# SEAGRASS DIEBACK

# IN NORTH WESTERN TORRES STRAIT

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# Executive Summary

To assess the magnitude and extent of a reported seagrass decline in north-western Torres Strait the distribution and abundance of seagrass from a survey of 332 sites in November 1993 (post-impact) in a study area of 4,388 $km^2$ was compared with historical data of the distribution and abundance of seagrass collected at 498 sites in the study area between 1986 and 1989 (pre-impact).

There was an estimated loss of 1,199 $km^2$ of seagrass in the north-eastern region of the study area, in the main impact area, which represented a 60% loss of seagrass there. In contrast there was little change in the area of seagrass which was mapped for the southern region of the study area.

On the foreshore areas at three locations where quantitative samples of seagrass biomass were taken at 201 sites with a 0.07 $m^2$ core a the biomass of a mixed assemblage of seagrasses on the foreshore and shallow subtidal areas along the southern margin of Boigu Island at the northern end of the study area was significantly lower in the post- than pre-impact surveys. Before the November 1993 survey the seagrass beds were numerically dominated by Cymodocea serrulata, Thalassia hemprichii and Enhalus acoroides with high biomass, 66 g.m-2, whereas in the November 1993 survey only T. hemprichii and to a lesser extent C. serrulata was common and biomass, 18 g.m-2, and diversity was significantly lower. In contrast there were no significant differences between estimates of seagrass biomass for the historical 1986–1989 and the November 1993 survey at two 'control' locations just south of the study area at Badu Island. The species composition was also similar for the historical data and the November 1993 survey at these locations.

In addition to the changes in seagrass in the northern section of the study area there were also large changes in the distribution and abundance of epifauna in this region over a three year period from 1989 to 1993. Whereas there was dense or sparse epifauna present throughout much of the study area north of Buru Island in May and June 1989, epifauna was mostly sparse or absent in the November 1993 survey.

Analysis of a coral head of Porites sp. from Boigu Island indicated that freshwater runoff from the Mai River in the 1990/91 wet season was very unusual with a short but intense run-off at the end of the season, which correlated well with the changes in seagrass, epifauna and areas with high abundance of sea urchins in the northern and north eastern region of the study area.

## Introduction

The decline and loss of seagrass is being reported at an increasing rate around the world (den Hartog, 1970; Preen et al., 1995). Changes in seagrass occur at a range of spatial and temporal scales due to anthropogenic and natural causes, and the complex interaction of the two (den Hartog 1970). Anthropogenic causes related to decrease in water quality have been linked to seagrass decline in coastal waters (Walker and McComb, 1992). Natural effects include cyclones and storm events which physically removes seagrass by scouring, and indirectly through lowered salinity and increased turbidity (Preen et al., 1995).

In the early 1990's there were reports by rock lobster fishermen and Torres Strait Islanders that seagrass was disappearing in north western Torres Strait. The anecdotal evidence was corroborated by CSIRO scientists doing ongoing field work in north western Torres Strait on the rock lobster *Panulirus ornatus* (Pitcher et al., 1994). In addition to the seagrass decline they also noted that epifauna had declined and that there was an abrupt increase in the abundance of sea urchins in the area. Concerns over the possible repercussions of a seagrass dieback on the dugong, prawn and fish populations prompted a survey of the seagrass, epifauna and sea urchins of north western Torres Strait in November 1993 (hereafter called the dieback survey). There was extensive qualitative historical data (1984–1989) of seagrass presence or absence in the inter-reefal areas (Long and Poiner 1993). There was also detailed historical quantitative data of seagrass biomass collected along the southern margin of Boigu Island and two bays at the southern and eastern end of Badu Island (ibid.). These two historical data sets provided the necessary information on the distribution and abundance of seagrass in the area before the reported dieback to compare with data collected after the impact for a Before/After/Control/Impact experimental design which is a prerequisite for detecting an environmental impact (Underwood, 1993). To identify possible environmental causes of the reported dieback freshwater run-off events from nearby rivers which discharge into the area were correlated with changes in seagrass. The patterns of growth of coral heads, which accurately record freshwater run-off events (Isdale, 1996), were analysed as there was no data available on freshwater discharge by rivers into the study area.

## Materials and Methods

### *Description of the study area*

Torres Strait lies between the NW coast of Cape York Peninsula and the S coast of Papua New Guinea, and connects the Coral and Arafura Sea (Fig. 1). The physical oceanography and sedimentary geology has been described by Wolanski et al. (1988), Harris (1988) and Bode and Mason (1994). The Straits are shallow (< 15 m) with strong tidal currents due to large pressure gradients between the Arafura and Coral Sea (Bode and Mason, 1994). Water speeds exceeding 2.5 $m.s^{-1}$ occur in the narrow channels between some islands and reefs (Admiralty, 1973).

