangroves in the Fisherman Islands study area (351 ha) (WBM Oceanics Australia, 1992) represents 2.7% of the 13900 ha mangrove resource of Moreton Bay, from the southern tip of south Stradbroke Island to Caloundra (Hyland and Butler 1988).

The structure of the mangrove forests in the study area varies from low shrubland to forest and is typical of mangrove communities occurring at the mouths of rivers along western Moreton Bay.

The changes in areas of mangroves at Fisherman Islands will be calculated from aerial photographs at the completion of bund wall extensions currently under construction. Bund walls will be completed in June/July 1993, and therefore areas of disturbance will be calculated in the 1993/1994 report.

TABLE 2.1: MANGROVE SPECIES WHICH OCCUR WITHIN THE MORETON REGION

SCIENTIFIC NAME	COMMON NAME
Avicennia marina (Forskal) Vierh. var. *australasica* (Walp.)*	grey mangrove
Aegiceras corniculatum (L.) Blanco*	river or black mangrove
Ceriops tagal var. *australis* C.T. White*	yellow-leaved spurred mangrove
Rhizophora stylosa Griff.*	spotted-leaved red mangrove
Bruguiera gymnorhiza (L.) Lam*	large-fruited orange mangrove
Exocoecaria agallocha L.	milky (blind-your-eye) mangrove
Lumnitzera racemosa Wild.	white-flowered black mangrove

* recorded in Fisherman Islands study area

2.3 ECOLOGICAL IMPORTANCE

Mangroves are highly productive ecosystems which contribute significantly to the coastal ecosystem through export of organic matter. The primary food source for aquatic organisms in most mangrove dominated estuaries, such as Moreton Bay, is particulate organic material (detritus) derived from the decomposition of mangrove forest litter (leaves, twigs, and reproductive or fruit material; Odum and Heald 1972). Mangrove plant litterfall (the most commonly measured component of net primary production) from Fisherman Islands and the Wynnum foreshores is 4.86 to 6.96 dry t/ha/yr (see Section 4.1.1).

During decomposition, mangrove litter becomes a food source for a wide variety of filter, particulate, and deposit feeders such as molluscs, crabs and polychaete worms. These primary consumers, which include representatives of most phyla, are food for secondary consumers, usually small forage fish species and juveniles of the larger predatory species that form the third consumer level (Odum and Heald, 1972). There are also important fisheries species which occupy both primary and secondary consumer levels. They feed directly on particulate organic detritus and also upon primary consumers.

Mangroves function as important fish nursery and feeding grounds. Numerous studies have noted that fishes (particularly juveniles) are more abundant in mangrove dominated areas than in other nearshore habitats (Robertson and Duke 1987, Morton 1990). Possible explanations for this increase in fish abundance near mangroves include high

availability of foods (Beumer 1978, Blaber 1980, Morton 1990) and a high degree of structural heterogeneity of habitat in the form of prop roots, pneumatophores and tree stems (Robertson and Duke 1987). Many of the fishes present near mangrove areas of subtropical Queensland are of direct fisheries value (WBM Oceanics Australia 1991).

Morton (1990) examined fish communities using foreshore mangrove stands at Lota Creek (10 km south of the Fisherman Islands). He noted that:

- 46% of the species, 75% of the number of fishes and 94% of the biomass taken during the study were of direct importance to regional fisheries.

- Standing crop estimates for fish occurring within the mangroves were amongst the highest recorded for estuarine areas in Australia, whilst those for adjacent waters were comparable to those of other estuarine studies.

- A conservative estimate of the value of mangroves to fisheries was $8380/ha/yr. This was based upon the monetary value of fish caught during the study and does not take into account the numerous commercially important juveniles captured or non-commercial values (recreation, education).

Some prawn species, especially banana prawns, also rely heavily upon mangrove areas as nursery grounds (see Dall 1985 for review, Staples *et al.* 1985, Robertson and Duke 1987). Banana prawns (*Penaeus merguiensis*) are taken by beam trawlers operating near the mouth of the Brisbane River but are a relatively minor component of the Moreton Bay fisheries (WBM Oceanics Australia 1991). Staples *et al.* (1985) concluded that banana prawns are almost exclusively found along the mud banks immediately adjacent to the mangrove fringe. Prawns and similar macrobenthos within mangroves are also important food sources for many fish species (Blaber 1980, Morton 1990).

Few mammals, amphibians or reptiles inhabit subtropical mangroves exclusively. Mangroves generally provide an extension of their range or a bridging habitat between terrestrial habitats. Mangroves provide roosting (and to a lesser extent, feeding) sites for fruit bats and many species of estuarine birds.

Mangroves also stabilise foreshores, minimising erosion (Bird 1971, Bird and Barson 1977).

3.0 MONITORING PROGRAMME

The present monitoring program is a continuation of the mangrove productivity studies initiated in September 1991 (WBM Oceanics Australia 1992). This quantitative ecological data will assist in making objective assessments of any impacts to the mangroves resulting from proposed reclamation works.

Selection of monitoring sites, and monitoring parameters, was undertaken in consultation with PBA environmental personnel. Monitoring studies commenced in September 1991. The results of continued monitoring, up to May 1993, is documented in this report.

3.1 MONITORING SITES

Six sites were identified by the PBA for the mangrove study; sites 1 and 6 in the eastern Fisherman Islands region, sites 2 and 5 fringing the Boat Passage and sites 3 and 4 on the Wynnum foreshores near Whyte Island (Figure 3.1).

All sites are dominated by grey mangrove *(Avicennia marina* var. *australasica)* although red mangrove *(Rhizophora stylosa)* and yellow mangrove (*Ceriops tagal* var. *australis*) are numerically very minor components at some sites. No other mangrove species were observed at any of the sites although other species occur landward.

Each of the six sites is immediately landward of the fringing mangrove community. These communities were selected for study because:

- the stature of their component trees and their open structure allowed efficient measurement.

- their position slightly landward from the water's edge afforded some protection from human interference with measuring equipment.

- the mangrove communities at the six sites did not appear to be adversely affected by sediment runoff from landward reclamation works that have occurred for port development.

The structure of the mangrove community at each site is summarised in Section 4.0.

3.2 MONITORING METHODS

3.2.1 Forest Structure

A detailed description of the techniques adopted for measurement of forest structure was provided in an earlier report (WBM Oceanics Australia 1992).

The variables measured in September 1991 to characterise forest structure at the six Fisherman Islands and Wynnum foreshore mangrove monitoring sites were:

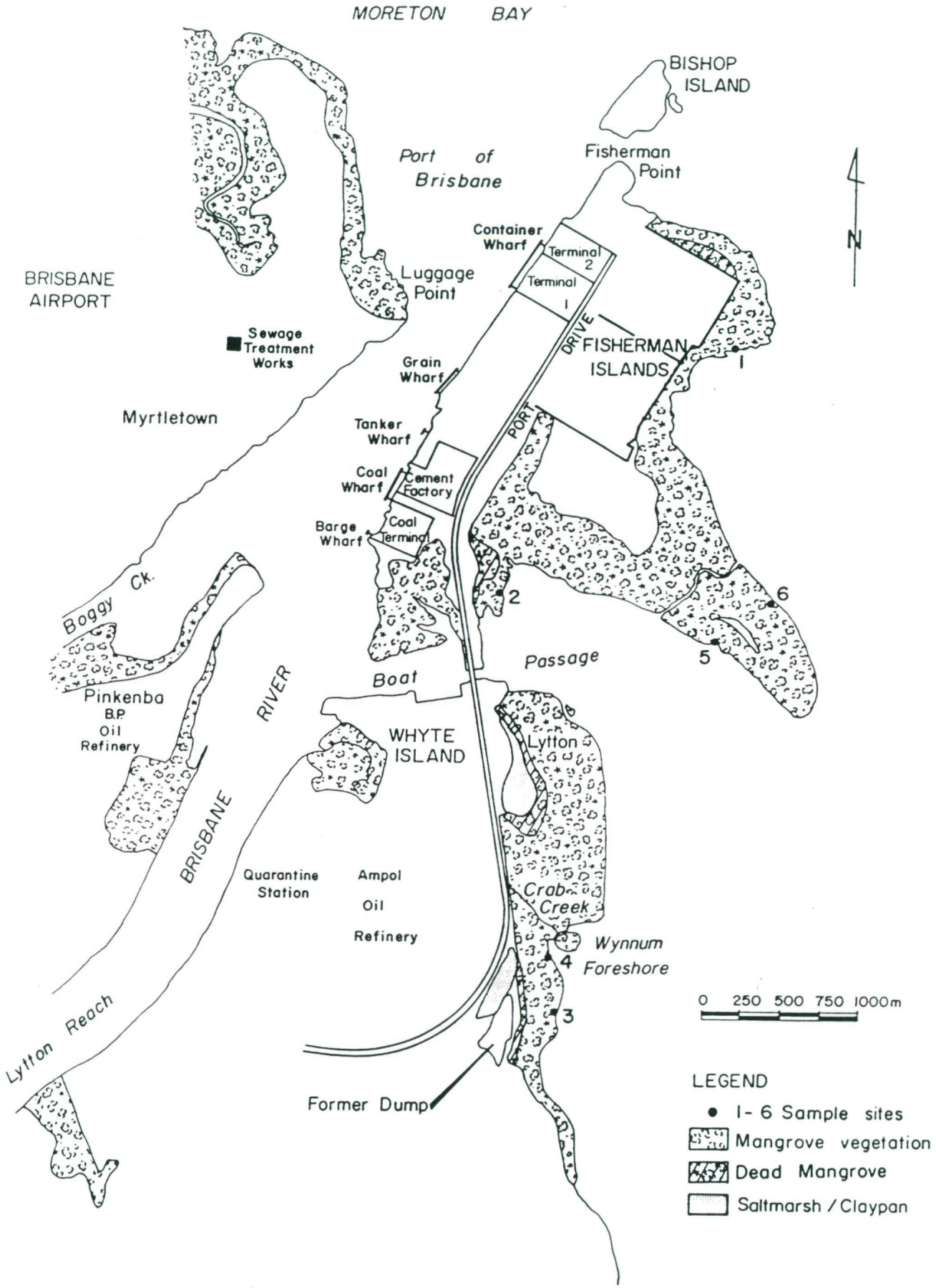
(i) Projective foliage cover
(ii) Canopy height
(iii) Stand density
(iv) Stand basal area

3.2.2 Litterfall

Primary production, from wetland plant communities, is the basis of the estuarine ecosystem (Hutchings and Saenger 1987). Net primary production estimates (gross production less production lost in plant respiration) are not available for Australian mangroves (Hutchings and Saenger 1987). Instead, components of net primary production which are easier to measure are used to compare the relative productivity of different plant communities.

Litter production is a component of net primary production commonly measured in mangrove studies because it is more readily obtained than estimates from gas exchange systems or micro-climatology measurements (Boto 1983).

Plant litterfall monitoring was conducted at sites 1,4,5 and 6 (Figure 3.1). On the 13th September 1991, fourteen randomly located litter catchers were suspended from canopy branches at each site to keep them clear of high tides. Since then, litterfall collection has occurred as detailed below.



MANGROVE VEGETATION, FISHERMAN ISLAND 1991

FIGURE 3.1

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1st Collection	December 1991
2nd Collection	February 1992
3rd Collection	May 1992
4th Collection	July 1992
5th Collection	September 1992
6th Collection	November 1992
7th Collection	January 1993
8th Collection	March 1993
9th Collection	May 1993

Each litter catcher comprised a metal ring 50 cm in diameter (0.2m^2 catching area) around which an inverted cone of shade-cloth (50% shade) was constructed.

After collection, the plant litter was sorted into leaf, stem and fruit material (including all stages from bud to fully developed propagule), oven dried at 80°C for 48 hours, then weighed (± 0.01 g).

3.2.3 Stem Girth Increment

Stem girth increment studies were initiated at all six sites when dendrometers were installed on the 25th of October, 1991. A detailed description of the construction and installation of these dendrometers is provided in WBM Oceanics Australia (1992).

Ten trees at each site were permanently fitted with dendrometers. The dendrometers were read at relatively distant intervals (February 1992, September 1992 and March 1993) to avoid the considerable short term variations that occur in stem growth (Carron 1968) and focus on long term changes.

3.2.4 Photographic Record

In addition to these quantitative measures, a photographic record of the mangrove community at each site was made by taking a photo facing each major cardinal point - north, south, east and west - from a reference point marked with a 2.4 m star picket. These photographs will allow gross structural changes in the communities to be monitored.

Statistical Analysis

Mangrove litterfall was compared between sites for the first complete year (September 1991 to September 1992) and for each bimonthly collection using a one-way ANOVA in conjunction with a test of least significant difference ($p = 0.05$).

Statistical analysis was carried out using the computer software SPSSPC (SPSS 1988).

4.0 RESULTS

The structural features of the mangroves at each site are summarised in Table 4.1, and described in detail in an earlier report (WBM Oceanics Australia 1992).

4.1 LITTERFALL

Litterfall production is examined under the following categories:

- Annual Production
- Site Differences
- Seasonal Patterns

4.1.1 Annual Production

Total and leaf litterfall at each site in the first complete year of the litterfall study (from installation of litterfall catches in September 1991 to the fifth collection in September 1992) is set out in Table 4.2 and illustrated in Figure 4.1.

Preliminary analysis of litterfall since the end of the first year (September 1992) suggests that annual production in the following year (1992/93) will be greater, due to a fruit litterfall event that did not occur in the first year of monitoring (see 'Seasonal Patterns', below).

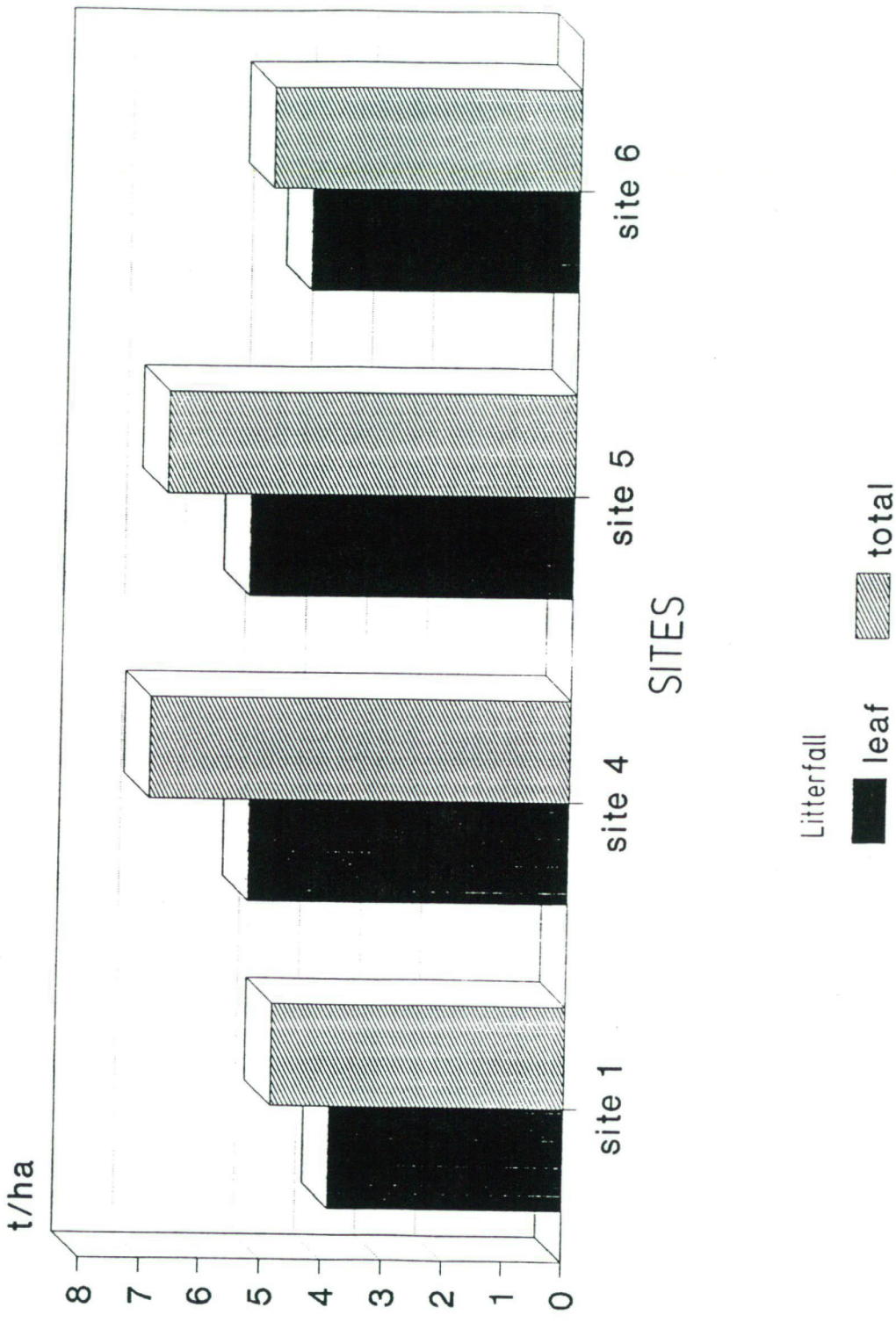
Total litterfall in the first year ranged from a low of 4.86 t/ha (site 1) to a high of 6.96 t/ha (site 4).

Leaf litterfall in the first year ranged from a low of 3.89 t/ha (site 1) to a high of 5.36 t/ha (site 5) and contributed from 76% (site 4) to 87% (site 6) of total litterfall (Table 4.2).

