Department of **Agriculture, Fisheries and Forestry**

Long-term seagrass monitoring in the Port of Thursday Island

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Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA

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Executive Summary

Seagrass habitats are valuable fisheries resources that show measurable responses to changes in water quality. These attributes make seagrasses an ideal metric to determine the health of estuarine and coastal environments. A network of long-term seagrass monitoring sites has been established at various port locations throughout Queensland by Fisheries Queensland to assess the condition of marine habitats. Outcomes of these programs assist in the planning and development of port operations, helping to achieve minimal environmental impact. Furthermore, these programs assist fisheries management to achieve protection of key fish habitats. This report details the findings from the fifth biennial Port of Thursday Island long-term seagrass monitoring program conducted in February 2012.

The 2002 baseline survey identified some of the best examples of intertidal and subtidal seagrasses in Queensland and provided a good foundation from which the biennial monitoring surveys in the Port of Thursday Island could be based. Nine seagrass meadows representative of the range of seagrass communities present and located in areas potentially influenced by port operations and developments were selected for long-term monitoring from the baseline survey.

The results of the February 2012 monitoring survey found that seagrasses were in a relatively healthy and productive condition. Seagrass above-ground biomass for the majority of monitoring meadows was the highest recorded since peak levels seen in 2004. Increases in meadow biomass from 2010 to 2012 ranged from 15% to 199%, with two thirds of the meadows increasing in biomass by over 100%. The area of the monitoring meadows has generally remained stable throughout the course of the monitoring program with modest increases or decreases in meadow distribution.

Seagrasses in the Port of Thursday Island are influenced by a complex interaction of a number of different climatic factors including rainfall, wind, solar irradiance, temperature, daytime tidal exposure and photosynthetically active radiation (PAR), which are known to affect seagrass growth, recruitment and mortality. It is likely that a combination of these factors has led to the observed changes to seagrass meadows in the Port of Thursday Island rather than any changes in port or anthropogenic activities.

This fifth biennial survey has helped establish a clearer picture of the natural inter-annual variations and the relationship between seagrass change and climate. However, correctly interpreting the causes of seagrass change is difficult when surveys are undertaken biennially. An annual seagrass program similar to other port locations throughout Queensland would provide a greater understanding of seagrass health and dynamics. The existing biennial program suggests the port's marine environment is relatively healthy with seagrasses in good condition. The range of natural seagrass changes measured to date will enable any future changes to be placed in a clearer perspective.

Introduction

Seagrass habitats are important fisheries resources providing both structural and feeding habitat for a number of juvenile commercial and recreational fisheries species. Furthermore, seagrass habitats provide food for endangered and threatened species such as the dugong (*Dugong dugon*) and the green sea turtle (*Chelonia mydas)*. The wide distribution of seagrass in Queensland and their capacity to show measurable responses to changes in water quality make them ideal candidates for monitoring the health of marine and coastal environments (Orth et al*.* 2006). In the Torres Strait seagrass habitats are of particular importance. Seagrass associated resources such as dugong, turtle and fisheries species form an important part of their cultural identity as well as supporting subsistence and commercial fisheries.

Some of the best examples of seagrass meadows in Queensland occur in the sheltered waters associated with commercial ports and harbours where seagrasses are at a heightened risk due to activities associated with port operations and development (Lee Long et al. 1996; Rasheed et al. 2007). Results from long-term monitoring programs have provided valuable information on the relationships between climatic shifts, anthropogenic disturbance and seagrass abundance. They have also indicated that healthy and productive seagrass habitats can co-exist with appropriately managed port facilities. Long-term seagrass monitoring programs have enabled port managers to make informed decisions regarding planning and development of port infrastructure, minimising disturbance to the marine environment. These interactive programs between environmental scientists and port managers are examples of international best practice in the environmental management of ports and facilitate the protection of key fisheries habitats facing high levels of anthropogenic threats.

Due to the high reliance on fishing in the Thursday Island area, habitats that support commercial and traditional fisheries, such as seagrasses, are of critical importance to the region. A fine-scale baseline survey of seagrass habitat conducted at the port in March 2002 identified seagrass as the dominant benthic habitat with over 1500ha of seagrass habitat mapped in the survey area (Rasheed et al. 2003). This has important implications for future port and coastal developments that may impact upon these extensive meadows.

Ports North is the authority responsible for the management of the Port of Thursday Island and they have recognised the importance of maintaining the health of seagrasses located within the port environment. Based on results of the 2002 baseline survey, Fisheries Queensland in conjunction with Ports Corporation Queensland, who managed the port at that time, implemented a biennial long-term seagrass monitoring program to ensure that the ongoing health of the port's marine environment could be monitored and maintained.

This was the fifth biennial survey since the 2002 baseline survey. The objectives of the survey were to:

1. Monitor the seagrass species composition, area and abundance of the nine seagrass meadows identified for monitoring within the port limits;
2. Assess changes in these seagrass meadows that have occurred since the baseline survey;
3. Incorporate the results into the Ports North/Fisheries Queensland Geographic Information System (GIS) developed for the Port of Thursday Island.

Ports North will use the results of seagrass habitat monitoring to assist in long-term management of the port to minimise potential impacts on these important fisheries habitats. The information may also act as a reference tool for other organisations involved in management of community use of the inshore area.

Methods

Seagrass surveys of the Port of Thursday Island were conducted on the 17th and 18th of February 2012. Nine seagrass meadows were selected from the baseline survey (Rasheed et al. 2003) for long-term monitoring. These meadows were representative of the range of seagrass meadows and communities identified in the baseline survey, and were also located in areas potentially influenced by port operations and developments.

Seagrass habitat observations included species composition, above-ground biomass, percent algal cover, sediment type, time and position (Global Positioning System (GPS)). Monitoring meadows were surveyed using a combination of helicopter aerial surveillance and boat based camera surveillance. A detailed description of the methods used to characterise the monitoring meadows is provided in Rasheed et al. (2003).

A

B

Seagrass monitoring methodology utilising (A) helicopter aerial surveillance and (B) boat based remote camera surveillance

Seagrass above-ground biomass was determined using a “visual estimates of biomass” technique (Mellors 1991; Rasheed & Unsworth 2011). This technique involves an observer ranking seagrass biomass in the field in three random placements of a $0.25m^2$ quadrat at each site. Ranks were made in reference to a series of quadrat photographs of similar seagrass habitat for which the above-ground biomass has previously been measured. Three separate biomass ranges were used: low biomass; high biomass; and an *Enhalus* range. The relative proportion of the above-ground biomass (percentage) of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (g DW m^2). At the completion of sampling each observer ranked a series of calibration quadrats that represented the range of seagrass biomass in the survey. After ranking, seagrass in these quadrats was harvested and the actual biomass determined in the laboratory. A separate regression of ranks and biomass from these calibration quadrats was generated for each observer and applied to the field survey data to determine above ground biomass estimates.

The results of the baseline surveys (Rasheed et al. 2003) suggest that meadows where *Enhalus acoroides* was present but not dominant, require a different approach to the analysis of biomass for meadows where *Enhalus acoroides* was dominant. The dry weight biomass for *Enhalus* is many orders of magnitude higher than other tropical seagrass species and dominates the average biomass of a meadow where it is present. Therefore, isolated *Enhalus* plants occurring within the *Halodule/Halophila* dominated meadows (Meadows 1, 5 and 8) were excluded from all biomass and species analyses in order to track the dynamics of these morphologically distinct species.

Habitat Mapping and Geographic Information System

Spatial data from the field surveys were incorporated into the Ports North/DAFF Thursday Island Geographic Information System (GIS). Three seagrass GIS layers were created in ArcMap:

- ***Habitat characterisation sites*** – point data containing above-ground biomass (for each species), dbMSL, sediment type, time, latitude and longitude from GPS fixes, sampling method and any comments.
- ***Seagrass meadow biomass and community types*** – area data for seagrass meadows with summary information on meadow characteristics. Seagrass community types were determined according to species composition from nomenclature developed for seagrass meadows of Queensland (Table 1). Density categories (light, moderate, dense) were assigned to community types according to above-ground biomass of the dominant species (Table 2).
- ***Seagrass landscape category*** – area data showing the seagrass landscape category determined for each meadow :

Isolated seagrass patches
The majority of area within the meadows consisted of un-vegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of un-vegetated sediment within the meadow boundaries

Continuous seagrass cover
The majority of area within the meadows comprised of continuous seagrass cover interspersed with a few gaps of un-vegetated sediment.

Table 1: Nomenclature for community types in the Port of Thursday Island 2012

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2: Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density in the Port of Thursday Island 2012

Density	Mean above ground biomass (g DW m^2)					
	H. uninervis **(narrow)**	***H. ovalis H. decipiens***	***H. uninervis*** **(wide)** ***C. serrulata S. isoetifolium***	***H. spinulosa***	***Z. capricorni***	***E. acoroides T. ciliatum***
Light	< 1	< 1	< 5	< 15	< 20	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60	40 - 100
Dense	> 4	> 5	> 25	> 35	> 60	> 100

Each meadow was assigned a mapping precision estimate (in metres) based on mapping methodology utilised for that meadow (Table 3). Mapping precision ranged from ±5m to ±10m for the monitoring meadows. The mapping precision estimate was used to calculate a range of meadow area for each meadow and was expressed as a meadow reliability estimate (R) in hectares. Additional sources of mapping error associated with digitising and rectifying aerial photographs onto base maps and with GPS fixes for survey sites were embedded within the meadow reliability estimates.