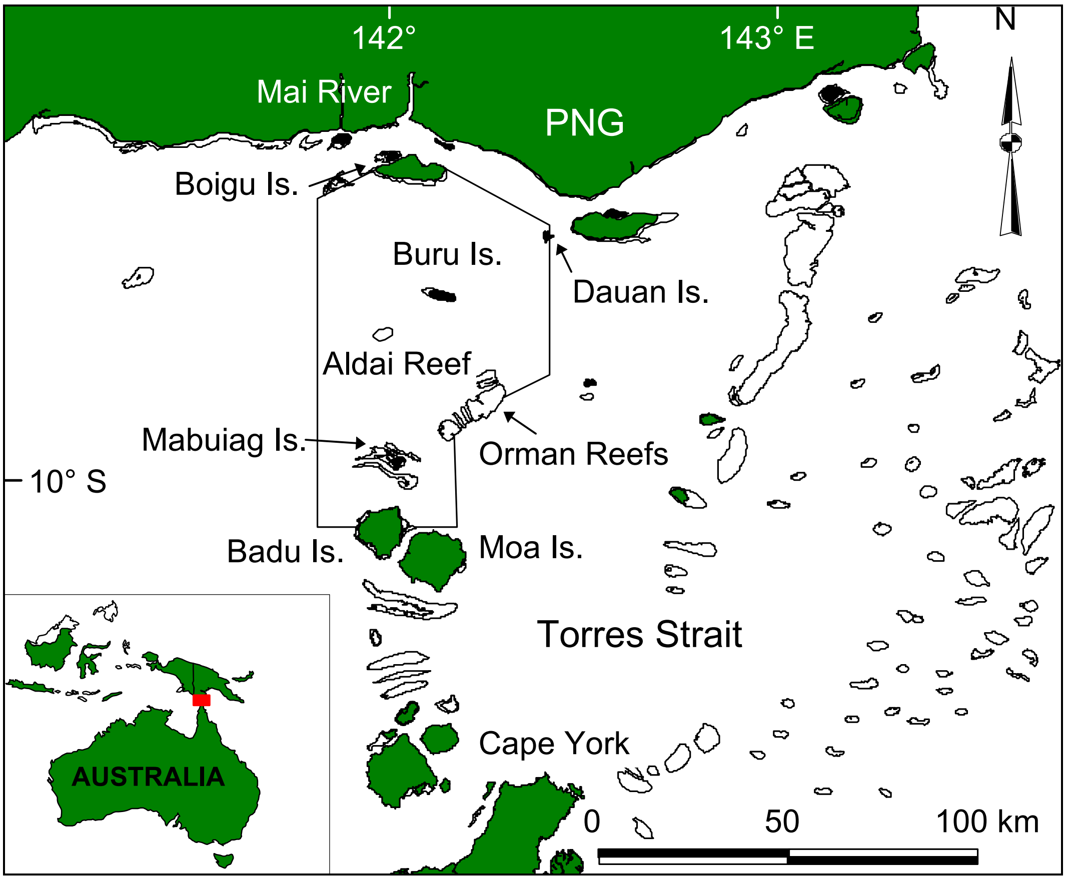



**Figure 1**. Map of Torres Strait, showing the boundaries of the seagrass dieback survey done in November 1993.

The strong tidal currents have created sand waves in many areas of Torres Strait (Harris, 1988) including north western Torres Strait. There are two distinct seasons in Torres Strait: a dry season which runs for seven months from May to November with an average rainfall of 21.4 mm month$^{-1}$, and a wet monsoon season which lasts for five months from December to April with an average monthly rainfall of 311 mm at Thursday Island (Admiralty, 1973). The prevailing winds for the two seasons are also distinct with south-east trade winds blowing from E and SE 90% of the time during the dry season whereas winds are more variable during the wet monsoon and blow from the NE, N and NW for 30% of the time. The average wind speed is lower in the wet monsoon, 5 knots.h$^{-1}$, than dry season, 7.9 knots.h$^{-1}$, and the number of calm days is also lower in the dry season, < 1 day.month$^{-1}$ than wet monsoon, 2.1 days.month$^{-1}$. There are more gales during the monsoon than dry season (6 and < 1 days.month$^{-1}$ respectively). There is little net flow of water through Torres Strait although there are seasonal differences in the direction of net flow with a net westwardly flow over the dry season with the south-east trade winds and a net eastwardly flow over the wet monsoon season when westerlies and north westerlies prevail (Wolanski et al., 1988). The winds and currents stir up the bottom sediments in shallow water areas of central Torres Strait which results in a turbidity maximum zone in central Torres Strait (Harris, 1988).

Seagrass was reported to be declining in north western Torres Strait, north of Buru Island, however, the extent of the dieback was not known so a study area large enough to encompass much of north western Torres Strait was defined. The southern limits of the study area were Badu and Moa Island, situated mid-way across the Straits; Boigu and Dauan Island near the S coast of Papua New Guinea formed the northern boundary; the eastern limit of the study area were formed by a line NE from Moa Island through the Orman reefs and N to Dauan Island; and the 142$^{nd}$ meridian of longitude formed the western boundary (Fig. 1).

## *Field sampling: Inter-reefal areas*

### Historical data

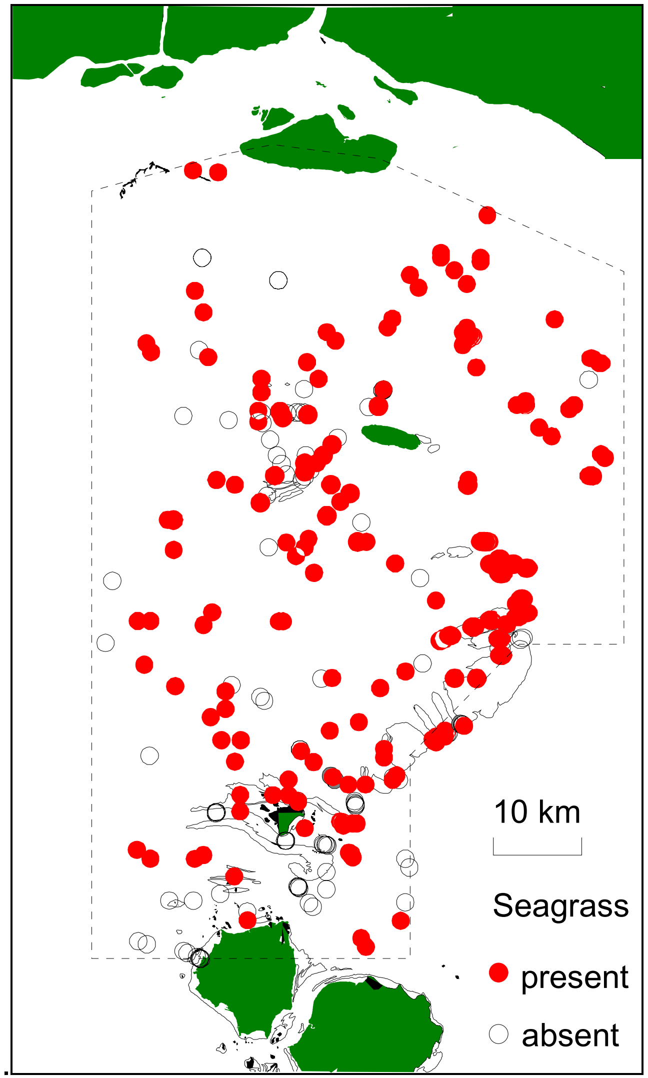
The percentage cover of seagrass in 0.25 m$^2$ quadrats along 20 m transects were recorded by divers at 253 subtidal sites in the study area in north western Torres Strait during seven cruises from 1986 to 1989 as part of the seagrass study (Long and Poiner, 1993) (Fig. 2a). At a further 112 sites the relative cover of seagrass was recorded by divers for 500 m x 2 m transects sampled during a lobster survey in 1989 (Pitcher et al., 1992). Because the sampling methods differed the data from the seagrass study and the lobster survey were converted to seagrass presence or absence data which gave a total of 365 sites sampled on the seabed in the study area from 1986 to 1989.

In addition to the historical data on the distribution and abundance of seagrass there was extensive data on the distribution and abundance of epifauna in the region between Boigu and Badu Island which was collected as part of the lobster survey in 1989 (see Pitcher et al. 1992 for full details). Epifauna was recorded as dense, sparse, very sparse or absent for the 500 m x 2 m transects by divers at the 112 sites sampled in the study area. Sediment samples were taken at 9 sites within the study area during a seagrass survey in 1989.

### November 1993 survey

The seagrass at 251 subtidal sites in the study area were sampled in November 1993 to assess the magnitude and extent of the reported seagrass dieback (Fig. 2b). The study area was first divided into primary sampling units which were each 4.5 km east-west and 4.2 km north-south. The primary sampling unit area, 18.9 km$^2$, was chosen based on estimates of the time it would take to sample a site (15 min), the time to travel between sites and the total time (three weeks) available for field sampling. To give complete sampling coverage of the study area all primary sampling units were sampled. Because it was impractical to sample the whole primary sampling unit (18.9 km$^2$) the area sampled in the field were 100 m$^2$ sites. The position of each site within each primary sampling unit was chosen randomly. Global Positioning System (GPS) satellite navigation was used to locate the sites in the field. At all sites divers searched an area of approximately 100 m$^2$ and recorded the presence or absence of seagrass along with estimates of the abundance of sea urchins (per 25 m$^2$) as well as descriptions of the substratum and epifauna. The epifauna cover was scored into four categories: dense, sparse, very sparse and absent to conform with the categories devised by Pitcher et al. (1992). Water visibility (m) and water depth (m) were also recorded at each site and a sediment sample was taken for grain-size analysis.

a).

