Department of **Employment, Economic Development and Innovation**

Port Curtis and Rodds Bay seagrass monitoring program, November 2010

Chartrand K.M., McCormack C.V. & Rasheed M.A.

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EXECUTIVE SUMMARY

This report details the findings of the 2010 annual seagrass monitoring survey for Port Curtis and Rodds Bay and seasonal mapping of seagrasses within the Western Basin region of the port. The report integrates 2010 survey data with previous long-term monitoring assessments conducted since 2002, assessing seagrass meadow area, biomass and species composition. The 2010 survey included assessments of intertidal and shallow subtidal meadows in the Western Basin region from The Narrows to Boyne River as well as long-term monitoring meadows located in Rodds Bay. This survey was part of the Port Curtis Integrated Monitoring Program (PCIMP) and a bi-annual assessment of inner harbour seagrasses undertaken since November 2009 as a part of increased monitoring for planned harbour expansion and dredging programs.

Compared to the broad distribution of meadows mapped in the 2009 whole of port baseline reassessment, the November 2010 survey found a significant reduction in total area and biomass of seagrass throughout the Western Basin region. While the majority of seagrass loss was in the subtidal meadows, many intertidal meadows were reduced in density and abundance from previous years. In addition, some intertidal meadows where dugong feeding trails were consistently recorded in previous surveys had substantially reduced in seagrass coverage with no signs of recent feeding activity in November 2010.

In 2010, seagrass meadows that have been monitored annually since 2002 were in a more susceptible condition relative to previous years. Total distribution of the fifteen monitoring meadows (including the new monitoring meadows in the Narrows and surrounding the Channel Islands) was approximately 42% lower in 2010 from 2009 estimates. Specific concerns were those meadows absent in 2010 including the Fishermans Landing subtidal meadows and an intertidal South Trees meadow adjacent to major port facilities. Other intertidal meadows that had also contracted in distribution and abundance were uncharacteristic from previous assessments.

The major driver of seagrass change is likely to be climate related as similar declines have been observed state-wide following a significant wet season in late 2009 to early 2010. Rainfall, river flow and elevated temperature are suggested as the major drivers of seagrass dynamics in the Port Curtis area. Should climate conditions become more favourable to seagrass growth we would expect to see recovery of these seagrass meadows.

Since late 2009, assessments of light and temperature have begun to provide information on *in situ* conditions to evaluate changes occurring at the meadow scale. Long-term collection of such data within meadows will enhance the effectiveness of the monitoring program by distinguishing some natural versus anthropogenic drivers of seagrass change. Low light levels within a number of meadows suggest seagrass may already be subject to low light stress reducing their potential resilience to future impacts. The light data collected during 2010 supports a reduction in available light being one of the primary causes of seagrass decline.

The loss of some meadows, together with potential water quality issues have left the seagrasses of Port Curtis in a condition where they may be vulnerable to additional stresses including those associated with dredging. A more complete understanding of the environmental requirements of seagrasses in Port Curtis is being developed as part of additional seagrass studies connected with the Western Basin development (Chartrand et al. 2010). These studies will help to accurately inform environmental management of future developments.

INTRODUCTION

Seagrass meadows are important ecosystem service providers to coastal environments. They provide functions such as coastal protection, nutrient cycling and particle trapping (Costanza et al. 1997, Hemminga and Duarte 2000). They also provide additional economic value in terms of nursery and feeding habitats for commercial and recreational fisheries species (Watson et al. 1993; Unsworth and Cullen 2010). Seagrasses are also considered to be internationally important due to the food resources they provide for IUCN endangered and vulnerable species such as dugong and turtles (Hughes et al. 2009). Such species are also recognised in Australia under the *EPBC Act* 1999. With globally developing carbon markets, the role that seagrasses play in sequestering carbon is also becoming more widely recognised (Kennedy and Björk 2009).

Seagrasses show measurable responses to changes in water quality (Dennison et al. 1993), making them ideal candidates for monitoring the “health” of port environments. Results from long-term monitoring programs throughout other Queensland port locations have provided valuable information on the relationships between climatic changes, anthropogenic disturbance and seagrass abundance.

Understanding the large spatial extent of seagrass meadows in port areas by creating a ‘baseline’, and monitoring a sub-section of meadows over the long-term has enabled port managers to make informed decisions regarding planning and development of port infrastructure. This has minimised the impact of port developments on fisheries and the marine environment. With recognition of ecological resources an important focus of planning, healthy and productive seagrass habitats can co-exist with the economic development of port facilities.

Within the Port of Gladstone area (Port Curtis) the value seagrasses provide to dugong has been recognised by the declaration of the Rodds Bay Dugong Protection Area (DPA), while previous surveys indicate that seagrass habitats in the harbour contain a diverse and productive macro-benthic fauna (Lee Long et al. 1992; Rasheed et al. 2003). Seagrass meadows in Port Curtis have subsequently been recognised by Port Curtis Integrated Monitoring Program (PCIMP) and Gladstone Ports Corporation (GPC) to be an important and sensitive component of the marine habitats within the port. This is part of their commitment to maintaining the health of the marine environment within the port.

In 2002, GPC commissioned the Queensland Primary Industries and Fisheries (Now Fisheries Queensland, Department of Employment, Economic Development and Innovation (DEEDI)) to conduct a baseline, fine-scale survey of seagrass resources within the port limits and nearby Rodds Bay (Rasheed et al. 2003). The 2002 baseline survey identified large areas of seagrass within the port limits. A re-commission of the baseline survey was completed in November 2009 (Thomas et al. 2010). The 2009 baseline survey mapped 12040.3 ± 2556.1 ha of seagrass habitat within Port Curtis and Rodds Bay. Meadows in 2009 appeared to be healthy with the greatest distribution of seagrass recorded since surveys began in 2002. However, detailed historical comparisons were not possible prior to the 2002 baseline as this was the first fine scale survey of the region. An annual seagrass monitoring program was developed in 2004 by GPC in response to a whole of port review (SKM 2004) and following recommendations from the PCIMP. This was based upon the knowledge that seagrasses show measurable growth responses to changes in water quality and their extensive distribution through the port made them an ideal candidate for monitoring the marine environmental health.

Results of the 2002 baseline survey and consultation with port users enabled thirteen seagrass meadows to be selected for monitoring. These monitoring meadows represent the range of seagrass communities within the port and include meadows considered in 2004 to most likely be impacted by port facilities and developments. Monitoring meadows include both intertidal and subtidal seagrasses as well as meadows preferred by dugong and those likely to support high fisheries productivity. Three meadows in Rodds Bay (outside of the port limits) were also selected to monitor in order to provide information on seagrasses unlikely to be impacted by port activity and to assist in separating out port related versus regional causes of seagrass change detected in the monitoring program (i.e. as a reference site).

The annual monitoring since 2004 (Rasheed et al. 2006; Taylor et al. 2007; Rasheed et al. 2008; Chartrand et al. 2009) and data collected in 2002 has documented considerable inter-annual variability in seagrass meadow biomass and area. This variability in seagrass from 2002 to 2008 was most likely the response of meadows to regional and local climatic factors (Chartrand et al. 2009). Such climate induced inter-annual variability is common throughout tropical seagrass meadows of the Indo-Pacific (Agawin et al. 2001). The annual monitoring of the port since 2004 has also documented the prevalence of dugong feeding trails within seagrass meadows throughout the port. The PCIMP seagrass monitoring program (that includes data back to 2002) has allowed PCIMP and Fisheries Queensland to begin to understand cycles of natural variability of Port Curtis seagrass meadows and be in a strong position to discern natural changes from human induced or port related change.

In 2009 proposed infrastructure developments within the port area, including a number of reclamation and dredge projects, lead to the requirement for an updated complete distribution of seagrasses (baseline update) within the port limits and adjacent areas. Since that survey, more detailed information on inter- and intra-annual seagrass dynamics in the Gladstone area has been required due to large scale dredging and port development programs. Fisheries Queensland was contracted in 2009 to undertake summer and winter surveys of all Western Basin seagrasses in addition to the annual long-term monitoring meadows in the port and Rodds Bay.

The objectives of the survey were to:

1. Document the spatial extent and biomass of intertidal and shallow subtidal seagrass meadows within the Western Basin of Port Curtis (from The Narrows to the mouth of the Boyne River) bi-annually to assess seasonal dynamics prior to and during large scale dredging.
2. Conduct annual long-term seagrass monitoring within Port Curtis and Rodds Bay based on information collected in the 2002 baseline survey.
3. Provide the distribution, abundance and species composition of seagrass monitoring meadows within Port Curtis and Rodds Bay.
4. Analyse changes in seagrass monitoring meadows measured since the baseline during subsequent annual monitoring surveys.
5. Document temporal physicochemical water quality parameters at selected seagrass meadows within Port Curtis.
6. Interpret the affects of changes in temporal physicochemical water quality (as well as additional climate variables) parameters on distribution, abundance and species composition of selected seagrass meadows within Port Curtis.
7. Place observed changes within a local, regional and state-wide context.

One of the outcomes of the 2009 baseline survey was the addition of two monitoring meadows to the PCIMP program to more accurately represent the range of seagrass meadows that would likely be impacted by the recent Western Basin port developments. The additional meadows are located in the direct vicinity of the planned development (Channel Islands) and upstream (the Narrows) to encompass areas also potentially impacted by large scale dredging.

Understanding levels of background natural variability in seagrass meadows and the factors driving these changes is critical for separating the effects of any future anthropogenic disturbance. Without detailed long-term datasets on the physiochemical conditions of seagrass meadows (i.e. canopy water temperature, turbidity, light and nutrient availability, and sediment movements) the means to investigate changes is reliant upon relating potential surrogates such as broad-scale weather data (i.e. rainfall, river flow, solar radiation, air temperature, wind and tidal exposure) to seagrass habitat descriptors (e.g. meadow biomass and area). Whilst both approaches do not provide 'cause and effect', *in situ* environmental data enhances the capacity to interpret changes in seagrass dynamics. Since late 2009, data loggers placed in many of the inner harbour monitoring meadows by GPC in conjunction with Vision Environment have provided the first steps to evaluate local seagrasses against their local conditions. The datasets will allow us to better distinguish anthropogenic versus natural impacts on the habitat. Results from the 2010 annual survey were analysed in relation to light and temperature data recorded in many of the Western Basin seagrass meadows as part of the GPC/Vision monitoring program.

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METHODS

Survey Approach

Seagrass surveys within the Western Basin of Port Curtis and Rodds Bay were conducted between the 3rd and 9th of November 2010. The survey had two major components:

1. Coastal (intertidal to shallow subtidal) seagrass survey
2. Annual long-term monitoring meadows survey

The survey was conducted during November as seagrasses in the region were likely to be at their maximum density and distribution in late spring. This also allowed direct comparisons with baseline surveys (conducted in 2002 and 2009) and also with the long-term monitoring program surveys which were all conducted in October/November. Thirteen meadows from the 2002 baseline survey (Rasheed et al. 2003) were previously selected for long-term monitoring as well as two new monitoring meadows selected from the 2009 baseline survey. The new meadow areas include Redcliffe (Meadow 23) and the Channel Islands (collectively Meadows 52-57). Monitoring meadows were representative of the range of seagrass communities identified in the baseline surveys and were also located in areas likely to be vulnerable to impacts from port operations and developments.

Seagrass habitat observations included species composition, above ground biomass, percent algal cover, depth below mean sea level (MSL) for subtidal sites, sediment type, time and position (Global Positioning System; GPS). Two sampling methods were used to survey the intertidal seagrass meadows; helicopter and divers. Offshore subtidal areas were sampled using a real time camera system towed behind the research vessel “Ovalis”. Offshore sites were randomly located throughout the survey area. A stratified random design was employed with a greater number of sites located in areas of particular interest such as the dredge spoil ground and in proximity to dredged channels. A detailed description of the methods used to characterise the different seagrass meadows is provided in (Rasheed et al. 2003).

Seagrass above ground biomass was determined using a “visual estimates of biomass” technique described by (Mellors 1991; Kirkman 1978). 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 had previously been measured. Two separate biomass ranges were used: low biomass and high biomass. The relative proportion of the above ground biomass (i.e. 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 observed during the survey. After ranking these quadrats, the seagrass 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.

Light and temperature loggers that are part of the GPC monitoring program were analysed in relation to seagrass trends between 2009 and 2010. Loggers and existing sources of daily weather data located in Western Basin seagrass meadows were evaluated against the distribution and biomass estimates recorded in the November 2010 survey. Daily weather data was sourced from the Australian Bureau of Meteorology (www.bom.gov.au) and tidal exposure data calculated from tidal height observations within Gladstone Harbour collected by Maritime Safety Queensland (www.msq.qld.gov.au).

Habitat Mapping and Geographic Information System

Spatial data from the field surveys were incorporated into the GPC/DEEDI Geographic Information System (GIS) database. Three GIS layers were created:

Site information – site data containing above ground biomass (for each species), depth below mean sea level (MSL) (for subtidal sites), sediment type, time, differential Global Positioning System (GPS) fixes (±1.5m) and sampling technique.

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 the Queensland region (Table 1). Abundance 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 unvegetated sediment interspersed with isolated patches of seagrass

Aggregated seagrass patches
Meadows are comprised of numerous seagrass patches but still feature substantial gaps of unvegetated 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 unvegetated sediment

Table 1 Nomenclature for community types in Port Curtis and Rodds Bay, November 2010

Community type	Species composition
Species A	Species A is 90-100% of composition
Species A with mixed species	Species A is 50-90% 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 Port Curtis and Rodds Bay, November 2010

Density	**Mean above ground biomass (g DW m^{-2})**				
	***H. uninervis* (narrow)**	***H. ovalis* *H. decipiens***	***H. uninervis* (wide) *C. rotundata***	***H. spinulosa***	***Z. capricorni***
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

Meadows were also assigned a mapping precision estimate (in metres) based on mapping methodology utilised for that meadow (Table 3). The mapping precision for coastal seagrass meadows ranged from ±5m for isolated seagrass patches to ±100m for subtidal meadows. For deepwater seagrass meadows where boundaries were determined by video sampling sites mapping was less precise and ranged from ±100m to ±300m dependant on the distance between sites (Table 3). 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 Port Curtis and Rodds Bay, November 2010

Mapping precision	**Mapping methodology**
≤5m	Meadow boundaries mapped in detail by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide, Relatively high density of mapping and survey sites, Recent aerial photography aided in mapping,
10m	Meadow boundaries determined from helicopter and diver surveys, Inshore boundaries mapped from helicopter, Offshore boundaries interpreted from survey sites and aerial photography, Moderately high density of mapping and survey sites,
20m	Meadow boundaries determined from helicopter and diver surveys, Some boundaries mapped from helicopter, Offshore boundaries interpreted from diver survey sites, Lower density of survey sites for some sections of boundary,
50m	Meadow boundaries determined from helicopter and diver surveys, Some boundaries mapped from helicopter, Some boundaries interpreted from helicopter survey sites, Low density of survey sites for some sections of boundary,
100m	Meadow boundaries determined from helicopter and diver surveys, Some boundaries mapped from helicopter, Some boundaries interpreted from satellite imagery/aerial photography, Lower density of survey sites for some sections of boundary,

Statistical Analysis

To determine inter-annual differences in seagrass biomass of individual meadows, an equal variance test was completed to determine the best fit test statistic for the analysis. If the data passed the equal variance test (i.e. Bartlett's), a simple one-way Analysis of Variance (ANOVA) was conducted in SigmaPlot v.11.0. Where data failed the equal variance test, a Behrens-Fisher test from Zar's 4th Edition Biostatistical Analysis was setup in Microsoft Excel 2000. 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 instead of α = 0.05 to minimise the possibility of recording a type 1 error (Underwood 1997). Detailed results are presented in Appendix A.

RESULTS

THE NARROWS, WESTERN BASIN AND RODDS BAY SEAGRASSES

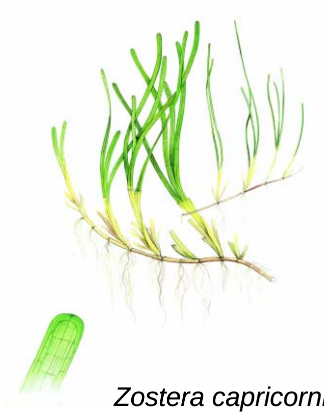
A total of 694 coastal habitat characterisation sites were surveyed throughout the Port Curtis Western Basin area and Rodds Bay monitoring meadows in November 2010 (Map 1) with a total of 2631.58 ± 517.66 ha of coastal seagrass habitat (<5m below MSL) identified in 68 separate meadows (Map 2).

Five seagrass species (from three families) were observed with the greatest distribution of seagrass present in the intertidal areas (Figure 1). Notably, *Halophila spinulosa* was not detected during the November 2010 survey as has been recorded in previous years.

Family CYMODOCEACEAE Taylor:
Halodule uninervis (wide and narrow leaf morphology) (Forsk.) Aschers. in Boissier
Cymodocea rotundata Ehrenb. et Hempr. ex Aschers.

Family HYDROCHARITACEAE Jussieu:
Halophila decipiens Ostenfeld
Halophila ovalis (R. Br.) Hook. F.

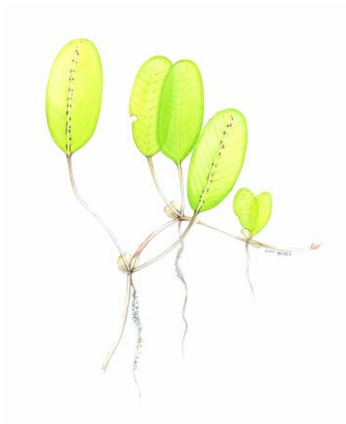
Family ZOSTERACEAE Drummortier:
Zostera capricorni Aschers.



Zostera capricorni

Halodule uninervis

Cymodocea rotundata



Halophila ovalis

Halophila decipiens

Figure 1 Seagrass species present in Port Curtis and Rodds Bay, November 2010

Western Basin Coastal Seagrass Species, Distribution and Abundance

Area of the 68 mapped seagrass meadows ranged from 0.03 ha for isolated patches and up to 625 ha for the largest intertidal meadow located at Pelican Banks (Maps 3-7). Seagrass cover for intertidal meadows located in The Narrows, Graham Creek, Fishermans Landing, Quoin Island and South Trees regions were generally patchy with isolated and aggregated patches of seagrass (Maps 3-7). The only meadow with a continuous cover of seagrass was observed at Pelican Banks (Maps 6).

Nine different community types were identified based on species presence and dominance (Maps 3-8; Tables 4-9). Communities dominated by *Zostera capricorni* were the most common followed by seagrass communities of *Halophila decipiens* and *Halophila ovalis*. Both community types were spread across the majority of the survey area on intertidal banks dominated by mud substrate from The Narrows to Wiggins Island and across towards Facing Island (Maps 3-8). Further south, *Halodule uninervis* communities occurred in more open coastal areas with predominantly sandy substrate including adjacent to Boyne Island and in the Quoin Island monitoring meadow (Maps 6-7). *Cymodocea rotundata*, which was first observed in Port Curtis in 2009, was recorded in the same isolated patches along the western shoreline of Facing Island in 2010 (Maps 6 and 7).

Above ground biomass for the intertidal meadows ranged from negligible (<0.01 g DW m^{-2}) where individual shoots of seagrass were present to 30.85 ± 2.68 g DW m^{-2} for a *Zostera capricorni* meadow located in the Pelican Banks region (Meadow 137; Map 6). Some isolated patches that were mapped had no recorded biomass due to random samples containing no seagrass despite seagrass in the immediate area in patchy and low abundance (e.g. Table 6, Meadow 54).