Table 3: Mapping precision and methodology for seagrass meadows in the Port of Thursday Island 2012

Mapping precision	Mapping methodology
±5m	All meadow boundaries mapped in detail by GPS using a combination of helicopter, underwater camera surveys and/or walking; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent aerial photography aided in mapping.
±10m	Inshore meadow boundary mapped in detail by GPS using a combination of helicopter and/or walking surveys; Offshore meadow boundary mapped by GPS using a combination of helicopter and boat based underwater camera surveys; Relatively high density of mapping and survey sites; Recent aerial photography aided in mapping.

Statistical Analysis

To determine differences in seagrass biomass of individual meadows, normality was assumed for all meadows and one-way Analysis of Variance (ANOVA) was conducted. Where data passed the equal variance test for pairwise comparisons, a LSD test was used. Where data failed the equal variance test, a Behrens-Fisher test was used (Zar 1999). The Behrens-Fisher is a two-tailed t test that uses a weighted degrees of freedom due to the unequal variances among the groups being tested.

The test statistic is:

$$t' = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

And the degrees of freedom is calculated as:

$$\nu' = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$

Since the majority of the data did not follow a normal distribution, an α level of 0.01 was used to minimise the possibility of recording a type 1 error (Underwood 1997). Detailed results are presented in Appendix 1.

Results

Seagrass species, distribution and abundance for monitoring meadows in 2012

Ten seagrass species (from three families) were identified in the February 2012 seagrass monitoring survey. For a complete list of seagrass species found within the port limits see Rasheed et al. (2003).

Family	Species			
CYMODOCEACEAE Taylor	*Cymodocea serrulata* (R.Br.) Aschers and Magnus		*Halodule uninervis* (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier	
	Cymodocea rotundata Ehrenb. et Hempr. ex Aschers		*Syringodium isoetifolium* (Ashcers.) Dandy	
ZOSTERACEAE Drummortier	*Zostera capricorni* Aschers.		*Thalassodendron ciliatum* (Forsk.) den Hartog	
HYDROCHARITACEAE Jussieu	*Enhalus acoroides* (L.F.) Royle		*Halophila ovalis* (R. Br.) Hook. F.	
	Thalassia hemprichii (Ehrenb.) Aschers. in Petermann		*Halophila decipiens* Ostenfield	

A total of 137 ± 13 ha of seagrass habitat was mapped in the nine seagrass monitoring meadows in 2012 (Table 6; Map 1). Meadow area ranged from 0.4 ha to 86.3 ha, with the smallest meadow located between the Engineers and Main Wharves on Thursday Island (meadow 3) and the largest located on Madge Reef (meadow 26) (Table 6; Maps 2 & 4). A total of 246 monitoring sites (excluding meadow boundary mapping sites) were surveyed, 85% of which had seagrass present (Map 1).

Mean above-ground biomass for the monitoring meadows in February 2012 ranged from 3.6 ± 0.9 g DW m^2 for the smallest *Halodule ovalis* dominated meadow on the southern foreshore of Thursday Island (meadow 3), to 78.5 ± 8.1 g DW m^2 for the larger *Enhalus acoroides* dominated meadow at Madge Reefs (meadow 26) (Table 5; Figure 1).

The nine monitoring meadows that were surveyed included eight different seagrass community types (Table 4; Maps 2-4). *Enhalus acoroides* dominated communities were the most common, followed by those dominated by *Halodule uninervis* (thin) and one *Halophila ovalis* dominated meadow. The *Enhalus acoroides* meadows were found in the lower intertidal region around Engineer's Wharf (meadows 4 and 6), and on Madge Reefs. The *Halodule uninervis* dominated meadows were all located high up on the intertidal banks on the southern and northern foreshores of Thursday Island. The *Halophila ovalis* dominated meadow was found high up on the intertidal bank between the Engineer's Wharf and the Main Wharf (Maps 2-4).

Although individual meadows were dominated by either *Enhalus acoroides, Halodule uninervis*, or *Halophila ovalis* the species composition of each meadow consisted of between two to eight species. Six seagrass meadows were comprised of aggregated patches of seagrass, including the *Halodule uninervis* and *Halophila ovalis* dominated meadows around Thursday Island and the *Enhalus acoroides* dominated meadows on Madge Reefs, which also contained isolated patches of seagrass on the far Western tips of the meadows (Meadows 26 and 27). The remaining *Enhalus acoroides* meadows were all found to have a continuous cover of seagrass (Table 4; Map 2). The majority of monitoring meadows were located on intertidal substrates dominated by either mud or sand. A number of meadows also contained areas that were dominated by reef structure.

Table 4: Community type, seagrass cover and species present in the nine Thursday Island monitoring meadows, February 2012.

Monitoring meadow ID no.	Community Type	Cover	Species Present (in order of dominance)
1	Dense *H. uninervis* (thin) with *T. hemprichii / H. ovalis*	Aggregated patches	*H. uninervis* (thin), *T. hemprichii, H. ovalis, H. decipiens*
2	Moderate *E. acoroides* with *T. hemprichii / C. serrulata*	Continuous cover	*E. acoroides, C. serrulata, T. hemprichii, S. isoetifolium, H. uninervis* (wide), *C. rotundata, H. uninervis* (thin), *H. ovalis*
3	Moderate *H. ovalis* with *H. uninervis* (thin)	Aggregated patches	*H. ovalis, H. uninervis* (thin)
4	Light *E. acoroides / T. hemprichii*	Continuous cover	*E. acoroides, T. hemprichii, H. uninervis* (thin), *C. serrulata, S. isoetifolium, H. uninervis* (wide), *C. rotundata, H. ovalis*
5	Dense *H. uninervis* (thin) with *T. hemprichii / H. ovalis*	Aggregated patches	*H. uninervis* (thin), *T. hemprichii, H. ovalis, C. serrulata*
6	Light *E. acoroides* with *C. serrulata/ T. hemprichii*	Continuous cover	*E. acoroides, C. serrulata, T. hemprichii, C. rotundata, S. isoetifolium, H. uninervis* (wide & thin),*T. ciliatum, H. ovalis*
8	Dense *H. uninervis* (thin) with *T. hemprichii/ C. rotundata*	Aggregated patches	*H. uninervis* (thin), *T. hemprichii, C. serrulata, C. rotundata, H. ovalis*
26	Moderate *E. acoroides* with *T. hemprichii*	Aggregated patches	*E. acoroides, T. hemprichii, C. rotundata, Z. capricorni, H. uninervis* (thin), *C. serrulata, S. isoetifolium, H. ovalis*
27	Moderate *E. acoroides* with *T. ciliatum*	Aggregated patches	*E. acoroides, T. ciliatum, Z. capricorni, T. hemprichii, H. uninervis* (thin), *C. rotundata, S. isoetifolium, C. serrulata*

Map 1. Port of Thursday Island seagrass monitoring meadows and survey sites, 2012

Background: Beach Protection Authority, 1:50,000, 19/6/92

Legend

- Seagrass absent
- Seagrass present
- Seagrass monitoring meadows 2012
- Complete seagrass distribution 2002 & 2004
- Port Limit
- Mangrove boundary

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Map 2. Port of Thursday Island southern foreshore seagrass monitoring meadows, 2012

Legend

Background image: Beach Protection Authority 1: 50000, 19/6/92

Complete seagrass distribution 2002 & 2004

Cover Type
- Aggregated patches
- Continuous cover

Community type
- Dense *Halodule uninervis* (thin) with *Thalassia hemprichii*
- Moderate *Enhalus acoroides* with *Thalassia hemprichii* / *Cymodocea serrulata*
- Moderate *Halophila ovalis* with *Halodule uninervis* (thin)
- Light *Enhalus acoroides* with *Thalassia hemprichii*
- Light *Enhalus acoroides* with *Cymodocea serrulata* / *Thalassia hemprichii*

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Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Map 3. Port of Thursday Island northern foreshore seagrass monitoring meadow, 2012

Background image: Beach Protection Authority 1: 50000, 19/6/92

Legend

Cover Type

Aggregated patches

Complete seagrass distribution 2002 & 2004

Dense *Halodule uninervis* (thin) with *Thalassia hemprichii* / *Cymodocea rotundata*

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Map 4. Port of Thursday Island seagrass monitoring meadows at Madge Reefs, 2012

Background image: Beach Protection Authority 1: 50000, 19/6/92

Legend

Complete seagrass distribution 2002 & 2004

Cover Type

Aggregated patches

Mangrove boundary

Community type

Moderate *Enhalus acoroides* with *Thalassia hemprichii*

Moderate *Enhalus acoroides* with *Thalassodendron ciliatum*

Port Limit

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Comparison with previous monitoring surveys

In 2012, seagrass above-ground biomass of the majority of monitoring meadows was the highest recorded since peak levels in 2004, while the area of the meadows generally remained within previously recorded ranges (Tables 5 & 6; Figure 1). Increases in meadow biomass from 2010 to 2012 ranged from 15% to 199% in meadows 5 and 27 respectively with two thirds of the meadows increasing by over 100% (Table 5; Figure 1).