TABLE 4.1: STRUCTURAL FEATURES OF FISHERMAN ISLANDS AND WYNNUM FORESHORES MANGROVE MONITORING SITES

	SITE					
	1	2	3	4	5	6
Vegetation structural form	Open forest	Open forest	Low open forest	Low open forest	Low closed forest	Open forest
Dominant species	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*
Projective foliage cover (%)	62	67	62	62	72	61
Canopy height (m)	10 - 13	10 - 13	8-10	8-10	8-10	10-13
Stand density (stems per ha)	334	462	830	876	893	380
Stand basal area (m^2/ha)	24.0	23.1	24.1	28.9	24.1	24.3
Stem Girth (cm)*	87.0 ± 4.4 (n=72)	73.5 ± 3.5 (n=68)	56.9 ± 2.5 (n=60)	59.7 ± 3.1 (n=60)	55.9 ± 2.2 (n=60)	86.1 ± 3.5 (n=60)
General description	Large tall trees, predominantly single-stemmed and widely spaced	Tall, medium diameter trees, single or double stemmed	Small crooked-stemmed trees, closely spaced	Small diameter, low spreading trees, crooked stems closely spaced.	Small trees, crooked stems, community of closely spaced trees.	Large tall trees, well spaced, predominantly single stemmed.

* mean ± standard error



LITTERFALL,
SEPTEMBER 91 to SEPTEMBER 92

FIGURE
4.1

TABLE 4.2: TOTAL AND LEAF LITTERFALL PRODUCTION
(t/ha; September 1991 - September 1992)

SITE	COMMUNITY STRUCTURAL TYPE	LITTERFALL COMPONENT		
		Total (t/ha) *	Leaf (t/ha) *	Leaf/Total (%)
1	*Avicennia marina* open forest	4.86 (0.36)	3.89 (0.25)	80
4	*A.marina* low open forest	6.96 (0.39)	5.29 (0.24)	76
5	*A. marina* low closed forest	6.75 (0.38)	5.36 (0.28)	79
6	*A. marina* open forest	5.08 (0.32)	4.44 (0.29)	87

* average (standard error)

4.1.2 Site Differences

The first year's total and leaf litterfall was significantly greater ($p=0.05$) in the low open and low closed *Avicennia marina* forests (sites 4 and 5 respectively), than in the taller *A.marina* open forests (sites 1 and 6, see Table 4.2 and Figure 4.1).

The trend of significantly higher litterfall production at sites 4 and 5 than at sites 1 and 6 was also apparent for many, but not all, of the bimonthly collections.

4.1.3 Seasonal Patterns

The seasonal pattern of average litterfall production, for the total and leaf litterfall components, is illustrated in Figures 4.2 and 4.3. The range in values for each collection, across all sites (1, 4, 5 and 6) is set out in Table 4.3. Site averages for leaf and total litterfall production had standard errors of less than 10% for most of the collections.

Total Litterfall

All sites displayed the same seasonal patterns in average total litterfall production (Figure 4.2) with maxima in May 1992 (autumn), November 1992 (spring) and March 1993 (autumn). Minima occurred in July and September 1992 (winter - spring).

TABLE 4.3: RANGE IN PRODUCTION (TOTAL AND LEAF LITTER) ACROSS ALL SITES (1, 4, 5 AND 6) OVER TOTAL MONITORING PERIOD.

COLLECTION	RANGE ($g/m^2/day$)	
	TOTAL COMPONENT	LEAF COMPONENT
December 1991	1.09 - 1.68	0.99 - 1.47
February 1992	1.76 - 2.68	1.40 - 2.01
May 1992	2.00 - 2.80	1.73 - 2.29
July 1992	0.80 - 1.31	0.56 - 0.96
September 1992	0.80 - 1.67	0.64 - 1.23
November 1992	2.26 - 3.46	2.10 - 2.95
January 1993	1.87 - 2.00	1.40 - 1.57
March 1993	2.83 - 4.09	0.84 - 1.00
May 1993	0.87 - 2.51	0.52 - 0.93

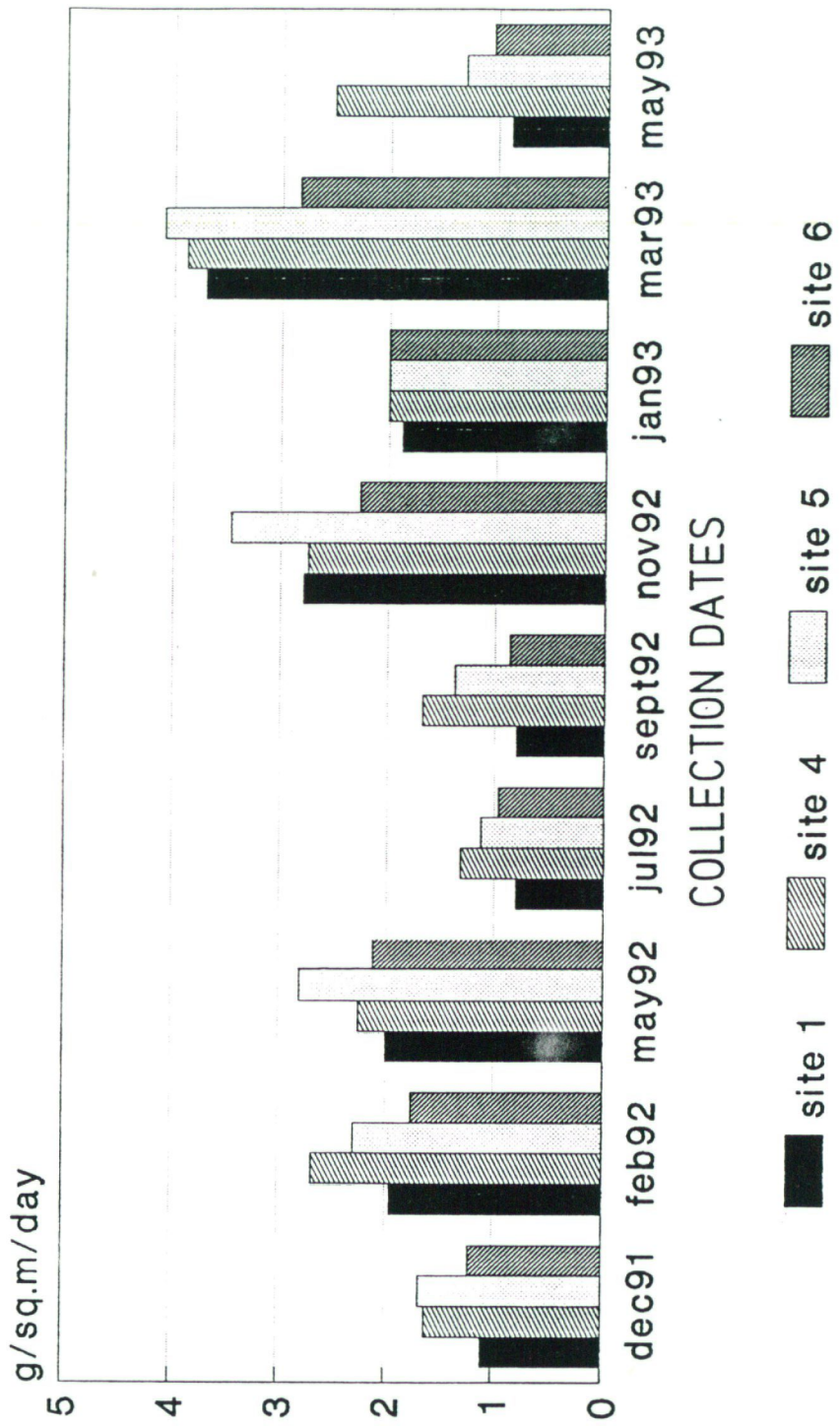
Leaf Litterfall

Similar seasonal patterns occurred in leaf litterfall production as for total litterfall with maxima in May 1992 (autumn) and November 1992 (spring) and minima in July and September 1992 (winter to spring) and May 1993 (autumn). This was expected, since leaf litterfall accounted for 60% or more of total litterfall at most of the collections. However, the peak in total litterfall, in March 1993 did not correlate with a peak in leaf litterfall which comprised only 23% to 30% of total litterfall. This was due to a heavy fall of fruit material (discussed below), which accounted for 60 to 69% of total litterfall.

Fruit Litterfall

Fruit litterfall made only a minor contribution to total litterfall for most of the bimonthly collections (usually less than 5%) until March 1993 where it accounted for 60% to 69% of total litterfall.

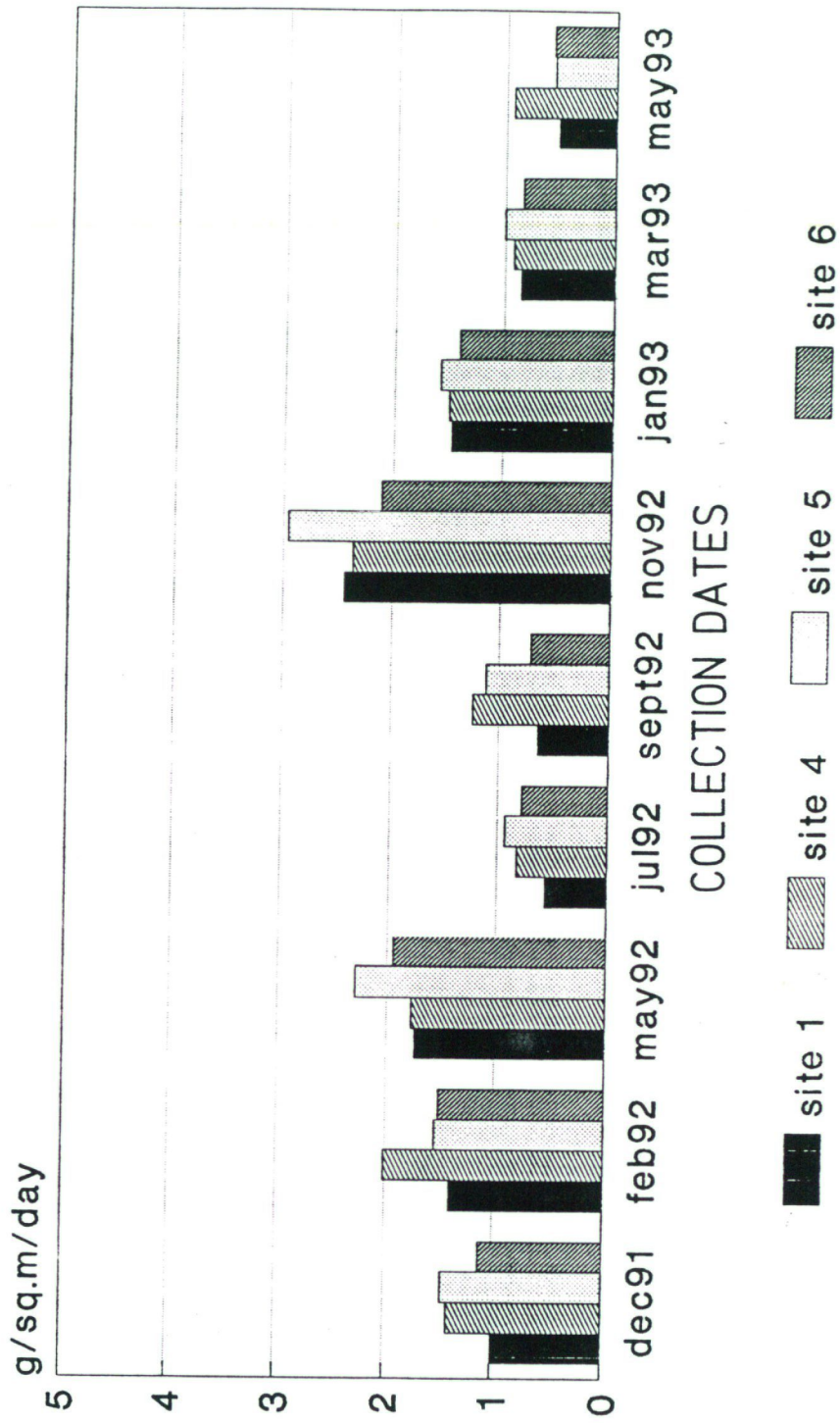
The fruit material collected in March 1993 was the first major fall of any fruit material since the study was initiated 21 months previous in September 1991.



AVERAGE TOTAL LITTERFALL

FIGURE

4.2



AVERAGE LEAF LITTERFALL

FIGURE

4.3

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Stem Litterfall

Stem litterfall values showed too much within-site variation for meaningful analysis. Standard errors of site mean stem litterfall were well above 10% at most of the collections. The reason for the high variability of stem litterfall values, compared to leaf litterfall values, is probably related to the greater variability in stem sizes (from small twigs to sections of large (dead) branches) and the more erratic nature of stem fall, compared to leaf fall.

4.2 STEM GIRTH INCREMENT

Results of the stem girth increment study are summarised in Table 4.4. Although tree girths within-site were relatively uniform, (standard error of average tree girth $< 10\%$), stem girth increment was highly variable (standard error of average increment $> 30\%$). Detailed analysis has thus not been made of average stem increment for each site. Instead, the range in girth increment is considered.

Girth increment across all six sites ranged from -4.1 mm to 1.8 mm at the first measurement period; -3.6 mm to 8.6 mm at the second and -3.8 mm to 12.5 mm at the third. The largest girth increments had occurred at sites 3 and 4 (12.5 mm, both sites) by the third measurement period, and to a lesser extent at site 5 (7.1 mm). The largest negative increments (decrements) by the third measurement period had occurred at sites 1 and 6 (-3.8 mm at both sites).

Stem girth decrement or girth shrinkage, was recorded at all three measurement periods, at all six sites (Table 4.4). Site 6 differs from the other sites because of the large number of stems exhibiting a decrement in girth - seven out of the ten trees at the first measurement period, six out of the ten at the second and five out of the ten at the third measurement period.

By contrast, the number of trees exhibiting a decrement in girth diameter at any of the five other sites, for all three measurement periods, was never more than five of the ten trees and usually less than four.

TABLE 4.4: SUMMARY OF STEM GIRTH INCREMENT (mm) FOR THE PERIOD 25/10/91 TO 12/3/92

Ten trees were monitored for stem girth increment at each site.

SITE	1	2	3	4	5	6
average girth*	753 ± 54.6	754 ± 48.2	636 ± 32.6	600 ± 26.8	773 ± 55.7	952 ± 62.7
range in increment:						
1st measurement period (25/10/92 - 7/12/92)	-0.8 to 1.8	-2.5 to 0.5	-2.5 to 0.5	-1.0 to 1.3	-2.3 to 1.8	-4.1 to 0.0
No. of trees with decrement	4	1	3	3	3	7
2nd measurement period (7/12/92 - 18/9/92)	-1.0 to 2.3	-2.5 to 3.1	-1.0 to 8.6	-0.1 to 5.6	-2.5 to 4.8	-3.6 to 1.3
No. of trees with decrement	3	2	1	3	4	6
3rd measurement period (18/9/92 - 12/3/93)	-3.8 to 3.3	-2.5 to 4.3	-0.3 to 12.5	-0.5 to 12.5	-2.5 to 7.1	-3.8 to 3.3
No. of trees with decrement	5	2	1	1	3	5

* average ± standard error

Photographic Record

The photographic record did not reveal any gross changes in the structure of the mangrove communities at the monitoring sites. Large changes were not expected, given the relatively short duration of the study (September 1991 to May 1993).

However, as noted in an earlier report (WBM Oceanics Australia 1992) a marked changed was noted on the mudflats immediately seaward of site 4, where a very large seedling population present in September 1991 (developed to about the second leaf-pair stage) experienced a mortality rate of greater than 90% by February 1992. By March 1993, these seedlings had not been replaced, probably as there had not been any significant falls of mature fruit (propagules) from adjacent mangrove communities since the demise of the previous crop of seedlings.

5.0 DISCUSSION

The importance of mangroves in the estuarine food chain and their role in shore stabilisation and protection are both connected with mangrove community structure (Rodriguez 1987) and have been the focus of much mangrove research.

The response of mangrove forests to stress (climatic and man-induced) can be identified with quantitative data (Odum et. al. 1982) hence the importance of continued collection of quantitative data by the Port of Brisbane Authority on the mangroves of the Fisherman Islands and Wynnum foreshores.

5.1 LITTERFALL

Estimates of average litterfall production (total and leaf components) were very reliable, with standard errors of within-site averages less than 10% for most of the collections made. This indicates that community structure, and particularly canopy cover was relatively homogeneous within each site and was effectively sampled by the number and spatial arrangement of litterfall catchers.

Averaged over all sites and all collections (December 1991 to May 1993), leaf fall accounted for 66% of total litterfall, while the fruit and stem components comprised only 16% and 18% respectively.

However, the March 1993 collection recorded the first major fruit litterfall event since the commencement of monitoring in September 1991 and fruit comprised 60% of total litterfall.

5.1.1 Annual Production

A review of studies of mangrove communities from around the world (Hutchings and Saenger 1987) reveals a wide range in litterfall production from 0.8 t/ha/yr in a temperate/subtropical *Rhizophora mangle/Laguncularia racemosa/Avicennia nitida* forest in Southern Florida (25°N) to 28.1 dry t/ha/yr in a mixed species tropical mangrove forest in North Queensland, Hinchinbrook Island (18°S, Table 5.1). Litter production is typically higher in tropical than in temperate mangroves, although there is considerable variation within a given mangrove community (Hutchings and Saenger 1987).