Signs of dugong feeding activity were significantly lower in November 2010 from all previous surveys undertaken for the seagrass monitoring program in Port Curtis. Dugong feeding trails (DFTs) which are evident from the helicopter during low tide surveys had been present during annual assessments in Wiggins Island, South Fisherman's Landing and Pelican Banks meadows since 2004 (Meadows 5, 6 and 43 respectively; Maps 5-6). In November 2010, DFTs were only observed at the southern extent of Pelican Banks meadow (Meadow 43).

Comparison with 2009 and June 2010 Assessments

Distribution of seagrass in the Western Basin November 2010 survey was significantly lower than what was observed during the November 2009 survey. Overall, there was a net loss of seagrass between years of 1557 ha (Map 10a, b). An additional survey of the area in June 2010 (i.e. winter), demonstrated the significant seasonal decline characteristically observed following wet season flooding with a loss of 2241 ha from November 2009 (Map 9a, b). Typically, seagrass recovery during late winter/spring results in seagrass abundance and distribution returning to pre-flood levels by October/November. However, recovery of only 46% of the total distribution by November 2010 suggests seagrasses were severely impacted over the 2009/2010 cycle.

The greatest loss in area over the 12 month period was in the Fishermans Landing intertidal and subtidal meadows (Meadows 6-9; Table 11). These losses are discussed in greater detail within the annual monitoring section of the present report in addition to loss recorded in the Rodds Bay monitoring meadows (Map 10b).

The Narrows north of Laird Point had a substantial net loss of 719 ha. The area lost was of patchy seagrass meadows consisting of *Zostera capricorni* and *Halophila ovalis* on the intertidal mudbanks lining the creeks and mangroves.

ANNUAL PCIMP SEAGRASS MONITORING (2002 – 2010)

A total of 1508 ± 158 ha of seagrass was mapped within the fifteen Port Curtis and Rodds Bay monitoring meadows in November 2010. The largest of these meadows was at Pelican Banks (Meadow 43) which covered 625.05 ± 14.2 ha. Subtidal meadows in Fishermans Landing (7 and 9) as well as the coastal monitoring meadow at South Trees (Meadow 58) were absent during the survey (Table 11).

The thirteen monitoring meadows that were present included six different community types depending on species presence and dominance (Maps 11-15). The majority of these meadows were comprised of aggregated patches of seagrass, with Pelican Banks the only meadow with a continuous cover. Communities that were dominated by *Zostera capricorni* were the most common followed by communities dominated by *Halophila ovalis*.

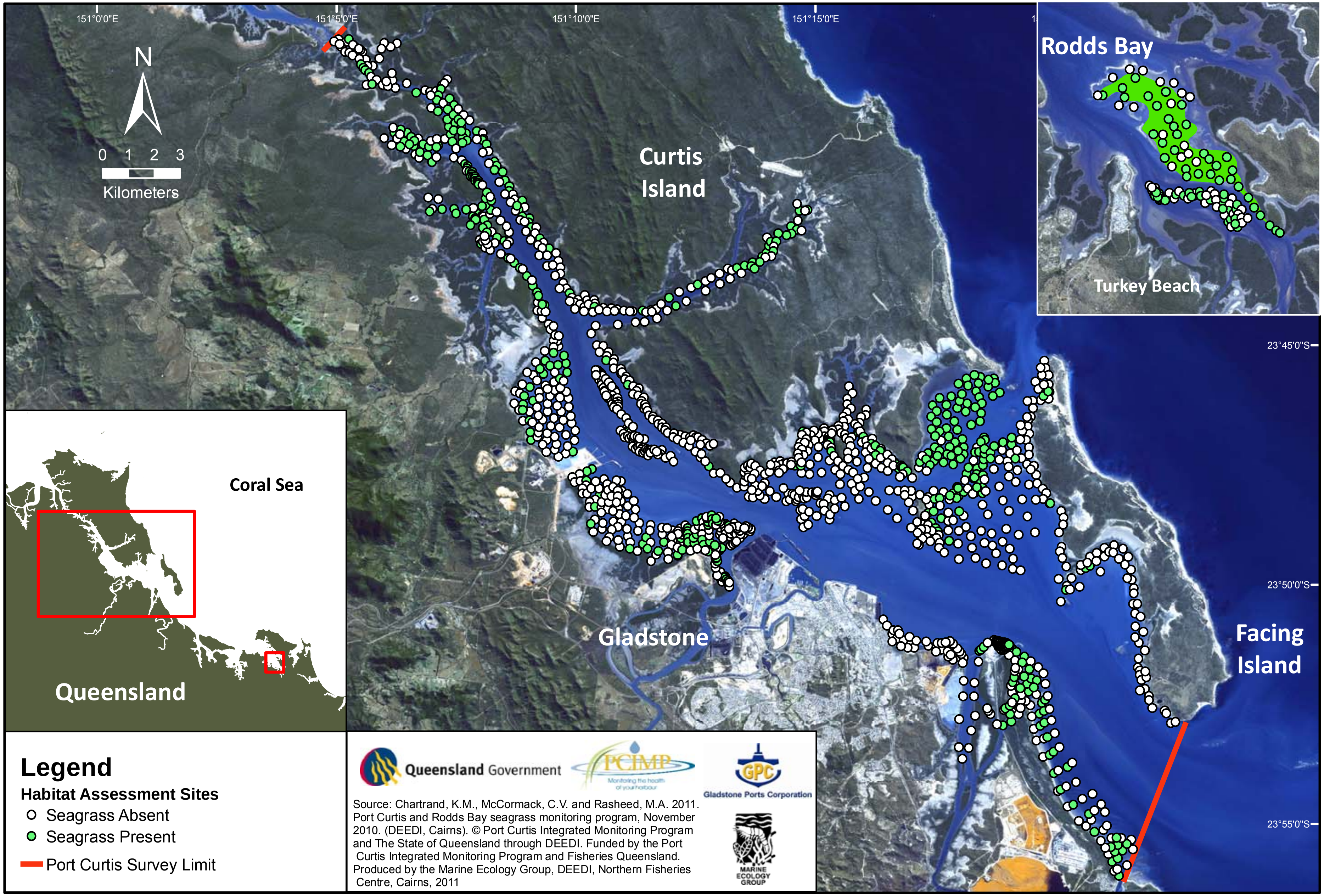
Mean above ground biomass for the monitoring meadows present ranged from a negligible 0.02 ± 0.003 g DW m^{-2} in the once light *Zostera capricorni* meadow at Wiggins Island (Meadow 4) to 21.53 ± 2.81 g DW m^{-2} in the large Pelican Banks monitoring meadow (Table 12).

Fishermans Landing intertidal meadows (Meadows 6 and 8) were reduced to their smallest distribution recorded since surveys began in 2002 and were limited to isolated patches with extremely low biomass (Map 5; Table 11-12). While seagrass at West Wiggins meadow (Meadow 5) was fairly consistent with previous surveys, Wiggins Island meadow (Meadow 4) was reduced to an isolated patch of seagrass less than two hectares in size and consisting solely of *Halophila ovalis*.

The majority of the monitoring meadows were located on sediments dominated by mud often combined with a smaller component of sand and/or shell, while the Quoin Island meadow (Meadow 48) maintained its predominantly sandy substrate. The most notable change in sediment occurred in the West Wiggins meadow. Shifting sand from heavy catchment flows out of the Calliope River likely buried the majority of seagrass present as well as altering the sediment environment typical of this intertidal area.

Dugong feeding activity was observed in only one of the fifteen intertidal seagrass monitoring meadows surveyed. Observations of DFTs were at Pelican Banks meadow (Meadow 43) and were localised to the southern extent of the meadow. Previous annual surveys found consistent DFTs in South Trees meadow (Meadow 58; Map 17), the Wiggins Island meadows (Meadows 4 and 5; Map 15), the South Fishermans meadow (Meadow 6), and the North Fishermans meadow (Meadow 8) in addition to Pelican Banks meadow (Meadow 43; Map 6).

Map 1. Location of November 2010 Port Curtis and Rodds Bay Habitat Characterisation Sites



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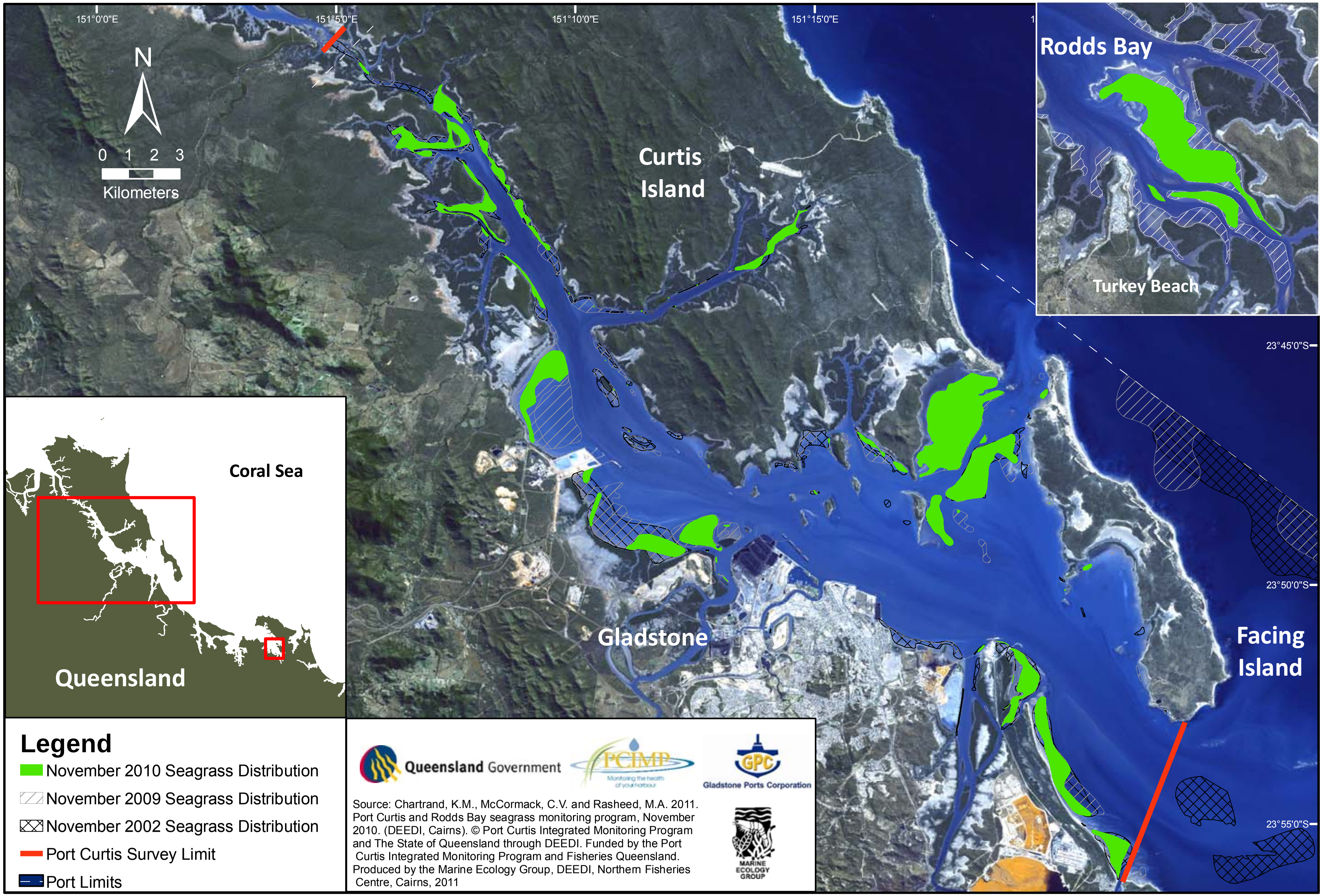
Map 2. November 2010 seagrass distribution in the Gladstone Western Basin region and Rodds Bay monitoring meadows



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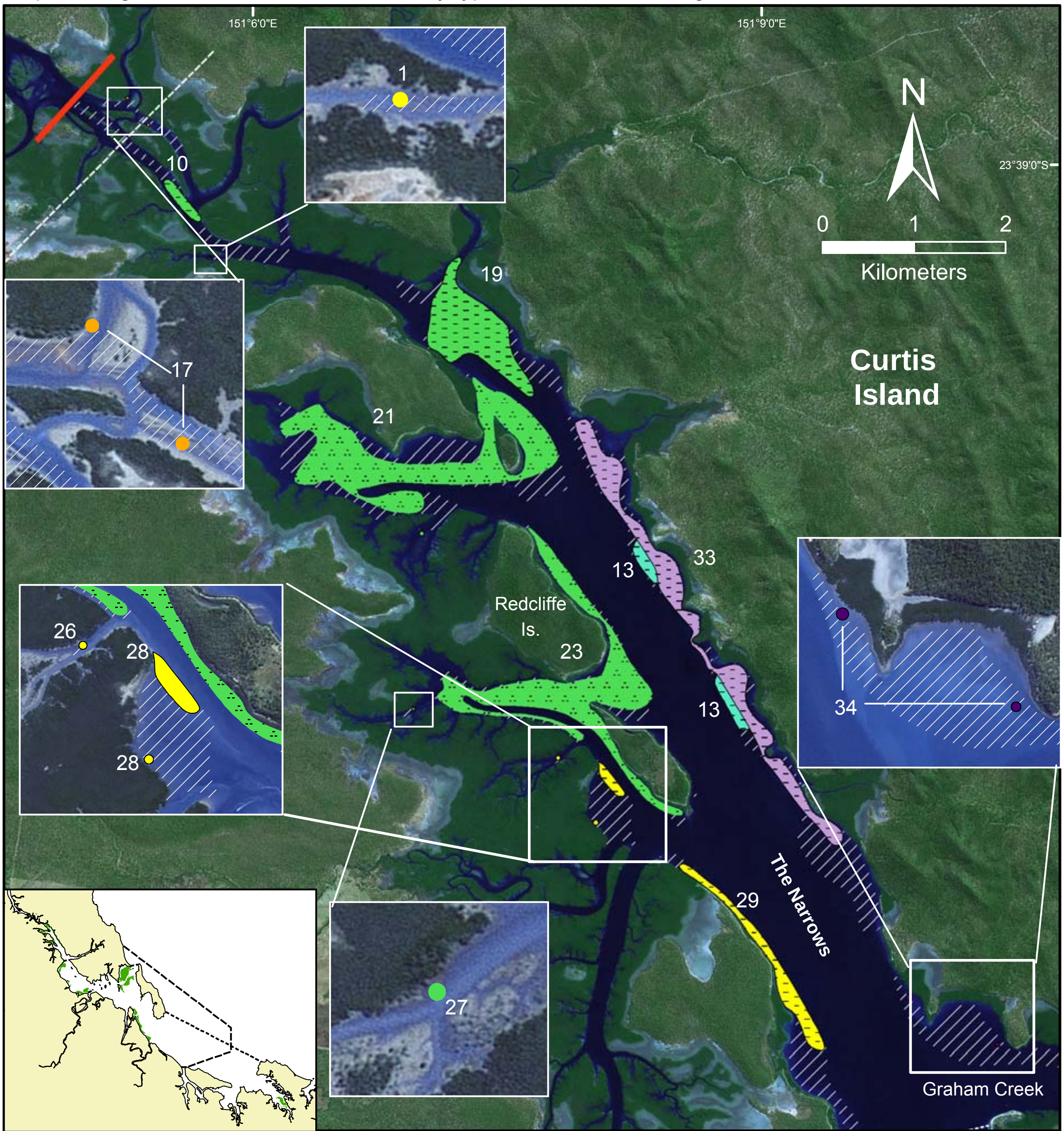
Map 3. Seagrass distribution and community types in The Narrows region, November 2010



Legend

November 2010 Seagrass Distribution

Community type

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate *Zostera capricorni*
- Light *Halophila ovalis*
- Light *Halophila ovalis* with mixed species
- Moderate *Halophila ovalis*
- Light *Halophila decipiens*
- Light *Halophila decipiens* with mixed species

Cover

- Isolated Patches
- Aggregated Patches
- Continuous Cover
- November 2009 Seagrass Distribution
- Port Curtis limits
- Survey Limit

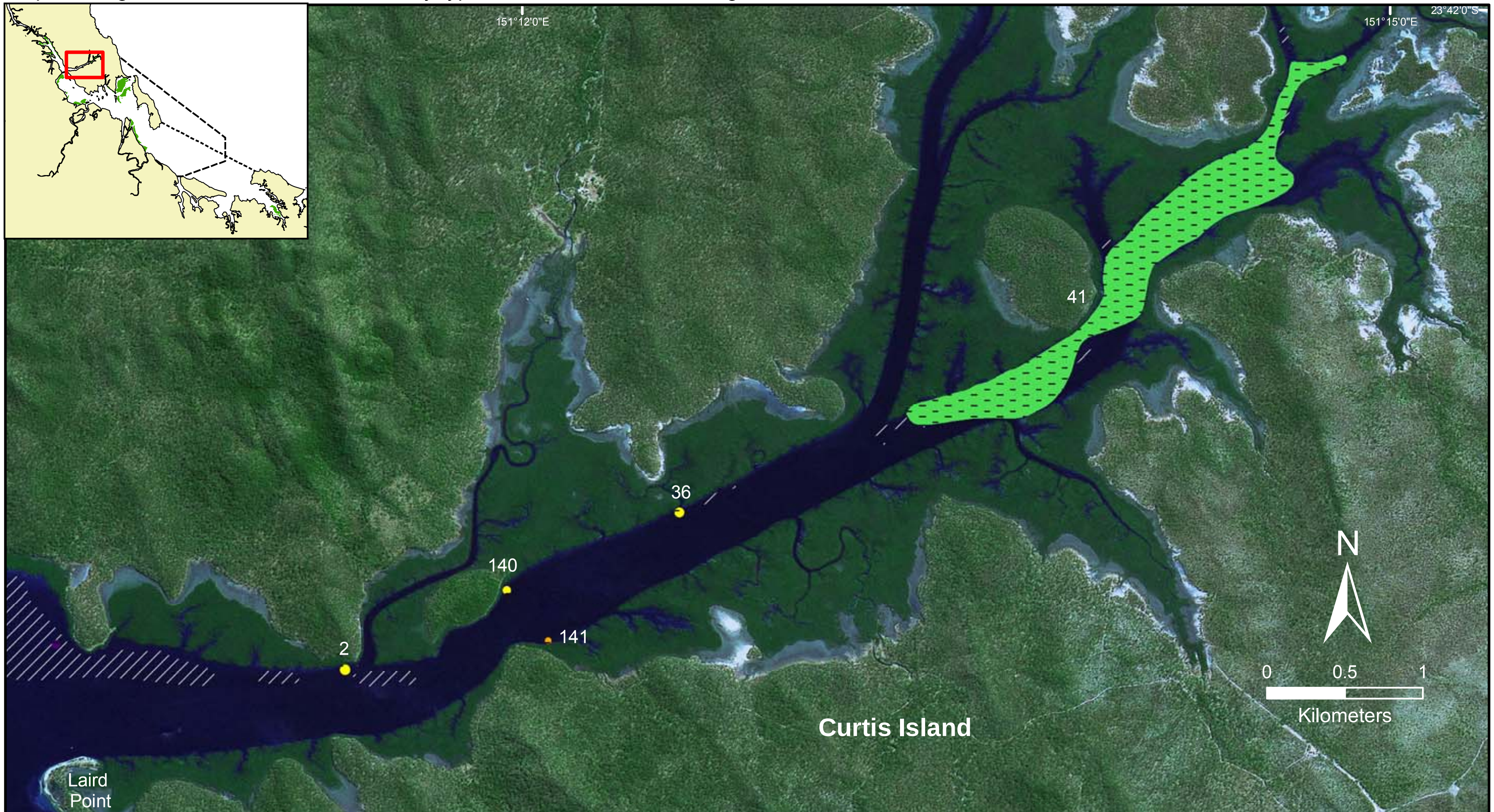
Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Table 4 Seagrass community type, seagrass cover and species present in The Narrows region, November 2010 (see Map 3; all values ± standard error)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
1	7.24†	0.05 ± 0.05	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
10	0.49 ± 0.48	5.37 ± 0.6	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
13	0.63 ± 0.23	10.31 ± 14.4	Light *Halophila decipiens* with mixed species	Isolated patches	*Halophila decipiens, Zostera capricorni*
17	0.51 ± 0.51	0.97 ± 0.2	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
19	2.36 ± 0.78	62.91 ± 8.5	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
21	9.46 ± 2.23	133.34 ± 23.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
23	2.20 ± 0.42	102.88 ± 14.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
26	1.01†	0.18 ± 0.1	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni, Halophila ovalis*
27	0.70†	0.08 ± 0.1	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
28	3.87 ± 1.46	4.0 ± 2.6	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni, Halophila ovalis*
29	0.80 ± 0.69	25.20 ± 5.2	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni, Halophila ovalis*
33	0.014 ± 0.004	74.36 ± 11.7	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis, Zostera capricorni*
34	1.21 ± 0.69	0.53 ± 0.2	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
139	0.54 ± 0.54	0.26 ± 0.2	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (narrow), *Halophila ovalis*