While the total area of Thursday Island monitoring meadows has remained relatively stable since monitoring began, mean above-ground biomass has varied between surveys with a downward trend from 2004 through to 2010 when some recovery was observed (Figure 1; Maps 5-7; Appendix 1). By 2012 significant increases from the low values seen in 2008 had occurred in both the *Enhalus* and *Halodule*/*Halophila* dominated meadows.

Over the course of the monitoring program, the density of *Enhalus acoroides* dominated meadows was generally much lower in 2006 and 2008 compared to other sampling years. By 2010 all five of these meadows had shown signs of increasing biomass, although these changes were not statistically significant (Figure 1; Appendix 1). This upward trend continued in 2012 with three of the five *Enhalus* meadows showing significant increases in density compared to 2010, and all five meadows were similar to other high biomass years such as 2004 (Figure 1; Appendix 1). All *Enhalus* meadows within the Port increased in biomass by over 100% compared to 2010. For example, above-ground biomass increased in the Madge Reef meadows from 23.5 ± 3.5 g DW m^2 to 70.2 ± 11.9 g DW m^2 in meadow 27 and from 34.2 ± 4.3 g DW m^2 to 78.5 ± 8.1 g DW m^2 in meadow 26 (Table 5; Figure 1). The area of the *Enhalus acoroides* meadows remained within the reliability range of previous years monitoring (Table 6; Figure 1; Maps 5-7).

Density of the intertidal, lower biomass *Halodule/Halophila* dominated meadows has shown high inter-annual variability over the course of the monitoring program with declines and increases in biomass over multiple years (Table 5; Figure 1; Appendix 1). Above-ground biomass in meadow 8 on the northern foreshore of Thursday Island has ranged from 0.4 ± 0.3 g DW m^2 in 2002 to 16.0 ± 1.9 g DW m^2 in 2012 (Table 5; Figure 1). These changes are considered within the normal scope for low biomass, patchy and naturally dynamic species. Biomass had increased in all of these meadows since 2010 with a statistically significant increase in meadow 1 (Table 5; Appendix 1). In previous years, meadow 3 was strongly dominated by *Halodule uninervis*, however, in the present survey biomass between *Halodule uninervis* and *Halophila ovalis* was more balanced, with *Halophila ovalis* having slightly more of a presence in the meadow (Figure 1). Despite this shift in the dominant species the change in biomass between 2010 and 2012 in this meadow was not significant (Appendix 1).

Halodule dominated meadows 1, 5 and 8 were at their highest recorded levels in 2012 since monitoring began (Table 5; Figure 1). Meadow 5, located on the southern foreshore of Thursday Island, recorded this increase despite having decreased in area between 2008 and 2010 by 2.1ha and remained below the 2008 distribution in 2012. Meadow 8, located on the northern foreshore of Thursday Island continued the trend from the 2010 survey having increased substantially in area as well as biomass in 2012 (Table 6). The increase in biomass recorded in this meadow may be due in some part to the addition of *Cymodocea serrulata* to the meadow, a larger, heavier species, combined with the slight increase in meadow area (Table6; Figure 1; Map 6; Appendix 1). The two remaining *Halodule uninervis* meadows on the southern side of Thursday Island (1 and 3) had both increased slightly in area but remain within the limits of reliability in 2012, after being at their peak distribution in 2008 (Table 6; Figure 1; Map 5).

The species composition of the monitoring meadows remained relatively consistent between surveys with some changes to the composition of the minor species occurring (Figure 1). The changes to the minor species were usually related to small increases or decreases of one or two species per meadow. A general trend of increasing seagrass diversity since 2008 continued in this latest survey. One overall pattern noted was the slight increase in presence and density of *Halophila ovalis* in all but one meadow in which it was a dominant species, reversing the trend of decline seen in the 2010 survey (meadows 1, 5 & 8; Figure 1). For meadow 3, this increase in *Halophila ovalis* shifted the dominant species in the meadow from *Halodule uninervis* to *Halophila ovalis*.

Within individual monitoring meadows, six of the nine meadows displayed changes that were noteworthy. In 2008 meadow 4 recorded a displacement of high biomass *Enhalus acoroides* with smaller, lower biomass species. This pattern was reversed in 2010 with *Enhalus* becoming the dominant species again and this trend continued in 2012 (Figure 1). *Cymodocea serrulata* was observed for the first time in two of the monitoring meadows (meadows 5 & 27), and was present again in meadows 4 and 8 after being absent from the meadows in the 2010 survey. Finally, as was noted in the 2010 monitoring report, the increasing height of the southern edge of Madge Reefs meadow 26 due to sediment accretion, was obvious again in 2012. A large mangrove forest is becoming more dominant in this region of the meadow, displacing seagrass that was once present; this area has been highlighted on Map 4.

Table 5: Mean above-ground biomass (g DW m^2) for Thursday Island monitoring meadows, March 2002, 2004, 2006, 2008 and February 2010, 2012; 2005 for Meadows 26 and 27 only.

Meadow ID no.	Mean Biomass (g DW m^{-2}) (% change) (no. sites within meadow)						
	2002	2004	2005	2006	2008	2010	2012
1	0.3 ± 0.1 (10)	3.7 ± 0.8 (n/a)** (28)	-	4.3 ± 1.2 (+16%) (23)	4.2 ± 0.4 (-3%) (22)	4.2 ± 0.7 (+0.3%) (27)	8.4 ± 1.5 (+100%) (17)
2	43.3 ± 6.3 (12)	75.4 ± 6.9 (+74%) (14)	-	38.2 ± 3.7 (-49%) (20)	23.4 ± 1.9 (-39%) (19)	27.7 ± 3.4 (+19%) (40^)	72.4 ± 4.6 (+161%)” (25)
3	0.8 ± 0.1 (3)	2.5 ± 1.2 (n/a)** (7)	-	1.0 ± 0.1 (-60%) (8)	3.7 ± 0.4 (+271%) (8)	2.1 ± 0.3 (-62%) (12)	3.6 ± 0.9 (+70%) (5)
4	32.8 ± 8.5 (14)	56.2 ± 13.1 (+71%) (6)	-	30.2 ± 5.7 (-46%) (5)	17.3 ± 4.6 (-43%) (5)	19.3 ± 2.9 (+11%) (19^)	46.1 ± 8.5 (+139%) (17)
5	3.4 ± 1.3 (8)	7.9 ± 1.2 (n/a)** (26)	-	5.7 ± 1.1 (-28%) (25)	4.8 ± 0.7 (-16%) (26)	9.5 ± 1.3 (+99%) (18)	10.9 ± 1.5 (+15%) (21)
6	55.7 ± 8.9 (6)	48.2 ± 8.5 (-13%) (18)	-	25.6 ± 6.0 (-47%) (22)	26.3 ± 3.8 (+3%) (24)	26.9 ± 4.2 (+2%) (52^)	59.7 ± 5.7 (+122%)” (27)
8	0.4 ± 0.3 (8)	7.4 ± 1.3 (n/a)** (31)	-	10.5 ± 1.6 (+42%) (3)	4.6 ± 0.5 (-56%) (34)	11.7 ± 2.3 (+154%) (23)	16.0 ± 1.9 (+37%)” (31)
26	68.8 ± 9.8 (18)	48.8 ± 5.4 (-29%) (31)	24.1 ± 3.0 (-51%) (25)	41.9 ± 4.7 (+74%) (32)	22.0 ± 2.0 (-47%) (33)	34.2 ± 4.3 (+56%) (33)	78.5 ± 8.1 (+129%) (26)
27	175.9 ± 0* (1)*	47.8 ± 10.6 (n/a)** (13)	24.4± 5.7 (-23%) (8)	32.4 ± 6.2 (+32%) (10)	16.7 ± 3.5 (-48%) (10)	23.5 ± 3.3 (+40%) (25)	70.2 ± 11.9 (+199%) (20)

*Based on one site not representative of entire community
** Too few sites surveyed in March 2002 to allow reasonable biomass comparison
^ Some sites were omitted from biomass calculations where camera visibility prevented viewing of an entire quadrat
“ Some sites were omitted form biomass calculations where isolated patches of *E. acoroides* were present in a *H. univervis* or *H. ovalis* meadow

Table 6: Seagrass meadow area (ha) for Thursday Island monitoring meadows, March 2002, 2004, 2006, 2008, and February 2010, 2012.