The range in annual total litterfall production for this study (4.86 t/ha to 6.96 t/ha) is comparable to the estimate of 6.42 t/ha for a low closed *Avicennia marina* forest on Mud Island, Moreton Bay (Davie 1984). The similarity between the two estimates suggests

that the productivity of the Fisherman Islands mangroves, has not been adversely affected by port-related activities.

This study and that of Davie (1984) are among the few long-term (> 12 month) studies of mangrove productivity in Moreton Bay. Continued monitoring of litterfall production will provide the Port Authority with data which it can use to assess the effects of port-related activities on mangroves.

5.1.2 Site Differences

The first year of monitoring (September 1991 to September 1992) revealed greater total and leaf litterfall production at sites 4 and 5 than at sites 1 and 6. This difference was also apparent in many of the bimonthly collections.

The significantly greater litterfall production (leaf and total components) at sites 4 and 5 may be due to their forests being in an immature development stage and growing more rapidly than the forests at sites 1 and 6. The structural features of the forests at sites 4 and 5 - lower canopy height, smaller average stem girths and higher stem densities - may also indicate their relative immaturity compared to sites 1 and 6. Stem girth increments at the last (third) measurement period were also greater at sites 4 and 5 than at 1 and 6, indicating the former sites are probably more actively growing than the latter pair.

TABLE 5.1: LITTERFALL VALUES FOR MANGROVE FORESTS IN AUSTRALIA AND USA (FLORIDA)

LOCATION	FOREST TYPE	LEAF LITTER (t/ha/yr)	TOTAL LITTER (t/ha/yr)	STUDY PERIOD	REFERENCE
Moreton Bay, Brisbane	*Avicennia marina* low closed forest to open forest	3.89 - 5.36	4.86 - 6.96	Sep 1991 - 1992	This study
Middle Harbour, Sydney	*A. marina* low closed forest	4.6	5.8	Mar 1977 - Apr 1978	Goulter and Allaway (1979)
Moreton Bay, Brisbane	*A. marina* low closed forest	-	6.42	Aug 1979 - Dec 1980	Davie (1984)
Moreton Bay, Brisbane	*A. marina* low open shrubland	-	1.94	Jan 1980 - Dec 1980	Davie (1984)
Missionary Bay, Hinchinbrook Island, North Queensland	mixed species	-	3.7 - 28.1	1975 - 1978	Bunt (1982)
Missionary Bay, Hinchinbrook Island, North Queensland	*Avicennia* sp. forest	6.6	9.5	1975 - 1976	Duke *et al* (1981)
Florida	*Avicennia germinans* forest	-	3.7 - 5.6	-	Lugo *et al.* (1980) cited by Odum *et al.* (1982)

5.1.3 Seasonal Patterns

(i) *Total Litterfall*

Maxima in total litterfall production occurred in May 1992 (autumn), November 1992 (spring) and March 1993 (autumn). A 17 month litterfall study in similarly structured mangroves (low closed *Avicennia marina* forest) on Mud Island, Moreton Bay, recorded peaks of litter production in the spring of 1979 and 1980 and minor peaks through autumn (Davie 1984). Periods of heavy litterfall were attributed to periods of shoot growth (Davie 1984).

The period of minimum litterfall production for both this study and that on Mud Island occurred during winter, when there is minimal shoot growth (Davie 1984).

There appears to be broad agreement in seasonal patterns of litterfall production between this study and the study on Mud Island (Davie 1984). Some variation might be expected, given the considerable temporal separation between these two studies.

(ii) *Leaf Litterfall*

Peaks and troughs in leaf litterfall generally mirrored that of total litterfall. This was expected, since leaf litterfall usually comprised 60% or more of total litterfall for most of the collections. The exception was the March 1993 collection, when there was a heavy fall of fruit material. In the weeks leading up to this event, it is likely that there was little shoot growth, with most of the plants' resources going towards production of reproductive material.

(iii) *Fruit Litterfall*

In the 21 months of the study to date, the March 1993 collection contained the first major fall of fruit material.

Other studies have also recorded fruit production in *Avicennia marina* during similar times of the year.

The occurrence of mature propagules on *Avicennia* on the central Queensland coastline has been recorded over the months of January, February and March, while on the eastern coast of South Africa, the fruiting period for *Avicennia marina* is March to April (Hutchings and Saenger 1987). Fruiting times for other mangrove species on the eastern

Australian coast are also reported to occur in the summer months (Hutchings and Saenger 1987).

The single fruit litterfall event recorded in the 21 months of this study indicates that *Avicennia marina* in the Fisherman Islands regions, do not fruit annually. A similar finding was made in a study of *Avicennia marina* in Westernport Bay, Victoria, where propagules are produced only every second or third year (Clough and Attiwill 1982).

In tropical areas, fruit production is an annual event (Hutchings and Saenger 1987), suggesting that the tropical environment is more favourable to mangrove fruit production than the sub-tropical environment of Moreton Bay or the temperate environment of Westernport Bay, Victoria.

A knowledge of when and how often the mangroves of the Fisherman Islands fruit will be vital to the Port of Brisbane Authority, if it plans to conduct any mangrove regeneration projects in the port's vicinity.

Mangrove fruit, or propagules, may not necessarily be washed into areas prepared for mangrove regeneration, thus it will be necessary to know when mature propagules can be collected from existing mangrove forests. Continuing the litterfall study into the coming years will aid the Port Authority in predicting when and how often mangrove propagules can be collected.

5.2 STEM GIRTH INCREMENTS

The small girth increments recorded during the study may be due to the relatively short length of the study (September 1991 to March 1993). As no other published studies of stem girth growth rates of mangroves were found, it has not been possible to assess how fast or slow the Fisherman Islands mangroves are growing.

The decrement in girth recorded on many of the stems at the first reading was first thought to be related to a settling-in of the dendrometers after their installation. However, decrements in girth recorded in the next two measurement periods at all six sites suggests that stem shrinkage is occurring.

Shrinkage is a common phenomenon in tree stems (Bormann and Kozlowski 1962) that have been attributed to low rainfalls preceding recordings. Rainfall for 1991 was 861.2mm, well below the long term average for Brisbane of 1150mm (140 year record to the end of 1991, source: Bureau of Meteorology). However, in 1992 Brisbane received above average rainfall of 1203.4mm (Bureau of Meteorology). Insufficient

study has been conducted on the relationship between stem growth of mangroves and environmental factors (climatic, edaphic and biotic) to isolate the effects of particular factors such as rainfall and stem shrinkage may be due to a variety of factors.

The large number of stems exhibiting decrement in girth at site 6 compared to the other sites may be related to the apparent maturity of the mangrove community of site 6. The trees at site 6 may no longer be increasing in girth and the changes recorded may be responses to short-term environmental perturbations

Measurement of stem girth increment has not revealed any large changes in stem girth. However, continued recording of stem increment with the dendrometers is relatively inexpensive and if continued into the coming years may record stem growth data that can be more readily interpreted and related to productivity measured in the litterfall studies.

5.3 OVERVIEW

- mangroves at the monitoring sites are all healthy
- litterfall monitoring is proceeding without major technical problems and is probably the longest of such studies to be conducted in Moreton Bay
- within-site estimates of average litterfall are very reliable (low standard error)
- annual litterfall production is comparable to studies elsewhere in Moreton Bay
- seasonal and annual variation in litterfall production demonstrate the importance of long-term monitoring
- the first major fruit litterfall event for the 21-month study was recorded in March 1993, indicating that fruit production in the *Avicennia marina* mangroves of the Fisherman Islands is not always an annual event
- very little change in stem girth was recorded
- continued monitoring of stem girth will be relatively inexpensive and over the longer-term may provide more readily interpreted data
- the photographic record indicates that the monitoring sites have not changed perceptibly in structure

6.0 RECOMMENDATIONS

It is recommended that litterfall collections be continued to the end of the second year (September 1993) and into the following year to:

- establish whether the seasonal patterns observed in the first year are typical
- determine the extent of annual variation in litterfall production
- monitor the quantity and the periodicity of fruit production.

Information on when, and how often, fruit production occurs in the mangroves of the Fisherman Islands could be used by the Port Authority when planning fruit collection for mangrove regeneration projects.

Despite stem increment being less than was anticipated since installation of monitoring equipment in October 1991, it is recommended that:

- monitoring of stem girth increment be continued over a longer period to provide data showing larger movements that can be more readily interpreted.

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8.0 GLOSSARY OF TERMS

Saltpan/Claypan: unvegetated high tidal flats, generally landward of mangroves.

Edaphic: soil or substratum conditions.

Estuarine: of, or pertaining to an estuary.

Girth: measurement around a tree's circumference (Π.diameter).

Intertidal: land between high and low tides.

Mangroves: the term is used here interchangeably to refer to an individual species of plant or to a stand or forest of plants belonging to many species (after Hutchings and Saenger, 1987); a community (or a plant thereof) arising from an estuarine or tidal mudflat.

Saltmarsh: high tidal flats landward of mangroves vegetated by saltcouch grass and samphire bushes.

Seagrass: marine flowering plant growing on intertidal to subtidal flats.

Subtidal: below the level of lowest astronomical tides

Wetlands: plant habitats subject to tidal action including subtidal areas to an Australian Height Datum (AHD) depth of 6 m; encompassing saltmarsh/saltpan, mangroves and seagrass communities.

FISHERMAN ISLANDS

TIDAL WETLANDS STUDY

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EXECUTIVE SUMMARY

Fisherman and Whyte Islands have been developed as a major port facility at the Brisbane River mouth by the Port of Brisbane Authority (PBA). The PBA foresees the need to expand port capacity which will involve disturbance of intertidal and subtidal lands of the Fisherman Islands, some of which are vegetated by mangroves.

This report describes the results of a study, commissioned by the PBA, to collect baseline data on mangrove communities in the Fisherman Islands region and initiate monitoring programs.

Of the tidal wetlands in the study area (Fisherman Islands, Whyte Island and the Wynnum foreshore) - mangroves, seagrass and saltmarsh - mangroves are the most conspicuous.

Saltmarsh vegetation collectively covers only a few hectares in the study area and is probably of much lesser importance to fisheries than mangroves or seagrasses. Saltmarsh vegetation is associated with unvegetated intertidal areas, referred to as claypan, which combined with saltmarsh, occur over less than 25 ha of the study area.

Mangrove areas cover 351 ha. Mangrove communities of Moreton Bay are highly productive and structurally complex. They provide large amounts of plant litter, an important primary food source for aquatic organisms of mangrove-dominated estuaries. Mangroves are also important nursery and feeding grounds for many fishes and crustaceans, most of which are of direct importance to commercial and recreational fisheries.

Seagrass beds, ranging in cover from high density to sparse, occur in intertidal and subtidal areas covering approximately 1200 ha in the Fisherman Islands region. Seagrass beds provide large amounts of leaf litter (the basis of important food chains), and are important feeding areas for dugong, turtles, some fishes and juvenile prawns. Natural disturbances can cause wide variations over time in the extent and distribution of seagrass beds whilst mangrove forests tend to be more temporally stable.

In a regional context, the mangroves of the study area represent 2.5% of the 13900 ha of mangroves in Moreton Bay. The saltmarsh-claypan of the study area represents 0.5% of the 5000 ha that occurs in Moreton Bay. Previous reclamation in the study area has reduced the

mangrove resource from 532 ha in 1958 to 351 ha in 1991, and the saltmarsh-claypan complex from 121 ha in 1958 to less than 25 ha in 1991.

The mangrove study has gathered data on the structure and productivity of mangrove communities at six sites in the study area during September 1991 to February 1992. This data will enable detailed comparisons to be drawn between mangrove communities prior, during and following reclamation works. Key findings of the baseline studies are:

- The mangroves at the monitoring sites were typical in structure and composition to mangrove communities elsewhere in Moreton Bay.

- Mangroves are not subject to on-going adverse impacts.

- Litterfall averaged 1.8 dry g/m^2/day over the 17 weeks of the study. Extrapolated to an annual figure of 6.6 dry t/ha/yr, it agrees closely with other litterfall studies conducted in Moreton Bay.

- Stem growth over the duration of the study was very small, probably indicating that the mangrove communities at the monitoring sites are mature and are at, or near, a climax phase.

- No major structural changes in the mangrove communities at the sites were observed over the monitoring period (September 1991 to February 1992), nor were they expected although changes may occur over a longer term.

Further monitoring is necessary to reveal seasonal patterns in litterfall and stem growth rates and provide data appropriate to quantifying any long term impacts to mangrove communities adjacent to Fisherman Islands resulting from reclamation operations.

Litterfall monitoring continued over the next 6-8 months would provide data encompassing the full range of seasonal variation in productivity. Litterfall collection should be made preferably at intervals of no more than two months; longer than this and trapped litter begins to decompose and result in litterfall production being underestimated.

Stem increment/decrement readings need only be collected every four months. These readings should also be continued for at least one year to be able to arrive at an actual annual stem girth increment figure.

The first 12 months of monitoring would provide the minimum necessary for a baseline data set. Further monitoring should then continue during and following reclamation, to assess any impacts upon mangrove productivity. The frequency of future monitoring could be assessed on the basis of the results from the baseline study and proposed reclamation schedules.

1.0 INTRODUCTION

The Port of Brisbane Authority (PBA) has developed Fisherman and Whyte Islands as a major port facility at the mouth of the Brisbane River. Tidal wetlands (saltmarsh, mangroves and seagrass) occur on and adjacent to the islands.

The PBA has identified a long term need to expand the capacity of the port to accommodate a future expansion in port usage. The draft Moreton Bay Strategic Plan, designed to ensure appropriate land use within Moreton Bay, identifies lands adjacent to Fisherman Islands for port related activities.

Further expansion of port related facilities on the southern side of the mouth of the Brisbane River, proposed by the PBA, will require disturbance of intertidal and subtidal lands near the Fisherman Islands, some of which support mangroves.

WBM Oceanics was commissioned by the PBA to undertake studies of tidal wetlands occurring on and adjacent to Whyte and Fisherman Islands and the Wynnum foreshores. The study area is shown diagrammatically in Figure 1.1, in recent aerial photography (1991) in Figure 1.2 and in historical aerial photography (1958) in Figure 1.3.

The studies were to:

- describe the ecological value of wetlands adjacent to Fisherman Islands.

- document the existing distribution and structure of mangroves in the vicinity of the Port and;

- to initiate a program of monitoring mangrove areas.

The results of the study will provide the PBA with background information for port management and development strategies. Section 9.0 provides a glossary of terms used in this report.