† One isolated patch so no standard error calculated

Map 4. Seagrass distribution and community types in the Graham Creek region, November 2010



Legend

Seagrass community Type

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate *Zostera capricorni*
- Light *Halophila ovalis*
- Light *Halophila ovalis* with mixed species
- Moderate *Halophila ovalis*
- Light *Halophila decipiens*
- Light *Halophila decipiens* with mixed species

Cover

- Isolated Patches
- Aggregated Patches
- Continuous Cover
- November 2009 Seagrass Distribution

Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Table 5 Seagrass community type, seagrass cover and species present in the Graham Creek, November 2010 (see Map 4; all values ± standard error)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
2	0.026†	0.32 ± 0.1	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
36	0.008†	0.28 ± 0.1	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
41	0.12 ± 0.078	78.18 ± 7.8	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
140	0.009†	0.21 ± 0.1	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
141	0.043†	0.13 ± 0.1	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis, Zostera capricorni*

† One isolated patch so no standard error calculated

Map 5. Seagrass distribution and community types in the Fishermans Landing region, November 2010

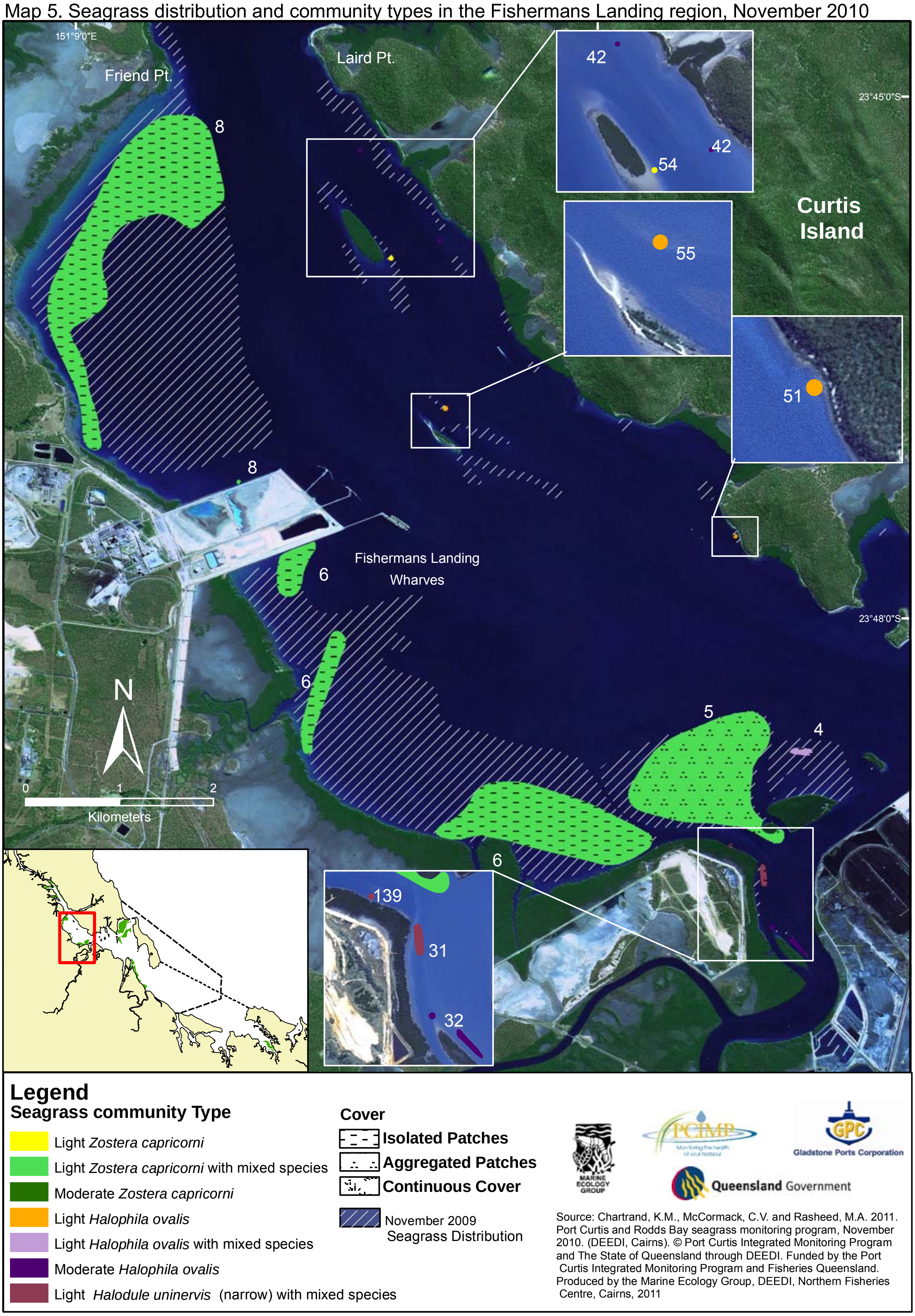


Table 6 Seagrass community type, seagrass cover and species present in the Fisherman's Landing region, November 2010 (see Map 5)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
4	0.024 ± 0.003	1.45 ± 0.5	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis, Zostera capricorni*
5	0.68 ± 0.22	120.72 ± 5.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
6	0.22 ± 0.08	139.66 ± 18.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
8	0.58 ± 0.23	180.27 ± 18.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
31	0.01 ± 0.004	1.27 ± 1.2	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (narrow), *Halophila ovalis*
32	1.87 ± 1.05	1.17 ± 1.6	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
42	2.74 ± 2.73	0.31 ± 0.2	Moderate *Halophila ovalis*	Isolated patches	*Halophila ovalis*
51	0.013[†]	0.16 ± 0.1	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
54	Not recorded	0.22 ± 0.1	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
55	0.01[†]	0.23 ± 0.1	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
139	0.54 ± 0.54	0.26 ± 0.2	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (narrow), *Halophila ovalis*

† One isolated patch so no standard error calculated

Map 6. Seagrass distribution and community types in the Quoin Island region, November 2010

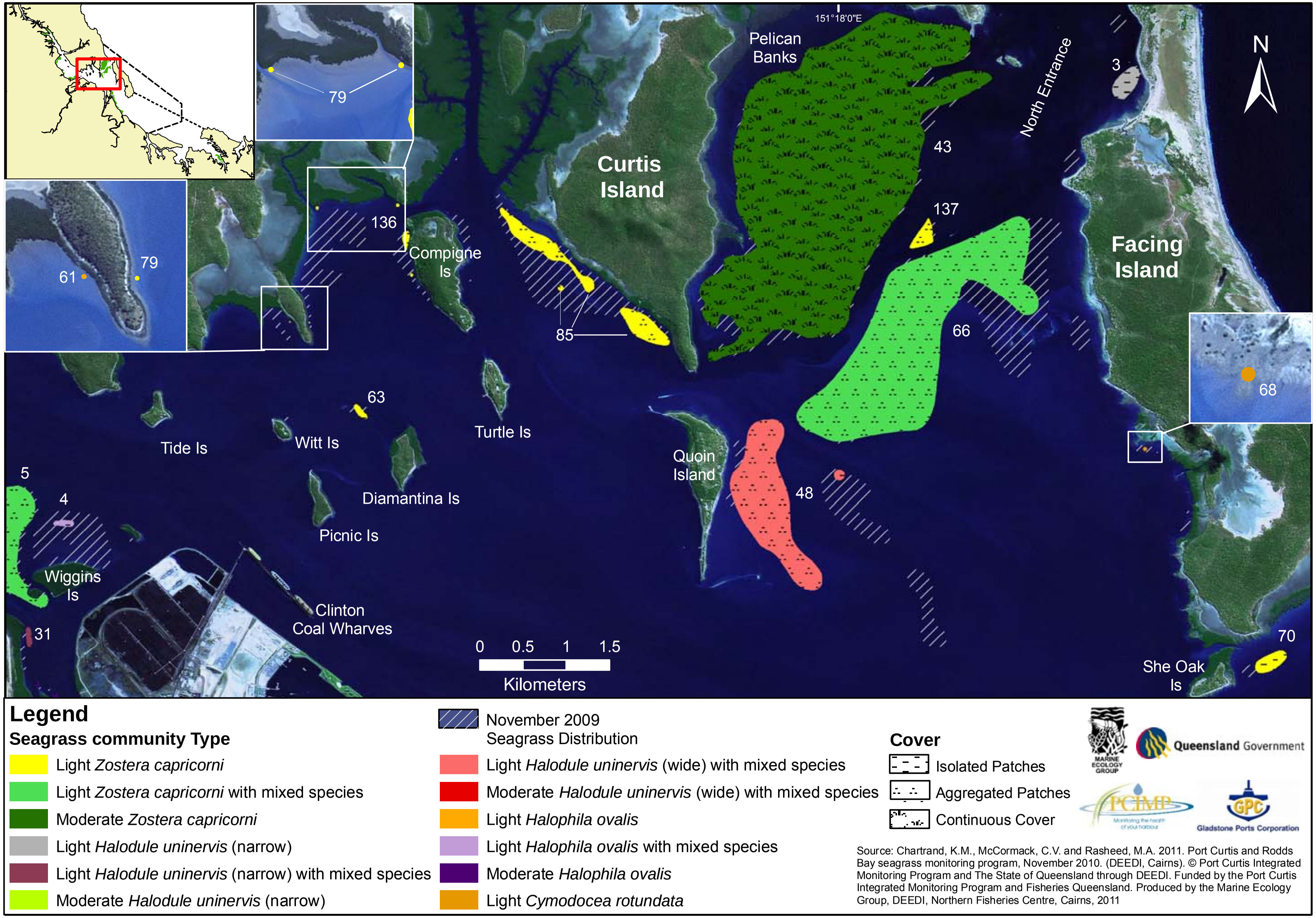
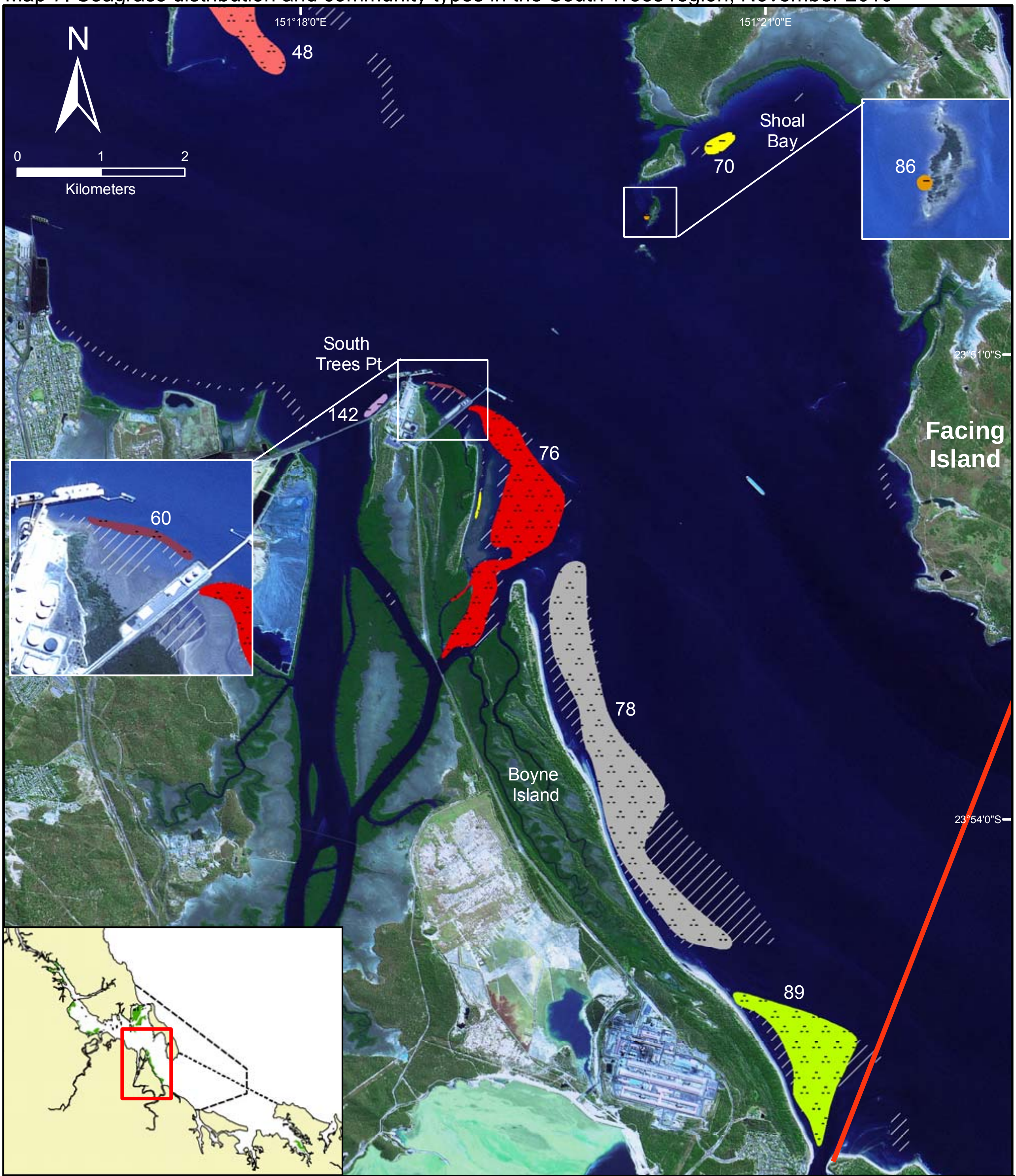


Table 7 Seagrass community type, seagrass cover and species present in the Quoin Island region, November 2010 (see Map 6)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
3	0.0005 ± 0.0003	6.83 ± 2.1	Light *Halodule uninervis* (narrow)	Isolated patches	*Halodule uninervis* (narrow)
4	0.024 ± 0.003	1.45 ± 0.5	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis, Zostera capricorni*
5	0.68 ± 0.22	120.72 ± 5.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
31	0.008 ± 0.004	1.27 ± 1.2	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (narrow), *Halophila ovalis*
43	21.53 ± 2.81	625.05 ± 14.2	Moderate *Zostera capricorni*	Continuous cover	*Zostera capricorni, Halophila ovalis*
48	0.44 ± 0.28	83.30 ± 58.09	Light *Halodule uninervis* (wide) with mixed species	Aggregated & Isolated patches	*Halodule uninervis* (wide and narrow)
61	0.013†	0.03 ± 0.05	Light *Halophila ovalis*	Isolated patches	*Halophila ovalis*
63	0.006 ± 0.006	1.23 ± 0.25	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
66	3.40 ± 0.98	262.32 ± 45.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halodule uninervis* (wide and narrow)
68	0.71†	0.16 ± 0.1	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
70	0.21 ± 0.21	5.41 ± 0.5	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
79	0.30 ± 0.27	0.26 ± 0.25	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni, Halophila ovalis*
85	1.55 ± 0.93	27.46 ± 4.67	Light *Zostera capricorni*	Aggregated & Isolated patches	*Zostera capricorni, Halophila ovalis*
136	6.81 ± 2.37	1.33 ± 0.7	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
137	30.85 ± 2.68	4.73 ± 1	Light *Zostera capricorni*	Aggregated patches	*Zostera capricorni*

† One isolated patch so no standard error calculated

Map 7. Seagrass distribution and community types in the South Trees region, November 2010



Legend

Seagrass community type

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Moderate*Zostera capricorni*
- Light *Halophila ovalis* with mixed species
- Light *Halodule uninervis* (narrow) with mixed species
- November 2009 Seagrass Distribution
- Light *Halodule uninervis* (narrow)
- Moderate *Halodule uninervis* (narrow)
- Light *Halodule uninervis* (wide) with mixed species
- Moderate *Halodule uninervis* (wide) with mixed species
- Light *Cymodocea rotundata*