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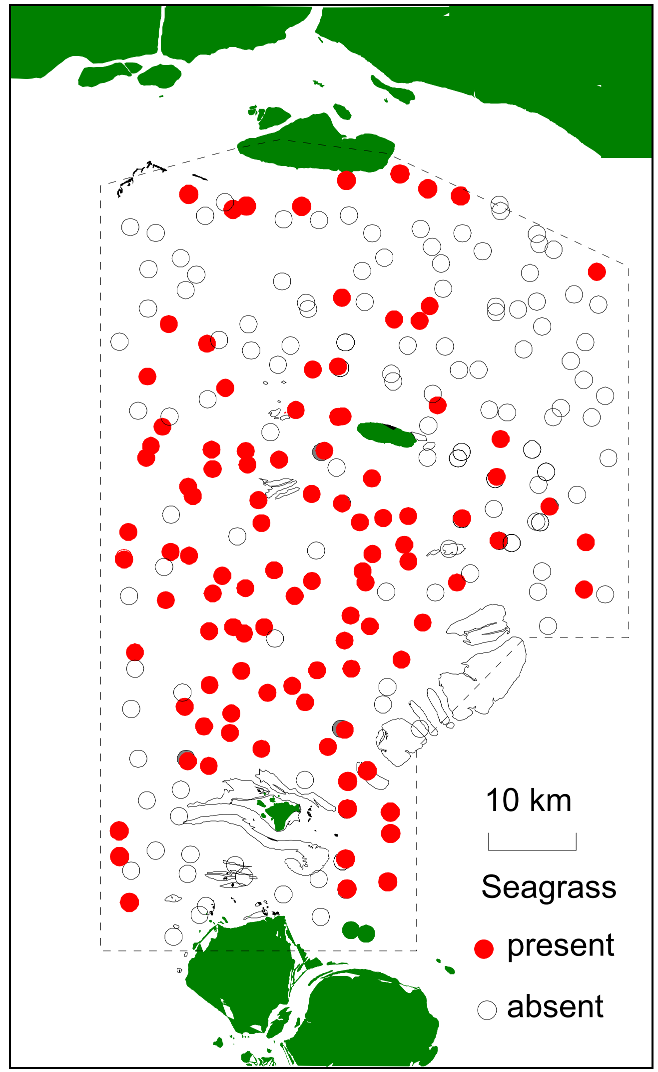



**Figure 2**. Seagrass presence or absence data from the a). historical (1986–1989) seagrass data; and b). November 1993 survey.

### *Field sampling: Foreshore areas and shallow embayments*

#### Historical data

Quantitative samples of seagrass biomass were collected with a 0.07 $m^2$ shovel by divers from a dinghy at 133 sites sampled on foreshore and shallow subtidal areas at three locations in the study area (Fig. 3a & b). At each site 3 to 5 shovel samples were taken at fixed intervals down a 20 m transect (for full details of the sampling see Long and Poiner 1993). The seagrass was placed in a divers mesh bag and returned to the surface where it was sieved over the side of the dinghy in a 10 mm lug basket to remove the sediment from the rhizomes, labelled and stored on ice for further processing at the CSIRO marine laboratories, Cleveland, Qld. The location sampled on the foreshore area on the southern side of Boigu Island was selected as the impact location in the Before/After/Control/Impact analysis. Forty-three sites were sampled there in an area of 3.413 $km^2$ from 1986 to 1989 before the reported dieback (Fig. 3a). Two embayments just south of the study area at the south and east end of Badu Island were selected as control locations with 38 and 54 sites sampled from 1986 to 1989 in an area of 2.02 and 1.911 $km^2$ respectively (Fig. 3b).

#### November 1993 survey

Quantitative sampling of seagrass biomass was done at Boigu and Badu Islands to match up with the historical data sampled at these three locations in the Before/After/Control/Impact (BACI) experimental design to test for significant changes in seagrass biomass at these locations (Green 1993). At the location on the foreshore area of the southern margin of Boigu Island (impact location), 24 core samples were taken with a 0.07 $m^2$ seagrass grab (Long et al. 1994) along two transects separated approximately 1 km east-west and 170 m north-south to match up with the samples taken there from 1986 to 1989 (Fig. 3a). At the east and south end of Badu Island, just south of the study area (control locations) in sheltered embayments of the island, 21 samples were taken from each location respectively in a grid arrangement with 310 m separation in both the east-west and north-south directions to match up with the samples taken there from 1986 to 1989 (Fig. 3b).

Back at CSIRO Marine Laboratories the seagrass samples were placed in a 10% solution of orthophosphoric acid for 30 min to clean the epiphytes from the shoots (refer to Long and Poiner, 1993 for full details). The samples were rinsed in freshwater and separated into species and the above-ground shoots and stems were separated from the below ground rhizomes. The seagrass was dried at 60°C until a constant weight and weighed to the nearest 0.1 g.

### *Data Analysis*

#### Mapping — seagrass presence or absence

Point-to-area spatial data transformations with a Geographic Information System (GIS) was used to create Voroni maps of seagrass presence or absence for the study area for the historical (1986–1989) and the November 1993 survey data. The two maps were overlaid to produce a third which mapped areas where seagrass was present over the entire eight year study period; seagrass was absent over the study period; seagrass was present during the survey but was absent before the survey and; seagrass was absent during the survey but was present before the survey. The last category mapped areas where seagrass had disappeared.

a). b).

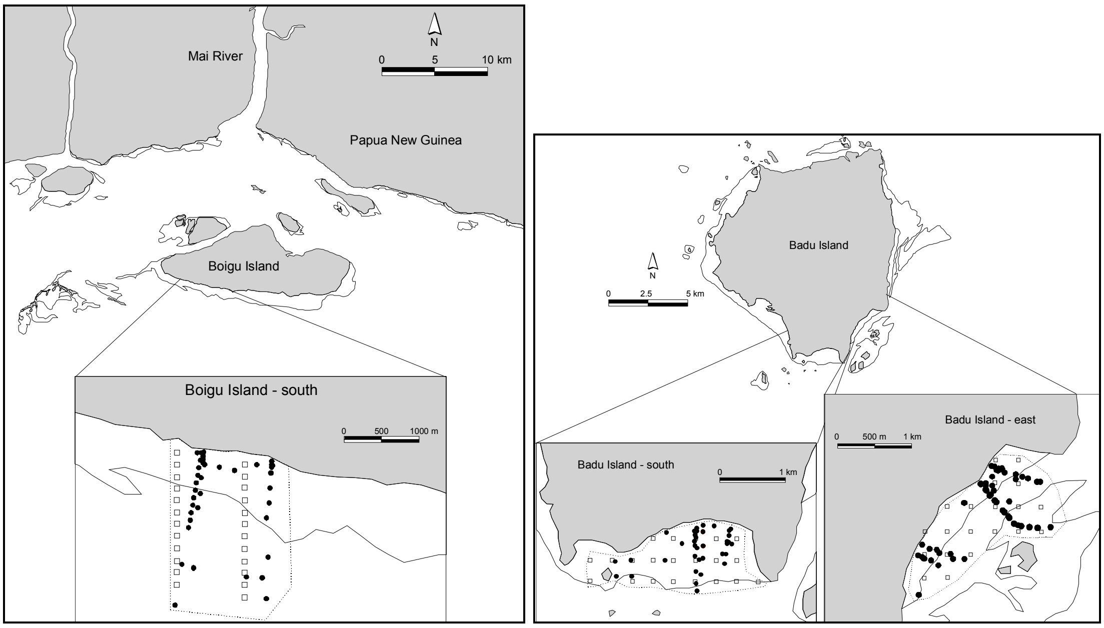



**Figure 3**. Sites sampled on the foreshore in the impact area at a). the south side of Boigu Island; and control areas at b). the east and south end of Badu Island. ●: Historical sites; circle, □: November 1993 seagrass dieback survey; dotted line - convex hull around sample points.

#### BACI analysis

The seagrass biomass sampled at 135 sites on the foreshore and shallow water embayments of Boigu and Badu Island from 1986 to 1989 were not suitable for a simple BACI ANOVA because sampling was not random as the sites were spatially clumped mainly along transects. Therefore large scale spatial trends at each location and each time on the foreshore areas of Boigu and Badu Island were investigated by fitting a loess response surface to latitude and longitude. The residuals from the trend surface were then examined, first to assess the appropriateness of the assumptions that the residuals were normally distributed with constant variance, and secondly to assess the extent of any smaller scale spatial correlation. For each site and sample time, a robust estimate of the semi-variogram was generated (Cressie,1993) and plotted against inter-sample distance.