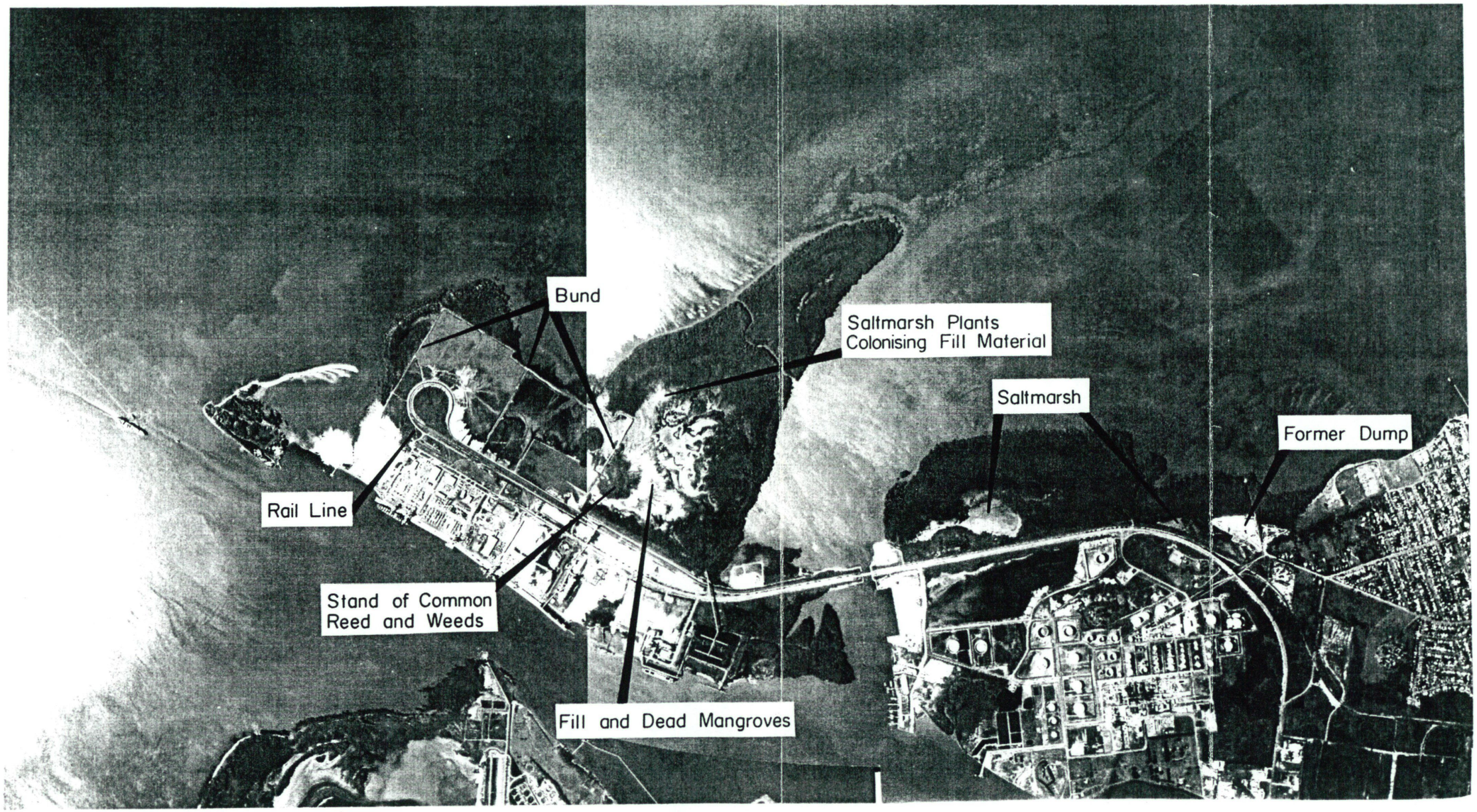

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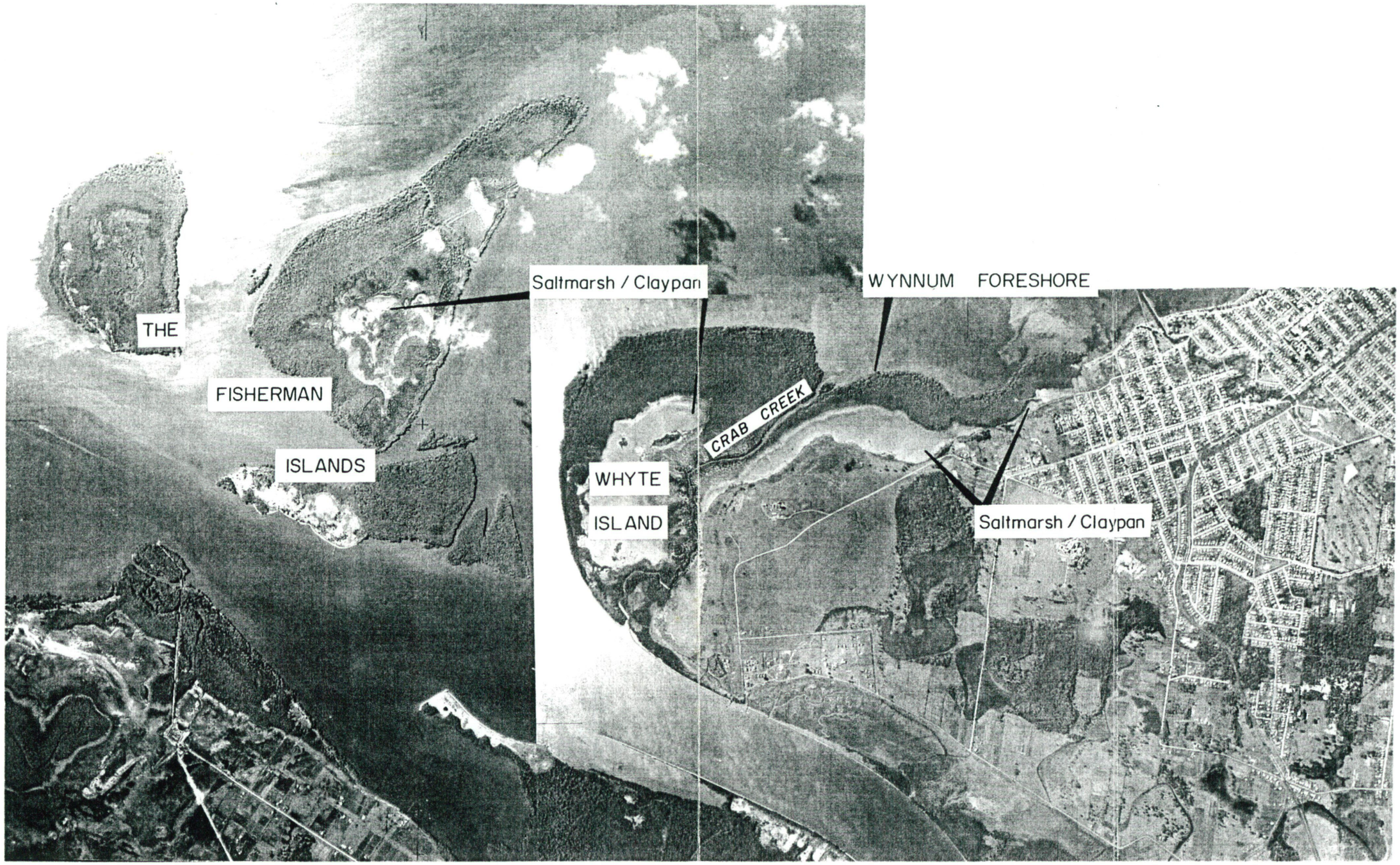
FIGURE

1991 AERIAL PHOTOGRAPHY OF STUDY AREA 1.2

WBM OCEANICS AUSTRALIA



FIGURE

1958 AERIAL PHOTOGRAPHY OF STUDY AREA 1.3

WBM OCEANICS AUSTRALIA

2.0 ECOLOGICAL VALUE OF WETLANDS

The term tidal wetland is used in the present study to refer to plant communities influenced by tidal action. It includes subtidal areas to an Australian Height Datum (AHD) depth of 6 metres.

Estuarine wetlands, including mangroves, are among the most productive natural ecosystems in the world providing:

- nursery and feeding grounds for commercially important fish and other estuarine fauna.

- breeding, roosting and feeding areas for local and migratory birds.

- nutrient sinks, regulating nutrient flow into the estuary and nearshore region.

- contaminant traps and sediment filters (Hutchings and Saenger 1987).

2.1 SALTMARSHES

Almost all available literature on Australian saltmarsh is descriptive, with information on its vegetation, either as species lists or as factors producing zonation patterns (Clark and Hannon 1967).

The dominant vegetation of saltmarshes in the Moreton Region is samphire bushes (eg. *Sarcocornia quinqueflora, Suaeda australis*) and marine couches *(Sporobolus virginicus*; Durrington 1974, 1977). Approximately 15% of the high tides inundate this habitat annually. The most comprehensive study on saltmarshes in the Moreton Region was by McLeod (1969). That study provided a general description of mangrove and saltmarsh vegetation in the Region, described the algae present, and gave a global literature review of the macroscopic algae in saltmarshes and mangroves.

Only one study (Morton et. al. 1988) has examined the fisheries value of Australian saltmarshes and most available information relates to the North America region. Australian and American saltmarshes are markedly different in structure and species composition and comparisons between them are spurious at best.

Studies by Morton et al. (1988) at Coomera Island (southern Moreton Bay) concluded that:

- relatively few fish utilise saltmarsh, as aquatic habitat is limited to isolated pools filled by rainwater and large spring tides.

- the abundance of fish fluctuates widely on a seasonal basis with most fish occurring in summer months when pool water levels are high.

- relatively few species important to commercial fisheries use the upper littoral saltmarsh habitat.

Tidal inlets to saltmarshes, which are often lined with mangroves, provide habitat for juvenile fish (Morton et. al. 1987). The diversity of fish assemblages utilising such inlets is low compared to those occurring in lower littoral mangrove areas. Tidal inlets serve as feeding areas for certain species (some of which are of direct fisheries value), however, it is unlikely that any of these species rely on specific areas. Although the value of a single saltmarsh area for maintenance of fish populations is perhaps not critical, intertidal lands in Moreton Bay contain large areas (approximately 5000 ha, Hyland and Butler 1988) of saltmarsh and associated tidal inlets. When considered in total, these inlets constitute a major habitat for estuarine fishes and provide rich feeding grounds for certain types of fishes.

2.2 MANGROVES

Mangroves are the most conspicuous component of tidal wetlands in the Fisherman Islands region and occur from the mean tide level to extreme high water spring level. Seven mangrove species (Table 2.1) occur in Moreton Bay (Hyland and

Butler, 1988), five of which were observed during the present field surveys on Fisherman and Whyte Islands and the adjacent Wynnum foreshores.

Hutchings and Saenger (1987) noted that in terms of the number of species and structural complexity of forests, the Moreton Region has one of the most highly developed mangrove areas along the east coast of Australia.

TABLE 2.1
MANGROVE AND SEAGRASS SPECIES WHICH OCCUR WITHIN THE MORETON REGION

SCIENTIFIC NAME	COMMON NAME
MANGROVES	
Avicennia marina (Forskal) Vierh. var. *australasica* (Walp.)* Mold.*	Grey Mangrove
Aegiceras corniculatum (L.) Blanco*	River or Black Mangrove
Ceriops tagal var. *australis* C.T. White*	Yellow-leaved Spurred Mangrove
Rhizophora stylosa Griff.*	Spotted-leaved Red Mangrove
Bruguiera gymnorhiza (L.) Lam*	Large-fruited Orange Mangrove
Exocoecaria agallocha L.	Milky (blind-your-eye) Mangrove
Lumnitzera racemosa Wild.	White-flowered Black Mangrove
SEAGRASSES	
Zostera capricorni Aschers.*	Eel Grass
Halodule uninervis (Forsk.) Aschers, in Boisser*	A sea grass
Halophila ovalis (R.Br.) J.D. Hook*	Sea-wrack
Halophila spinulosa (R. Br.) Aschers*	Spiny sea-wrack
Cymodocea serrulata (R. Br.) Aschers and Magnus	A sea grass
Syringodium isoetifolium (Aschers.) Dandy	A sea grass

* recorded in Fisherman Islands study area

Mangroves are highly productive ecosystems which contribute significantly to the coastal ecosystem through export of organic matter. The primary food source for aquatic organisms in most mangrove dominated estuaries, such as Moreton Bay, is particulate organic material (detritus) derived from the decomposition of mangrove forest litter (leaves, twigs, and reproductive or fruit material). Average mangrove plant litterfall (the most commonly measured component of net primary production) from Fisherman Islands and the Wynnum foreshores over summer months is 1.8 dry $g/m^2/day$ (see Section 5.0).

During decomposition, mangrove litter becomes a food source for a wide variety of filter, particulate, and deposit feeders such as molluscs, crabs and polychaete worms. These primary consumers, which include representatives of most phyla, are food for secondary consumers, usually small forage fish species and juveniles of the larger predatory species, that form the third consumer level (Odum and Heald, 1972). In addition, there are important fisheries species which occupy both primary and secondary consumer levels. They feed directly on particulate organic detritus and also upon primary consumers.

Mangroves function as important fish nursery and feeding grounds. Numerous studies have noted that fishes (particularly juveniles) are more abundant in mangrove dominated areas than in other nearshore habitats (Robertson and Duke 1987, Morton 1990). Possible explanations for this increase in fish abundance near mangroves include high availability of foods (Beumer 1978, Blaber 1980, Morton 1990) and a high degree of structural heterogeneity of habitat in the form of prop roots, pneumatophores and tree stems (Robertson and Duke 1987). Many of the fishes present near mangrove areas of subtropical Queensland are of direct fisheries value (WBM Oceanics 1991).

Morton (1990) examined fish communities, using foreshore mangrove stands at Lota Creek (10 km south of Fisherman Islands). He noted that:

- 46% of the species, 75% of the number of fishes and 94% of the biomass taken during the study were of direct importance to regional fisheries.

- Standing crop estimates for fish occurring within the mangroves were amongst the highest recorded for estuarine areas in Australia, whilst those for adjacent waters were comparable to those of other estuarine studies.

- A conservative estimate of the value of mangroves to fisheries was $8380/ha/yr. This was based upon the monetary value of fish caught during the study and does not take into account the numerous commercially important juveniles captured or non-commercial values (recreation, education).

Some prawn species, especially banana prawns, also rely heavily upon mangrove areas as nursery grounds (see Dall 1985 for review, Staples et al. 1985, Robertson and Duke 1987). Banana prawns (*Penaeus merguiensis*) are taken by beam trawlers operating near the mouth of the Brisbane River but are a relatively minor component of the Moreton Bay fisheries (WBM Oceanics 1991). Staples et. al. (1985) concluded that banana prawns are almost exclusively found along the mud banks immediately adjacent to the mangrove fringe. Prawns and similar macrobenthos within mangroves are also important food sources for many fish species (Blaber 1980, Morton 1990).

Few mammals, amphibians or reptiles inhabit subtropical mangroves exclusively. Mangroves generally provide an extension of their range or a bridging habitat between terrestrial habitats. Mangroves provide roosting (and to a less extent, feeding) sites for fruit bats and many species of estuarine birds.

Mangroves also stabilise foreshores, minimising erosion (Bird 1971, Bird and Barson 1977).

2.3 SEAGRASSES

Seagrasses are marine angiosperms occurring in shallow coastal tropical and subtropical seas. Unlike seaweeds, seagrasses have a true root or rhizome system which grows into the top few centimetres of substrate to derive nutrients. Seagrasses are amongst the most productive of all coastal ecosystems.

In Moreton Bay, most seagrasses grow on mudflats or mudbanks exposed at low tide. Seagrasses generally grow in mixed species communities. Six species of seagrasses (Table 2.1) are found in Moreton Bay occurring from the mid-intertidal zone down to 1-2m below mean low water. The dominant species *Zostera capricorni, Halodule uninervis* and *Halophila ovalis* are usually found in intertidal areas, although in clear waters may extend into subtidal regions. All three species are widely distributed along the Queensland coast and are tolerant of a wide range of environmental conditions. *Halophila spinulosa, Cymodocea serrulata*, and

Syringodium isoetifolium are all tropical species, occur below spring low tide levels, and are poorly represented within Moreton Bay.

Young and Kirkman (1975) and Kirkman (1975, 1976) have described the seagrass communities of Moreton Bay, while Poiner (1984) used aerial photographs to examine the stability of seagrass beds over a 25 year period. Hyland *et. al.* (1989) provided recent maps of the location and species distribution of seagrasses in the Moreton Region. Most seagrass communities in Moreton Bay occur south and west of the Little Sandhills on Moreton Island, to Dunwich on North Stradbroke Island and encompassing the Moreton and Amity Banks and the foreshore of North Stradbroke Island between Amity and Dunwich. These banks cover approximately 10 000 ha and form about 70% of the seagrass communities in Moreton Bay.

Studies by CSIRO (Cleveland) for the PBA have mapped and described the seagrass areas adjacent to Fisherman Islands. High density seagrass covers 810 ha of intertidal mudflats, while patching to very sparse seagrass occurs over another 420 ha.

Seagrass beds are important feeding areas for a variety of organisms. Dugong, turtles, and some fishes (garfish) feed directly on seagrass whilst most other animals feed upon epiphytes, detritus, microfauna and the benthos associated with seagrass areas. Harlin (1980) reported that seagrass provides an extensive surface area for large numbers of epiphytes which are grazed by amphipods and gastropods (Orth and Van Montfrans 1984). These animals are eaten by higher order animals. Very few studies have been conducted on the fishes associated with seagrass beds in Queensland. Studies in New South Wales have shown that seagrass beds support a large variety of fishes many of which are important to fisheries. Small epibenthic crustaceans were noted as a main part of the diet of juvenile fish in seagrass (Pollard 1984).

Young (1978) made a detailed study of juvenile prawn habitats in Moreton Bay and concluded that seagrasses provide an important settlement area for the postlarval stage of several species of penaeid prawns. The postlarval stage follows the plankton stage and adopts a bottom dwelling (or demersal) lifestyle. Seagrass beds

are considered valuable prawn nursery grounds, especially for the tiger prawn, *Penaeus esculentus* (Young 1978, Staples et. al. 1985, Coles and Lee Long 1985) and endeavour prawns, *Metapenaeus endeavouri*, and *M. ensis* (Coles et. al. 1987). Post larval and juvenile stages are found almost exclusively in seagrass beds. Within seagrass beds, tiger prawns (*Penaeus esculentus*) feed on polychaetes, gastropods, algae and seagrass (*Zostera capricorni*) seedcases (Wassenberg and Hill 1987). It is probable that if larval tiger or endeavour prawns do not settle in an area of seagrass they will be unlikely to survive and will be lost to the fishery.

Seagrasses provide shelter for fish and prawns, however the degree of shelter apparently varies between different seagrass beds. Seagrass leaf shape, bed density, species type and bed elevation (intertidal vs subtidal) have an important bearing on the amount of shelter afforded.

Seagrass beds are known to vary substantially in extent over time. Natural events, such as storms and cyclones, atypical tidal conditions, floods and sediment movements can have a marked influence on seagrass distribution. For example, extreme flooding in Moreton Bay in 1974 lead to a substantial loss of seagrass both in western regions of the Bay and in the Southport Broadwater. Following the flood, the seagrass beds above low water spring tides in the Fisherman Islands and Wynnum areas expanded from an estimated 524 ha in 1974 to 1024 ha in 1980 (Forbes 1984).

Large natural fluctuations in seagrass distribution complicate identification of man-induced impacts that may result from reclamation, dredging, pesticides, industrial effluents or sewage.

3.0 MANGROVE AREAS ADJACENT TO FISHERMAN AND WHYTE ISLANDS AND THE WYNNUM FORESHORES

Mangroves within the study area (defined in Figure 3.1) were mapped on the basis of 1991 aerial photography (Lands Department, Sunmap Photography QC 4951; Run 12, Photo 117, Run 11 Photo 186) and detailed field surveys which involved inspection of most landward fringes and all seaward fringes. Areas of saltmarsh and claypan were also inspected during field surveys and mapped where possible. Areas of saltmarsh have not been mapped separately from claypan because there are few areas larger than 2000 m^2 (total saltmarsh area is estimated at $<$ 3.0 ha). As a result, this study has placed emphasis on mangrove areas.

The present studies estimate that 220 ha of mangroves occur on Fisherman Islands and 131 ha occur on Whyte Island/Wynnum foreshores. Saltmarsh-claypan covers 11 ha of Whyte Island and the Wynnum foreshores and less than 10 ha on the Fisherman Islands.