Cover

- Isolated Patches
- Aggregated Patches
- Continuous Cover
- Survey Limit

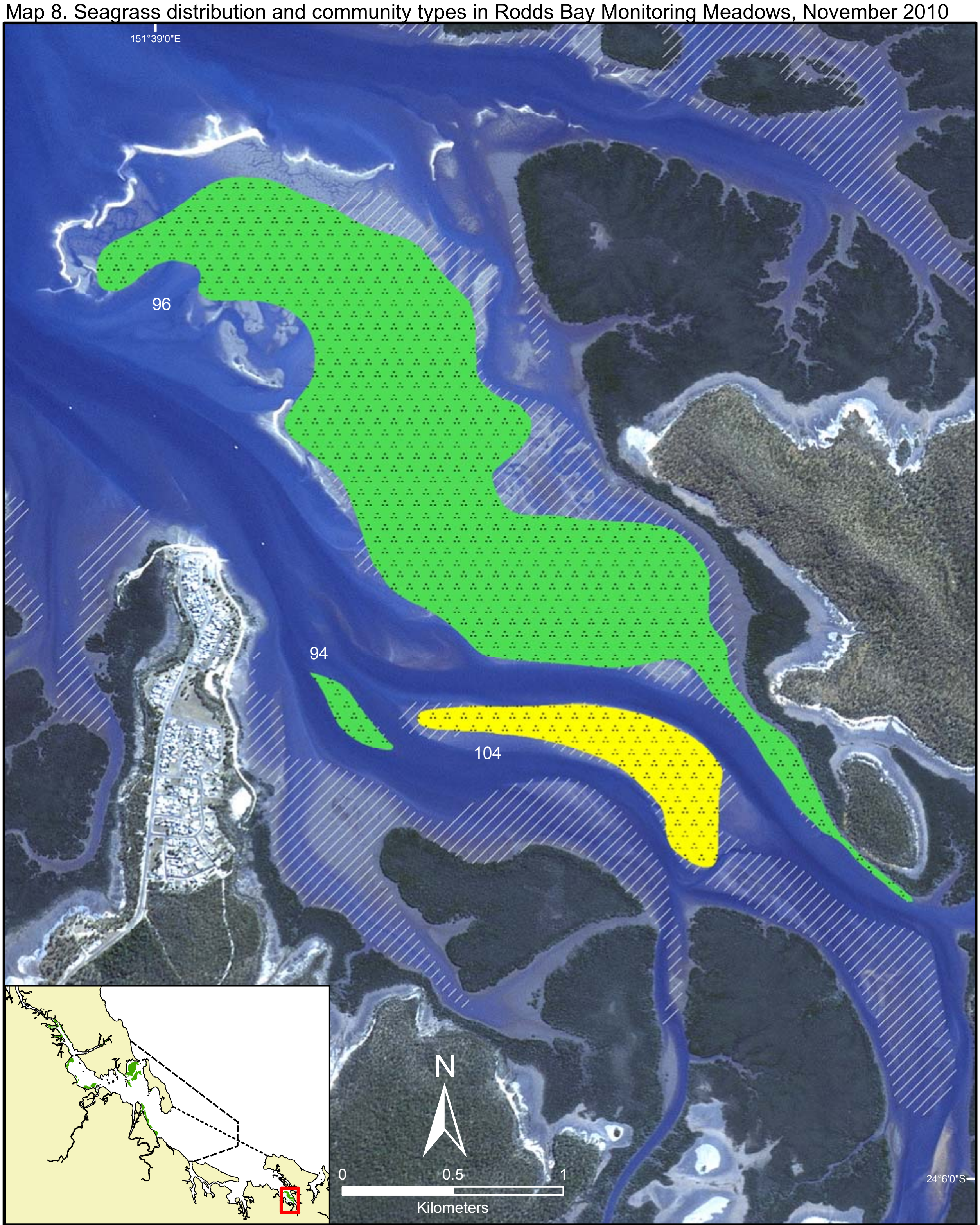
Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Table 8 Seagrass community type, seagrass cover and species present in the South Trees region, November 2010 (see Map 7)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
48	0.44 ± 0.28	83.3 ± 58.09	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide and narrow)
60	0.71 ± 0.28	1.66 ± 2.1	Light *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis (narrow), Halophila ovalis*
70	0.21 ± 0.21	5.41 ± 0.5	Light *Zostera capricorni*	Isolated patches	*Zostera capricorni*
76	5.24 ± 2.54	120.41 ± 86.6	Moderate *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide and narrow), *Halophila ovalis*
78	0.82 ± 0.75	0.61 ± 0.23	*Light Halodule uninervis (narrow)*	Aggregated patches	*Halodule uninervis (narrow)*
86	0.026†	0.32 ± 0.1	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
89	3.80 ± 1.14	87.0 ± 25.9	Moderate *Halodule uninervis (narrow)*	Isolated patches	*Halodule uninervis (narrow)*
142	0.01 ± 0.001	2.61 ± 1.7	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis, Halodule uninervis (narrow)*

† One isolated patch so no standard error calculated

Map 8. Seagrass distribution and community types in Rodds Bay Monitoring Meadows, November 2010



Legend

Seagrass community type

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- November 2009 Seagrass Distribution

Cover

- Isolated Patches
- Aggregated Patches
- Continuous Cover

Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Table 9 Seagrass community type, seagrass cover and species present in the Rodds Bay monitoring meadows, November 2010 (see Map 8)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
94	0.34 ± 0.19	3.95 ± 1.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
96	1.57 ± 0.34	217.88 ± 22.2	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
104	0.58 ± 0.32	30.76 ± 3.4	Light *Zostera capricorni*	Aggregated patches	*Zostera capricorni*

Inter-annual Variability of PCIMP Seagrass Monitoring Meadows

Of the fifteen PCIMP seagrass monitoring meadows, all except the Quoin Island meadow (Meadow 48) decreased in total area from 2009 to 2010. The subtidal monitoring meadows in Fishermans Landing meadow (Meadows 7 and 9) as well as the coastal monitoring meadow at South Trees (Meadow 58) were absent during the survey (Table 11). Mean biomass also generally declined however results varied by meadow (Figure 2; Table 12; Appendix A).

The North Fishermans Landing intertidal meadow (Meadow 8) declined 42% in area from 2009 to 180.27 ± 18.40 ha in 2010, its lowest recorded area since 2002 (Table 11; Map 12). The meadow was patchy as in previous years and above-ground biomass was similar to both 2008 and 2009 levels (Figure 2; Appendix A). The species composition has remained unchanged since monitoring began with *Zostera capricorni* dominating the meadow with a smaller component of *Halophila ovalis* present.

The South Fishermans Landing meadow (Meadow 6) also contracted to fragmented isolated patches of *Zostera capricorni* and *Halophila ovalis* covering 139.66 ± 18.70 ha (Table 11). Mean above-ground biomass was also significantly lower than in 2009 ($p< 0.01$; Table 12; Appendix A).

Total area of the West Wiggins Island meadow (Meadow 5) was similar to previous surveys, however above-ground biomass had significantly reduced to 0.024 ± 0.003 gDW m^{-2} in 2010 ($p<0.01$; Appendix A; Table 11-12). Conversely, Wiggins Island meadow 4 contracted to 1.45 ± 0.5 ha from a meadow relatively consistent in area at approximately 40 ha (Table 11; Figure 2; Map 12). The isolated patches remaining were extremely low in above-ground biomass, however not statistically lower due to the high variability inherent in the meadow (Figure 2; Appendix A).

Of the two new monitoring meadows, Redcliffe Island monitoring meadow (Meadow 23) in The Narrows was consistent in area between 2009 and 2010 while the Channel Island meadows (Meadows 52-57) declined to two isolated patches across both island sandbanks (Map 11-12; Table 11). Biomass at Redcliffe was significantly lower, with a decline from 19.33 ± 4.65 to 2.20 ± 0.42 gDW m^{-2} ($p<0.01$; Table 12; Appendix A), while Channel Island meadows were negligible (one site with recorded biomass) and therefore statistics were not run despite the clear reduction in area and abundance (Table 11-12).

In 2009, a significant decline in area of the Quoin Island meadow was well outside the range of expected change, with the meadow fragmenting into three smaller patches of seagrass (Map 6 and 13). In 2010, seagrass distribution returned to a continuously connected area of 83.3 ± 58.09 ha despite remaining well below the total hectares of previous years (Figure 2B; Map 13). While seagrass biomass remained low in this meadow, it was significantly greater than 2009 levels

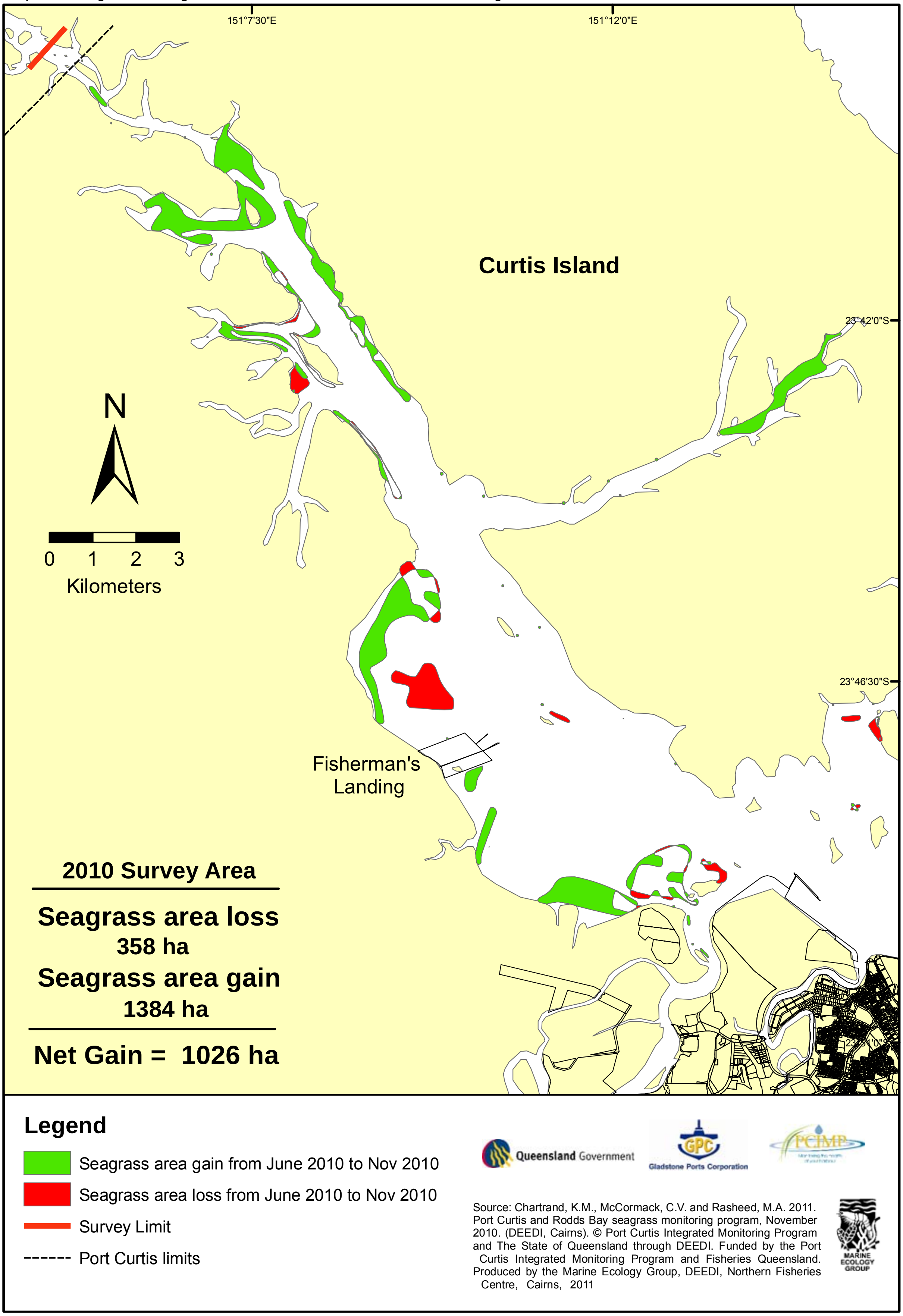
(Figure 2B; Appendix A). Species composition has mostly stayed the same since 2002, with shifts between the narrow and wide morphotypes of *Halodule uninervis* (Map 13; Figure 2).

Pelican Banks meadow (Meadow 43) was the only monitoring meadow in Port Curtis to maintain a moderate density of seagrass and continuous cover in 2010. The meadow has had no overall change in composition since 2002 with *Zostera capricorni* and *Halophila ovalis* maintaining a predictable distribution and little change in biomass over the shallow bank in this area (Map 13; Table 11-12).

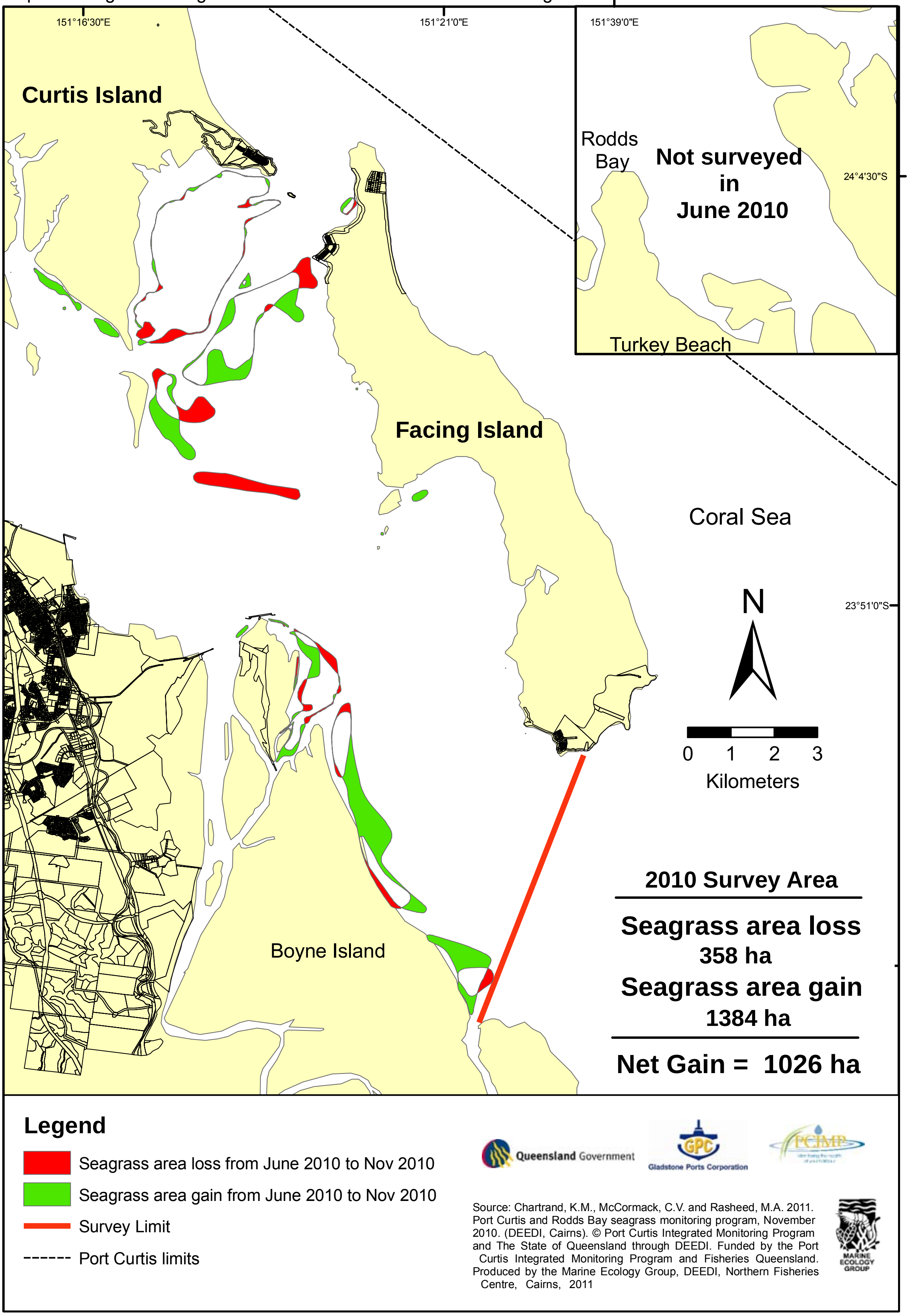
The South Trees meadow (Meadow 58), which was absent in 2010, has previously had low cover and small distribution. South Trees meadow (Meadow 60) was also reduced to a small strip of seagrass at the low tide mark which had previously occurred in 2004 (Map 14; Table 11). There was a species shift with the narrow form of *Halodule uninervis* comprising the majority of the seagrass present (Figure 2B). This species has not previously been recorded in this meadow.

Rodds Bay monitoring meadows maintained their typical composition of *Zostera capricorni* with *Halophila ovalis* present as a secondary species in two of the three meadows (Map 15; Figure 2C). While seagrass was extremely low for all three meadows in both 2009 and 2010, a small but significant increase was recorded in meadow 94 while a significant decline occurred in meadow 96 ($p<0.01$; Table 12; Appendix A).

Map 9a. Seagrass area gain and loss in the northern Port Curtis region from June 2010 to November 2010

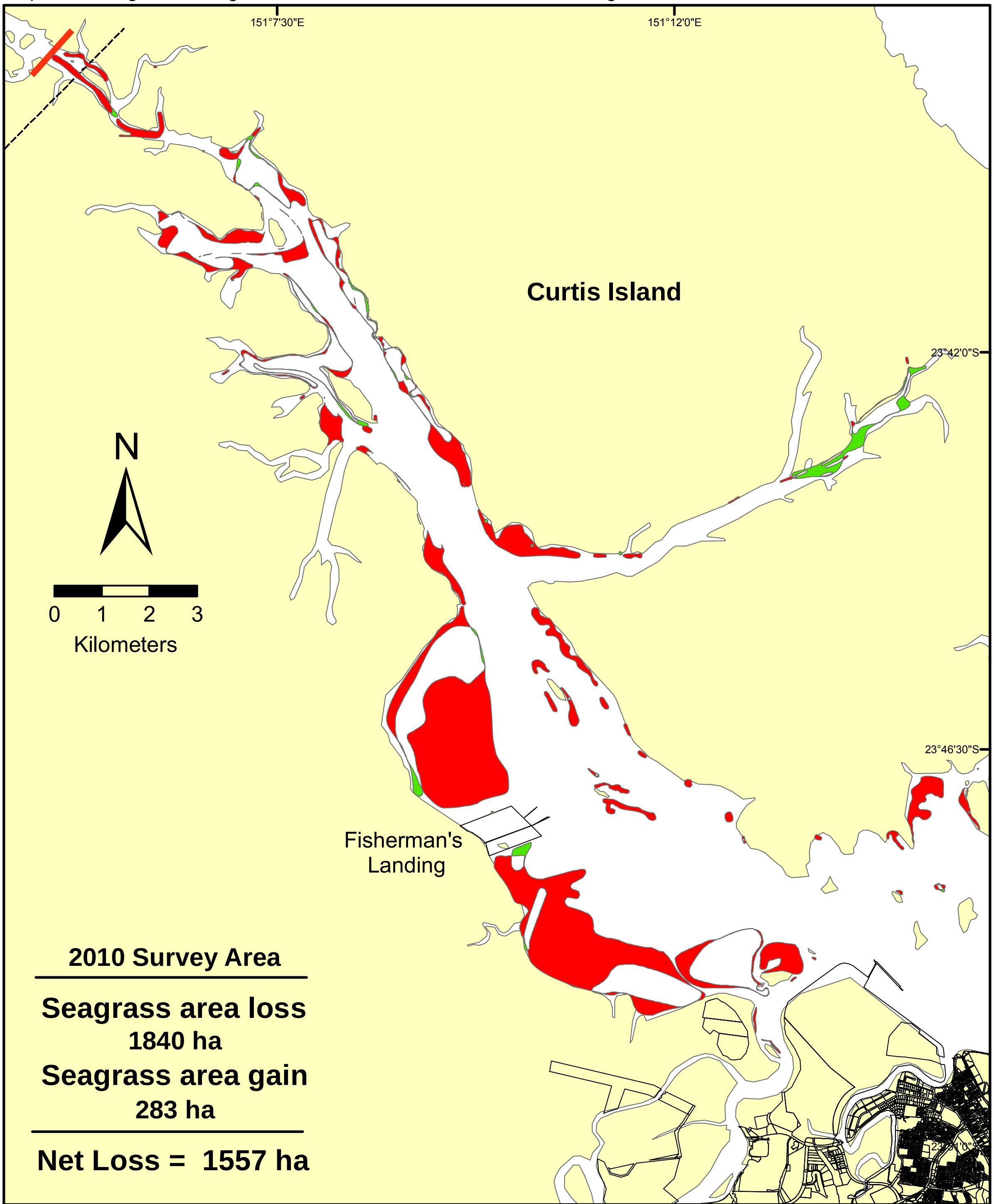


Map 9b. Seagrass area gain and loss in the southern Port Curtis region from June 2010 to November 2010



Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Map 10a. Seagrass area gain and loss in the northern Port Curtis region from November 2009 to November 2010