Because the location of samples differed between time points, any spatial trends or dependencies would result in biased estimates of change over time. To accommodate these effects, the different time points were compared by estimating the mean response (from the fitted surface and/ or semi variogram) in a fixed polygon (i.e. the same polygon was used for both times). For this analysis the spatial response was modelled as a polynomial in latitude and longitude. Whilst less flexible than a loess surface, this yields simple expressions for the estimated mean response, and for the standard error of the estimated mean.

In the presence of spatial correlation, the standard error is based on equations given in Cressie (1993). In the absence of such spatial correlation the standard error is simpler. Since the estimated mean is simply a linear combination of the regression coefficients for the fitted surface, it can be obtained directly from the estimated co-variance matrix of the parameters.

The polygon for each site (Fig. 3) was based on a convex hull around the set of sample points (aggregated over both sample times). A regular grid of points was generated within the polygon, and the response integrated by a process of simple averaging. A fifty point grid was used in each dimension.

### *Sediment grain size analysis*

Sediment samples collected during the historical and November 1993 survey were analysed for gran size fractions by the method given in Folk 1968 to give percentage grain size for mud (< 62 μm), sand (62–1,000 μm) and gravel (> 1.0 mm). There were too few sediment samples (9) taken in the study area for an accurate ANOVA of grain size fractions so historical and November 1993 samples were matched by geographic location and a paired sample t-test was used to compare the sediment grain sizes between the historical and November 1993 surveys. To do this 17 samples taken in 1993 which were within a 4 km radius of the 9 sites sampled in 1989 were paired up. The three grain size fractions, gravel, sand and mud, of the November 1993 sediment samples were averaged for each of the 9 sites to give a paired comparison.

Coral heads were collected from Boigu, Aldai and Mabuiag reef to provide proxt information about the recent history of seasonal freshwater inputs to the area. The timing and intensity of fluorescing bands in coral skeletons have been found to correlate quite well with instrument records of river runoff from adjacent tropical coasts (Isdale, 1996). We used the bands in coral from Boigu to qualitatively reconstruct the freshwater input history to the study area for the period of interest.

CSIRO scientists researching the tropical rock lobster have been monitoring three sites in the study area north of Buru Island on a yearly basis from 1989 to 1993. Descriptions of the epifauna and substrate type were recorded. This data provided ancillary information on changes of seagrass and epifauna at these three sites over a six year period.

# Results

## Seagrass mapping: Inter reefal areas

Seagrass was distributed widely throughout the entire study area from 1986 to 1989 (Fig. 2a). The area of seagrass mapped with GIS, 3,078 $km^2$, was larger than seagrass absent, 1,188 $km^2$ (Table 1). In contrast, the area of seagrass, 1,871 $km^2$, was lower than seagrass absent, 2,394 $km^2$ (Fig. 2b). An overlay of the two maps of seagrass presence or absence of the historical and November 1993 survey data indicated that the largest loss of seagrass was in the north and north eastern region of the study area between Boigu and Buru Island, and south east between Buru Island and the top of the Orman Reefs in region A (Fig. 4). In region A, 1,993 $km^2$, or two thirds (60.2%) of the area had seagrass before the November 1993 survey and none during the survey. Very little of region A, 3.6%, had no seagrass before the survey and seagrass during the November 1993 survey. There was a large area, 195 $km^2$, in the north west of the study area which had no seagrass over the seven year study period from 1986 to 1993. In contrast there was little evidence to suggest that seagrass had declined in the southern half of the study area between Buru and Badu Island in region B (Fig. 4). In region B, 2,201 $km^2$, about half the area (40%) had seagrass before and during the November 1993 survey; 23% had seagrass before the November survey and no seagrass during; 19% had no seagrass before the survey and seagrass during the November 1993 survey; and seagrass was absent over the seven year study period in the remaining 17% of region B.

**Table 1**. Area analysis of seagrass change ($km^2$) based on the overlay of maps of seagrass presence or absence from historical 1986-1989 data and the November 1993 seagrass dieback survey data.

| Seagrass | Region A | Region B | Total |
|---|---|---|---|
| Absent before, absent now | 289 | 365 | 653 |
| Absent before, present now | 72 | 412 | 485 |
| Present before, absent now | 1,199 | 515 | 1,714 |
| Present before, present now | 433 | 908 | 1,342 |
| Total | 1,993 | 2,200 | 4,194 |

## Seagrass change: foreshore and shallow water embayments

The seagrass beds on the shallow water foreshore areas on the southern side of Boigu Island were lush, mixed species assemblages from 1986 to 1989 numerically dominated by *Cymodocea serrulata*, *Thalassia hemprichii*, *Cymodocea rotundata* and *Enhalus acoroides* (Fig. 5). In contrast the seagrass beds there during the November 1993 survey were mainly stunted *Thalassia hemprichii* with scattered *Cymodocea serrulata*. The detailed survey of east and south Badu Island indicated that the species composition of seagrass had not changed and were numerically dominated by *Cymodocea rotundata* and *Thalassia hemprichii* at south Badu and *Enhalus acoroides*, *C. serrulata* and *T. hemprichii* at east Badu Island (Fig. 5).

An analysis of variance for the Loess surface indicated that there were statistically significant medium-scale (100's of metres) spatial trends at East Badu before the impact, and South Boigu after the impact (Table 2).

**Table 2**. Fit of Loess trend surface by location and sampling occasion. ***: $P < 0.0001$.

| | Before | | After | |
|---|---|---|---|---|
| Location | F | p Value | F | p Value |
| South Badu | 0.30 | 0.966 | 2.50 | 0.074 |
| East Badu | 3.68 | 0.000*** | 1.26 | 0.340 |
| South Boigu | 1.43 | 0.217 | 5.26 | 0.000*** |

## Small Scale Spatial Dependencies

The Loess response surface was removed from the data before calculation of the semi-variogram for all three locations, before and after impact (Fig 6a–c). All of the variograms were essentially flat, which provided little evidence of any spatial dependency, once the larger scale spatial trends were removed. Thus at the scale of spatial separation in our study, different samples may be construed as essentially independent.

## Fitted Response

There were no significant differences among locations before the reported seagrass dieback but there were significant differences after the impact (Table 3). The control versus impact contrast was also statistically significant for the change over time. That is, the change over time for South Boigu was statistically significantly different from the change over time for South and East Badu. Furthermore, this difference arose from a greater decrease in seagrass biomass over time for South Boigu than the control locations.

**Table 3**. Fitted response for each location, Before and After Impact and the estimated change in mean response over time for each location, and a comparison of the control locations (mean of East Badu and South Badu versus South Boigu).

| | Pre Impact | | Post Impact | | Change | |
|---|---|---|---|---|---|---|
| Location | Mean | $s^2$ | Mean | $s^2$ | Mean | $s^2$ |
| East Badu | 4.032 | 0.064 | 3.503 | 0.204 | 0.529 | 0.268 |
| South Badu | 4.298 | 0.150 | 2.717 | 0.152 | 1.581 | 0.302 |
| South Boigu | 4.646 | 0.025 | 1.260 | 0.057 | 3.385 | 0.081 |
| Control vs Impact | -0.481 | 0.078 | 1.850 | 0.146 | -2.330 | 0.224 |
| *Z*-score | -1.718 | | 4.849 | | -4.926 | |