Meadow ID no.	Area (ha) (mapping precision range)					
	2002	**2004**	**2006**	**2008**	**2010**	**2012**
1	2.3 (1.5-3.1)	2.5 (1.6-3.4)	2.2 (1.4-3.0)	3.8 (3.0-4.6)	2.5 (1.7-3.2)	3.2 (2.5-4.0)
2	7.7 (5.4-10.0)	7.8 (6.2-9.4)	7.8 (6.2-9.4)	8.6 (7-10.2)	8.9 (7.4-10.4)	8.7 (7.1-10.2)
3	0.1 (0.05-0.15)	0.2 (0.1-0.3)	0.3 (0.1-0.5)	0.8 (0.6-1.0)	0.3 (0.1-0.5)	0.4 (0.2-0.6)
4	1.3 (0.7-1.9)	1 (0.5-1.5)	0.8 (0.3-1.3)	1.1 (0.6-1.6)	0.8 (0.3-1.3)	0.9 (0.5-1.4)
5	2.1 (1.3-2.9)	1.9 (1.1-2.7)	2 (1.1-2.9)	5.3 (4.3-6.3)	3.2 (2.3-4.1)	3.6 (2.7-4.6)
6	13.2 (10.6-15.8)	12.4 (10.0-14.8)	12.7 (10.2-15.2)	16.2 (13.3-19.1)	13.2 (10.7-15.7)	12.7 (10.5-14.8)
8	12.3 (10.3-14.3)	10.4 (8.2-12.6)	12.2 (10.4-14.0)	8.9 (7-10.8)	13.4 (10.7-15.1)	14.3 (11.5-17.0)
26	94.5 (93.0-96.0)	87.7 (84.2-91.2)	89 (85.9-92.1)	83.5 (80.9-86.1)	89.2 (87.0-92.4)	86.3 (83.1-89.4)
27	6.1 (5.4-6.8)	7 (6.1-7.9)	5.8 (5.1-6.5)	5.9 (5.2-6.6)	8.2 (7.3-9.1)	7.2 (6.3-8.0)
Total	**139.6 (128.2-151.0)**	**130.9 (117.9-143.9)**	**132.8 (120.7-144.9)**	**134.1 (121.9-146.3)**	**139.7 (126.6-152.8)**	**137.3 (124.4-150.2)**

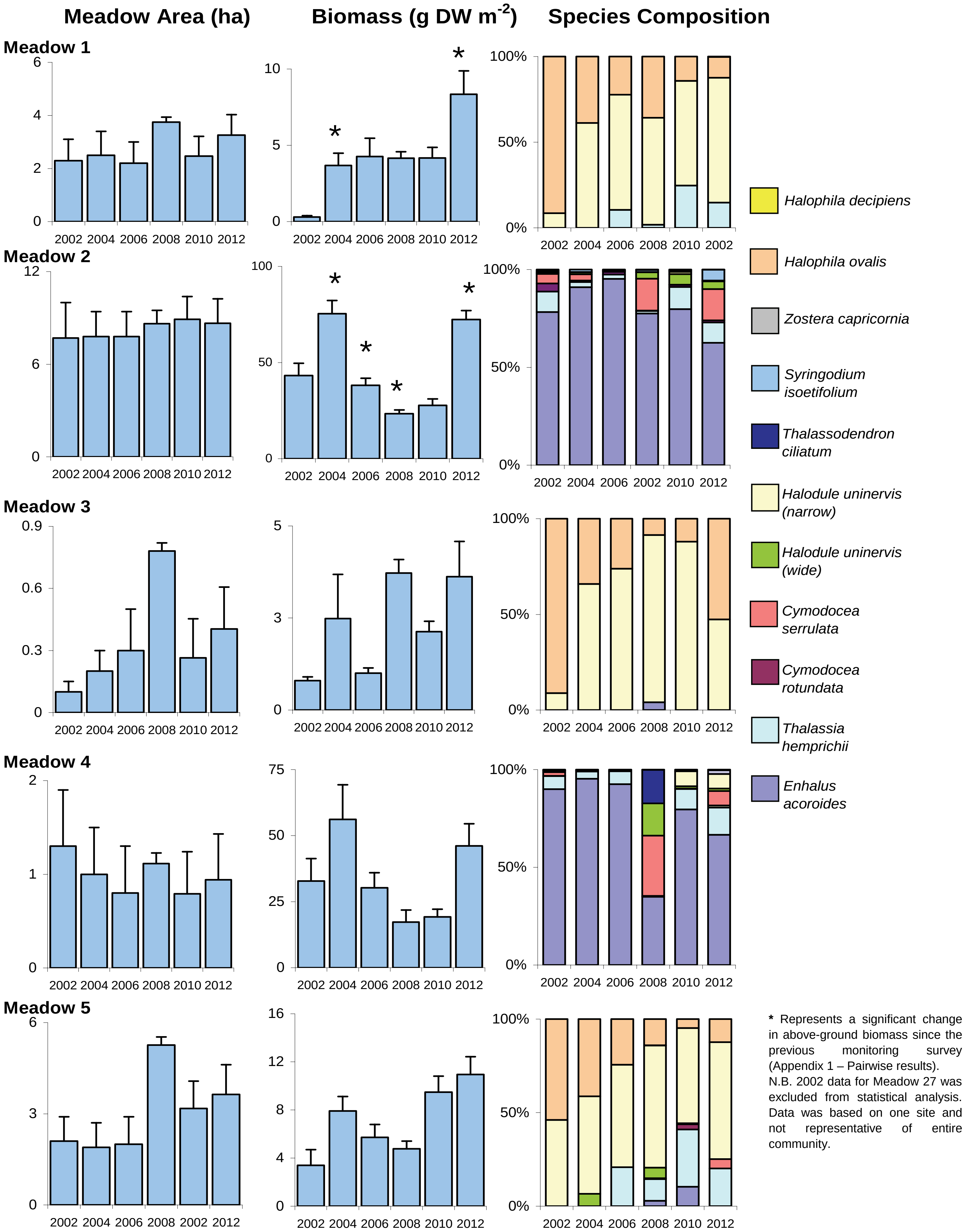
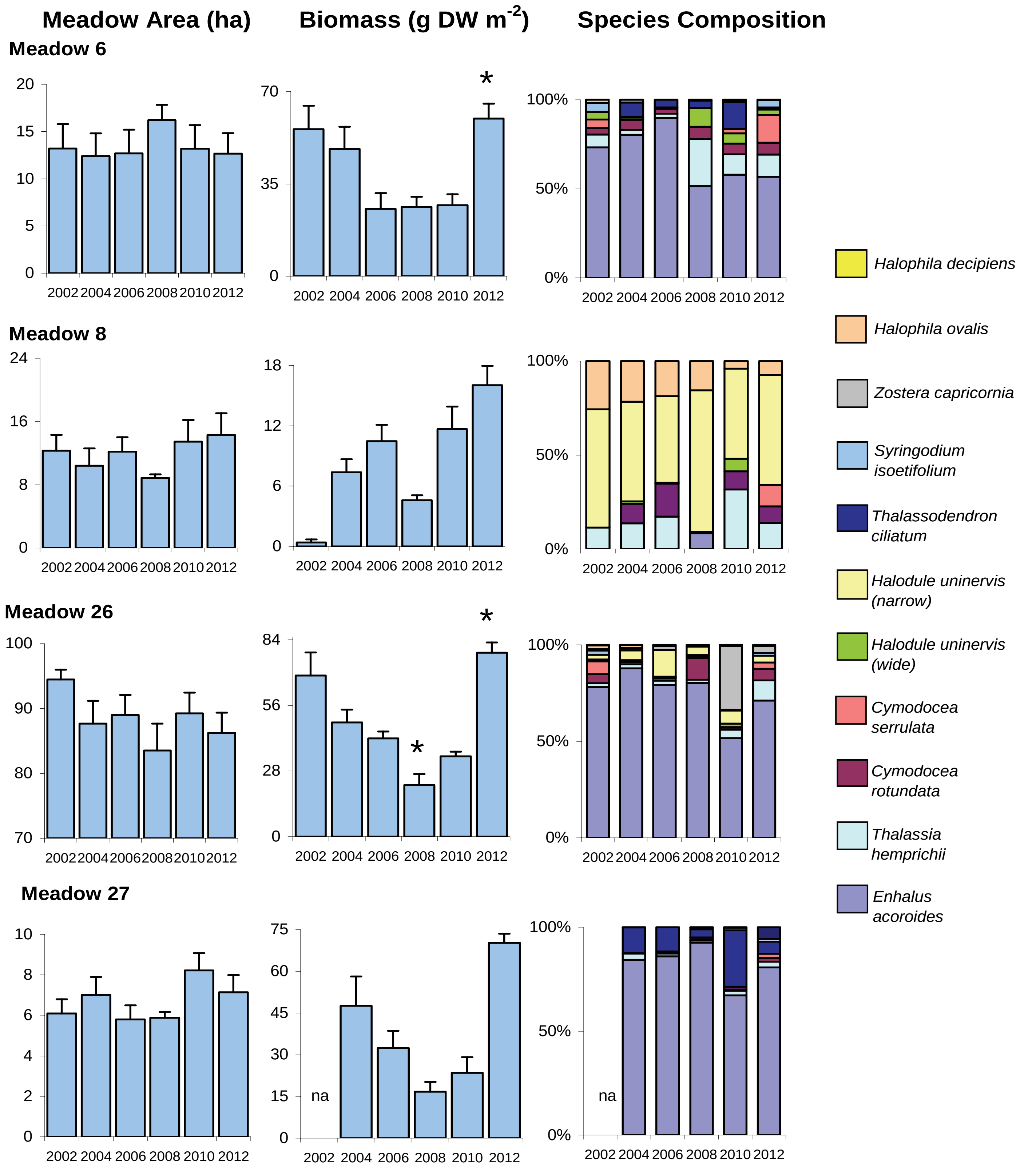


Figure 1. Changes in biomass, area and species composition for monitoring meadows in 2002, 2004, 2006, 2008, 2010 and 2012 (Biomass error bars = SE; Area error bars = "R" reliability estimate).



* Represents a significant change in above-ground biomass since the previous monitoring survey (Appendix 1 – Pairwise results).
N.B. 2002 data for Meadow 27 was excluded from statistical analysis. Data was based on one site and not representative of entire community.