Areas of saltmarsh-claypan on the Fisherman Islands were not mapped due to the difficulty in distinguishing claypans naturally occurring from those resulting from filling (reclamation) operations (see Section 3.2) although naturally occurring claypans probably cover $<$ 10 ha.

3.1 HISTORICAL CHANGES

The mangroves within the study area have been subjected to varying degrees of disturbance. Filling works have occurred landward of all mangroves in the study area, replacing the original vegetation and altering natural drainage patterns.

Fisherman Islands

Reclamation works have amalgamated what used to be several islands, collectively known as the Fisherman Islands, virtually into a single island (compare Figures 3.1 and 3.2 and Figures 1.2 and 1.3). This has lead to a reduction in mangrove area

from 342 ha in 1958 to 220 ha in 1991, and a reduction in saltmarsh-claypan from 19 ha in 1958 (Figure 3.2) to less than 10 ha in 1991.

The mangroves fringing the Fisherman Islands are in an apparently healthy condition although some landward portions are degraded as a result of adjacent reclamation works. In many areas, filling of bunded areas has not been completed and areas of standing dead mangroves remain. The bunded areas are isolated from tidal influence and are of negligible ecological value.

Some mangroves adjacent (external) to bunds have died (Figure 3.1) apparently because their pneumatophores (air breathing roots) have been buried by sediment runoff from the bunds. Sediment runoff appears to have occurred within a short time of bunds being constructed, prior to bund material stabilising. Mangroves seedlings are becoming established amongst dead trees. The adverse effects of sediment runoff decrease with increasing distance from the bund wall; most mangroves more than 50 m away from the bunds appear healthy and not affected.

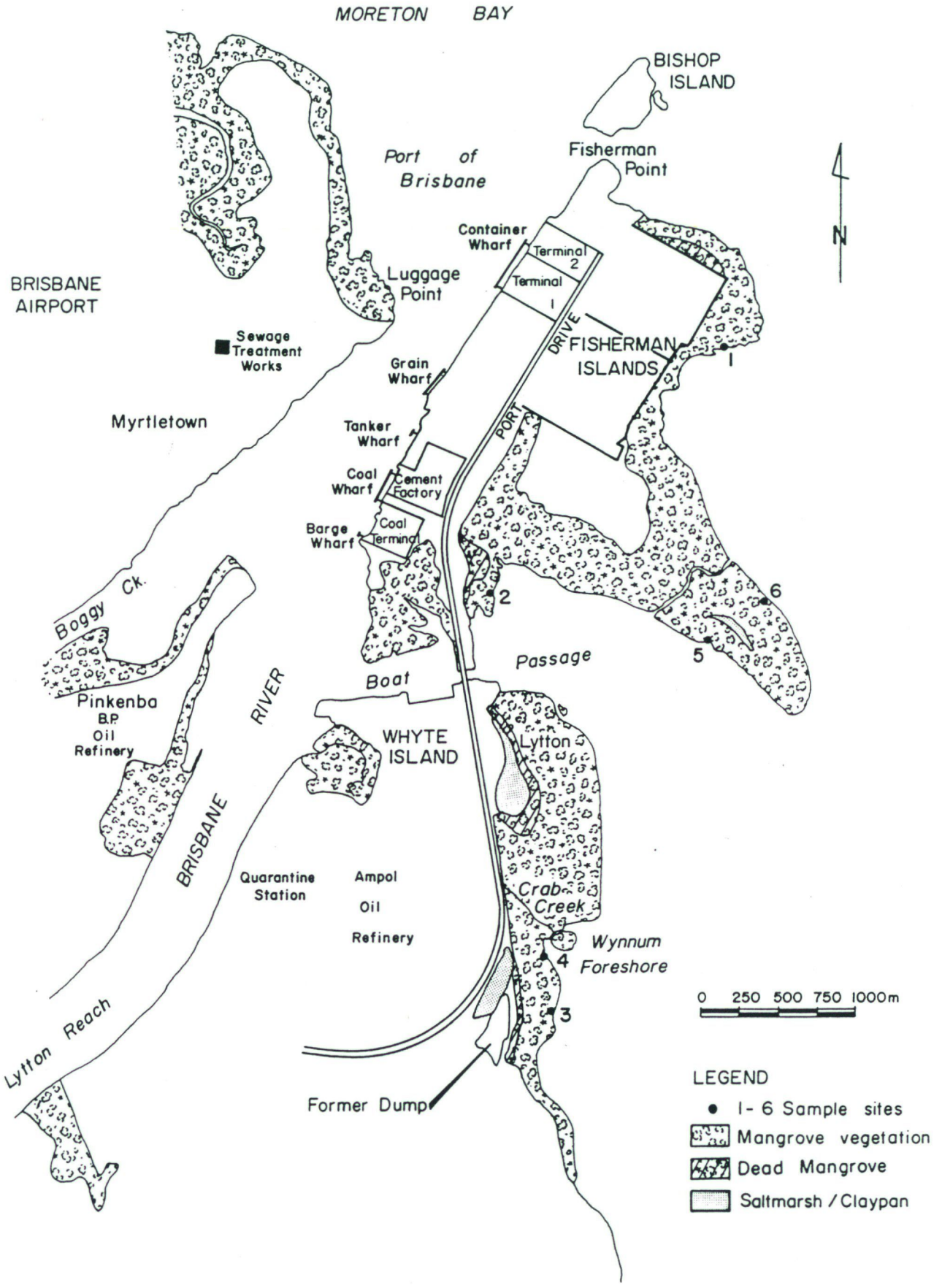
Overall, mangroves fringing Fisherman Islands are subject to no apparent ongoing adverse impacts.

Whyte Island and Wynnum Foreshores

Reclamation works on Whyte Island ceased approximately 5 years ago.

Since 1958 the area of mangroves of Whyte Island and the Wynnum foreshores has declined from 190 ha to 131 ha in 1991. In the same period, saltmarsh- claypan has declined from 102 ha to 11 ha (compare Figures 3.1 and 3.2). Adverse effects of bund wall runoff to mangroves are less conspicuous than on Fisherman Islands because regrowth of mangroves has occurred in the affected areas. Bund walls are older and hence more stable and less prone to stormwater erosion than recently bunded areas at Fisherman Islands.

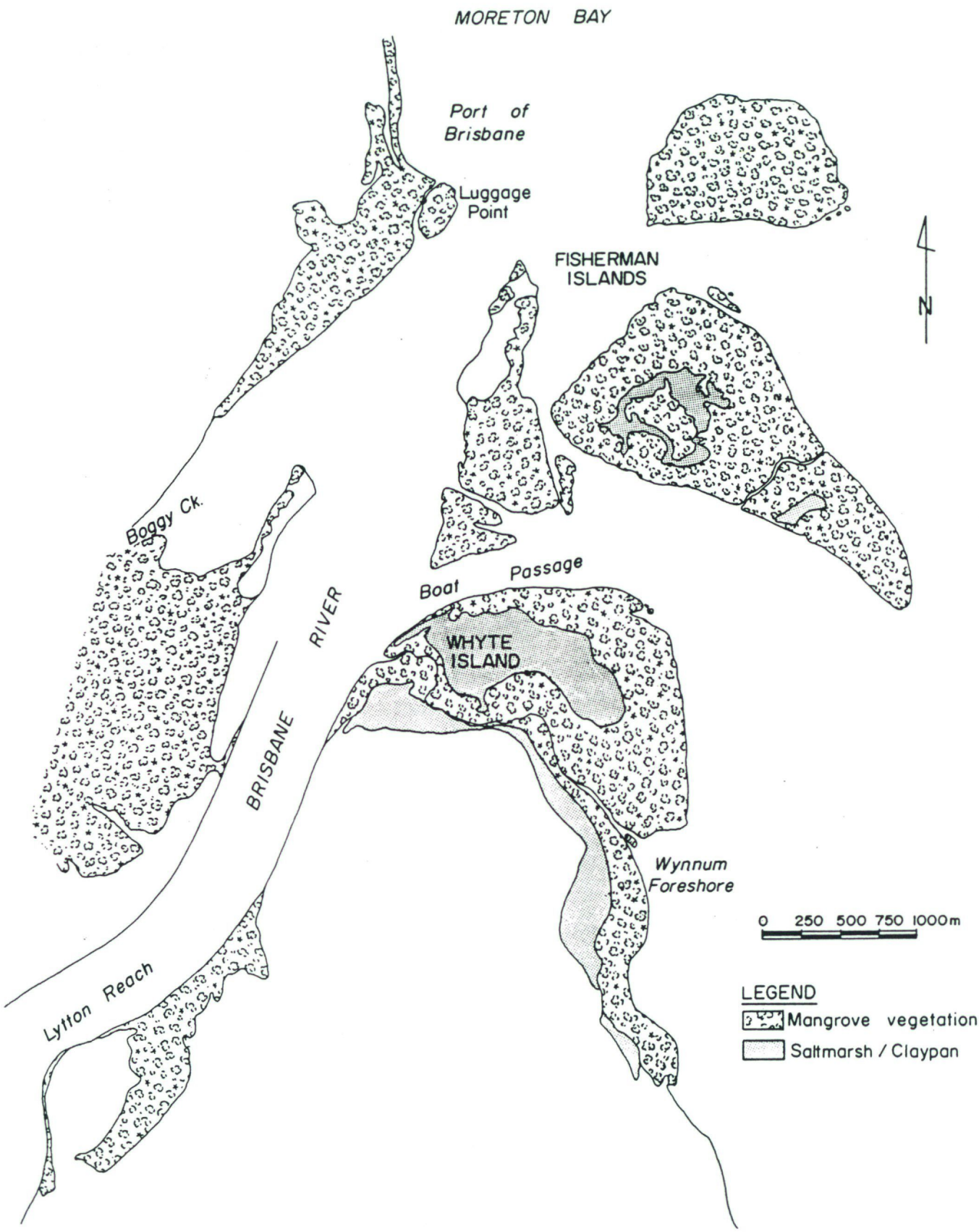
Secondary treated sewage effluent discharges via an open concrete drain into Crab Creek, north of Wynnum foreshore monitoring sites 3 and 4 (Figure 3.1). A dirt



MANGROVE VEGETATION, FISHERMAN ISLAND 1991

FIGURE 3.1

WBM OCEANICS AUSTRALIA



MANGROVE VEGETATION IN STUDY AREA, 1958

FIGURE 3.2

WBM OCEANICS AUSTRALIA

access track along the drain has been used by people to dump rubbish into the creek and surrounding mangroves, including old car bodies and mattresses. Large rocks have since been placed across the track to curb such activities. Sewage discharges presumably contain elevated nutrient levels and may be partly responsible for extensive algal growth in Wynnum foreshore mangrove communities near the mouth of Crab Creek. Green filamentous algae occurs on substrates, pneumatophores and tree trunks. Such algal growth is not typically observed in mangrove forests in the Moreton Region.

The extent of beneficial and/or detrimental effects to mangroves of sewage input are unknown. Mangroves have the capacity to assimilate high levels of nutrients, particularly those contained in sewage (Nedwell 1974).

The Wynnum rubbish tip is located on the landward fringes of the Wynnum foreshore mangroves (Figure 3.1). Although the tip is now disused, leachates from the tip appear to be entering the mangrove communities. Mangroves bordering the tip are subjected to leachates which have "oily" characteristics as evident by the sheen on substrates at low tide. The influence of leachates upon mangrove communities and associated fauna is uncertain given the unknown composition of leachates. The tip is in an industrial area and it is possible that some industrial wastes have been dumped.

Litter occurs throughout the mangroves adjacent to the tip. Additionally, indiscriminate dumping of rubbish has occurred in mangrove areas fringing the tip. Rubbish dumping reduces the aesthetic appeal of the area near the tip.

Overall, the mangroves within the study area fringing Whyte Island and those adjacent to the mouth of Crab Creek along the Wynnum foreshores are subject to ongoing adverse influences from both the Wynnum rubbish tip and the sewage outfall from Crab Creek.

3.2 WETLAND REGIONAL SIGNIFICANCE

Previous Studies

The most recent wetland study of the Fisherman Islands area (prior to the present study) was conducted for the Brisbane City Council in 1989 (CCM 1989). The vegetation maps produced (Figure 3.3) indicated that the Fisherman Islands supported 65.8 ha of saltmarsh-claypan and 250.5 ha of mangroves. Whyte Island was reported to contain 21 ha of saltpan-claypan and 67.3 of mangrove. Wynnum North (referred to as the Wynnum foreshore in this study) contained 26.7 ha of mangroves. The CCM (1989) report did not describe methods used to map various wetland types, the degree of reliance upon aerial photography or the extent of ground surveys although it notes that "little opportunity was available for detailed field investigations".

Hyland and Butler (1988) also mapped (Figure 3.4) wetlands near the mouth of the Brisbane River using 1984 and 1986 aerial photographs and vegetation maps produced by Dowling (1986). They concluded that the Fisherman and Whyte Island region supported 445.2 ha of mangroves and 109 ha of saltmarsh-claypan although the boundaries of the region they considered were not clearly identified in their report. Based on the scale of their vegetation map however (Figure 3.4), the area of saltmarsh-claypan is closer to 18 ha on the Fisherman Islands and 24 ha in the Whyte Island/Wynnum foreshore region.

Comparisons to the Present Study

Saltmarsh-claypan

As noted previously, the area of claypan within the study area has not been mapped in the present study because of difficulties in distinguishing naturally unvegetated saline flats from those resulting from filling operations. A conservative estimate of natural claypan area would be < 20 ha. Although saltmarsh areas have not been mapped, it is estimated that the total area of saltmarsh within the study area is < 3.0 ha with no individual areas > 0.2 ha.

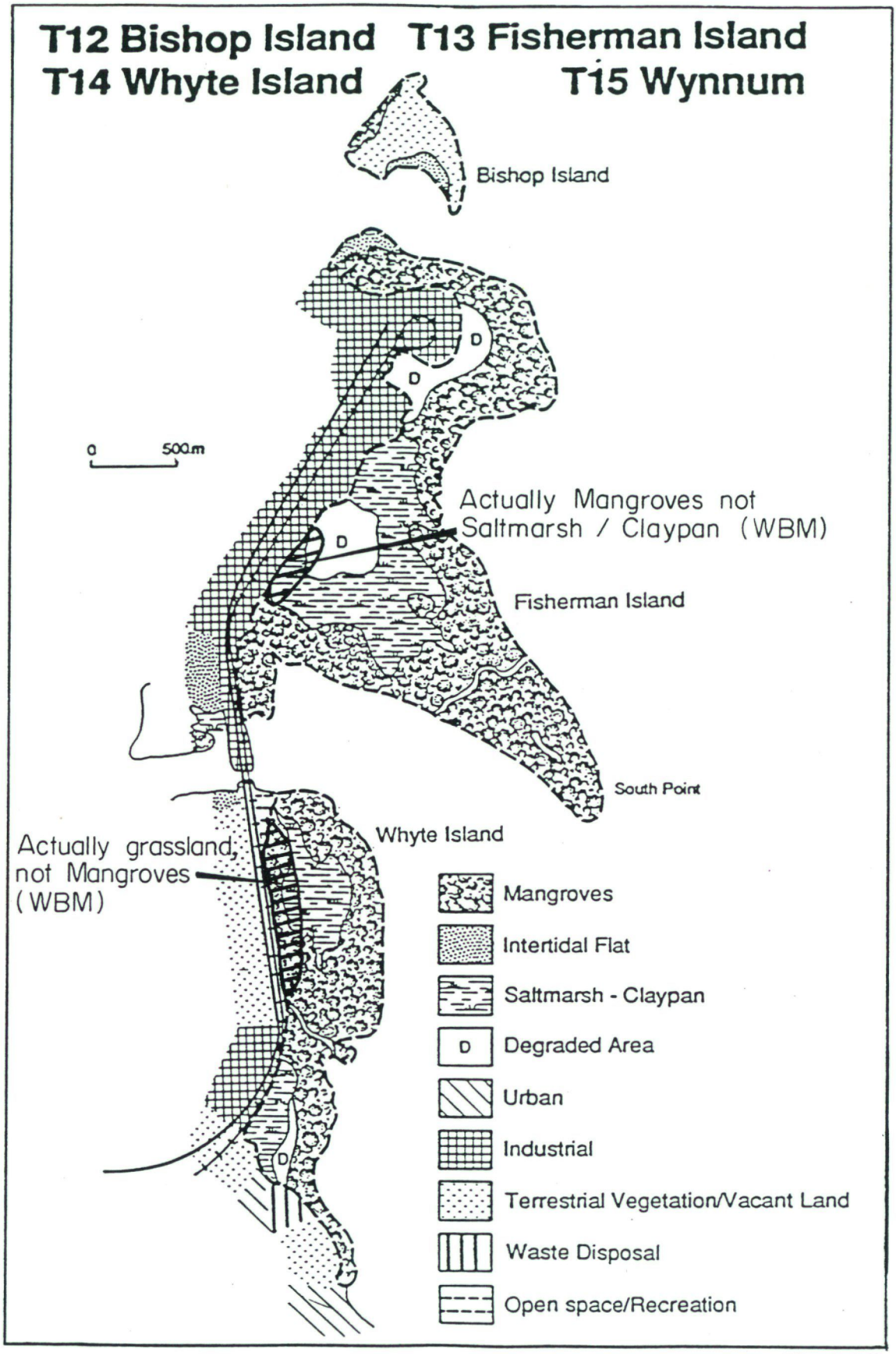
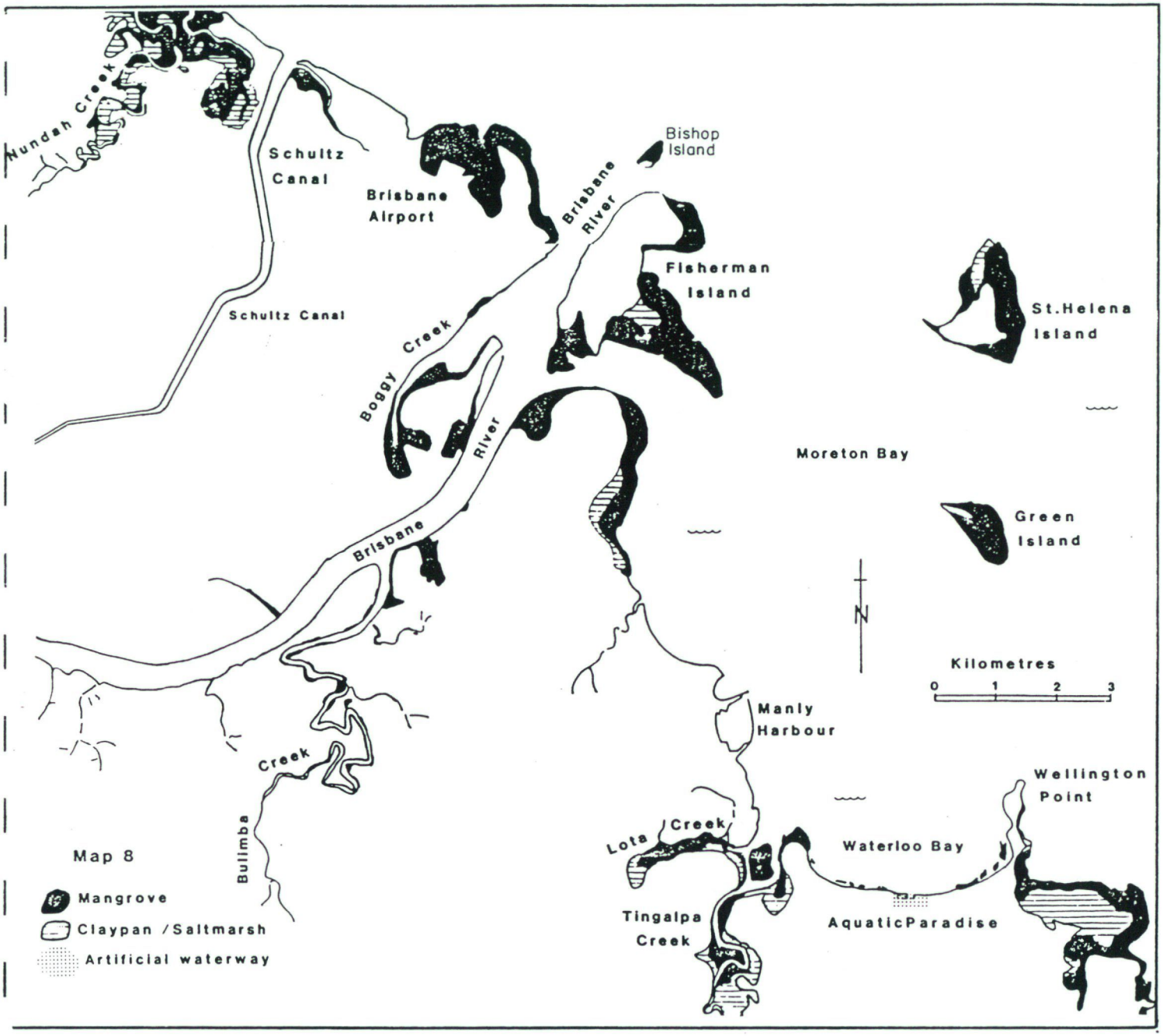