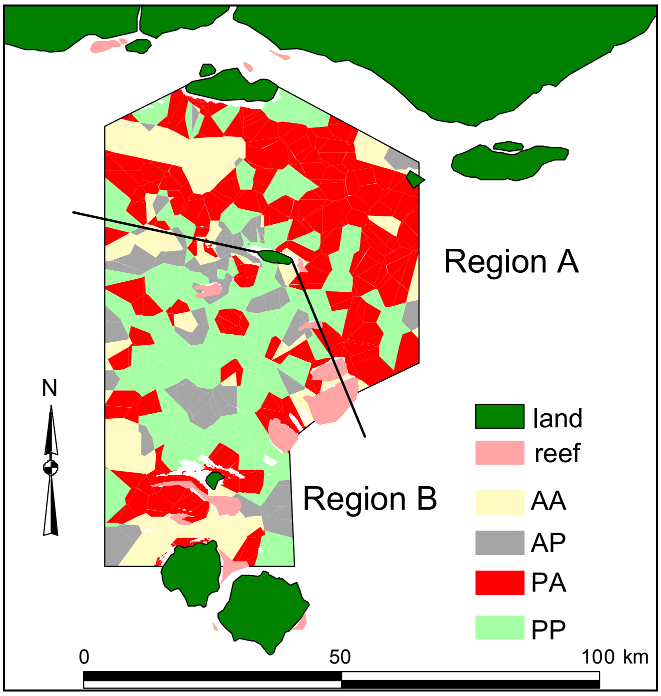



**Figure 4**. Torres Strait: Area analysis of change of seagrass produced by overlaying a seagrass presence or absence map based on data collected from 1986–1989 and a seagrass presence or absence map based on data collected during the November 1993 seagrass dieback survey. PA: seagrass present before but absent during the November 1993 survey; AA: seagrass absent before and during the November 1993 survey; AP: seagrass absent before but present after the November 1993 survey; PP: seagrass present before and after the November 1993 survey. For the main impact region A, and remaining study areas region B.

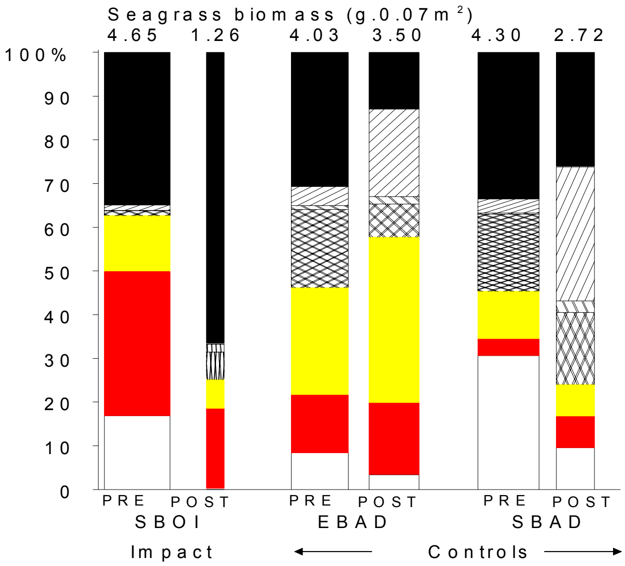
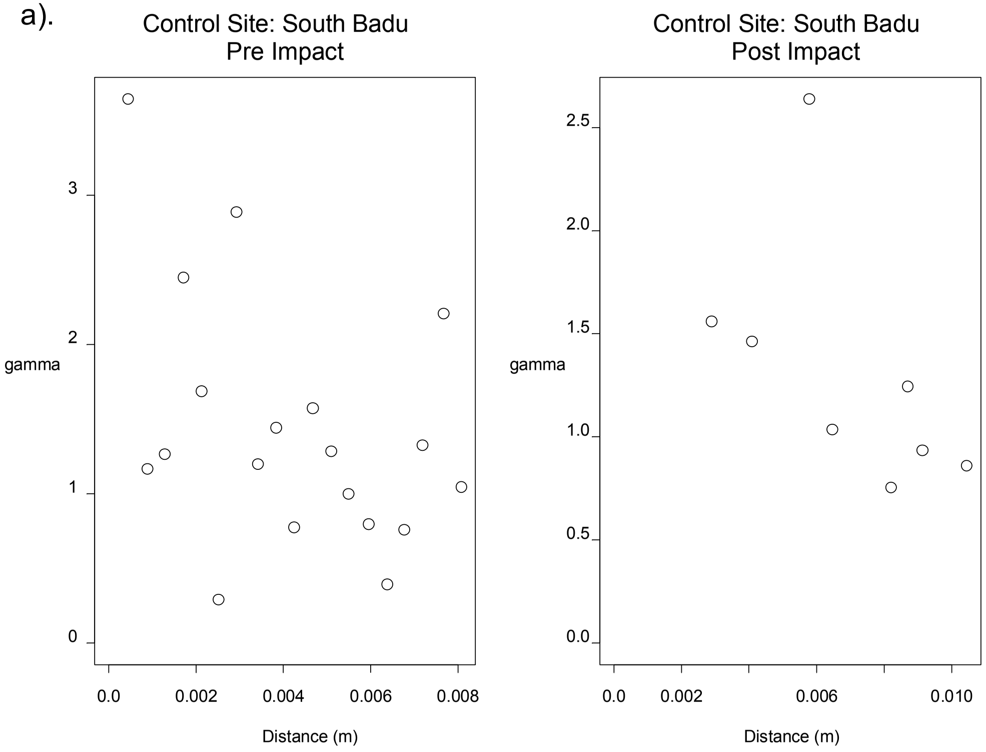



**Figure 5.** Comparison of above-ground biomass broken down by species for east, south and west Badu, and south Boigu. Sampling occasions — PRE: historical 1984 to 1989 data; DIE: November 1993 seagrass dieback survey. Locations — EBAD: east Badu; SBAD: south Badu; SBOI: south Boigu and WBAD: west Badu Island for [white box]: *Cymodocea rotundata*; [red box]: *Cymodocea serrulata*; [yellow box]: *Enhalus acoroides*; [hatched box]: *Halophila ovalis*; [hatched box]: *Syringodium isoetifolium*; [black box]: *Thalassia hemprichii*; and [cross-hatched box]: *Halodule uninervis*.. Vertical axis: proportion of total.

a).


Control Site: South Badu
Pre Impact
gamma
Distance (m)
Control Site: South Badu
Post Impact
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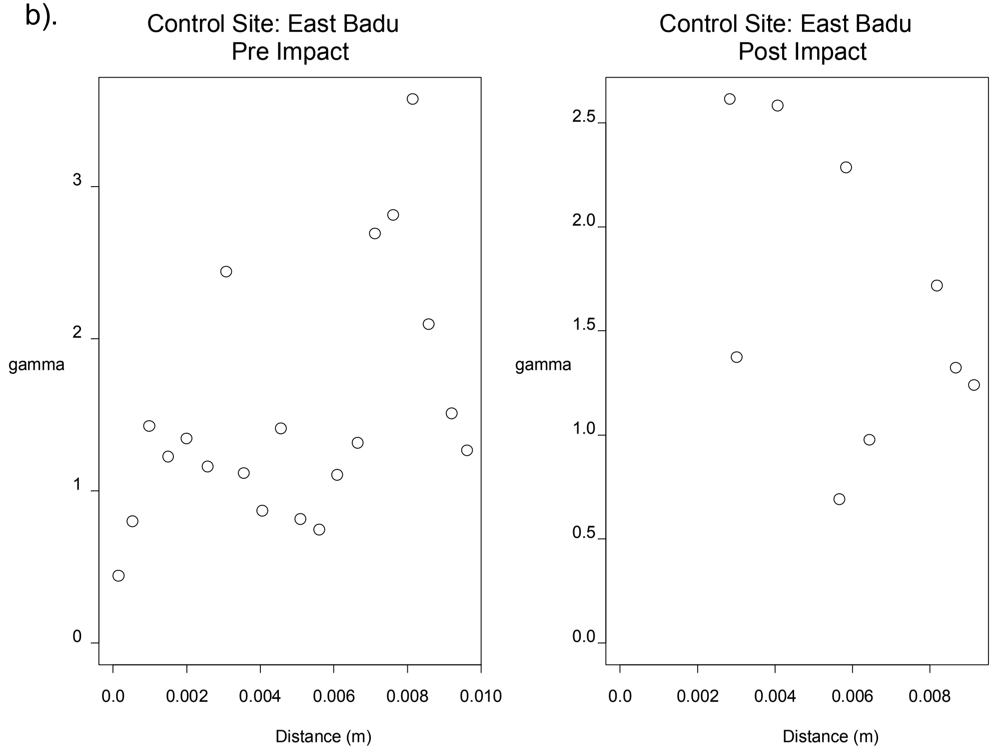
Distance (m)

b).