Figure 1. Changes in biomass, area and species composition for monitoring meadows in 2002, 2004, 2006, 2008, 2010 and 2012 (Biomass error bars = SE; Area error bars = "R" reliability estimate.

Map 5. Comparision of the southern foreshore seagrass monitoring meadows in the Port of Thursday Island in 2002, 2004, 2006, 2008, 2010 & 2012

Background image: Beach Protection Authority 1:50000, 19/6/92

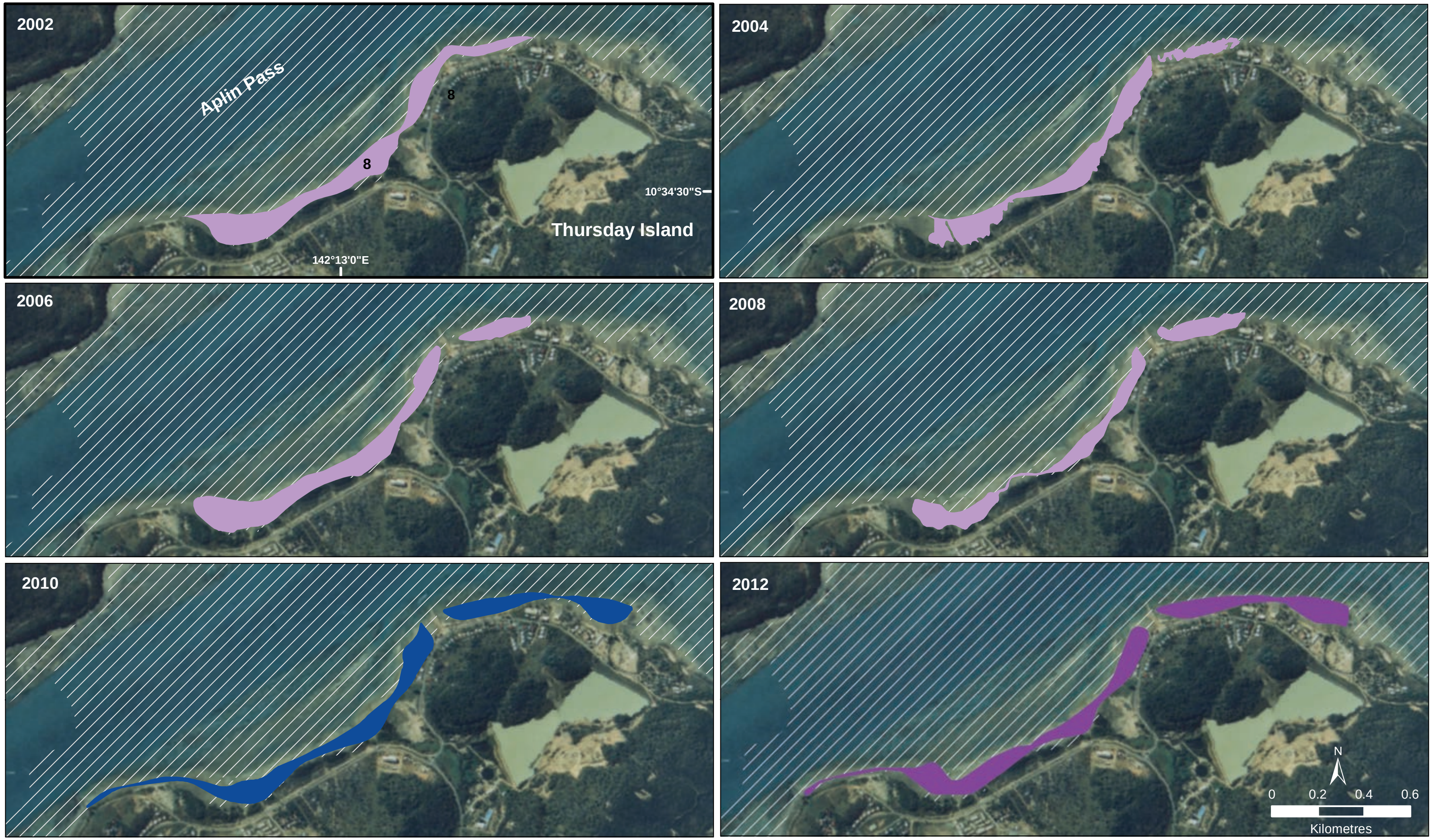
Legend

Community type

- Complete seagrass distribution 2002 & 2004
- *Enhalus acoroides* dominated
- *Halodule uninervis* (thin) dominated
- *Halodule uninervis* (thin)/ *Enhalus acoroides* dominated
- *Halophila ovalis* with *Halodule uninervis* (thin) dominated
- *Halodule uninervis* (thin)/ *Halophila ovalis* dominated
- *Halophila ovalis* dominated

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Map 6. Comparison of the northern foreshore seagrass monitoring meadows in the Port of Thursday Island in 2002, 2004, 2006, 2008, 2010 & 2012



Background image: Beach Protection Authority 1:50000, 19/6/92

Legend

Complete seagrass distribution 2002 & 2004

Community type

Halodule uninervis (thin) dominated

Halodule univervis (thin)/*Thalassia hemprichii* dominated

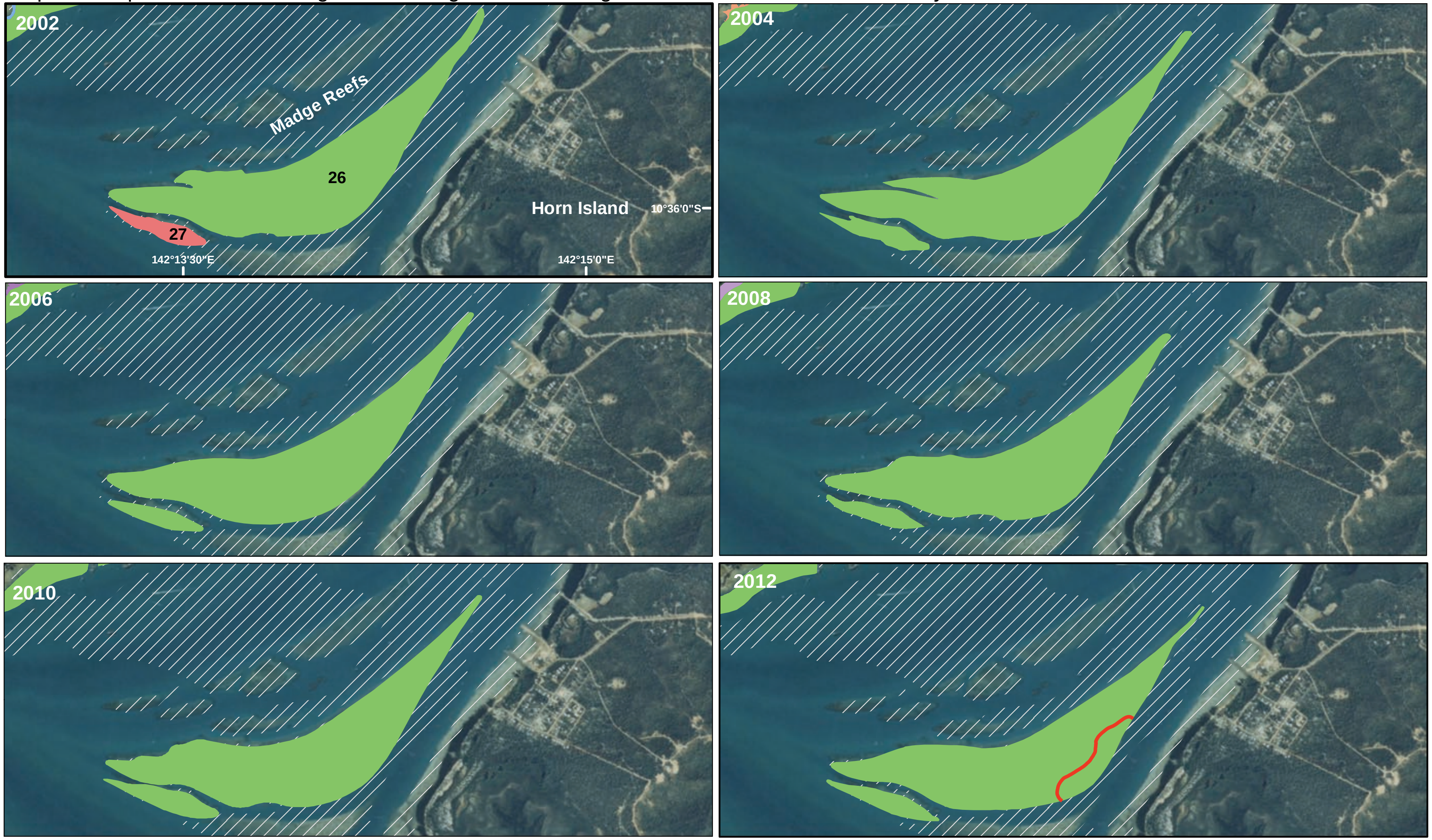
Halodule uninervis (thin) with*Thalassia hemprichii* / *Cymodocea rotundata* dominated

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Ports North

Queensland Government

Map 7. Comparision of the Madge Reefs seagrass monitoring meadows in the Port of Thursday Island in 2002, 2004, 2006, 2008, 2010 & 2012



Legend

Complete seagrass distribution 2002 & 2004

Community type

Thalassadendron ciliatum dominated

Enhalus acoroides dominated

Mangrove boundary

Background image: Beach Protection Authority 1:50000, 19/6/92

Source: Davies, JN, McKenna, SA, Rasheed, MA & Taylor HA 2012, 'Long-term seagrass monitoring in the Port of Thursday Island February 2012'. *DAFF Publication* (Fisheries Queensland, Northern Fisheries Centre, Cairns), 37 pp.