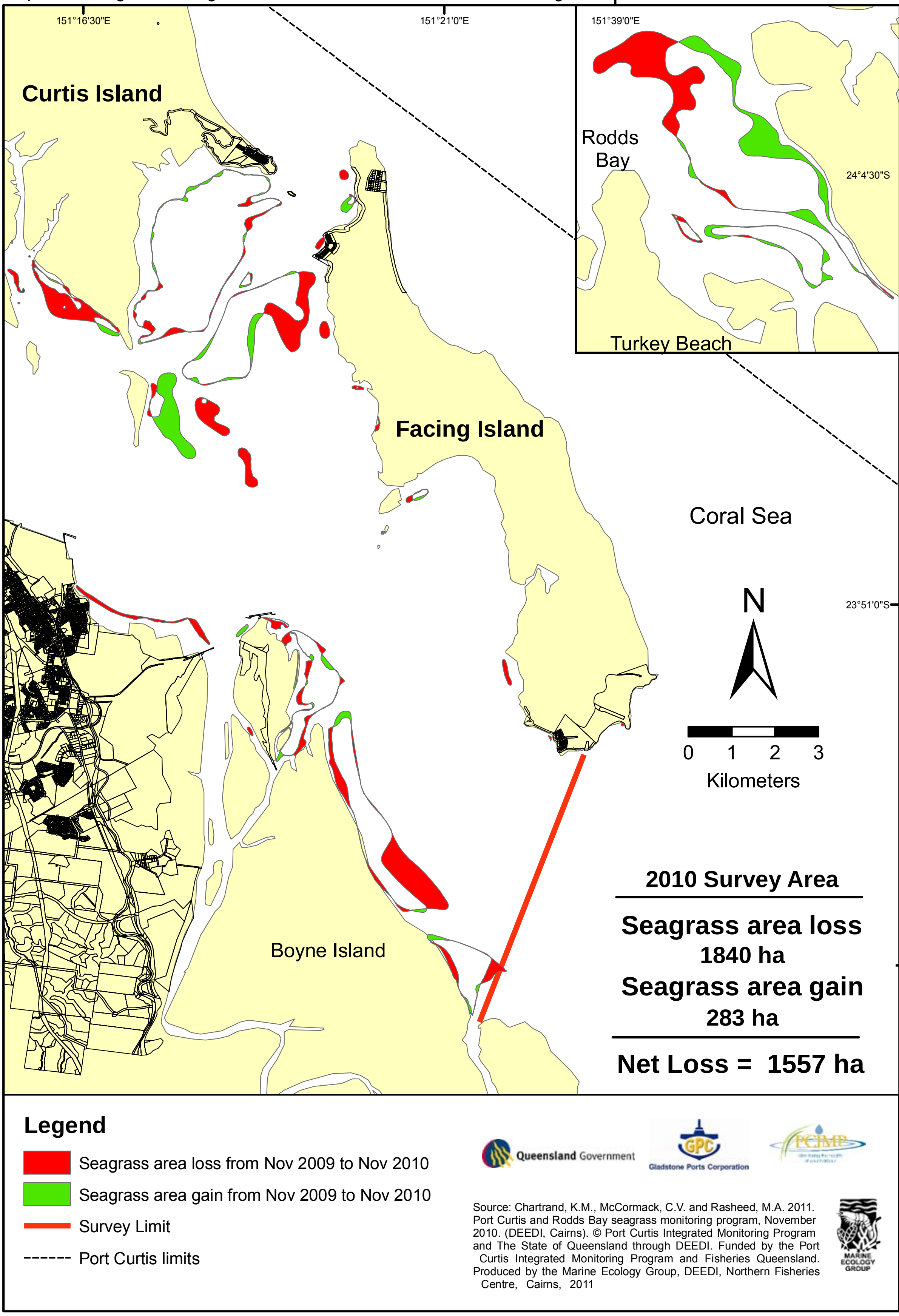


Legend

- Seagrass area loss from Nov 2009 to Nov 2010
- Seagrass area gain from Nov 2009 to Nov 2010
- Survey Limit
- ------ Port Curtis limits

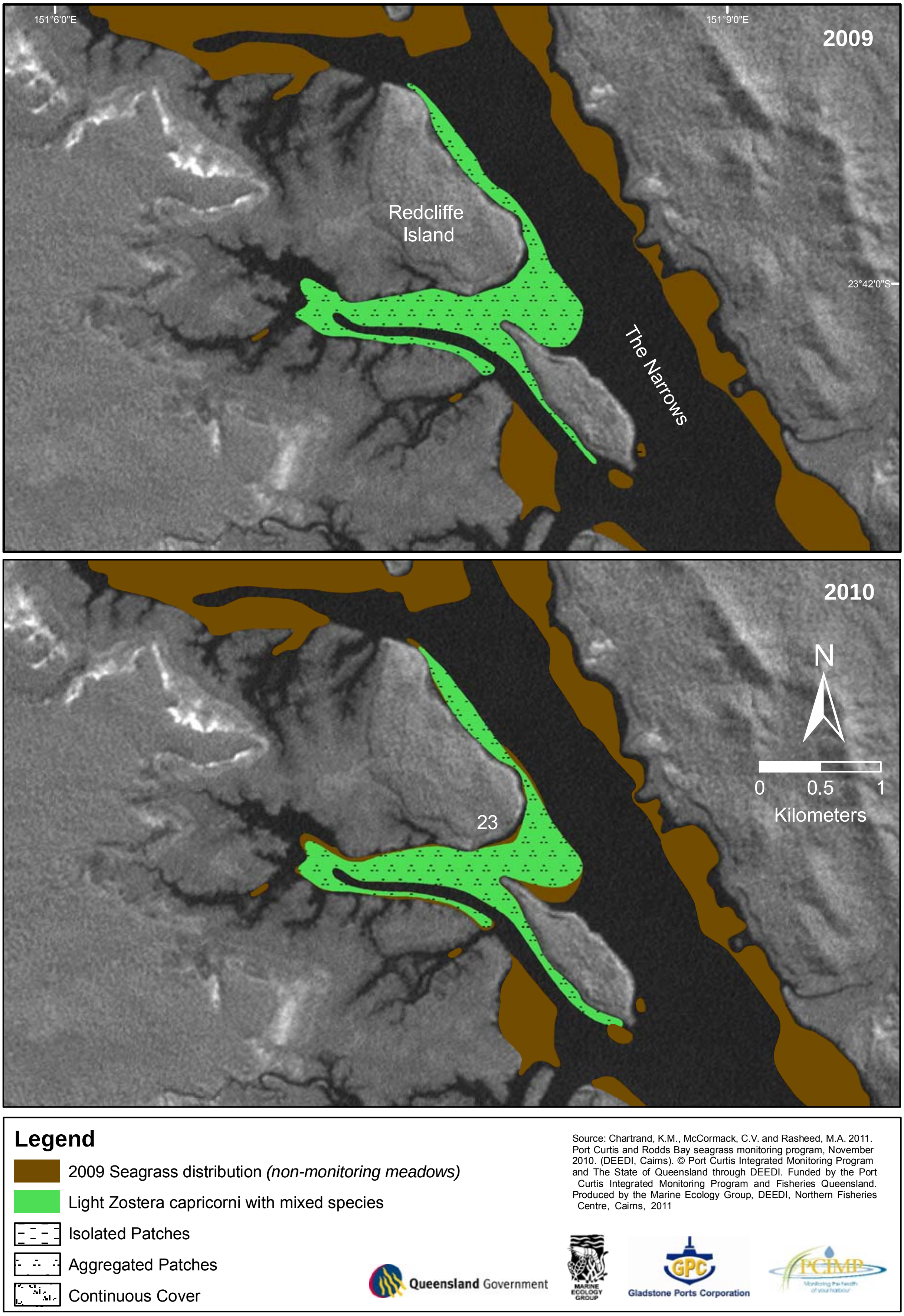
Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Map 10b. Seagrass area gain and loss in the southern Port Curtis region from November 2009 to November 2010

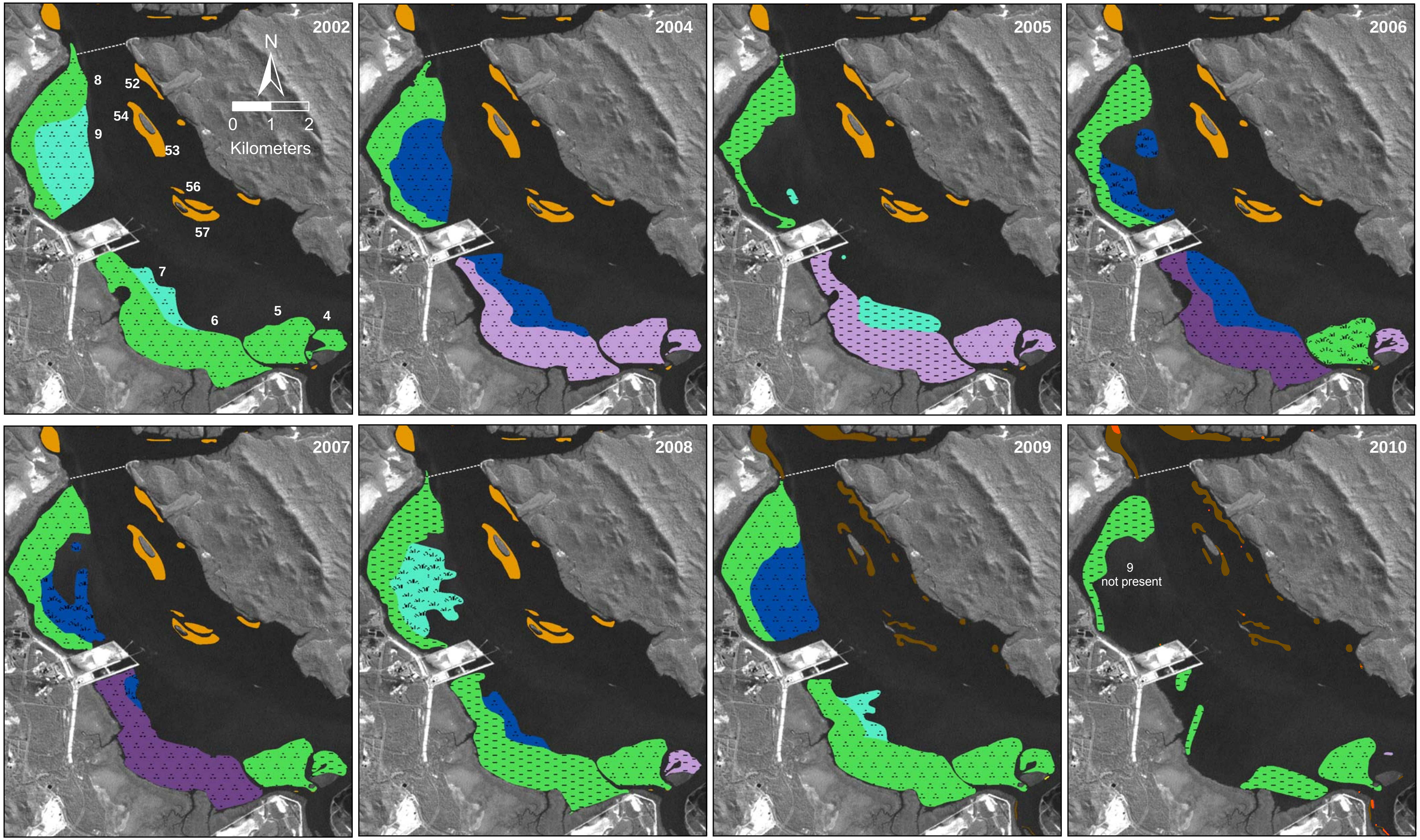


Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Map 11. Monitoring meadows comparison, Redcliffe Island region, 2009-2010



Map 12. Monitoring meadows comparison, Fishermans Landing region, 2002 and 2004 - 2010

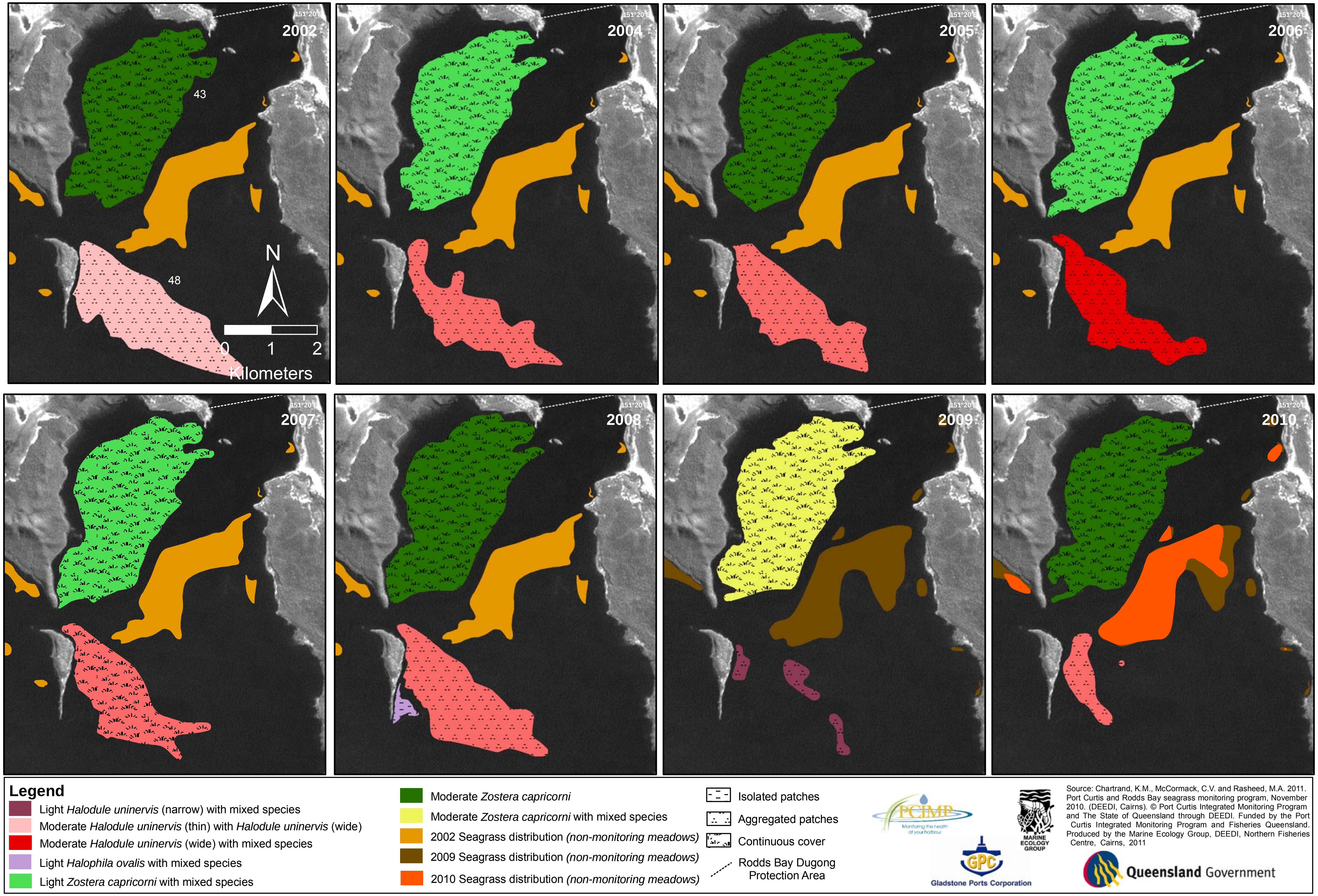


Legend

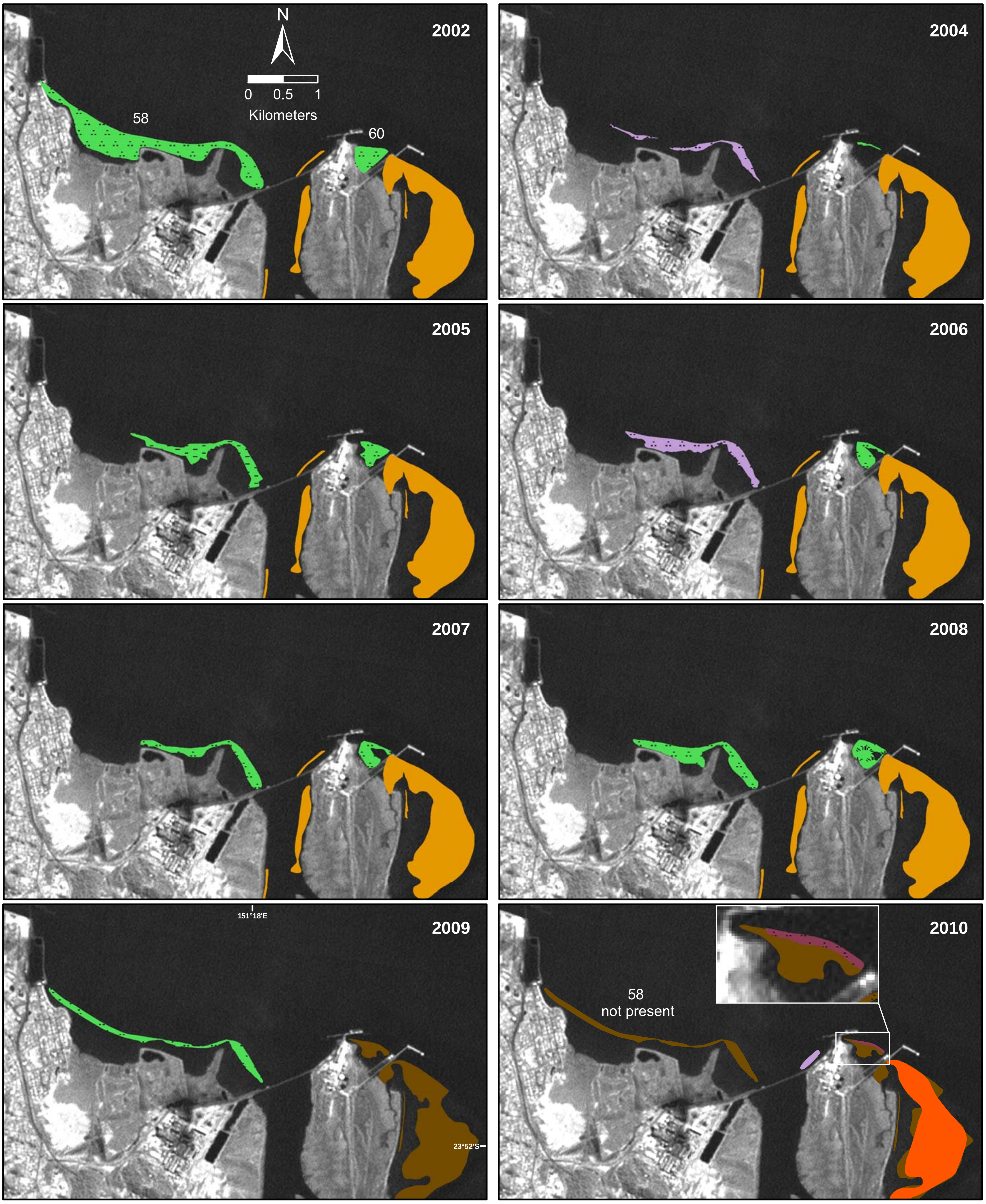
- Light *Zostera capricorni* with mixed species
- Light *Halophila ovalis* with mixed species
- Light *Halophila decipiens* with mixed species
- Moderate *Halophila ovalis* with mixed species
- Moderate *Halophila decipiens* with mixed species
- 2002 Seagrass distribution *(non monitoring meadows)*
- 2009 Seagrass distribution *(non monitoring meadows)*
- 2010 Seagrass distribution *(non-monitoring meadows)*
- Isolated patches
- Aggregated patches
- Continuous cover
- Rodds Bay Dugong Protection Area

Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Map 13. Monitoring meadows comparison, Pelican Banks region, 2002 and 2004 - 2010