Control Site: East Badu
Pre Impact
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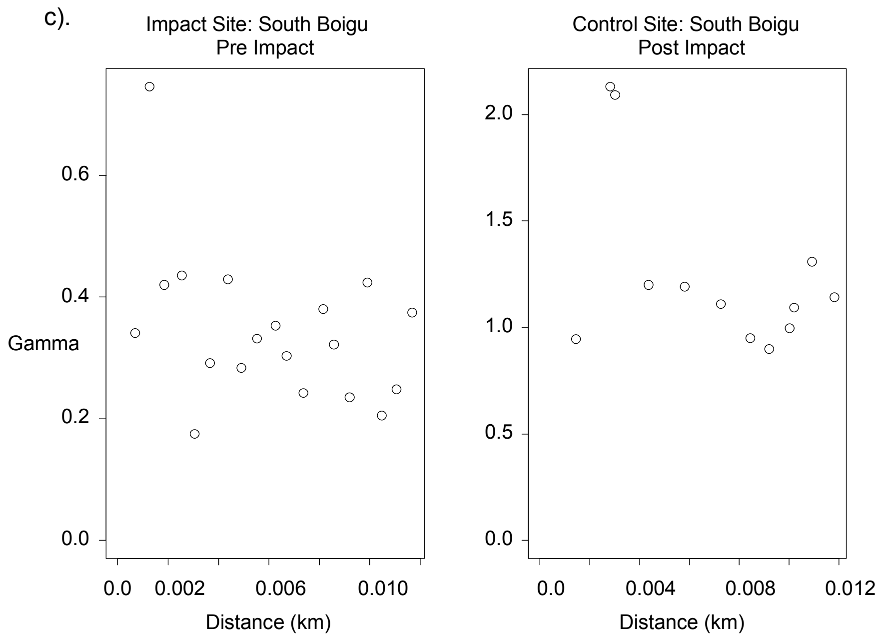


**Figure 6.** Torres Strait Before and After Impact (BACI) empirical variogram for Control areas: a). South Badu; and b). East Badu; and Impact area: c). South Boigu Island.

## Environmental data

The sediments in the study area were mainly gravelly sands with mud (Fig. 7). The average percentage fraction of gravel in region A of the study area in the November 1993 survey, 18.75%, was significantly lower than 1989, (33.37%) based on the paired *t*-test (Table 4). The sand fraction in the November 1993 survey, 73.23%, was significantly higher than 1989, 57.58%. In contrast, there was no significant difference in the percentage mud between the two years with an pooled average of 8.5% mud. At a couple of sites, we recorded on our data sheets that there was a thin layer (cm's) of clean sand overlying a muddy sand base.

**Table 4**. T-test for paired comparison of percentage grain size fraction of gravel, sand and mud for sediment samples taken in 1989 and the November 1993 survey. $\bar{D}$ : mean difference of 1989 samples - 1993 samples; $s_D$: std. of the difference; $\bar{s}_D$ stderr. of the difference; $t_s$ : t-statistic. *: $P < 0.05$.

| | %Gravel | %Sand | %Mud |
|---|---|---|---|
| 1989 | 33.37 | 57.58 | 9.04 |
| 1993 | 18.75 | 73.23 | 8.03 |
| $\bar{D}$ | 14.62 | -15.65 | 1.02 |
| $s_D$ | 16.42 | 16.43 | 4.54 |
| $\bar{s}_D$ | 5.47 | 5.48 | 1.51 |
| $S_t$ | 2.67* | -2.86* | 0.67 |

## Ancillary data

Epifauna was dense or sparse throughout much of the study area north of Buru Island in 1989 (Fig. 8a) whereas epifauna was sparse or absent in during the November 1993 survey (Fig. 8b). A visual comparison of the two maps indicated that epifauna had been affected over a larger area than seagrass. At a couple of sites north of Buru Island we recorded the presence of white dead corals with little algal growth on them which were partly covered by clean sand.

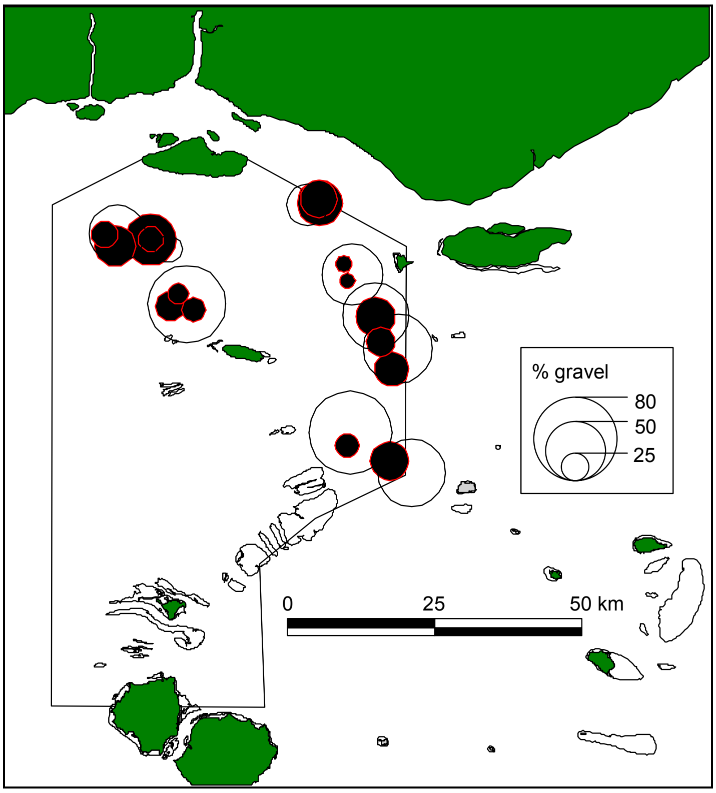


**Figure 7**. Bubble plots of percentage gravel fraction (> 1.0 mm) at 9 sites sampled in the study area during 1989 (clear bubbles) and 16 sites sampled within a 4 km radius of the 1989 samples during November 1993 (solid bubbles).

The sea urchin, *Prionocidaris* sp. was sampled only in region A of the study area and where present, their abundance ranged from 2 to 20 animals per 25m$^2$ (Fig. 9). To test for significant differences between areas where seagrass was lost and the remaining areas an ANOVA was done on square-root transformed abundance of urchins. The results indicated that the abundance of *Prionocidaris* sp. was significantly higher ($P < 0.005$) in areas where seagrass was lost (2.326 animals.25m$^2$; se = 0.503) than remaining areas in region A (0.365 animals.25m$^2$; se = 0.293).

Examination of the coral heads from Boigu, Aldai and Mabuiag reefs indicated that only the *Porites spp*.coral head from Boigu was suitable for providing a seasonal proxy record of freshwater inputs to the area. The corals taken from Aldai and Mabuiag reef were unsuitable because the corallite dimensions were coarse, a feature of most of the Favid species . Analysis of the fluorescence in the coral head from Boigu indicated that there were four abnormal seasons: 1982/83, 1983/84, 1984/85 and 1990/91 (Fig. 10). The 1982/83 and 1984/85 seasons were wetter than averga and run-off was in a single long seasonal pulse. In contrast the 1983/84 season was apparently very dry. The 1990/91 season was very unusual. It started normally and run-off occurred as a consistent pulse until near the end of the season, where reduced somewhat, but then showed a short but intense run-off period shortly after December 1990.