Ports North

Queensland Government

Port of Thursday Island climate data

Total annual rainfall in 2010 was above the 12 year annual average, predominantly due to rainfall records in January that were well above monthly averages from the past 73 years (Figure 2). Conversely, rainfall in 2011 fell below the 12 year annual average and was similar to total annual rainfall in 2008 and 2009. Rainfall in January of 2012 was similar to 73 year average for that month. Between 2002 and 2005, Horn Island had received below average rainfall creating an extended period of drought-like conditions (Figure 2). The dry season mean monthly maximum temperature (June-October) for 2010 and 2011 was above the 20 year average, continuing five years of above average temperatures (Figure 3). The mean annual maximum temperature for 2011 was close to the 12 year average. Solar radiation has been steadily increasing on Thursday Island since 2000 (Figure 4). Daytime tidal exposure in 2011 was average, however mean dry season exposure in 2010 and 2011 continue a decreasing trend in the number of hours exposed since 2005 (Figure 5).

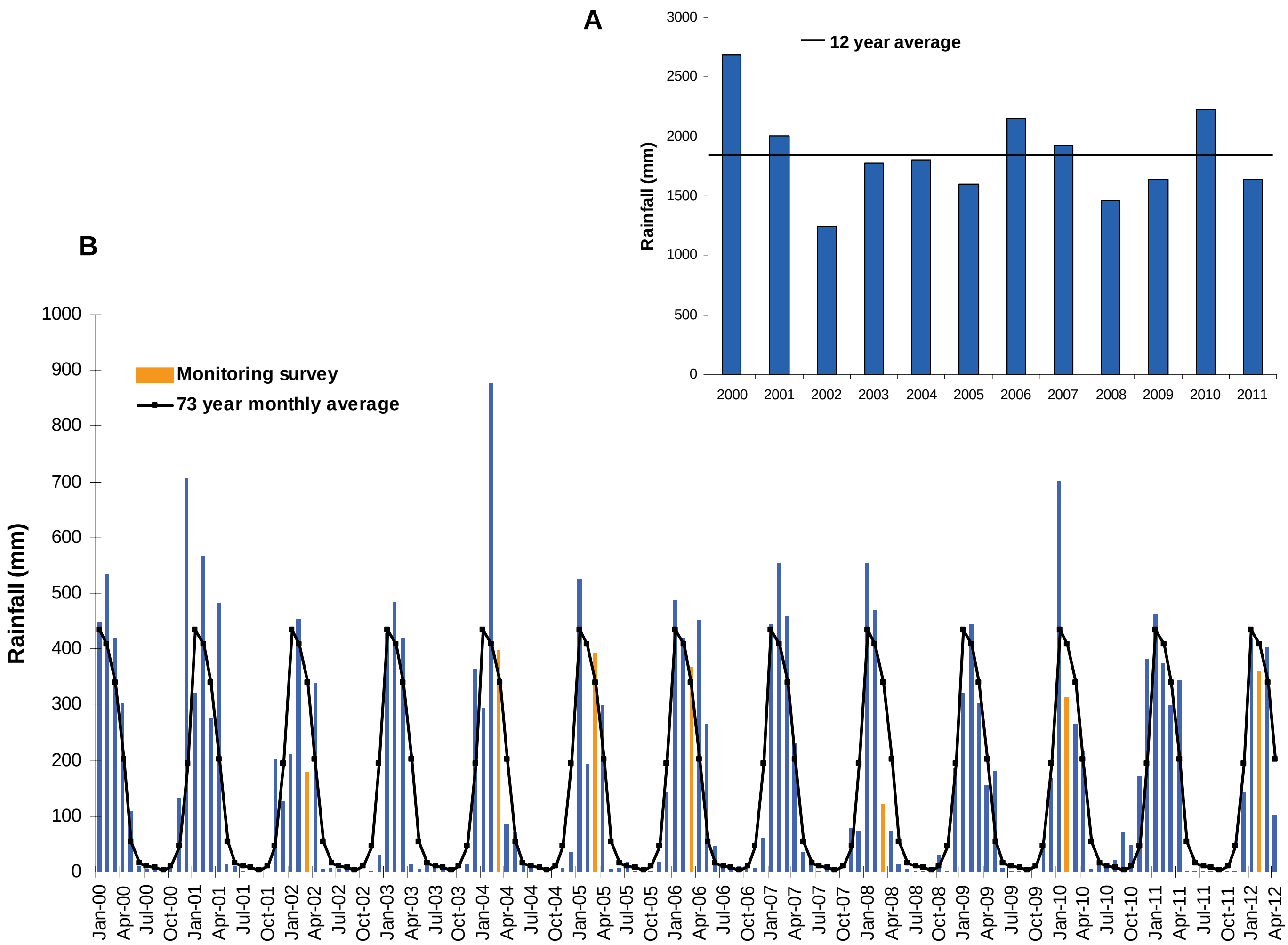


Figure 2. (A) Mean annual rainfall; and (B) Mean monthly rainfall recorded at Horn Island 2000 to 2011 (Bureau of Meteorology, 2012).

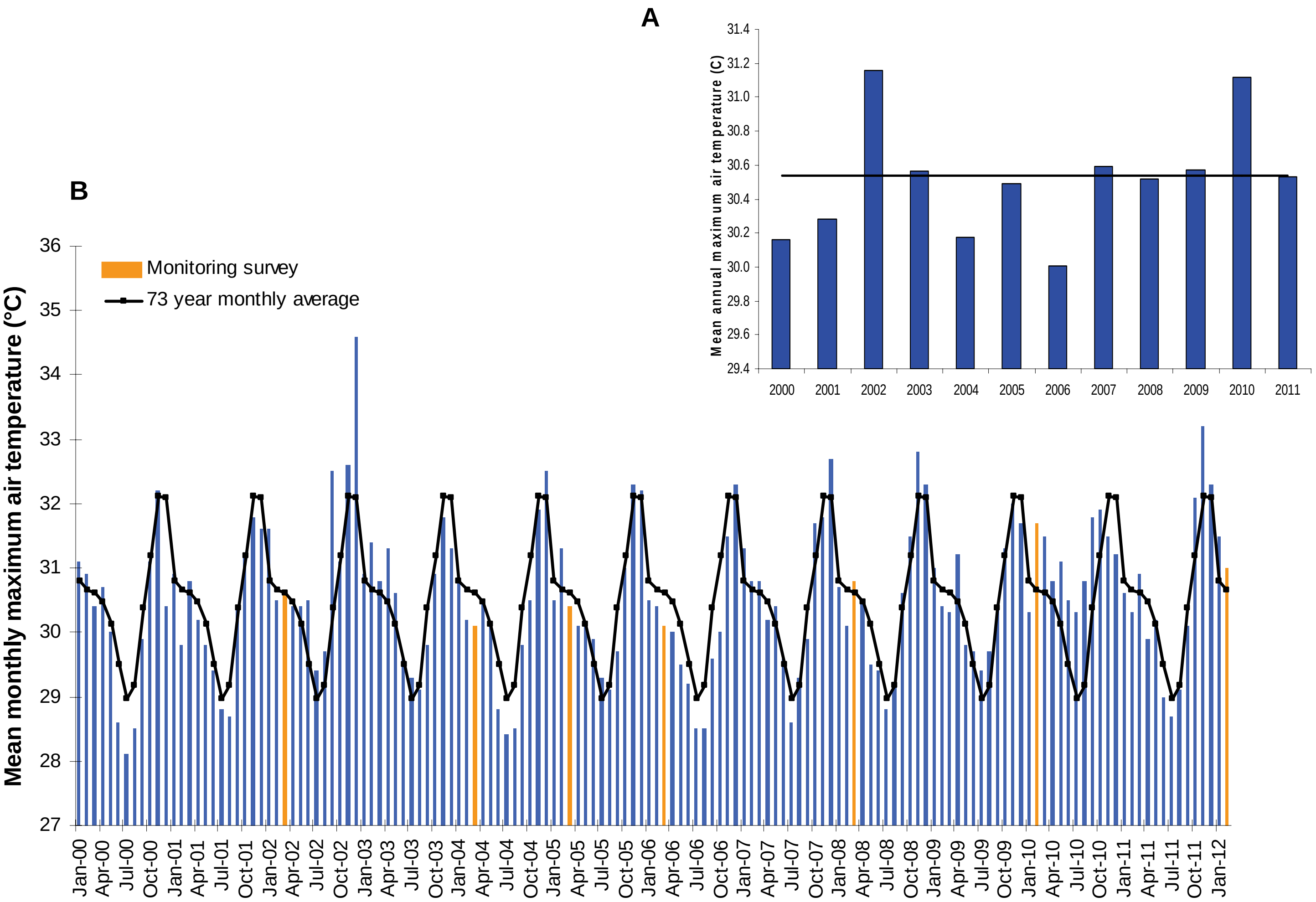


Figure 3. (A) Mean annual daily maximum air temperature; and (B) Mean monthly maximum air temperature recorded at Horn Island 2000 to 2011 (Bureau of Meteorology, 2012).