Fig. 2.2.8

From C.C.M. (1989)

FIGURE

VEGETATION MAPPED BY C.C.M. (1989) 3.3



From Hyland and Butler (1988)

TIDAL WETLAND MAPPED BY HYLAND AND BUTLER (1988)

FIGURE 3.4

WBM OCEANICS AUSTRALIA

The discrepancy between the present and previous studies apparently results from a combination of:

- the studies being conducted at different times. Reclamation of saltmarsh-claypan has occurred since 1986 in relation to the Hyland and Butler (1988) study, and since 1988, in relation to the CCM (1989) study.

- misclassification of habitat types. Many of the saltmarsh-claypan areas shown by Hyland and Butler (1988) and CCM (1989) are reclaimed lands (see Plate 3.1). For example, much of the saltmarsh-claypan mapped in the CCM (1989) report was subtidal lands that separated the Fisherman Islands and was reclaimed in the early 1970's (compare Figures 1.2 and 3.1 with Figures 1.3 and 3.2). Similarly, areas on both Fisherman Islands and Whyte Island classified by previous studies as saltmarsh-claypan are reclaimed lands. Dead mangrove stems amongst these areas attests to the original vegetation of these areas (Plate 3.2).

Some of the reclaimed lands are presently being colonised by saltmarsh vegetation *(Suaeda australis, Sesuvium portulacastrum, Sarcocornia quinqueflora)* although generally not covering continuous areas of > 2000 m^2 (Plate 3.2). Other species growing on reclaimed land are opportunistic and weed species and include *Phragmites australis* (Common Reed), *Fimbristylis polytrichoides* (Fringerush), *Cyperus polystachyos* (Bunchy Sedge), *Chloris gayana* (Rhodes Grass), *Rynchelytrum repens* (Red Natal Grass), *Cenchrus echinatus* (Mossman River Burr), *Sesbania cannabina* (Sesbania Pea), *Crotalaria zanzibarica* (Cursara Pea) and *Aster subulatus* (Wild Aster).

Mangroves

The area of mangroves recorded in the present study (351 ha) is comparable to that recorded by the CCM (1989) study (344.5 ha).

However, there is a difference of 30.5 ha in the mangrove area estimated for the Fisherman Islands (220 ha this study c.f. 250.5 ha CCM 1989). Differences in

estimates can arise through different methods of measurement (planimeter versus grid paper) and/or operator error. Mistakes can also be made in aerial photo interpretation, which appears to have occurred in the CCM study (1989), where an area of grassland has been mapped as mangroves on Whyte Island and an area of mangroves on the Fisherman Islands being mapped as saltmarsh-claypan (Figure 3.3).

There is a considerable discrepancy between the estimate of mangrove area made in this study (351 ha) and that from Hyland and Butler's (1988) study (445.2 ha). The difference (94 ha) is likely to result from; mangrove removal (eg. on Whyte Island) since the 1986 maps used by Hyland and Butler (1988), misclassification of habitat types (eg. Bishop Island is shown on Figure 3.4 as mostly mangroves although it is actually covered in terrestrial vegetation) and differing study area boundaries.

Overview

The present study provides an accurate assessment of mangrove areas near Fisherman and Whyte Islands. In contrast to previous studies, the assessment has been undertaken using a combination of aerial photography and detailed ground surveys.

The area of mangroves in the Fisherman Islands study area (351 ha) represents 2.5% of the 13900 ha mangrove resource of Moreton Bay, from the southern tip of south Stradbroke Island to Caloundra (Hyland and Butler 1988).

The structure of the mangrove forests in the study area varies from low shrubland to forest and is typical of mangrove communities occurring at the mouths of rivers along western Moreton Bay.

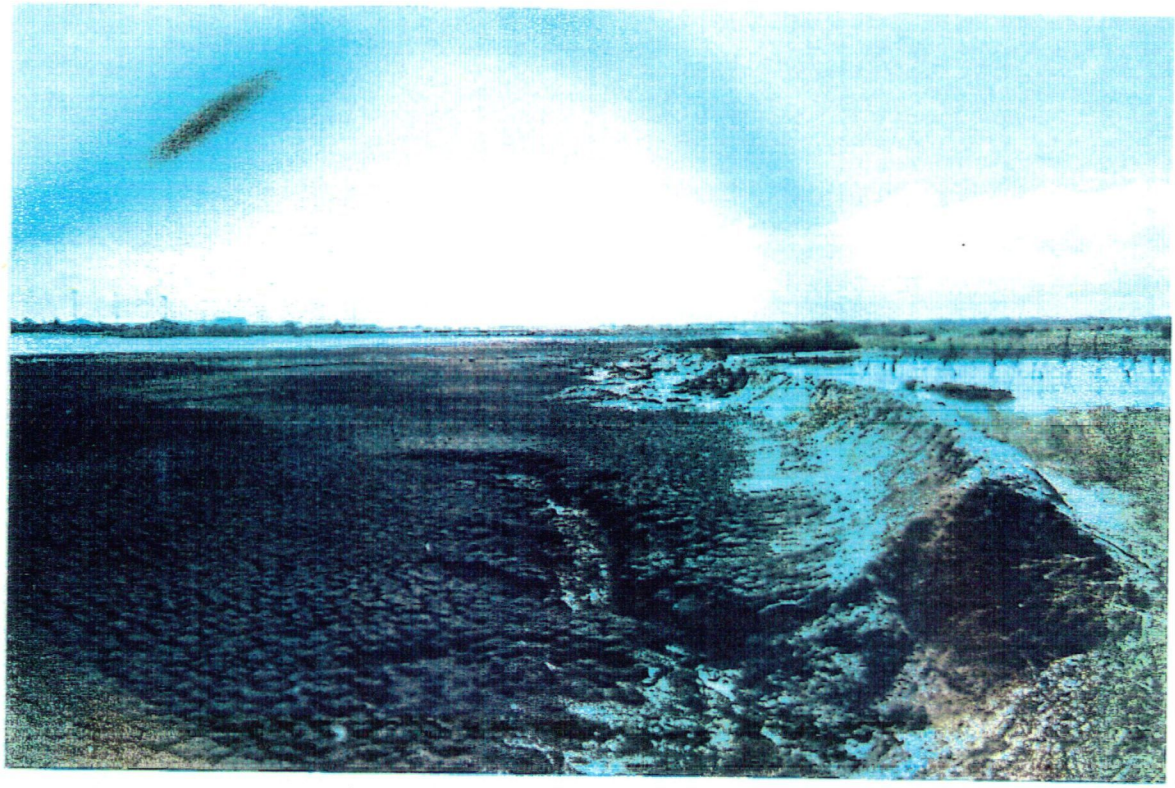


Plate 3.1 Unvegetated filled areas. Fisherman Islands.



Plate 3.2 Saltmarsh colonising partially filled mangrove area, southern Fisherman Islands.

4.0 MONITORING PROGRAMME

The present monitoring program was implemented to provide quantitative baseline data on mangrove communities adjacent to the Fisherman Islands prior to any future reclamation works for the Port of Brisbane. Quantitative ecological data will allow objective assessment of any impacts to the mangroves resulting from proposed reclamation works.

Selection of monitoring sites, and monitoring parameters, was undertaken in consultation with PBA environmental personnel. Monitoring studies commenced in September 1991. A variety of mangrove community structure parameters were measured. Some parameters were remeasured (as detailed below) in December 1991 and February 1992. Future measurements are proposed to occur on a regular basis to provide baseline data prior to reclamation works.

4.1 MONITORING SITES

Six sites were identified by the PBA for the mangrove study; sites 1 and 6 in the eastern Fisherman Islands region, sites 2 and 5 fringing the Boat Passage and sites 3 and 4 on the Wynnum foreshores near Whyte Island (Figure 3.1).

All sites are dominated by the Grey Mangrove *(Avicennia marina* var. *australasica)* although the Red Mangrove *(Rhizophora stylosa)* is numerically a very minor component at some sites. No other mangrove species were observed at any of the sites although other species occur landward.

Each of the six sites is immediately landward of the fringing mangrove community. These communities were selected for study because:

- they were considered to be in areas most appropriate to monitor effects of altered current patterns/water sediment loads.

- the stature of their component trees and their open structure allowed efficient measurement.

- their position slightly landward from the water's edge afforded some protection from human interference with measuring equipment.

- the mangrove communities at the six sites appeared to be unaffected by sediment runoff from landward reclamation works that have occurred for port development.

The structure of the mangrove community at each site is described in Section 5.0.

4.2 MONITORING METHODS

The following variables were measured in September 1991 to characterise the six Fisherman Islands and Wynnum mangrove monitoring sites:

(i) Projective foliage cover
(ii) Canopy height
(iii) Stand density
(iv) Stand basal area

Plant litterfall traps were installed at sites 1, 4, 5 and 6 in September 1991 and litter data collected in December 1991 and February 1992. Stem girth increment/decrement monitoring dendrometers were installed in October 1991 and measurements taken in February 1992.

A brief explanation of each of the variables measured is provided below.

Projective Foliage Cover

Projective foliage cover (PFC) estimates the horizontal cover of a site by the overstorey canopy and provides a measure of a plant community's potential productivity (Specht 1981). PFC was determined at each site from 100 random point quadrat sitings within the mangrove community and expressed as a percentage.

Canopy Height

The canopy height of the overstorey, or tallest stratum of a plant community, combined with PFC, provide an approximation of the major biomass of a stand and are the basis for the widely used vegetation classification scheme of Specht (1970), (Appendix A, Table 1).

Canopy height was indirectly determined by heighting ten "typical" trees in the overstorey canopy at each site with a Suunto Clinometer.

Stand Density, Stand Basal Area and Stem Girth Distribution

Stand density (number of tree stems per hectare, s/ha) and stand basal area (stem sectional area at breast height per hectare, m^2/ha) were determined by the point-centred quarter sampling method (Cottam and Curtis 1956). For this study, trees were defined as mangrove plants over 10 cm in diameter at breast height, breast height being 1.3 m above ground level (Carron 1968). The choice of a 10 cm diameter was arbitrary, however plants smaller than this were usually not tree-like in stature.

The tree stem measurements made for the estimation of stand basal area also allowed the derivation of stem girth distributions for the mangrove communities at each site. A stem girth distribution shows, by means of a table and/or diagram, the allocation of trees within the community across size classes.

Litterfall

Primary production, from wetland plant communities, is the basis of the estuarine ecosystem (Hutchings and Saenger 1987). Net primary production, gross production less production lost in the respiration of plants, is not available for Australian mangroves (Hutchings and Saenger 1987). Instead, components of net primary production which are easier to measure are used to compare the relative productivity of different plant communities.

Litter production is a component of net primary production commonly measured in mangrove studies because it is more easily obtained than estimates from gas exchange systems or micro-climatology measurements (Boto 1983).

Plant litterfall monitoring was conducted at sites 1,4,5 and 6. On the 13th September 1991, fourteen randomly located litter catchers were suspended from canopy branches at each site to keep them clear of high tides.

Each litter catcher comprised a metal ring 50 cm in diameter ($0.2m^2$ catching area) around which an inverted cone of 50% shade-cloth was constructed. Fourteen catchers per site was considered sufficient to provide an acceptable level of data reliability, given the relatively uniform overstorey canopies of the mangrove communities at each site, and results from a previous mangrove litterfall study at nearby Mud Island (Davie 1984).

The first litter collection was made on 4th December 1991 and the second on 7th February 1992. After collection, the plant litter was sorted into leaf, wood and fruit material (including all stages from bud to fully developed propagule), oven dried at 80°C, then weighed ($\pm$ 0.01 g).

Stem Girth Increment/Decrement

Stem girth increment/decrement studies were initiated on 25th October 1991 at all six sites when dendrometers were installed. Dendrometers comprised a length of 30 mm wide brass shim wrapped around the tree at breast height and held in tension by a spring. A vernier scale inscribed on the band allowed changes in tree girth (to a precision of 0.025 mm) to be recorded. A detailed description of the construction and use of these dendrometers is provided by Liming (1957).

Ten trees at each site were permanently fitted with dendrometers. The dendrometers were read only at the end of the study (February 1992), to avoid the considerable short term variations that occur in stem growth (Carron 1968) and focus on long term trends.

Photographic Record

In addition to these quantitative measures, a photographic record of the mangrove community at each site was made by taking a photo facing each major cardinal point - north, south, east and west - from a reference point marked with a 2.4 m star picket. These photographs will allow gross structural changes in the communities to be monitored.

Statistical Analysis

Mangrove litterfall was compared between sites within monitoring periods using a one-way ANOVA in conjunction with Duncan's Multiple Range test (Walpole, 1974). A t-test was used to compare sites between monitoring periods.

Statistical analysis was carried out using the computer software SPSSPC.

5.0 RESULTS

The structural features of the mangroves at each site are summarised in Table 5.1, and described in detail below.

Projective Foliage Cover (%)

Projective Foliage Cover (PFC) ranged from 62% to 72%. All but site 5 had a PFC of less than 70%, the cut-off point between vegetation communities classed as open (<70%) and those classed as closed (> 70%; Appendix A, Table 1). The mangrove community at site 5 (PFC 72%), was only marginally above this cut-off point.

Canopy Heights

Canopy height at sites 3, 4 and 5 was up to 10 m and between 10 and 13 m at sites 1, 2 and 6 (Table 5.1). Vegetation communities classed as low are < 10 m (Appendix A, Table 1).

Stand Density, Stand Basal Area and Stem Girth Distribution

Stand densities (number of stems per hectare) of the mangrove communities at the six sites fell into two groups. Sites 3, 4 and 5 were similar with stand densities of 830, 876 and 893 s/ha respectively (Table 5.1). Stand densities at sites 1, 2 and 6 however, were much lower, at 334, 462 and 380 s/ha respectively (Table 5.1).