Map 14. Monitoring meadows comparison, South Trees, 2002 and 2004 - 2010

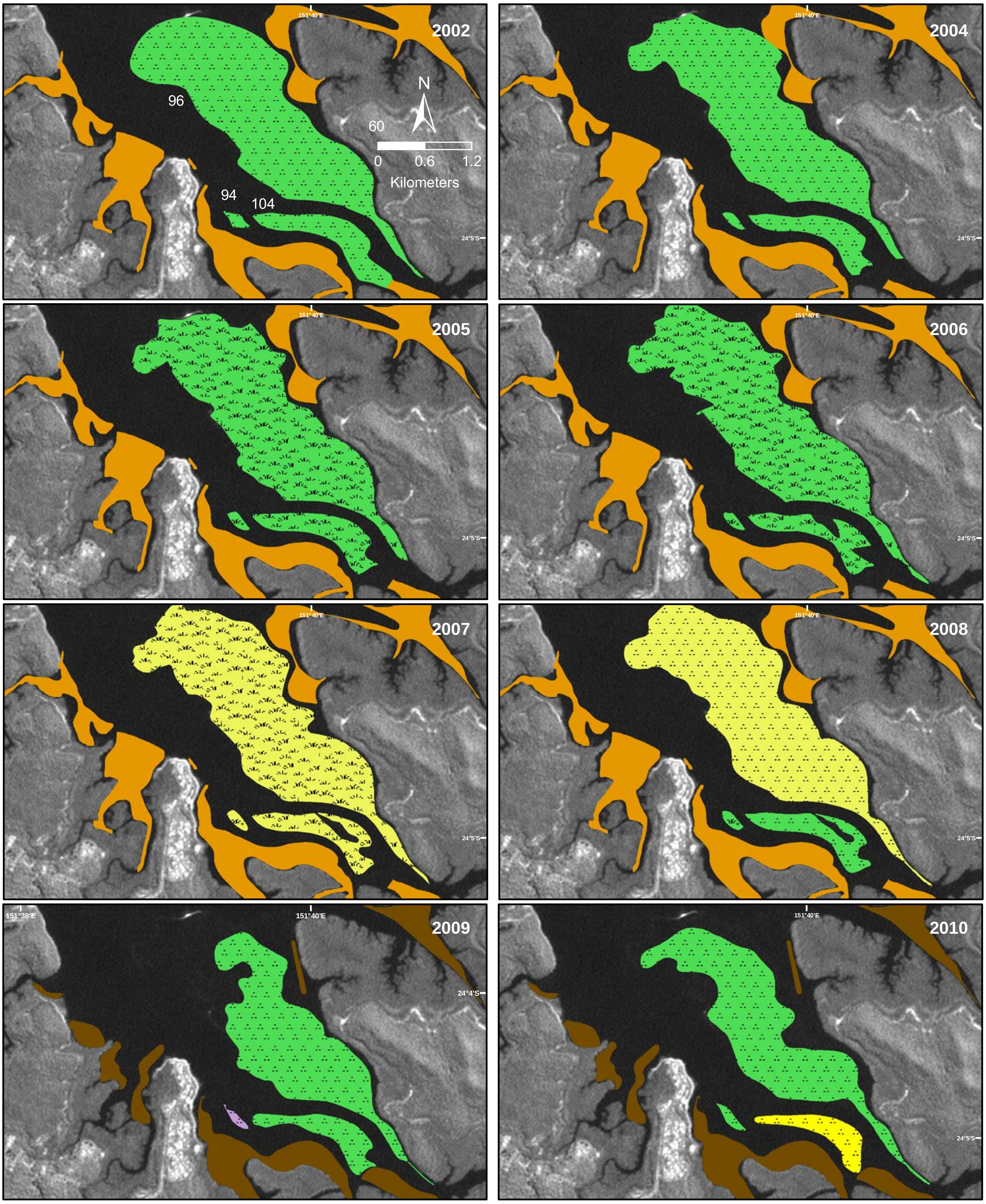


Legend

- Light *Zostera capricorni* with mixed species
- Light *Halodule uninervis* (narrow) with mixed species
- Light *Halophila ovalis* with mixed species
- 2010 Seagrass distribution *(non-monitoring meadows)*
- 2009 Seagrass distribution *(non-monitoring meadows)*
- Isolated Patches
- Aggregated Patches
- Continuous Cover
- 2002 Seagrass distribution *(non-monitoring meadows)*

Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Map 15. Monitoring meadows comparison, Rodds Bay, 2002 and 2004 - 2010



Legend

- Light *Zostera capricorni*
- Light *Zostera capricorni* with mixed species
- Light *Halophila ovalis* with mixed species
- 2009 Seagrass distribution *(non-monitoring meadows)*
- 2002 Seagrass distribution *(non-monitoring meadows)*

- Isolated Patches
- Aggregated Patches
- Continuous Cover

Source: Chartrand, K.M., McCormack, C.V. and Rasheed, M.A. 2011. Port Curtis and Rodds Bay seagrass monitoring program, November 2010. (DEEDI, Cairns). © Port Curtis Integrated Monitoring Program and The State of Queensland through DEEDI. Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2011

Table 11 Area (ha) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006, October 2007, November 2008, November 2009 and November 2010

Meadow ID	See map	Location	Meadow Depth	Meadow Area (ha)							
				2002	2004	2005	2006	2007	2008	2009	2010
4	12	Wiggins Island	intertidal	35.8 ± 1.7	35.6 ± 1.7	32.5 ± 1.9	35.9 ± 2.1	40.2 ± 2.0	34.6 ± 1.8	41.0 ± 1.8	1.5 ± 0.5
5	12	Wiggins Island	intertidal	149.8 ± 2.5	143.6 ± 2.5	140.11 ± 2.5	147.4 ± 2.5	147.5 ± 2.9	151.2 ± 2.7	154.7 ± 2.9	120.7 ± 5.1
6	12	South Fishermans	intertidal	464.0 ± 12.9	373.5 ± 11.9	406.4 ± 12.7	428.8 ± 13.0	470.1 ± 12.9	453.1 ± 13.2	457.3 ± 6.0	139.7 ± 18.7
7	12	South Fishermans	subtidal	72.6 ± 11.4	185.6 ± 8.7	112.1 ± 12.3	203.1 ± 8.2	20.6 ± 2.4	65.9 ± 5.1	60.0 ± 10.8	n.p.
8	12	North Fishermans	intertidal	269.1 ± 11.3	268.3 ± 12.5	231.1 ± 12.3	275.2 ± 12.0	309.9 ± 12.0	294.9 ± 12.6	311.8 ± 10.4	180.3 ± 18.4
9	12	North Fishermans	subtidal	268.3 ± 14.9	284.4 ± 7.1	7.0 ± 1.1	143.9 ± 8.0	153.0 ± 8.3	242.5 ± 8.2	286.7 ± 14.2	n.p.
23	11	The Narrows	intertidal							111.4 ± 14.4	102.9 ± 14.1
43	13	Pelican Banks	intertidal	624.8 ± 12.3	592.8 ± 12.4	614.6 ± 11.9	606.8 ± 14.5	662.0 ± 13.2	681.4 ± 12.8	644.1 ± 13.3	625.0 ± 14.2
48	13	Quoin Island	intertidal/ subtidal	421.4 ± 10.2	285.8 ± 21.8	316.6 ± 18.7	285.1 ± 19.9	301.7 ± 19.8	370.9 ± 19.4	62.9 ± 6.8	83.3 ± 58.1
52	12	Channel Islands	intertidal							5.3 ± 0.6	0.4 ± 0.2
58	14	South Trees	intertidal	71.9 ± 3.9	11.2 ± 2.3	23.7 ± 2.4	24.0 ± 2.4	18.9 ± 2.1	27.4 ± 2.2	22.2 ± 3.5	n.p.
60	14	South Trees	intertidal	11.1 ± 0.7	0.8 ± 0.4	7.7 ± 0.6	7.5 ± 0.8	7.9 ± 0.8	10.7 ± 0.9	6.4 ± 0.7	1.66 ± 2.1
94	15	Rodds Bay	intertidal	3.1 ± 0.4	2.7 ± 0.8	3.1 ± 0.8	2.9 ± 0.8	3.2 ± 0.8	3.2 ± 0.8	2.6 ± 0.5	3.9 ± 1.1
96	15	Rodds Bay	intertidal	321.9 ± 10.6	303.5 ± 10.3	314.8 ± 10.6	324.4 ± 11.9	327.0 ± 11.5	329.9 ± 11.6	209.1 ± 10.0	217.9 ± 22.2
104	15	Rodds Bay	intertidal	47.7 ± 4.3	38.9 ± 3.8	41.94 ± 3.8	35.6 ± 4.5	36.7 ± 5.2	37.7 ± 5.0	36.4 ± 1.9	30.8 ± 3.4

n.p indicates no seagrass was present during the survey

Table 12 Mean above ground biomass (g DW m^{-2}) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006, October 2007, November 2008, November 2009 and November 2010

Meadow ID	See map	Location	Meadow Depth	Mean biomass (g DW m^{-2})							
				2002	2004	2005	2006	2007	2008	2009	2010
4	12	Wiggins Island	intertidal	0.8 ± 0.4	0.74 ± 0.36	0.33 ± 0.15	0.74 ± 0.26	1.20 ± 0.67	0.78 ± 0.47	1.47 ± 0.45	0.024 ± 0.003
5	12	Wiggins Island	intertidal	1.4 ± 0.3	0.57 ± 0.19	0.86 ± 0.5	3.73 ± 0.77	8.78 ± 1.17	6.92 ± 1.03	1.38 ± 0.32	0.68 ± 0.22
6	12	South Fishermans	intertidal	1.1 ± 0.1	0.24 ± 0.09	0.94 ± 0.61	2.65 ± 0.66	6.32 ± 0.86	1.42 ± 0.32	3.05 ± 0.97	0.22 ± 0.08
7	12	South Fishermans	subtidal	0.9 ± 0.2	1.91 ± 0.36	0.03 ± 0.02	3.7 ± 0.95	4.16 ± 1.36	1.20 ± 0.53	0.26 ± 0.12	n.p.
8	12	North Fishermans	intertidal	2.1 ± 0.3	0.14 ± 0.08	0.06 ± 0.04	1.28 ± 0.49	3.89 ± 0.77	0.69 ± 0.25	0.74 ± 0.25	0.58 ± 0.23
9	12	North Fishermans	subtidal	0.9 ± 0.3	1.93 ± 0.27	0.001 ± 0.001	4.98 ± 0.72	4.64 ± 0.63	0.30 ± 0.09	2.49 ± 0.44	n.p.
23	11	The Narrows	intertidal							19.33 ± 4.65	2.20 ± 0.42
43	13	Pelican Banks	intertidal	20.8 ± 3.1	18.71 ± 2.13	28.3 ± 3.3	14.17 ± 1.07	13.87 ± 2.24	25.96 ± 3.03	20.46 ± 2.02	21.53 ± 2.81
48	13	Quoin Island	intertidal/ subtidal	1.8 ± 0.2	1.11 ± 0.2	2.12 ± 1.01	9.52 ± 1.85	6.21 ± 0.80	2.81 ± 0.60	0.13 ± 0.04	0.44 ± 0.28
52	12	Channel Islands	intertidal							0.03 ± 0.01	0.005
58	14	South Trees	intertidal	1.8 ± 0.5	0.47 ± 0.12	1.19 ± 0.35	0.44 ± 0.34	5.60 ± 1.24	4.89 ± 1.26	5.14 ± 1.50	n.p.
60	14	South Trees	intertidal	9.4 ± 3.3	0.08 ± 0.01	0.09 ± 0.03	4.23 ± 0.58	9.04 ± 2.40	11.29 ± 3.65	2.16 ± 0.46	0.71 ± 0.28
94	15	Rodds Bay	intertidal	15.1 ± 11.8	2.3 ± 0.51	17.11 ± 3.02	10.54 ± 1.38	28.11 ± 7.67	17.33 ± 8.70	0.01 ± 0.01	0.34 ± 0.19
96	15	Rodds Bay	intertidal	6.4 ± 3.1	0.9 ± 0.5	3.62 ± 1.41	7.7 ± 1.58	21.56 ± 4.88	24.84 ± 5.01	8.96 ± 1.38	1.57 ± 0.34
104	15	Rodds Bay	intertidal	8.4 ± 3.7	1.26 ± 0.43	10.73 ± 2.62	10.76 ± 1.81	25.20 ± 7.09	18.89 ± 4.84	2.56 ± 0.89	0.58 ± 0.32

n.p indicates no seagrass was present during the survey

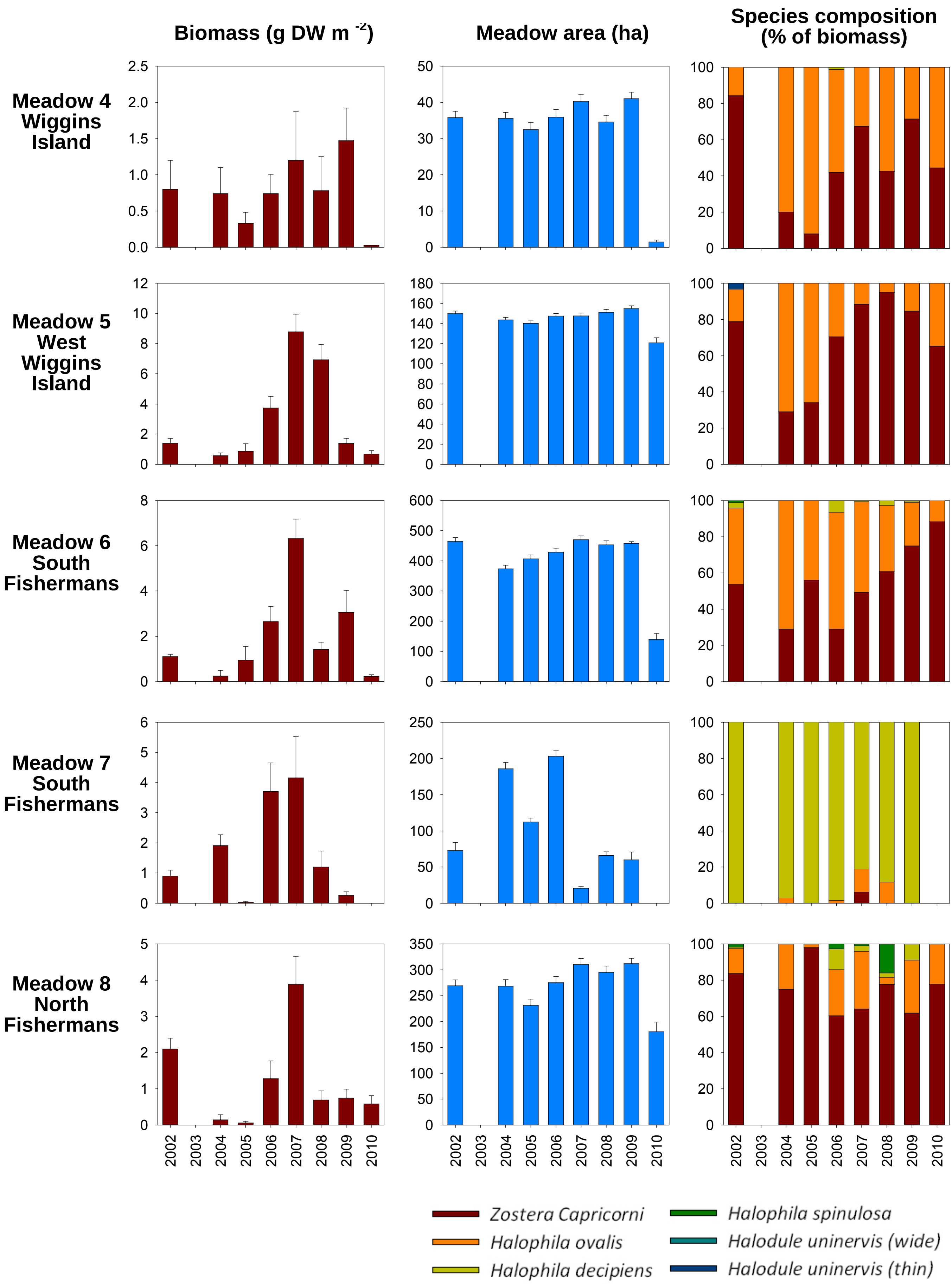


Figure 2(A) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2010 (Biomass error bars = SE; Area error bars = “R” reliability estimate)

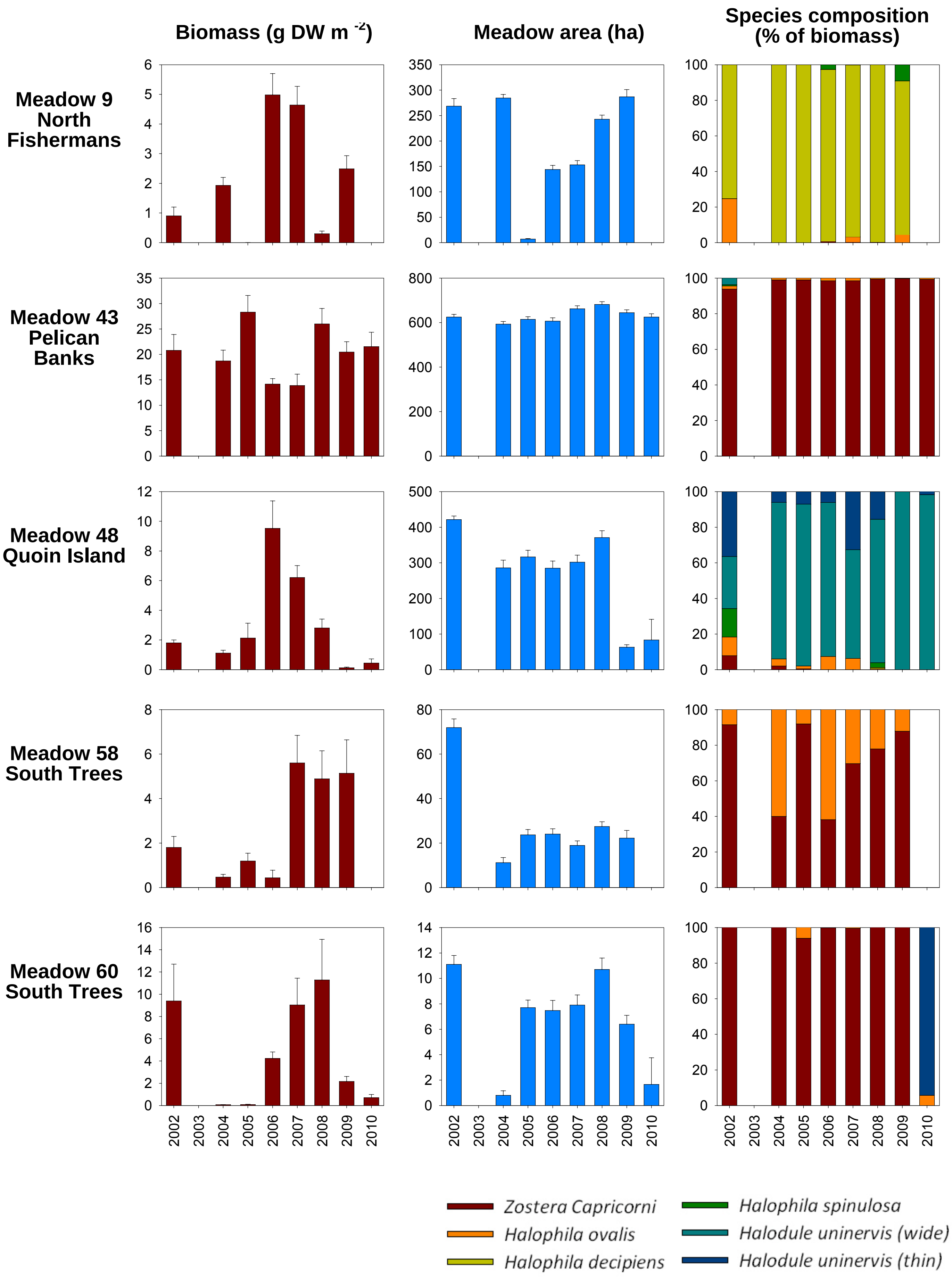


Figure 2(B) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2010 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