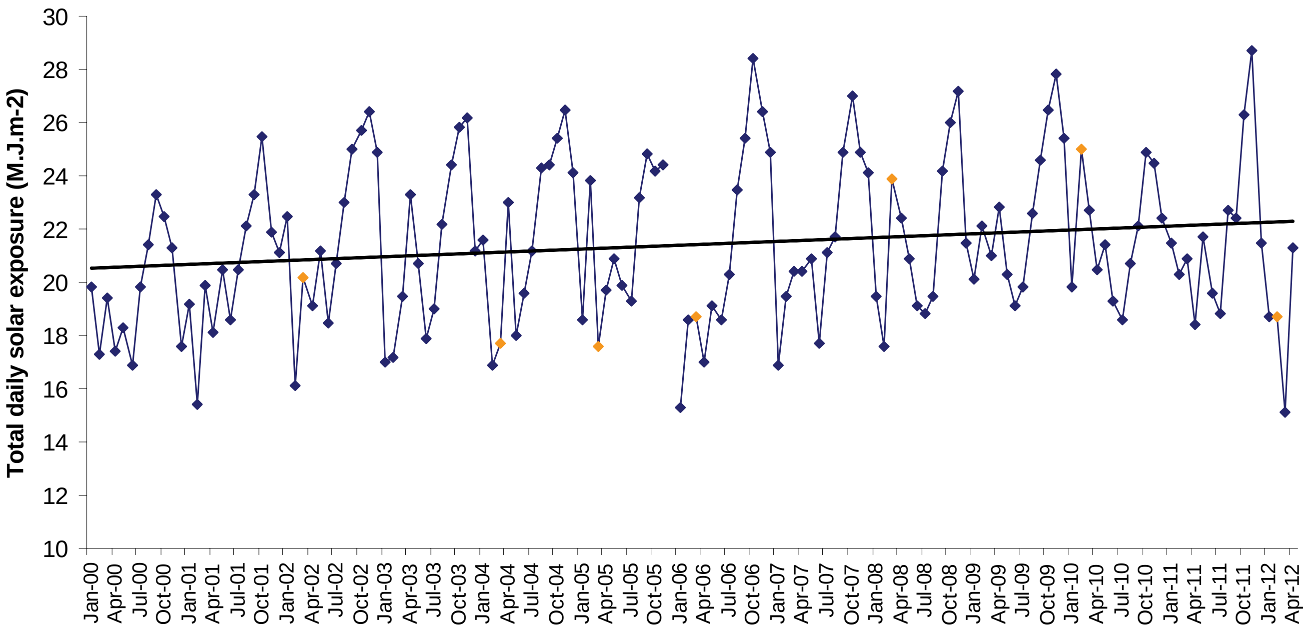


Figure 4. Total daily solar exposure recorded at Thursday Island 2000 to 2011 (Bureau of Meteorology).

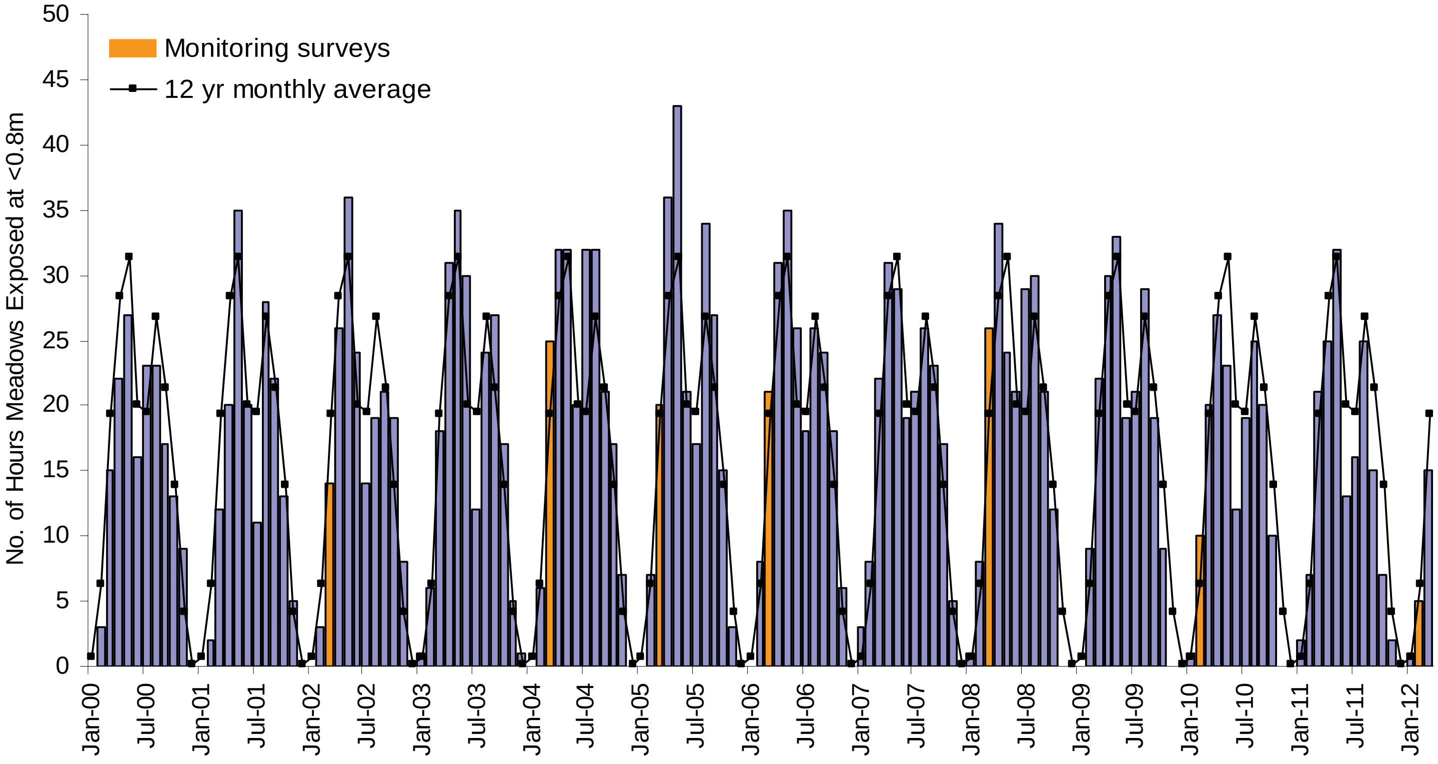


Figure 5. Total number of hours per month that seagrass meadows are exposed on low tide, recorded at Thursday Island 2000 to 2012 (Bureau of Meteorology, 2012)

DISCUSSION

Seagrass Distribution and Abundance

The results of the 2012 monitoring survey found that seagrasses in the Port of Thursday Island were in a healthy and productive condition with evidence of recovery occurring (2010 and 2012 surveys). Seagrass above-ground biomass for the majority of monitoring meadows was at the highest recorded since peak densities seen in 2004. Seagrass meadow area was similar to 2010 and has generally remained stable throughout the course of the monitoring program with only modest increases and decreases in distribution throughout most of the monitoring meadows. Changes to seagrass meadows in the Port of Thursday Island are likely due to a combination of regional and local climatic conditions rather than any changes in port related or anthropogenic activities.

Tropical seagrass meadows can be highly dynamic (McKenzie 1994), varying in biomass and plant growth by up to a factor of four (Brouns 1985; Erftemeijer and Herman 1994; Lanyon and Marsh 1995). Seagrasses within the Port of Thursday Island and elsewhere throughout Queensland are influenced by a complex interaction of a number of climatic factors including rainfall, wind, solar irradiance, temperature, daytime tidal exposure and photosynthetically active radiation (PAR), which are all known to affect seagrass growth, recruitment and mortality (e.g. Rasheed and Taylor 2008; Rasheed et al. 2008a; 2008b; Rasheed and Unsworth 2011; Chartrand et al. 2012). For example, high amounts of tidal exposure coupled with high daytime temperatures can lead to high levels of PAR and ultra violet radiation, as well as desiccation and temperature stress leading to physiological stress to the leaf structure and photosystems (Stapel 1997; Bjork et al. 1999; Kahn and Durako 2009; Rasheed and Unsworth 2011; Chartrand et al. 2012).

Results of the monitoring at Thursday Island have shown that years in which *Enhalus* declines have been observed, correspond to years of above average daytime tidal exposure during the dry-season, and years where *Enhalus* biomass has increased or remained stable correspond to lower than average levels of daytime tidal exposure for the preceding dry season (June – October) (Figure 5). Results from monitoring *Enhalus* meadows in Weipa, have also demonstrated a negative correlation between biomass and tidal exposure (Unsworth et al. 2012). Trends in *Enhalus* meadow biomass found in both the 2010 and 2012 surveys at Thursday Island conform to this pattern; in both these years, the amount of hours that seagrasses have been exposed, particularly through the dry-season, was below average (Figure 5). Similarly, the mean annual maximum temperature for Thursday Island in 2011 was on par with the 12 year average, also providing a climate more conducive to for growth of seagrass meadows in the port (Figure 3B).