Stand basal area (stem sectional area at breast height per hectare) did not divide the sites into similar groupings as for stand density. All stand basal areas were around 23 to 24 m^2/ha (Table 5.1) except at site 4 (28.9 m^2/ha).

TABLE 5.1.
STRUCTURAL FEATURES OF FISHERMAN ISLANDS AND WYNNUM FORESHORES MANGROVE MONITORING SITES

	SITE					
	1	2	3	4	5	6
Vegetation structural form (after Specht 1970)	Open forest	Open forest	Low open forest	Low open forest	Low closed forest	Open forest
Dominant species	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*	*Avicennia marina*
Projective foliage cover (%)	62	67	62	62	72	61
Canopy height (m)	10 - 13	10 - 13	8-10	8-10	8-10	10-13
Stand density (stems per ha)	334	462	830	876	893	380
Stand basal area (m^2/ha)	24.0	23.1	24.1	28.9	24.1	24.3
Stem Girth (cm)*	87.0 ± 4.4 (n=72)	73.5 ± 3.5 (n=68)	56.9 ± 2.5 (n=60)	59.7 ± 3.1 (n=60)	55.9 ± 2.2 (n=60)	86.1 ± 3.5 (n=60)
General description	Large tall trees, predominantly single-stemmed and widely spaced	Tall, median diameter trees, single or double stemmed	Small crooked-stemmed trees, closely spaced	Small diameter low spreading trees, crooked stems closely spaced.	Small trees, crooked stems, community of closely spaced trees.	Large tall trees, well spaced, predominantly single stemmed.

* mean ± standard error

Average stem girths of the mangrove communities at each site are shown in Table 5.1 and stem girth distributions displayed in Figure 5.1. The size class intervals in Figure 5.1 span 10 cm up to and including the value indicated for each class, hence the first size class spans from 0.30 m - 0.39 m (inclusive). The final size class however, includes all trees equal to or greater than one metre in girth, to allow the representation (and comparison) of all sites on one page.

At sites 3, 4 and 5 the number of trees declined from the smaller to the larger size classes (Figure 5.1). Sites 1 and 6 showed the opposite trend with the number of trees increasing from the smaller to the larger size classes. Site 2 had a fairly even distribution of trees across all size classes but still with a large number of trees in the final size class ($\geq$ 1.0 m girth), compared to sites 3, 4 and 5.

Litterfall

Total

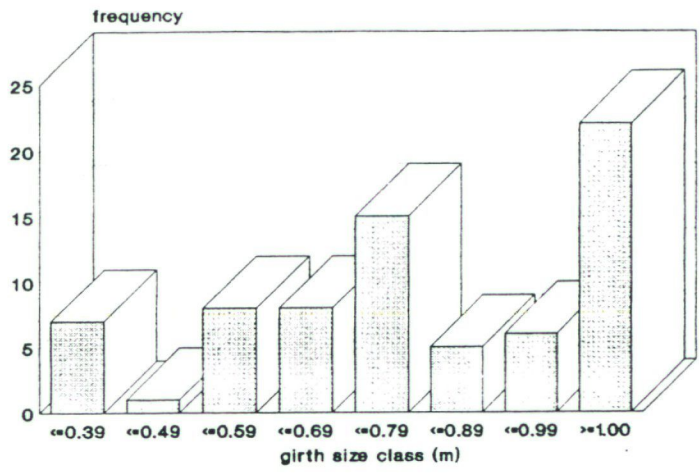
Total litterfall, averaged over the 14 litter-catchers at each of the four sites (1, 4, 5 and 6) for the first collection (December 1991), ranged from 1.1 g/m^2/day (site 1) to 1.7 g/m^2/day (site 5; Figure 5.2, Table 5.2). Within-site standard errors ranged from 8 to 10% of the mean.

Total litterfall for the second collection (February 1992), ranged from 1.8 g/m^2/day (site 6) to 2.7 g/m^2/day (site 4; Figure 5.2, Table 5.2). Within-site standard errors for the February collection were over 10% of the mean for sites 1 and 4, due mainly to a large and highly variable wood component in the litterfall.

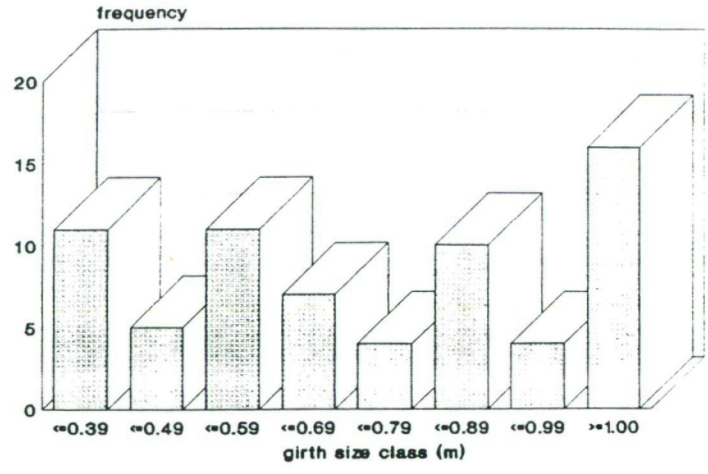
Leaf

Leaf litterfall ranged from 1.0 g/m^2/day (site 5) to 1.5 g/m^2/day (site 1) for the December collection (Table 5.2). Within-site standard errors ranged from 8 to 11% of the mean.

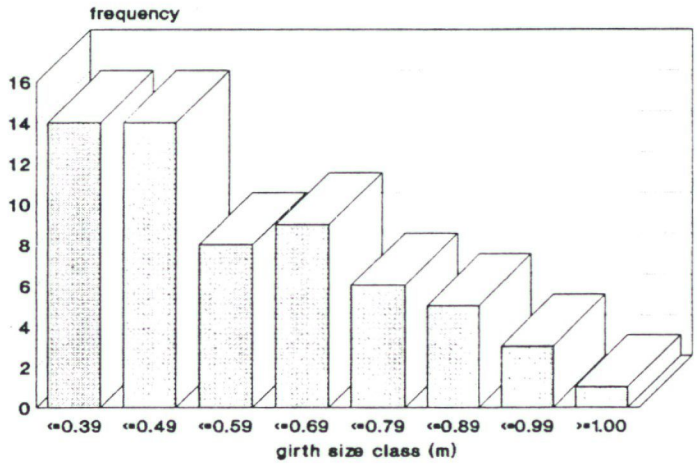
Site 1, Eastern Fisherman Is.



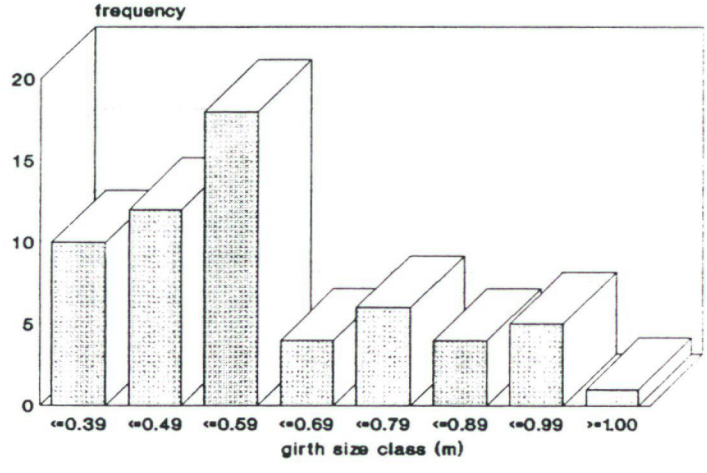
Site 2, Boat Passage



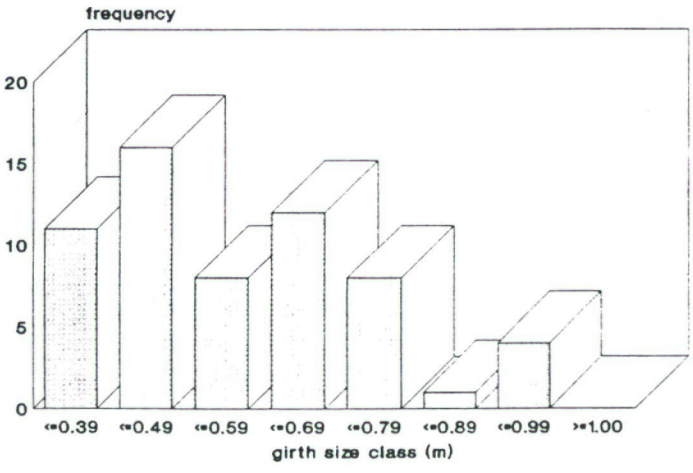
Site 3, Wynnum



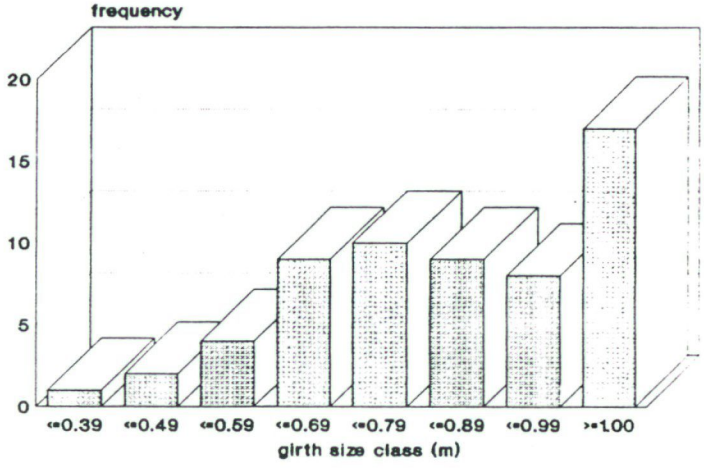
Site 4, Wynnum



Site 5, Boat Passage



Site 6, Eastern Fisherman Is.



STEM GIRTH DISTRIBUTION

FIGURE 5.1

WBM

For the February 1992 collection, leaf litterfall rates ranged from 1.4 (site 1) to 2.0 g/m^2/day (site 4). Within-site standard errors for the February collection ranged from 5 to 11% of the mean.

Wood

Wood litterfall values ranged from 0.1 (site 1 and 6) to 0.2 g/m^2/day (site 4 and 5) for the December collection, to 0.2 (site 6) to 0.7 g/m^2/day (site 4) for the February collection. Within-site variability in wood litterfall was high, standard errors ranging from 15 to 22% of the mean at the first collection, and 19 to 54% of the mean at the second collection.

TABLE 5.2
TOTAL AND COMPONENT LITTERFALL VALUES (MEAN ± STANDARD ERROR) FISHERMAN ISLANDS AND WYNNUM FORESHORES (g/m^2/day)

		COMPONENT			
Site (Structural Form)*	Collection**	Total	Leaf	Wood	Fruit
1 (*Avicennia marina* open forest)	1	1.10 ± 0.11	1.00 ± 0.11	0.10 ± 0.015	0.00 ± 0.00
	2	1.95 ± 0.32	1.40 ± 0.15	0.52 ± 0.28	0.03 ± 0.01
4 (*A. marina* low open forest)	1	1.64 ± 0.14	1.43 ± 0.12	0.20 ± 0.04	0.01 ± 0.00
	2	2.68 ± 0.33	2.01 ± 0.12	0.63 ± 0.24	0.04 ± 0.01
5 (*A. marina* low closed forest)	1	1.71 ± 0.17	1.51 ± 0.15	0.18 ± 0.03	0.01 ± 0.01
	2	2.29 ± 0.20	1.54 ± 0.12	0.67 ± 0.12	0.08 ± 0.01
6 (*A. marina* open forest)	1	1.25 ± 0.10	1.14 ± 0.09	0.09 ± 0.02	0.01 ± 0.01
	2	1.76 ± 0.12	1.51 ± 0.08	0.21 ± 0.04	0.04 ± 0.02

* after Specht (1970)

** Collection 1 4th December 1991 (initiated 13 September 1991)
Collection 2 7th February 1992

Fruit

Fruit litterfall made only a minor contribution to total litterfall over both collections. In the December collection it ranged from 0.00 to 0.01 g/m^2/day and in the February collection, from 0.03 to 0.08 g/m^2/day.

Comparisons between sites

For the December 1991 collection, total litterfall at sites 4 and 5 was significantly greater than at sites 1 and 6 ($p < 0.05$, Duncan's multiple range test). Leaf litterfall was also greater at sites 4 and 5 than at site 1 ($p < 0.05$) but only site 5 had a significantly greater ($p < 0.05$) leaf litterfall than site 6.

For the February collection site 4 had a significantly ($p < 0.05$) greater total litterfall than site 1 and 6, and a significantly greater leaf litterfall than all other sites.

Differences in wood litterfall and fruit litterfall were considered too variable within-site for meaningful comparisons to be made between sites.

Comparisons between collections

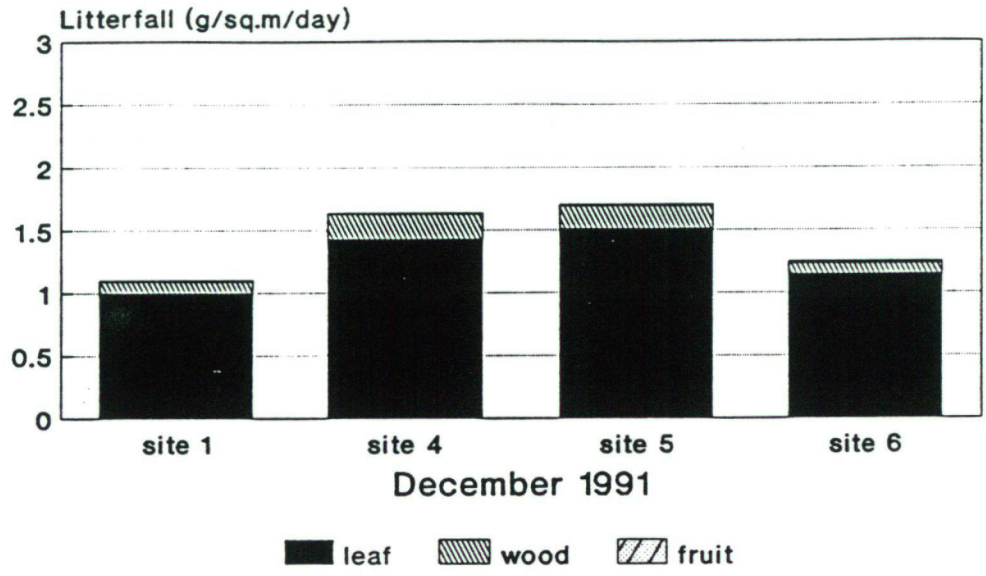
Total litterfall increased significantly ($p < 0.05$, t-test) from the December 1991 to the February 1992 collection at all sites. Leaf litterfall also increased significantly ($p < 0.05$) from the December to the February collection at all sites except site 5, where it remained relatively constant (Figure 5.2; Table 5.2).

However, the percentage contribution of the leaf component to total litterfall declined markedly from the December collection (87-91%) to the February collection (67-86%). Conversely, the contribution of the wood component to total litterfall, increased from December (7-12%) to February (12-29%) (Figure 5.2).

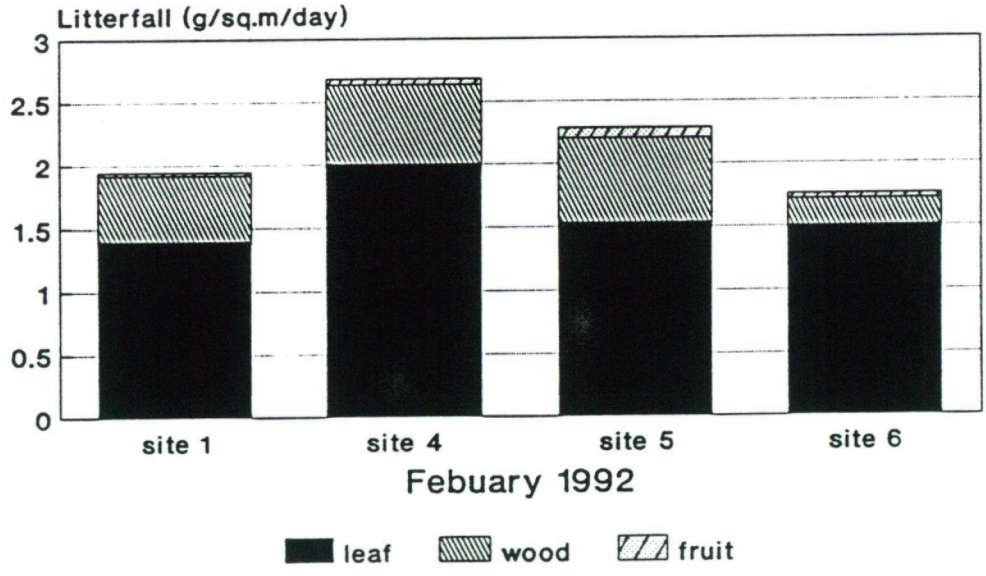
No statistical analysis was made of the differences between collections for the wood component, because of its high within-site standard error (15 to 22% of the mean for December and 19 to 54% of the mean for February).

Fruit litterfall also showed a small increase in its contribution to total litterfall, from 0 to 1% in December to 2 to 4% in February. No statistical analysis of the difference in fruit litterfall between collections was conducted because of its high within-site variability.