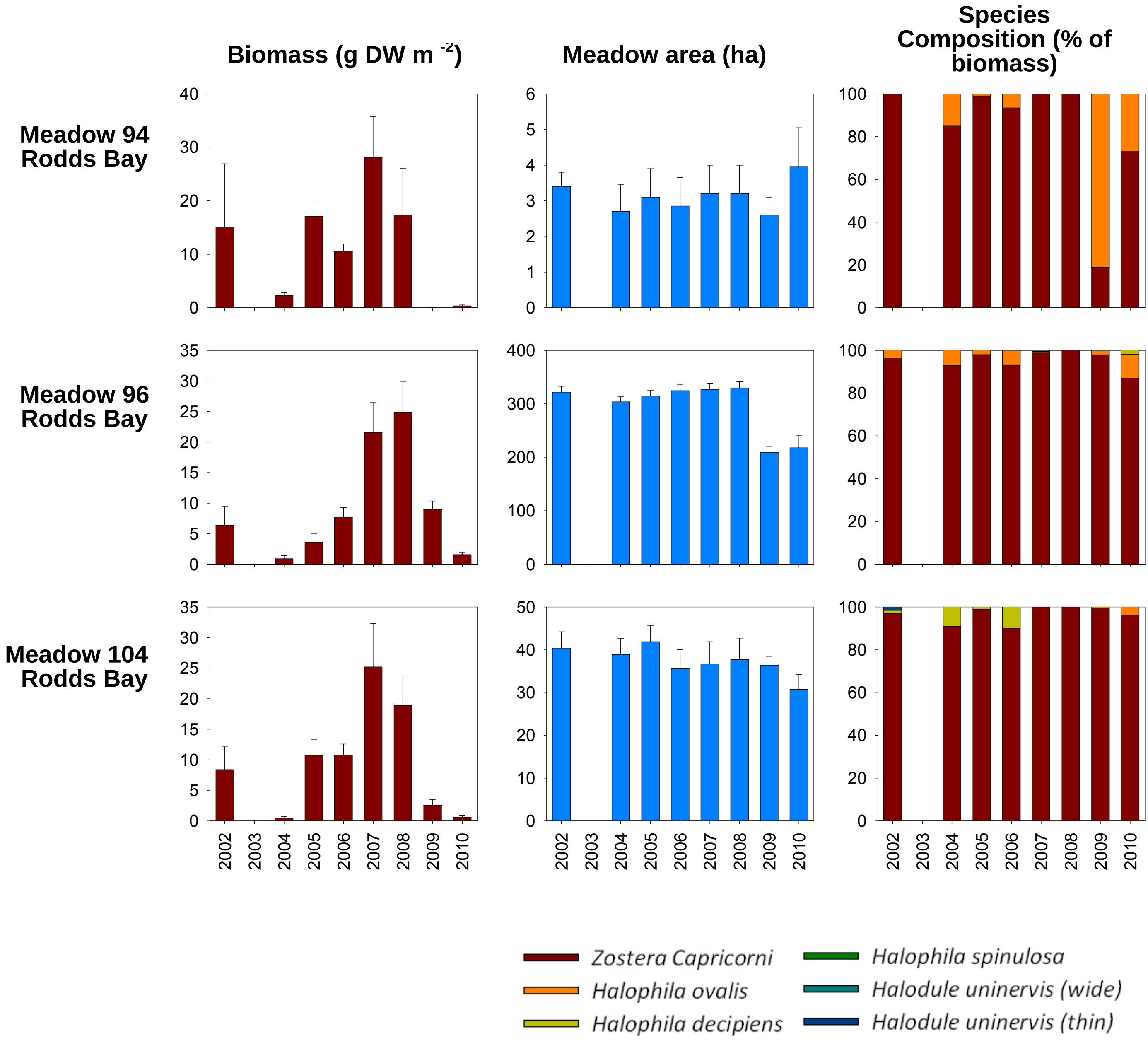


Figure 2(C) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2010 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

Gladstone Environmental Parameters

Tidal exposure in 2010 (measured as numbers of hours seagrass meadows were subjected to tides of <1m during the day) was the lowest recorded since monitoring began in 2002 (Figure 3). Total annual rainfall was almost 40% higher in 2010 than in 2009 and was the second highest level recorded over the course of the monitoring program (Figure 3). Mean daily wind speed (18.22 ± 7.41 $km.hr^{-1}$) was close to the long-term average (from 2002 to 2010; Figure 3).

Mean maximum daily temperature at the seagrass canopy was higher over summer months (January and February) than winter months (June to August; e.g. Meadows 5 and 6; Figure 4). Maximum daily temperature was also higher and more variable at intertidal meadows (e.g. Meadow 5 and 6; Figure 4A) than at subtidal meadows (e.g. Meadow 7 and 9; Figure 4B). The highest temperature recorded was 42ºC at Wiggins Island in January and the lowest recorded was 8.5 ºC at Rodd's Bay in August.

Light data collected by Vision Environment demonstrated the naturally turbid environment in which seagrasses persist in the inner harbour. However turbidity is highly seasonal, with summer algal blooms and rainfall events affecting both the light environment and the growing conditions for seagrasses. For example mean benthic total daily PAR ($mol/m^2/day$) for intertidal monitoring meadows in the inner harbour (e.g. Meadow 5 and 6; Figure 5) was typically higher in summer months than winter months. Lower mean levels of total daily PAR coincided with periods of lower rainfall. Conversely, for subtidal meadows, mean total daily PAR was slightly higher in winter than summer months (e.g. Meadow 7 and 9; Figure 5). This further reflects the seasonality of turbidity in the inner harbour. In general, higher mean levels of total daily PAR coincided with periods of lower rainfall.

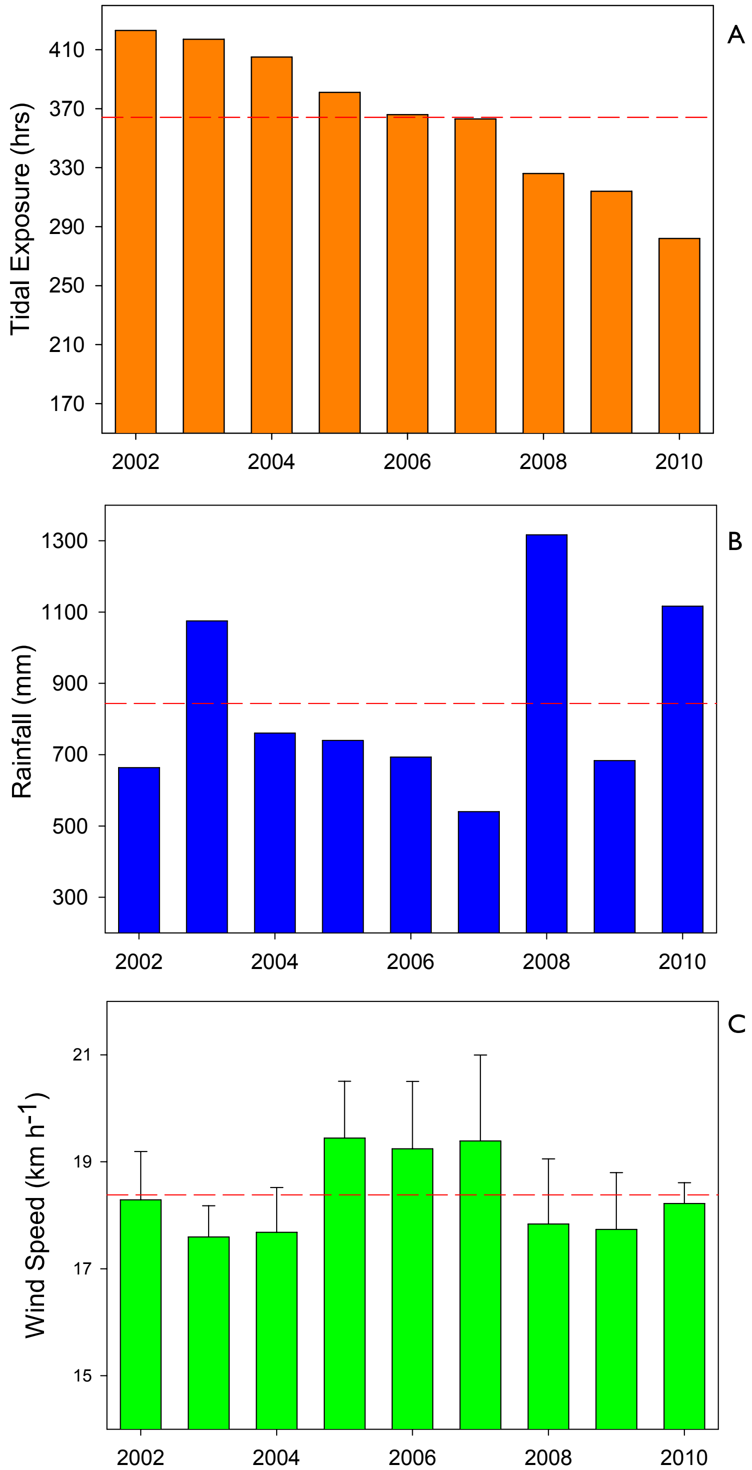


Figure 3 (A-C) Mean annual (Nov to Oct) climate and environmental parameters for Gladstone from 2002 to 2010. A) Total annual day light tidal exposure at <1.0m B) total annual rainfall C) mean annual daily wind speed. Long-term averages (from 2002 to 2010) are shown in red. All climate data is recorded at Gladstone Radar (BOM station 39123; www.bom.gov.au). All tidal data is from Gladstone Auckland Point (MSQ station 052027A; www.msq.qld.gov.au)

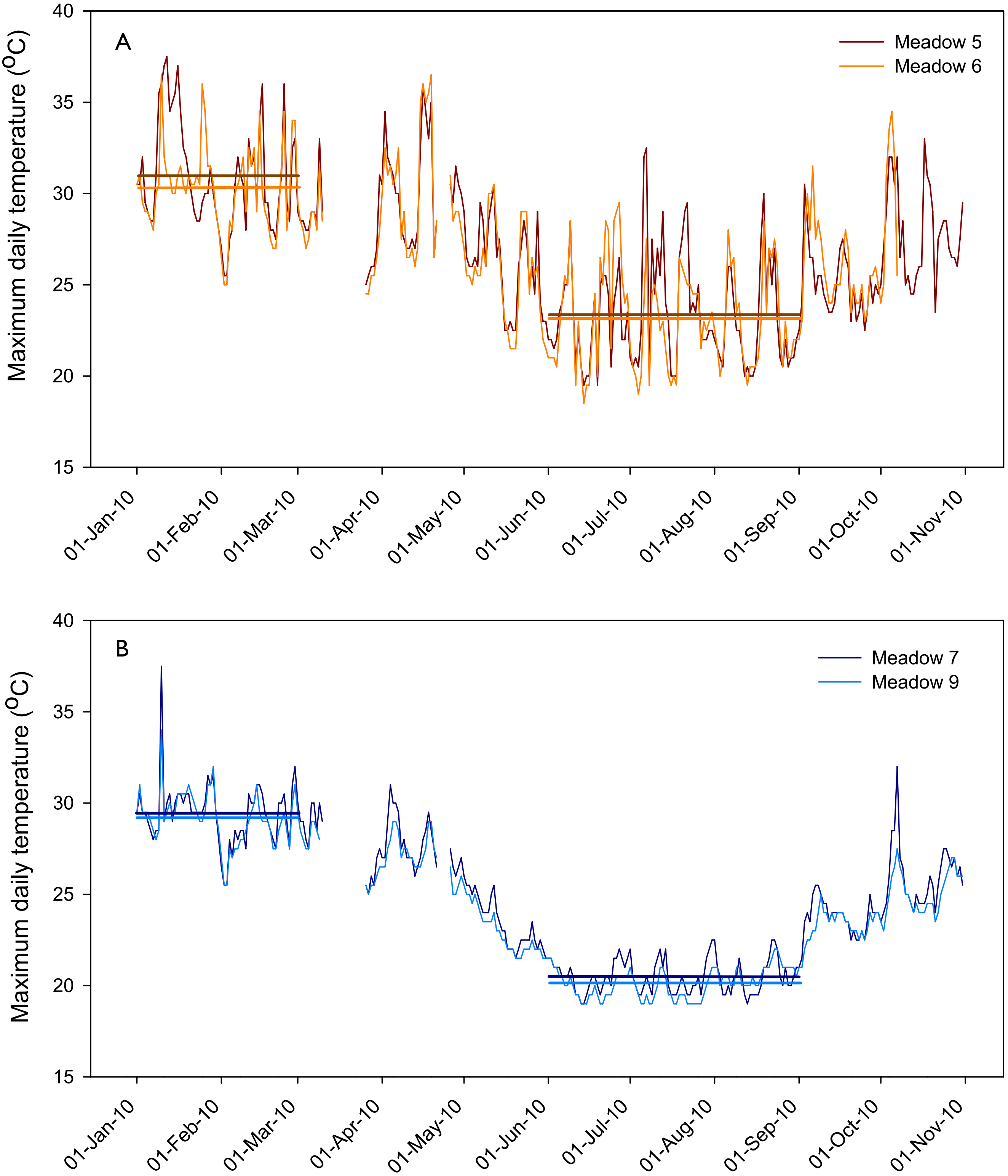
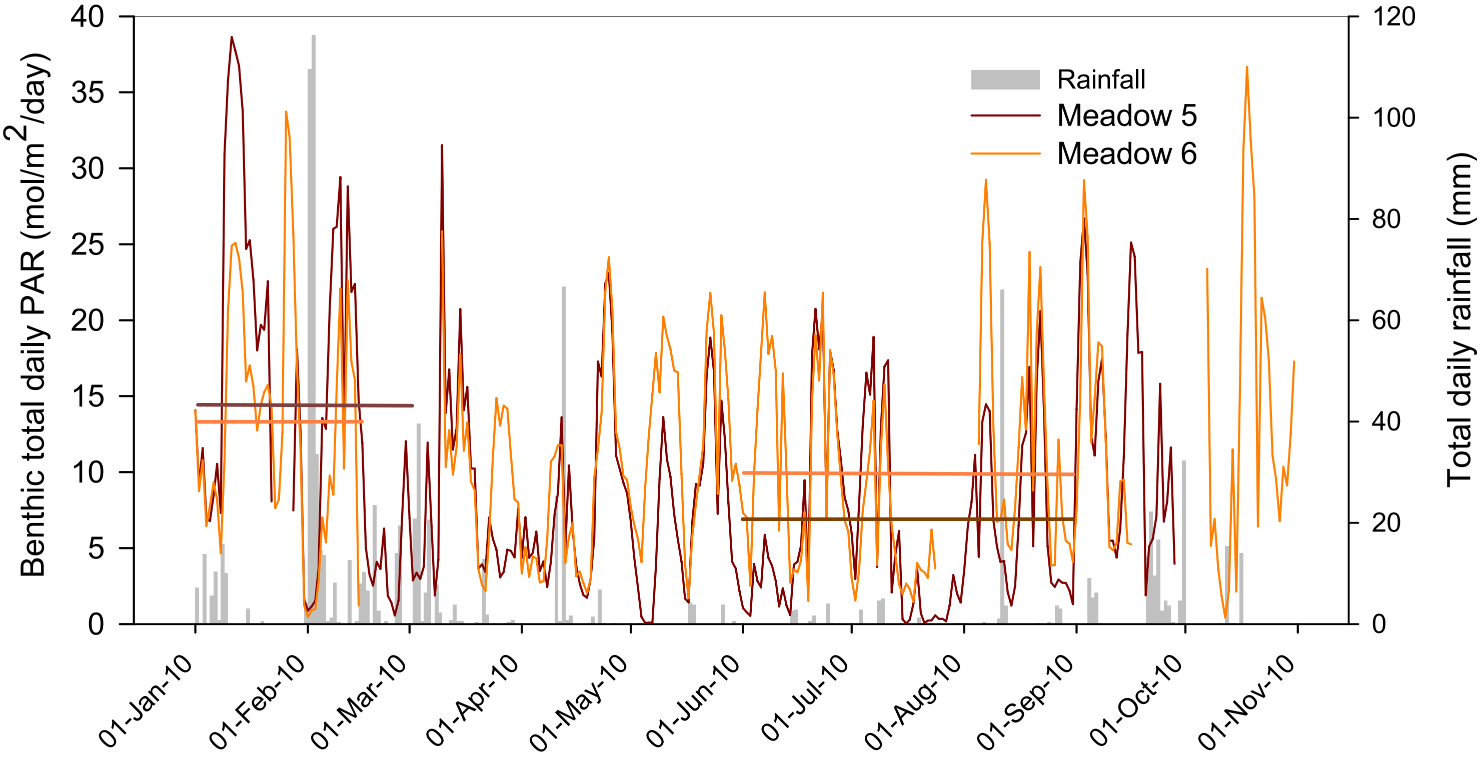


Figure 4 Maximum daily temperatures (ºC) recorded by *in situ* temperature loggers in the seagrass canopy for A) intertidal meadows 5 and 6 and B) subtidal meadows 7 and 9 in the Port of Gladstone. Mean maximum daily temperature is shown for summer months (Jan and Feb) and winter months (Jun to Aug).