## Discussion

More than 1,400 $km^2$ of seagrass north and north east of Buru Island in region A of the study area was lost between 1989 and 1993 which represented a 60% reduction in seagrass in the study area and a 10% reduction of the 13,425 $km^2$ of seagrass estimated for the whole of Torres Strait (Long and Poiner, 1997). The magnitude of the loss of seagrass in Torres Strait is the same as a recently reported dieback of > 1000 $km^2$ of seagrass reported in 1992 for Hervey Bay (Preen et al., 1995).

The results of the BACI analysis indicated that there was a significant reduction of seagrass on the foreshore areas along the southern margin of Boigu Island in the impact area than the control locations at South and East Badu Island. Moreover, because there was clear spatial structure in seagrass biomass for East Badu and South Boigu the analysis of change of seagrass over time must take into account any differences in the position of sample points. There were, however, no small scale spatial correlation among samples at the distances sampled (10's to 100's m apart) in this study. Thus the different samples may be construed as essentially independent. This finding greatly simplified the estimation of the standard error since the estimated mean is simply a linear combination of the regression coefficients for the fitted surface and can be obtained directly from the estimated co-variance matrix of the parameters.

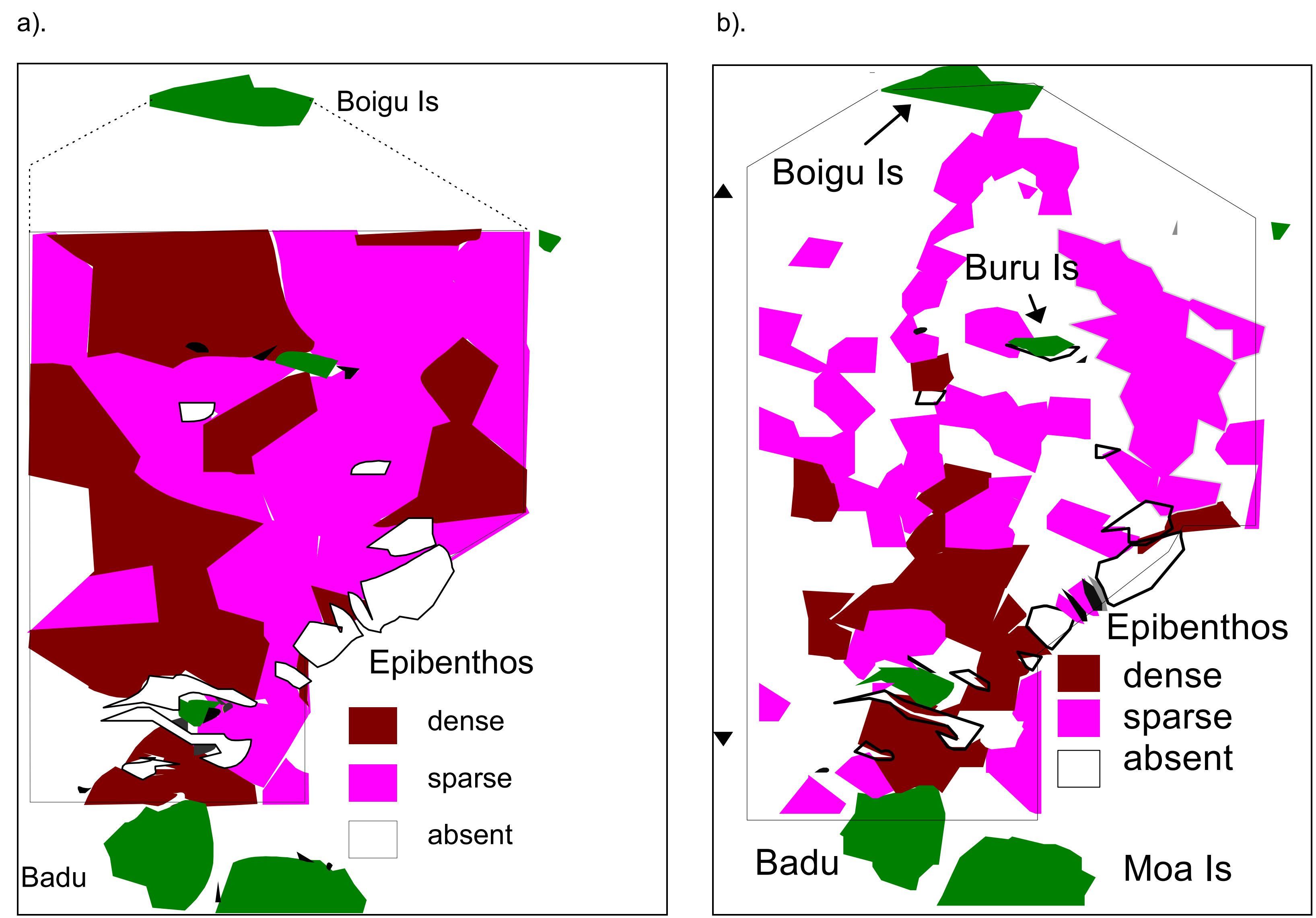


**Figure 8**. Distribution of epifauna in the study area in (a) 1989 lobster survey and (b) November 1993 survey.

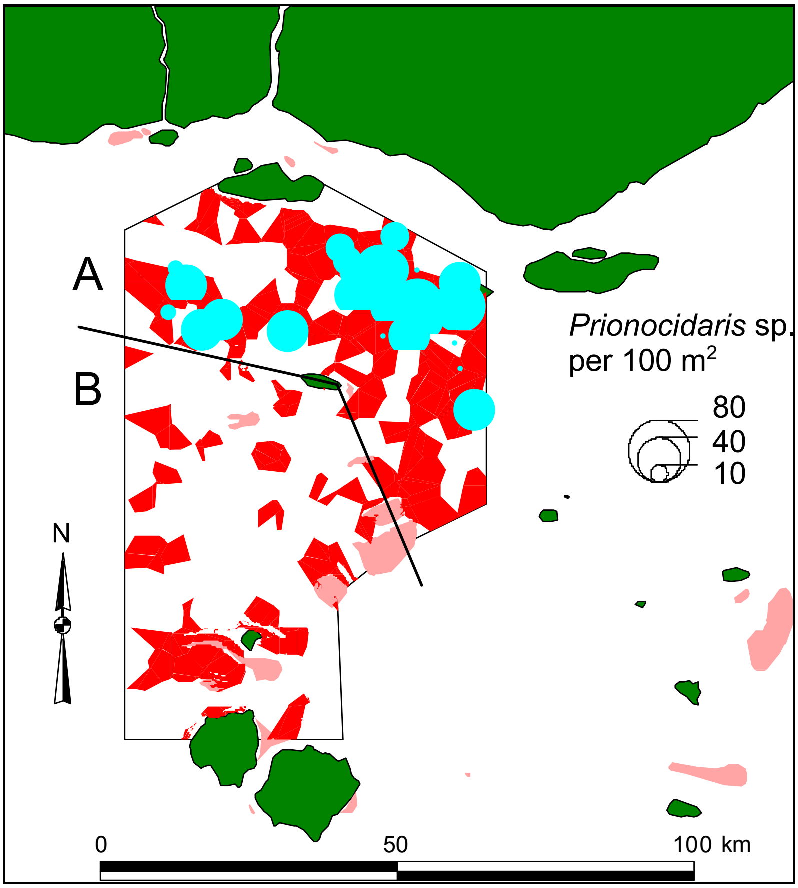


**Figure 9**. Bubble plot of the sea urchin, *Prionocidaris* sp. per m², estimated from the visual spot dives during the November 1993 seagrass dieback survey. red areas: Seagrass absent after the impact and present before. Region A: main area of impact; Region B: no impact.