Declines in seagrass biomass and area that were observed along the urbanised east coast of Queensland in 2011 such as Cairns, Mourilyan, Townsville and Abbot Point did not occur at Thursday Island and other Torres Strait monitoring sites. These declines on the east coast have been linked to high rainfall and flooding events to which these areas may be particularly susceptible (see McKenna & Rasheed 2011; McKenna & Rasheed 2012; Reason et al. 2012a; 2012b). However, meadows on Thursday Island are not heavily influenced by river flow and flooding and are therefore less susceptible to these events, allowing for continued plant growth and higher density. It is likely that a combination of environmental factors have driven changes to seagrass observed around Thursday Island.

The increase in biomass observed from 2010 to 2012 may also be partly attributed to the addition or increase in the amount of the heavier species *Cymodocea serrulata* in at least four of the monitoring meadows (4, 5, 8 & 27) (Lee Long et al. 1993, Terrados et al. 1998). Similarly meadows on Madge Reef show an increase in *Enhalus acoroides*, *Zostera capricorni* and *Thalassodendron ciliatum*; all of which are heavier, larger species (Nienhuis et al. 1989; Terrados et al. 1998). Some evidence suggests *Cymodocea* may be particularly susceptible to low salinities (Lee Long et al. 1993). Below average rainfall in the 12 months prior to the 2012 survey may have contributed to favourable growing conditions for this species. Alternatively, competition with other larger species such as *Enhalus acoroides, Thalassia hemprichii* and *Zostera capricorni* may restrict distributions (Coles et al*.* 1987).

The increase in the presence of *Zostera capricorni* within the Madge Reef meadows, particularly meadow 26 over the past two surveys may be a result of topographical changes to the intertidal bank. It has been noted over the past three surveys that sediment accretion has been occurring on the southern side of the bank upon which a large mangrove forest is becoming more dominant. It has also been noted by Fisheries staff that over the eastern half of this bank, there are more "high" spots of sediment accretion upon which the dominant species is *Zostera capricorni*. The increased height of the bank may be favouring hardier *Zostera capricorni* over the more desiccation prone *Enhalus acoroides*, allowing displacement to occur. Leuschner et al. (1998) reported that *Zostera* spp. can take up to five hours to reach 50% water loss from shoots (the level at which desiccation is defined as occurring), whereas Enhalus acoroides has been reported to reach that critical level after only 34 minutes (Bjork et al. 1999).

Seagrass resilience and ecosystem consequences of change

Seagrass species and communities vary in their sensitivity and resilience to impacts, including those associated with port and shipping activity (Erftemeijer and Lewis 2006). Seagrass meadows in north Queensland are typically known to have a high resilience to stress and a good capacity for recovery as long as propagules and established seed banks from which recovery can occur are locally available (Rasheed 2004; Unsworth et al. 2010; Taylor et al. 2011; Chartrand et al. 2012). The resilience of seagrass meadows is dependent upon a complex interaction of many factors, including their carbohydrate reserves, ability of photosystems to recover, capacity for vegetative propagation, seed bank occurrence and disturbance regime (Kenworthy 2000). It is likely that many of the meadows in the Port of Thursday Island have a high degree of resilience and a good capacity to recover from impacts. Surveys by Seagrass-Watch have documented that seagrass meadows on Horn and Thursday Island have good *Halodule uninervis* seed reserves and a high occurrence of *Enhalus acoroides* flowers during their peak reproductive season. Studies conducted by the group on Mabuiag Island in the Torres Strait have also found that significant intertidal and subtidal seed banks exist for the majority of species that are found in the Port of Thursday Island monitoring meadows (Taylor et al. 2011). Many of the species present in the Port of Thursday Island have also been found to have a capacity for rapid vegetative colonisation following disturbance (Rasheed 1999; Rasheed 2004; Taylor et al. 2011). However, continual declines over multiple years, such as those that occurred between 2004 and 2008, have the potential to significantly deplete seagrass energy stores, seed banks and standing crop, thereby reducing their natural levels of resilience to future impacts. Under this scenario seagrasses could become increasingly vulnerable to impacts to which they may previously have been resilient. Results from 2010 and 2012 indicate that seagrasses were likely to have recovered to a high level of resilience.

Seagrass species assemblages of the Port of Thursday Island are known to fulfil critical ecosystem functions providing important nursery grounds for a number of commercial fisheries species (Coles et al. 1993; Watson et al. 1993). Furthermore, these types of assemblages are those commonly preferred by dugong and green turtle (Bjorndal 1985; Aragones et al. 2006; Marsh and Kwan 2008).

Implications for management and future monitoring

Although the results of the 2012 monitoring survey indicate that seagrasses in the Port of Thursday Island were in a healthy and productive condition, the presence of these meadows and the potential for dugong and turtle activity in intertidal areas adjacent to port facilities and infrastructure has implications for management of the area. Future infrastructure developments such as wharves, breakwaters and reclamations would require careful management to ensure minimal impacts on these communities. The fact that healthy seagrass meadows have continued to exist within the port indicates that these important habitats can co-exist with well managed port activities and development.

It is difficult to conclusively determine the exact causes of change within the monitoring meadows in the Port of Thursday Island when sampling frequency is limited to biennial surveys and the catalyst for change could have occurred anytime within the 2 years prior to a survey event. While the exact causes of the declines between 2004 and 2008, and recovery observed in 2010 and 2012 are not clear, it is unlikely that the port operations or other anthropogenic (human) factors are responsible. It is most likely a result of a combination of favourable climatic factors which have allowed for favourable growing conditions. Seagrass meadows in other northern coastal areas such as Karumba and Weipa also showed increases in biomass and area in 2011 (Carter et al. 2012a; 2012b).

In summary this fifth biennial survey has built upon the established monitoring program to help provide a clearer picture of the natural inter-annual variations and the relationship between seagrass change and climate. However, correctly interpreting the causes of seagrass change is difficult when surveys are undertaken biennially. An annual seagrass program similar to other port locations would provide a greater understanding of seagrass health and dynamics. The existing biennial program suggests seagrasses and the marine environment in the port appear to be relatively healthy. The range of natural seagrass changes measured to date will enable any future changes to be placed in a clearer perspective.

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Appendix 1- Biomass Analysis

Summary of statistical results for mean above ground biomass versus year for monitoring meadows in Thursday Island (2002-2012). Bold numbers represent a result of no significant difference in biomass between years.

Meadow 1	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	453.33	90.67	4.20	<0.001
Within Years	122	2636.18	21.61		
Total	127	3089.51			
Meadow 2	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	56082.04	11216.41	35.36	<0.001
Within Years	125	39649.07	317.19		
Total	130	95731.11			
Meadow 3	**DF**	**SS**	**MS**	**F**	**P**
Between Years	4	40.86	10.21	1.85	**0.142**
Within Years	35	193.77	5.54		
Total	39	234.63			
Meadow 4	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	17543.28	3508.66	6.36	<0.001
Within Years	72	39737.61	551.91		
Total	77	57280.89			
Meadow 5	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	733.56	146.71	3.48	**0.006**
Within Years	123	5182.30	42.13		
Total	128	5915.86			
Meadow 6	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	28429.10	5685.82	8.22	<0.001
Within Years	143	98968.72	692.09		
Total	148	127397.83			
Meadow 8	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	2925.36	585.07	6.17	<0.001
Within Years	149	14124.14	94.79		
Total	154	17049.51			
Meadow 26	**DF**	**SS**	**MS**	**F**	**P**
Between Years	5	69158.11	13831.62	16.71	<0.001
Within Years	157	129964.91	827.80		
Total	162	199123.02			
Meadow 27	**DF**	**SS**	**MS**	**F**	**P**
Between Years	4	25601.69	6400.42	5.68	<0.001
Within Years	81	91246.59	1126.50		
Total	85	116848.28			

Meadow 1

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	YES					
2006	YES	NO				
2008	YES	NO	NO			
2010	YES	NO	NO	NO		
2012	YES	YES	YES	YES	YES	

Meadow 2

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	YES					
2006	NO	YES				
2008	YES	YES	YES			
2010	NO	YES	NO	NO		
2012	YES	NO	YES	YES	YES	

Meadow 3

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	NO					
2006	NO	NO				
2008	NO	NO	NO			
2010	NO	NO	NO	NO		
2012	NO	NO	NO	NO	NO	

Meadow 4

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	NO					
2006	NO	NO				
2008	NO	NO	NO			
2010	NO	NO	NO	NO		
2012	NO	NO	NO	NO	NO	

Meadow 5

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	NO					
2006	NO	NO				
2008	NO	NO	NO			
2010	NO	NO	NO	NO		
2012	YES	NO	NO	YES	NO	

Meadow 6

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	NO					
2006	NO	NO				
2008	NO	NO	NO			
2010	NO	NO	NO	NO		
2012	NO	NO	YES	YES	YES	

Meadow 8

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	YES					
2006	YES	NO				
2008	YES	NO	NO			
2010	YES	NO	NO	NO		
2012	YES	YES	NO	YES	NO	

Meadow 26

YEAR	2002	2004	2006	2008	2010	2012
2002						
2004	NO					
2006	NO	NO				
2008	YES	YES	YES			
2010	YES	NO	NO	NO		
2012	NO	NO	YES	YES	YES	

Meadow 27

YEAR	2004	2006	2008	2010	2012
2004					
2006	NO				
2008	NO	NO			
2010	NO	NO	NO		
2012	NO	NO	YES	NO	

*2002 data excluded as too few sites (≤3) were recorded.