Mangrove Litterfall
Leaf, wood and fruit/flower



Mangrove Litterfall
Leaf, wood and fruit/flower



MANGROVE LITTERFALL FOR DECEMBER AND FEBRUARY COLLECTION

FIGURE 5.2

WBM

Stem Girth Increment/Decrement

Stem increment/decrement measured as change in girth at breast height (1.3 m above ground level) varied from -4.10 mm to 1.80 mm (Table 5.3) over the 60 trees during the approximately 15 week monitoring period (25/10/91 to 7/2/92).

TABLE 5.3
SUMMARY OF STEM GIRTH INCREMENT/DECREMENT (mm) FOR THE PERIOD 25/10/91 TO 7/02/92
Ten trees were monitored for stem girth increment/decrement at each site.

SITE	1	2	3	4	5	6
average girth	753 ± 54.6	754 ± 48.2	636 ± 32.6	600 ± 26.8	773 ± 55.7	952 ± 62.7
range in increment/decrement	-0.76 - 1.80	-2.54 - 0.51	-2.54 - 0.51	-1.00 - 1.30	-2.3 - 1.80	-4.10 - 0.00
number of stems shrinking (decrement)	4	2	3	3	3	7
number of stems - no change	3	5	4	5	2	3

Girth increment/decrement for the sites ranged from -4.10 mm to 1.80 mm. The greatest increment (1.80 mm) was measured at sites 1 and 5, while the greatest decrement (-4.10 mm) was measured at site 6.

Twenty-two trees showed no change in girth during the monitoring period over all sites. Twenty-two trees decreased in girth over the monitoring period and the remaining 16 trees increased in girth. At any one site, the greatest number of trees increasing in girth was 5 (site 5) while the greatest number decreasing in girth was 7 (site 6).

Photographic Record

The photographic record did not reveal any gross changes in the structure of the mangrove communities at the monitoring sites. Large changes were not expected, given the short duration of the study (September 1991 to February 1992). However a marked changed was noted on the mudflats immediately seaward of site 4, (Plates 5.1 and 5.2) where a very large seedling population present in September 1991

(developed to about the second leaf-pair stage) experienced a mortality rate of greater than 90% by February 1992.



Plate 5.1 Large seedling population on mudflats seaward of site 4, 13th September 1991

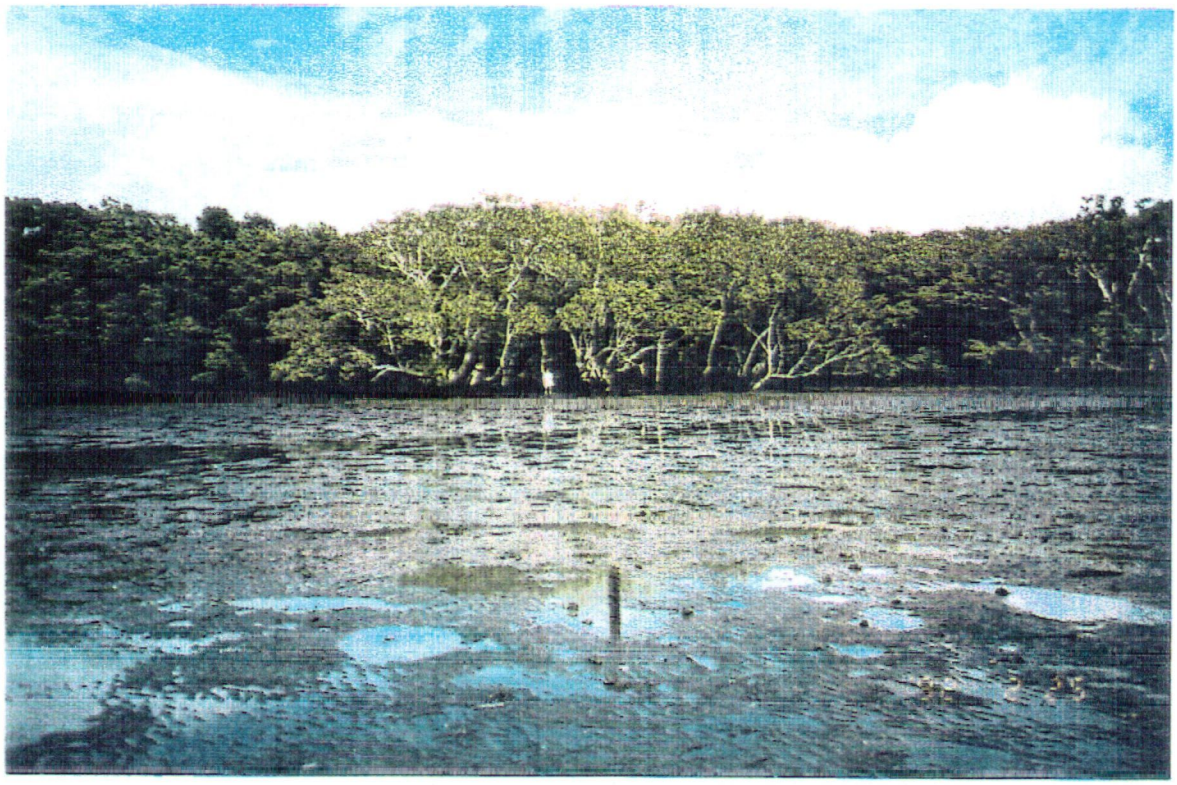


Plate 5.2. High mortality in same seedling population by 25th February 1992

6.0 DISCUSSION

The importance of mangroves in the estuarine food chain and their presumed role in land preservation are both connected with mangrove community structure (Rodriguez 1987) and have been the focus of much mangrove research.

The response of mangrove forests to stress (climatic and man-induced) can be identified with quantitative data (Odum et. al. 1982) such as that collected in the present study. Hence the importance of this baseline quantitative data on the mangroves of the Fisherman Islands and Wynnum foreshores.

Projective Foliage Cover and Canopy Height

Projective foliage cover and canopy heights recorded in this study are comparable to the results from other studies of mangrove communities in Moreton Bay (Durrington 1974, Dowling 1986). These two measures are almost standard in Australian studies for characterising plant community structure. Large changes over the medium to long-term in the values of these two variables would not be anticipated unless a drastic change in the local environment occurred such as large alterations of tidal regime.

Stand Density

The stand densities in the low closed to open forest mangrove communities of this study (334-892 s/ha) are comparable to similar mangrove communities in other parts of Moreton Bay. Dowling (1986) recorded stand densities ranging from 120 to 2900 s/ha for *Avicennia marina* low open forest and open forest at various locations in Moreton Bay. Durrington (1974) recorded densities of 100 to 800 s/ha for *A. marina* low open forest and open forest along Serpentine Creek, Moreton Bay. Much lower stand densities of 99 and 103 s/ha were recorded by Davie (1984) in low closed *Avicennia marina* forests on Mud Island in Moreton Bay. This variation is not surprising though, considering the wide range in mangrove stand structure in Moreton Bay (Dowling 1986).

Basal Area

Basal area (m^2/ha) is a structural variable less commonly measured in Australian mangrove studies, probably because of the irregular stem form of plants in many mangrove communities (Davie 1984).

On Mud Island, Moreton Bay, the basal area of a seaward low closed mangrove forest was 16 m^2/ha (Davie 1984), compared to the 24.1 m^2/ha for the low closed *A. marina* forest at site 5 (Boat Passage) in this study. The basal area of other mangrove communities investigated in this study (low closed forest - low open forest - open forest) ranged from 23.1 to 28.9 m^2/ha.

In riverine *A. marina* vegetation along Strangers Creek, Sydney, basal areas of 43 and 44 m^2/ha were recorded (Briggs 1977), perhaps indicating a much more productive environment than that of Fisherman Islands and the Wynnum foreshores.

Differences in basal area estimates may be partly due to the choice of criteria for defining which plants will be measured and not all mangrove studies clarify what is included in the basal area estimates, limiting the reliability of comparisons between studies.

Stem Girth Distribution

The stem girth distribution of the mangrove communities at sites 3,4 and 5 (many small trees and few large trees) is typical of uneven-aged forest stands (Carron 1968). The opposite trend at sites 1 and 6 may indicate that the mangrove communities at these sites are very mature and possibly over-mature or senescent. The large number of big trees ($\geq$ 1.0 m girth) at sites 1 and 6 may limit incoming solar radiation, nutrients and root space sufficiently to prevent the establishment and development of smaller mangroves. Some mortalities may occur over the next 10 to 20 years amongst the larger trees at sites 1 and 6 and would probably be followed, possibly with a 5 to 10 year lag, by an increase in the population of smaller, younger trees.

Litterfall

The increase in total litterfall from the first collection (December 1991) to the second collection (February 1992) in this study was accounted for largely by an increase in the wood component. This may have been due to an increase in rain and storm activity leading up to the second litterfall collection, dislodging dead wood in the mangrove canopies. Prior to the first litterfall collection there were just 16 rain days over the months of September, October and November 1991, whereas there were 20 rain days in December 1991 and January 1992, prior to the second litterfall collection (Bureau of Meteorology).

Litterfall collection in this study has only occurred on two occasions and will need to continue over a longer period to detect seasonal litterfall patterns. A 17 month litterfall study in a low closed forest on Mud Island in Moreton Bay found that litterfall peaked in September 1979 and August 1980 (late winter/early spring) while minimums occurred in November 1979 and March 1980 (late spring, early autumn) (Davie 1984).

Longer term litterfall collections are considered necessary to determine whether the present trend of sites 4 and 5 producing more litterfall than sites 1 and 6 continues. It may relate to features of the physical environment at sites 4 and 5; such as a higher nutrient input. This could be tested by conducting nutrient analyses of the receiving waters, the soils and the foliage at the various sites. The nutrient characteristics of the soil-water covering the roots of mangroves is thought to be a significant growth-limiting factor (Davie 1984).

The extrapolated average litterfall of 6.6 dry t/ha/yr for this study is comparable to the estimate of 6.42 t/ha/yr (Davie 1984) for low closed *Avicennia marina* forest on Mud Island, Moreton Bay. It is also comparable to data from studies elsewhere in the world in mangrove forests at similar latitudes (see Hutchings and Saenger 1987 and Table 6.1).

TABLE 6.1
LITTERFALL VALUES FOR MANGROVE FORESTS IN AUSTRALIA AND FLORIDA (USA)

Location	Forest Type	Leaf Litter (t/ha/yr)	Total Litter (t/ha/yr)	Study Period	Reference
Moreton Bay, Brisbane	*Avicennia marina* low closed forest to open forest	5.3 (extrapolated from 21 weeks)	6.6 (extrapolated from 21 weeks)	13th Sep 1991 - 7th Feb 1992	This study
Middle Harbour, Sydney	*A. marina* low closed forest	4.6	5.8	Mar 1977 - Apr 1978	Goulter and Allaway (1979)
Moreton Bay, Brisbane	*A. marina* low closed forest	--	6.42	Aug 1979 - Dec 1980	Davie (1984)
Moreton Bay, Brisbane	*A. marina* low open shrubland	--	1.94	Jan 1980 - Dec 1980	Davie (1984)
Missionary Bay, Hinchinbrook Island, North Queensland	mixed species	--	3.7-28.1	1975 - 1978	Bunt (1982)
Missionary Bay, Hinchinbrook Island, North Queensland	*Avicennia* sp. forest	6.6	9.5	1975 - 1976	Duke et al (1981)
Florida	*Avicennia germinans* forest	-	3.7-5.6	-	Lugo et al. (1980) cited by Odum et al. (1982)

A review of litterfall studies from mangrove communities around the world (Hutchings and Saenger 1987) reveals a wide range, from 0.8 dry t/ha/yr in a temperate/subtropical *Rhizophora mangle/Laguncularia racemosa/Avicennia nitida* forest in Southern Florida (25°N) to 28.1 dry t/ha/yr in a mixed species tropical mangrove forest in North Queensland, Hinchinbrook Island (18°S). Litter production is typically higher in tropical than in temperate mangroves, although there is considerable variation within a given mangrove community (Hutchings and Saenger 1987).

Human interference with the litterfall catchers has been confined to just one catcher out of the total of 56 in the period from 13th September 1991 to 7th February 1992, so continued measurements are feasible.

The litterfall collections for this study will provide valuable quantitative data on the productivity of the Fisherman Islands and Wynnum foreshore mangroves.

Stem Girth Increment/Decrement

Measurement of mangrove stem girth increment/decrement by dendrometers in the present study appears to be novel for Australian mangrove studies. The irregular stem form of individual mangroves in many mangrove communities in Australia would often rule out such measurements.

The small increments in stem girth noted in this study may be because monitoring has only been conducted over a short period at a time of year when mangrove productivity is typically low (Davie 1984).

The decrement in girth noted on 22 of the 60 stems measured may be due to actual stem shrinkage, faulty installation of the dendrometers, or a combination of both. Shrinkage is a common phenomenon in tree stems (Bormann and Kozlowski 1962) that has been attributed to low rainfalls in the week preceding recordings. For the months August 1991 to January 1992, preceding and during this study, there was a rainfall deficit of 184.4 mm compared to the long term average (Bureau of Meteorology). Differences in each tree's genotype governing its response to a

water deficit may account for the variation in tree growth rates. The possibility that shrinkages were due to faulty installation of the dendrometers is considered unlikely.

Continued recording of stem increment/decrement with the dendrometers as an adjunct to productivity measured by the litterfall catchers would be worthwhile. The readings taken from the dendrometers may indicate that the mangroves of the monitoring sites do not experience rapid stem growth, so measurements will become of more value as they are recorded over longer periods.

Photographic Record

The photographic record did not reveal any gross structural changes at the mangrove sites over the study's duration. Photos taken on the mudflats seaward of site 4 however, proved very useful in monitoring changes in exposed seedling populations. Future study could monitor this mudflat area and investigate what may have caused the large seedling mortalities observed. Possible causes are grazing by crabs and/or fish, a root pathogen or a severe storm event dislodging seedlings.

7.0 RECOMMENDATIONS FOR FUTURE MONITORING

The present study has provided important baseline data in regard to mangrove communities. However studies have:

- been conducted over a period (late spring to early autumn) typically associated with minimal litterfall (see Davie 1984) and therefore are likely to underestimate annual net primary production.

- been conducted over 5 months and do not provide data sufficient to reveal seasonal patterns. The absence of seasonal data severely limits the value of the study in describing baseline conditions and hence quantifying any long term impacts to mangrove communities adjacent to Fisherman Islands resulting from reclamation operations.

It is therefore recommended that litterfall monitoring should be continued for at least another 6-8 months to include the full range of seasonal variation in productivity. Litterfall collection should be made preferably at intervals of no more than two months; longer than this and trapped litter begins to decompose and results in litterfall production being underestimated.

Similarly further stem increment/decrement readings need to be taken to provide seasonal data. Readings need only be collected every four months. These readings should also be continued for at least 12 months to be able to arrive at an actual annual stem girth increment value.

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9.0 GLOSSARY OF TERMS

Claypan: unvegetated high tidal flats, generally landward of mangroves.

Diameter at breast height (dbh): standing trees are almost universally measured at a fixed height above ground level referred to as breast height which in Australia is set at 1.3 m (Carron 1968).

Estuarine: of, or pertaining to an estuary.

Intertidal: land between high and low tides.

Mangroves: the term is used here interchangeably to refer to an individual species of plant or to a stand or forest of plants belonging to many species (after Hutchings and Saenger, 1987); a community (or a plant thereof) arising from an estuarine or tidal mudflat.

Saltmarsh: high tidal flats landward of mangroves vegetated by saltcouch grass and samphire bushes.

Seagrass: marine flowering plant growing on intertidal to subtidal flats.

Subtidal: below the level of lowest astronomical tides

Wetlands: plant habitats subject to tidal action including subtidal areas to an Australian Height Datum (AHD) depth of 6 m; encompassing saltmarsh/saltpan, mangroves and seagrass communities.

APPENDIX A

APPENDIX A

TABLE 1
STRUCTURAL FORMS OF VEGETATION IN AUSTRALIA (MODIFIED FROM SPECHT 1970)

LIFE FORM AND HEIGHT OF TALLEST STRATUM	PROJECTIVE FOLIAGE COVER OF TALLEST STRATUM			
	Dense (70-100%)	Mid Dense (30-70%)	Sparse (10-30%)	Very Sparse (< 10%)
Trees* > 30 m	Tall closed-forest	Tall open-forest	Tall woodland	Tall open-woodland
Trees* 10-30 m	Closed-forest	Open-forest	Woodland	Open-woodland
Trees* 5-10 m	Low closed-forest	Low open-forest	Low woodland	Low open-woodland
Shrubs* 2-8 m	Closed-scrub	Open-scrub	Tall shrubland	Tall open-shrubland
Shrubs* 0-2 m	Closed-heath	Open-heath	Low shrubland	Low open-shrubland
Hummock grasses 0-2m	-	-	Hummock grassland	Open hummock grass-land
Herbs (incl. moss, ferns, hemicryptophytes, geophytes, therophytes, hydrophytes, helophytes)	Closed-herbland	Herbland	Open-herbland	-
	Closed-tussock grassland	Tussock grassland	Open-tussock grassland	-
	Closed-grassland	Grassland	Open-grassland	-
	Closed-herbfield	Herbfield	Open-herbfield	-
	Closed-sedgeland	Sedgeland	Open-sedgeland	-
	Closed-fernland	Fernland	Open-fernland	-
	Closed-mossland	Mossland	Open-mossland	-

* A tree is defined as a woody plant more than 5 m tall, usually with a single stem. A shrub is a woody plant less than 8 m tall, frequently with many stems arising at or near the base (slightly modified from Beadle and Costin, *Proc. Linn. Soc. N.S.W.* 77, 1952, 61)