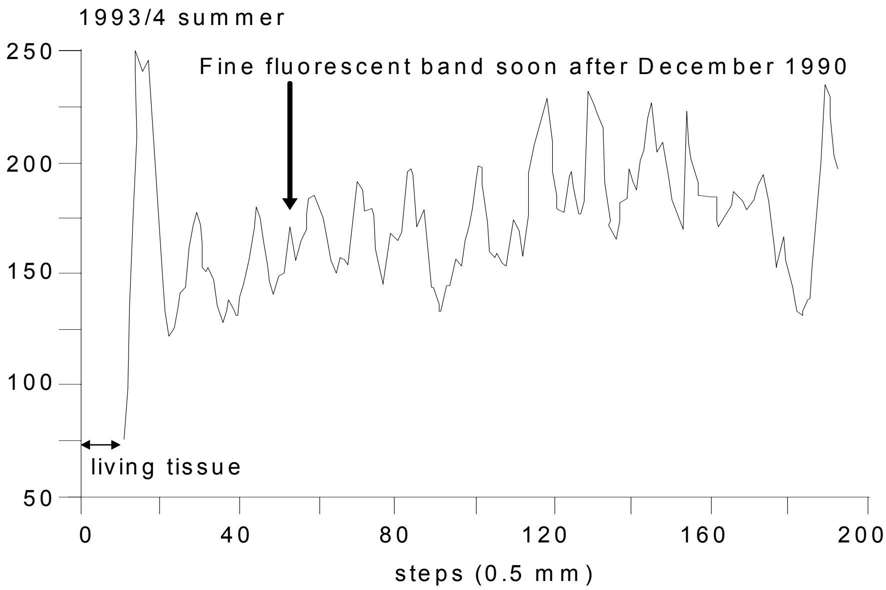


**Figure 10.** Plot of cross-sectional fluorescence of Porites sp. coral head from the reef flat at the east tip of Boigu Island. Vertical axis: Fluorescence (relative units)

There have been a number of reported seagrass diebacks in Torres Strait in the early 1970's which are in themselves anecdotal, but when taken together suggests that diebacks are a natural event in Torres Strait. The two main rivers that empty into Torres Strait are the Mai and the Fly river. There is no available data on river runoff by the Mai river. There has been no marked changes in land clearing practises in the mainland catchment of Papua New Guinea which empties into Torres Strait land and consequently land degradation with concomitant increased runoff and suspended sediment can not explain the loss of seagrass in this study. Preen et al. (1995) attributed the large loss of seagrass in Hervey Bay to a complex array of factors associated with a cyclone and flooding which was exacerbated by soil erosion due to land clearing in the adjoining catchment area.

Seagrass is critical habitat for many commercial important species of prawns and fish and is an important food source for dugongs and turtles. The distribution of dugongs are reliable indicators of seagrass distribution and disproportionately high concentrations of dugongs are associated with large seagrass beds in Torres Strait and the Starcke region of north Queensland (Preen et al. 1995). Torres Strait supports the largest reported population of dugongs in Australia and possibly the world (Marsh 1995) and the main area where the seagrass had disappeared coincided with the largest concentration of dugongs in Torres Strait in 1987 (Marsh 1995). A recent survey of dugongs in 1989 in Torres Strait has indicated that the largest concentrations of dugongs were now south of Buru Island (H. Marsh pers. comm.) which indicates that the dieback has affected the distribution of dugongs in northern Torres Strait. The seagrass dieback Hervey Bay was followed by a reduction in the population of dugongs from 1937 to less than 200 dugongs (Preen et al. 1995).

The maps of seagrass presence or absence indicated a change of seagrass distribution in inter reefal areas of north western Torres Strait. The biomass and community structure of seagrass was also affected shown by the decrease in biomass and diversity and change in species composition on the foreshore and shallow subtidal areas along the south side of Boigu Island at the northern end of the study area. There was a significantly lower biomass of seagrass on the foreshore areas and shallow subtidal areas along the south side of Boigu Island during the November 1993 survey than before and diversity was also significantly lower. There was a shift in the species composition of seagrass from a community dominated by *C. serrulata*, *T. hemprichii* and *E. acoroides* to an assemblage of low diversity dominated by a single species, *T. hemprichii.* In contrast, there were no significant differences in biomass at the south and east end of Badu Island at the southern end of the study area. The results of the BACI test and the seagrass mapping suggests that the dieback was largely restricted to the northern part of the study area.

Anecdotal evidence provided by CSIRO fisheries doing research in the area on *Panulirus ornatus* (tropical rock lobsters) also suggested that seagrass, lobsters and epifauna had declined in the area (Pitcher et al. 1994). At three sites north of Buru Island in the study area, descriptions of the epifauna and seagrass were recorded on a yearly basis from 1989 to 1993.

Lobsters were abundant at the three sites from 1989 to 1991 and were absent in 1992 and 1993. The Orman reef area, which is adjacent to the area of interest north of Buru Island, normally has abundant lobster but has shown a decline in lobsters in 1993 based on survey data and from changes in fishing effort by the rock lobster freezer boat fleet.

There have been dramatic changes in seagrass abundance at the three sample sites since 1989. Seagrass abundance declined from high in 1990 (higher even than in 1989) to low in 1991, to zero or near zero abundances in 1992. The decline was greatest for the ovoid species, *H. spinulosa* mainly and *H. ovalis* to a lesser degree, in part because they were the dominant of the two forms previously (CSIRO, unpublished data).

Sparse epibenthic 'garden' (hard corals, whips, sponges) bottom and Sargassum spp. were a common feature of consolidated sand bottoms in the area with occasional reef epibenthic assemblages on rock outcrops. There was a general decline in the amount of epifauna at these three sites with little or no epifauna recorded there in 1992.

The disappearance of seagrass in this area was also accompanied by a decline in epifauna, shown by the results of this study. The loss of seagrass could explain the reduction in epifauna in the northern region of the study area as the removal of seagrass can destabilise the sediments and often leads to blowout holes and a shift in the sediment grain size distribution to sandier sediments which could affect epifauna. There were significant changes in sediment grain size distribution in the northern region of the study area with sandier sediments during the November 1993 survey than before the survey which is consistent with this hypothesis. Alternately, the decline could have been caused by the movement of sand and suspended sediment in the area which smothered epifauna and reduced seagrass. There was evidence of this at a few sites where we recorded on the data sheets that there was a layer of clean sand over a muddier sand base and at some other sites where we recorded that the corals were partially buried by sand. There are mobile sand waves in many regions of Torres Strait including the west end of Buru Island and parts of the region are in a tidal bedload parting zone which is characterised by strong tidal currents and shifting sand waves (Harris 1991).

There was evidence of an unusually large but short-lived run-off event from the Mai River on the Papuan mainland north of Boigu at the end of the 1990/91 monsoon season. Reduced salinity was probably not the cause of the seagrass decline because seagrass was present on the foreshore areas along the south margin of Boigu Island and also at the east end of Boigu Island which is only a few km from the mouth of the Mai River. Thus the cause of the decline of seagrass can not be determined with any degree of certainty, however, the information suggests that a complex interaction of hydrological and sedimentary factors and river runoff event was responsible for the dieback These factors resulted in the loss of large areas of seagrass in the subtidal inter-reefal areas and a significant reduction in the biomass, but not complete loss of seagrass in the intertidal and shallow subtidal foreshore areas of south Boigu Island.

The abundance of the sea urchin, *Prionocidaris* sp. was high (up to 1 per $m^2$) in areas where seagrass had disappeared in the north eastern part of the study area and was significantly higher than other areas. Although they may not cause the dieback the large numbers in some areas may interfere with the recovery of seagrass. This aspect of the dieback requires further research.

The results of this study suggest that run-off pulses may well prove to be an important factor in structuring the seagrass and epifauna communities near the major rivers on the Papuan New Guinea coast which empty into Torres Strait.

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