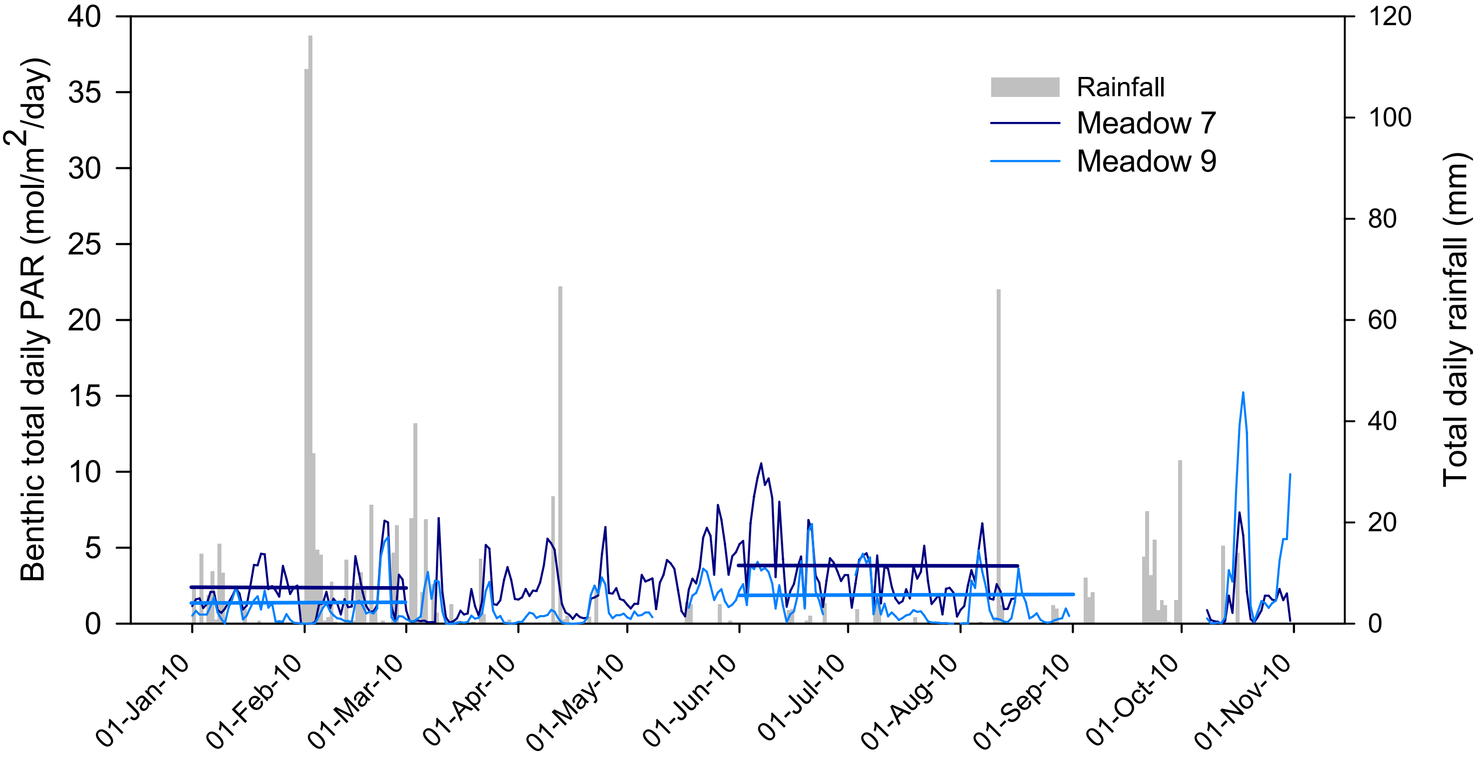


Figure 5 Benthic total daily PAR (mol/m²/day) recorded by *in situ* PAR loggers in the seagrass canopy for A) intertidal meadows 5 and 6 at and B) subtidal meadows 7 and 9 in the Port of Gladstone. Mean total daily PAR is shown for summer months (Jan and Feb) and winter months (Jun to Aug). PAR data for meadow 6 were not available for part of February. PAR data for meadow 7 were not available for part of August. Total daily rainfall was recorded at Gladstone BOM station 39123 (www.bom.gov.au)

DISCUSSION

The results of the seventh annual PCIMP seagrass monitoring program (PCIMP) and Western Basin survey found the majority of monitoring meadows had reduced to their smallest area and density recorded in the program and suggests that seagrasses were in a vulnerable condition. This is in contrast to 2009, where seagrasses in Port Curtis were at their peak abundance and distribution since monitoring began in 2002. Above average rainfall and flooding from local rivers and waterways likely led to the observed reduction in available light for seagrasses and resulting seagrass declines. The complete loss of the subtidal monitoring meadows at Fishermans Landing and intertidal meadow at South Trees is of particular concern. The contraction of the Wiggins Island monitoring meadow and lack of dugong feeding trails recorded during the aerial survey are key shifts from all previous monitoring surveys.

Port Curtis seagrass meadows are of high ecological and economic value. Their role includes providing important habitat and feeding resources for IUCN red-listed vulnerable species of dugong and green turtle (Hughes et al. 2009), supporting economically important fisheries (Watson et al. 1993; Unsworth and Cullen 2010), and playing an important role in nutrient and carbon cycling in the local environment (Costanza et al. 1997; Hemminga and Duarte 2000). Fisheries surveys in 1988 found Gladstone harbour seagrass meadows to be important habitat for a range of fish, crab and prawn species (Lee Long et al. 1992).

As the only known major area of seagrass between Hervey Bay (170 km south) and Shoalwater Bay (170 km north), seagrass meadows in Port Curtis and Rodds Bay play an important role for turtles and dugong in this region (Lee Long et al. 1992). Local meadows provide both a regular food source as well as a natural corridor between adjacent seagrass habitats. This value is recognised by the Dugong Protection Area (DPA: Zone B) declared for the majority of the surveyed area (www.gbrmpa.gov.au). Dugong and turtle (and their feeding trails) have been commonly observed throughout Port Curtis and Rodds Bay by the Marine Ecology Group (DEEDI) during habitat seagrass surveys over the last two decades (1988 to 2009). Corresponding with a reduction in seagrass area there was an absence of DFTs in many areas where they have consistently been recorded in previous surveys. However, the natural decline in seagrasses in the port area may have led to dugong utilising more appropriate feeding areas in the short term and feeding trails were observed in the Pelican Banks area where relatively dense seagrass remained. If local conditions continue to improve, signs of dugong activity would be expected to return in parallel with increased seagrass abundance during future surveys.

Light is considered to be the primary environmental variable determining seagrass distribution, abundance and productivity (Duarte et al. 1997; Vermaat et al. 1997). Seagrass minimum light requirements differ between species, yet it is well established that changes in the availability of light with increasing depth remains the primary factor affecting the distribution of seagrasses (Bjork et al. 1999; Hemminga and Duarte 2000; Erftemeijer and Lewis 2006; Ralph et al. 2007). Studies of seagrasses in tropical regions have indicated that genera such as *Zostera* and *Halodule* require significantly greater light requirements (Grice et al 1996; Bach et al 1998; Collier et al. 2009) than other genera such as *Halophila* and *Halodule* (Freeman et al. 2008). In Gladstone, it is likely that high turbidity from well above average river flooding in combination with a typically turbid port environment resulted in the greatly reduced light availability, potentially contributing to the widespread decline of intertidal meadows and loss of subtidal seagrass.

Many of the changes to seagrasses that were observed in Port Curtis in 2010 were indicative of low light conditions. Seagrasses growing near their minimum light requirements employ a range of physiological and morphological mechanisms to increase survival. In particular, shoot density, biomass, growth and shoot length decrease (Abal et al. 1994; Longstaff et al. 1999; Ralph et al. 2007; Collier et al. 2009), changes that were clearly identifiable in Gladstone seagrasses in 2010. In conditions of severe low light, periods around low tide for intertidal seagrasses can provide the necessary light needed to maintain a net positive balance of photosynthesis (Vermaat et al. 1997; Schwarz 2004). However, daytime exposure of intertidal seagrasses can also be damaging if high light and high temperatures persist over many hours for consecutive days. The combination of summer high temperatures during air exposure with otherwise extreme low light likely contributed to declines in inner harbour seagrass declines in 2010.

The complete loss of subtidal meadows such as Fishermans Landing (Meadow 7 and 9), suggests the overall light available was well below what is required to sustain these populations. *Halophila* species found in these meadows, while well adapted to lower light conditions and typically dominant in subtidal and highly turbid areas, decline quickly with adverse conditions such as extreme low light (Kenworthy et al. 1989; Durako et al. 2003). However, the same species are quick to respond positively when conditions such as light improve. *Halophila* species are fast growing and are early colonisers in suitable growing sediments when conditions are favourable (Hammerstrom et al. 2006). They are capable of producing relatively long lived seeds that can lay dormant in the sediment for at least two years. Given the natural variability in these subtidal meadows, it is likely that they will recover once conditions improve.

The broad distribution of meadows observed in the Western Basin region in 2010 is similar to those observed in 2009 (Thomas et al. 2010), but there was an overall reduction in area of ≈1600 ha. The majority of this loss was within the subtidal meadows around Fishermans Landing as well as the coastal area adjacent to Boyne Island (Maps 9-10). Additional loss in The Narrows led to patchy and low biomass strips of seagrass in this naturally turbid area. While seagrass losses were evident in the more industrial and urban areas of Port Curtis, where threats of anthropogenic stress are more apparent, natural climate related factors are likely the major driver of change observed in 2010 as opposed to port related disturbance.

Similar large scale declines of seagrass occurred during 2010 in other north-eastern Queensland coastal locations where the team conducts similar monitoring programs indicating a regional, rather than local, driver of seagrass change. Large declines occurred in Mourilyan Harbour, Cairns and Gladstone over the same period. The majority of intertidal *Zostera* meadows in Mourilyan and Townsville decreased in biomass in 2010 (Fairweather et al. 2011a; Taylor and Rasheed 2011), while monitoring in Cairns revealed that there were similar declines in intertidal and subtidal meadows (Fairweather et al 2011b). These declines corresponded with major rainfall events and severe episodic flooding that occurred across the state.

In contrast, seagrasses in the Gulf of Carpentaria and Torres Strait have generally increased in biomass and distribution over the same time period (McCormack et al. 2011; McKenna and Rasheed 2011; Taylor et al. 2011). In 2010 the Gulf of Carpentaria was not subjected to the same weather conditions and levels of flooding that the east coast experienced which may explain the different responses of seagrass populations in these areas.

There is potential for a full recovery of seagrasses however a second year of high rainfall following the November 2010 survey suggests seagrasses will remain well below previous years for some time. Additional stressors (natural or anthropogenic) over the next six months may have detrimental effects to seagrass meadows already in a reduced state. Natural recovery from a large loss can typically take up to five years (Preen et al. 1995), but could take longer if additional stressors (e.g. high turbidity and poor water quality) are present.

Implications for Port Management

Results of this survey indicate that seagrasses in Gladstone are in a susceptible state. The large declines in area and density are likely to have left seagrasses with substantially reduced resilience to further impacts than would normally be the case at this time of year. The continued presence of seagrasses within the port over the eight years of the monitoring program demonstrates that seagrasses and normal port activity can co-exist. However the current reduced state of seagrasses means they may be more susceptible to impacts they are normally be able to resist

The marine environment of Port Curtis and Rodds Bay continues to be at risk from the shipping activities at the port and development projects such as those planned in the Western Basin over the next few years. Dredging and shipping activities have commonly been observed in many locations to damage seagrass (Erftemeijer and Lewis 2006). Activities that reduce the available light to seagrass (i.e. turbidity plumes and sedimentation) will negatively impact upon seagrass growth and productivity, influencing their continued viability. Seagrasses in many areas of Port Curtis and Rodds Bay may already be living in conditions close to the limits of their environmental tolerance (i.e. poor light availability), restricting their level of resilience to future stressors. A range of additional seagrass studies and monitoring measures have been put in place by Gladstone Ports Corporation to better define the requirements of local seagrasses and develop ecologically relevant triggers and thresholds to protect seagrasses during dredging operations. These projects form part of the Dredge Management Plan for the Western Basin.

Although a causative link between seagrass loss and reduced light availability is well established (Erftemeijer and Lewis 2006), the interacting environmental stresses of high turbidity, intertidal exposure, temperature and water quality, are poorly understood in tropical coastal environments such as Port Curtis. Further investigation of these processes and their underlying mechanisms is underway as part of the Western Basin seagrass research and monitoring program. Results will lead to a more informed environmental management of future coastal developments in Port Curtis. The use of a seagrass monitoring program provides an excellent indicator of environmental change, enabling natural environmental change to be separated from any potential anthropogenic impacts. Understanding natural cycles of change in Port Curtis and Rodds Bay seagrasses is also important as natural events such as the recent flooding have the capacity to reduce the resilience of seagrasses in the region to human activities.

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APPENDIX

Summary of statistical results for mean above ground biomass versus year for monitoring meadows in Port Curtis and Rodds Bay (2002, 2004, 2005, 2006, 2007, 2008, 2009 & 2010).

Meadow 4**

Satisfied the equal variance test so a one-way ANOVA was run in place of the Behrens-Fisher test. No significant differences were found.

Source of Variation	DF	SS	MS	F	P
Between Groups	7	19.057	2.722	0.744	0.635
Residual	132	483.184	3.660		
Total	139	502.241			

All other meadows failed the equal variance test (i.e. Bartlett's test) and therefore the Behrens-Fisher test was used. Each cell contains the t' statistic for each comparison and degrees of freedom stated below in brackets. Shaded cells indicate a significant difference of p < 0.01. N.a. indicates no test run due to the absence of the meadow in 2010.

Meadow 5

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.5923 (55)							
2005	1.4918 (59)	0.9125 (54)						
2006	3.9800 (48)	5.6505 (41)	4.9125 (47)					
2007	6.1581 (33)	6.9225 (32)	6.6114 (33)	3.9391 (42)				
2008	5.1912 (35)	6.0510 (33)	5.7017 (35)	2.7599 (46)	1.1895 (60)			
2009	0.0641 (66)	2.1787 (59)	1.2663 (65)	3.8401 (55)	6.1088 (34)	5.1400 (37)		
2010	2.1325 (64)	0.3696 (69)	0.5420 (63)	5.3540 (45)	6.8022 (32)	5.9158 (34)	1.8075 (67)	

Meadow 6

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	5.1994 (54)							
2005	0.5181 (54)	2.5330 (45)						
2006	4.8083 (78)	7.8006 (68)	4.3616 (93)					
2007	6.0142 (47)	7.0346 (46)	5.9980 (53)	4.0396 (56)				
2008	0.9589 (55)	3.5392 (47)	1.1770 (75)	2.8139 (93)	5.3389 (57)			
2009	1.9946 (42)	2.8722 (41)	2.0965 (46)	0.3900 (47)	2.5235 (82)	1.5858 (49)		
2010	5.5009 (47)	0.1952 (48)	2.6457 (43)	7.9393 (66)	7.0691 (46)	3.6346 (46)	2.8988 (41)	

Meadow 7

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.3434 (13)							
2005	4.0094 (2)	5.1958 (13)						
2006	3.3756 (35)	2.0512 (43)	4.6194 (33)					
2007	2.3504 (4)	1.5972 (5)	3.0316 (4)	0.2927 (7)				
2008	0.5039 (12)	1.0964 (18)	2.2180 (10)	2.6113 (42)	2.0212 (5)			
2009	2.6435 (3)	4.3509 (16)	1.8863 (13)	4.2901 (34)	2.8564 (4)	1.7522 (11)		
2010	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

Meadow 8

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	5.7197 (36)							
2005	6.0832 (33)	1.0085 (46)						
2006	1.8610 (68)	3.8312 (44)	4.2199 (40)					
2007	2.1078 (49)	4.8118 (37)	4.9345 (36)	3.1484 (46)				
2008	3.3967 (63)	2.0994 (44)	2.5000 (38)	1.5628 (75)	3.9305 (43)			
2009	3.2624 (62)	2.2734 (42)	2.6758 (37)	1.4227 (74)	3.8640 (44)	0.1439 (73)		
2010	3.7564 (53)	1.7534 (25)	2.1704 (21)	1.9177 (59)	4.0965 (42)	0.3400 (55)	0.4865 (55)	

Meadow 9

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.4945 (15)							
2005	2.8130 (6)	7.0671 (15)						
2006	4.5109 (34)	3.4171 (35)	5.8537 (29)					
2007	5.3082 (28)	3.9366 (29)	7.3348 (22)	0.3226 (50)				
2008	1.1680 (9)	4.7075 (23)	3.4580 (28)	5.2145 (31)	6.4138 (24)			
2009	2.9589 (31)	1.0838 (49)	5.6609 (34)	2.6028 (44)	2.7925 (42)	4.3440 (41)		
2010	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

Meadow 23

YEAR	2009	2010
2009		
2010	3.6652 (29)	

Meadow 43

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	0.5558 (102)							
2005	1.7169 (111)	2.5902 (99)						
2006	1.8831 (86)	1.6989 (114)	4.1094 (83)					
2007	1.8021 (104)	1.5671 (121)	3.8280 (102)	0.1067 (109)				
2008	1.1803 (108)	1.9583 (95)	0.5456 (105)	3.4290 (79)	3.2071 (97)			
2009	0.0944 (100)	0.5981 (131)	2.1522 (98)	2.4316 (128)	2.1868 (127)	1.5097 (93)		
2010	0.1700 (114)	0.8008 (111)	1.6385 (111)	2.2700 (94)	2.1321 (113)	1.0723 (108)	0.3087 (111)	

Meadow 48

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.1990 (79)							
2005	0.6357 (85)	1.9983 (83)						
2006	6.7631 (28)	7.3614 (28)	6.1485 (34)					
2007	5.3715 (32)	6.2068 (32)	4.5203 (46)	2.4064 (47)				
2008	1.6183 (46)	2.6749 (44)	0.9646 (73)	5.2639 (41)	3.4068 (55)			
2009	8.0018 (38)	5.4372 (43)	4.6926 (60)	8.4681 (26)	7.8018 (28)	4.6681 (36)		
2010	3.7360 (22)	1.9354 (20)	3.1364 (57)	7.8388 (29)	6.8398 (34)	3.5711 (45)	1.5753 (9)	

Meadow 58

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.7841 (25)							
2005	1.0838 (43)	1.9609 (35)						
2006	2.8443 (24)	0.1706 (57)	2.0442 (35)					
2007	2.8471 (30)	4.1294 (23)	3.4315 (27)	4.1530 (23)				
2008	2.2741 (34)	3.4917 (27)	2.8294 (31)	3.5146 (27)	0.4001 (50)			
2009	2.1104 (50)	3.1124 (43)	2.5715 (46)	3.1315 (42)	0.2365 (64)	0.1266 (69)		
2010	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

Meadow 60

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	2.8372 (5)							
2005	2.8350 (5)	0.2849 (16)						
2006	1.4977 (6)	3.9277 (10)	3.9203 (10)					
2007	0.0867 (10)	3.7320 (10)	3.7289 (10)	1.8344 (14)				
2008	0.3869 (14)	3.0743 (10)	3.0723 (10)	1.8602 (12)	0.5156 (17)			
2009	2.1831 (5)	4.5307 (31)	4.5114 (31)	1.7989 (14)	2.8159 (11)	2.4851 (10)		
2010	2.6346 (5)	2.2793 (8)	2.2485 (8)	3.2180 (11)	3.4449 (10)	2.8921 (10)	2.6924 (38)	

Meadow 94

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	1.0803 (2)							
2005	0.1563 (3)	2.5839 (9)						
2006	0.3760 (2)	3.4576 (12)	1.0660 (12)					
2007	0.9267 (4)	3.3578 (9)	1.1500 (17)	2.1921 (11)				
2008	0.1550 (4)	1.7289 (10)	0.0214 (17)	0.7560 (11)	0.9300 (19)			
2009	1.2751 (2)	4.4573 (9)	2.9951 (9)	4.5239 (11)	3.6637 (9)	1.9955 (10)		
2010	1.2474 (2)	3.5779 (12)	2.9363 (9)	4.3688 (11)	3.6201 (9)	1.9575 (10)	1.6849 (15)	

Meadow 96

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	1.7376 (21)							
2005	0.8243 (27)	2.0006 (38)						
2006	0.3973 (25)	5.6730 (46)	2.4525 (59)					
2007	2.6183 (51)	4.2086 (34)	3.5579 (37)	2.7701 (36)				
2008	3.1286 (48)	4.7581 (32)	4.1112 (35)	3.3456 (34)	0.4697 (64)			
2009	0.7533 (28)	5.4847 (44)	2.8571 (64)	0.7150 (65)	2.4833 (38)	3.0586 (36)		
2010	1.5242 (20)	1.1612 (55)	1.5374 (33)	5.3410 (40)	4.0760 (33)	4.6300 (31)	5.1682 (39)	

Meadow 104

YEAR	2002	2004	2005	2006	2007	2008	2009	2010
2002								
2004	1.9262 (16)							
2005	0.4619 (30)	2.7607 (14)						
2006	0.6018 (20)	7.2005 (20)	0.0067 (18)					
2007	2.0993 (21)	3.3675 (14)	1.8389 (20)	2.0055 (15)				
2008	1.7216 (35)	3.6243 (20)	1.3793 (33)	1.6277 (23)	0.7337 (26)			
2009	1.5436 (18)	1.3066 (43)	2.3243 (16)	5.3716 (32)	3.1662 (14)	3.3162 (21)		
2010	2.1172 (16)	1.2339 (37)	2.9716 (14)	7.9407 (18)	3.4667 (14)	3.7721 (20)	2.0963 (38)	