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

Seagrasses of Port Curtis and Rodds Bay and long term seagrass monitoring, November 2009

Thomas, R., Unsworth, R.K.F. and Rasheed, M.A.

PCIMP Monitoring the health of your harbour

GPC Gladstone Ports Corporation

Toward Q2 Tomorrow's Queensland

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EXECUTIVE SUMMARY

This report details the findings of the 2009 annual seagrass monitoring survey for Port Curtis and Rodds Bay together with a reassessment of the whole of port baseline survey previously conducted in 2002. This report integrates 2009 survey data with previous long term monitoring assessments conducted since 2002. The 2009 survey included assessments of intertidal, shallow subtidal and deepwater meadows that measured seagrass meadow area, biomass and species composition. This survey was part of the Port Curtis Integrated Monitoring Program (PCIMP). Seagrass meadows in Port Curtis and Rodds Bay covered a total of 12040.3 ± 2556.1 ha in 2009. These extensive seagrass meadows are likely to be of regional significance as they are the only known major area of seagrass between Hervey Bay (170 km south) and Shoalwater Bay (170 km north).

The broad distribution of the meadows mapped in the 2009 whole of port baseline reassessment is similar to those observed in 2002 but there was a reduction in total area of approximately 1500 ha. The majority of this loss was within the deepwater meadows. However there was also some localised shallow coastal seagrass loss around Quoin Island and in Rodds Bay. The major driver of this change is likely to be climate related.

In 2009, seagrass meadows that have been monitored annually since 2002 were mostly in reasonable condition relative to previous years. However there were changes to specific meadows and locations that are of concern (Quoin Island and Rodds Bay). Total aerial coverage of the thirteen monitoring meadows was approximately 10% below the average (since 2002) in 2009. This decline relates to the reduction in area of specific meadows rather than declines throughout all meadows.

The drivers of long term seagrass change in Port Curtis monitoring meadows appear to be largely associated with local climate variability, fine scale variability in the physical meadow environment and natural resilience and capacity for recovery in individual seagrass meadows. Rainfall, river flow and elevated temperature were the major correlates of change throughout the thirteen meadows.

The continued presence of seagrass and dugong activity in intertidal areas adjacent to port facilities and infrastructure has implications for port management. Some of the seagrass meadows most commonly utilised by dugong appear to be those in closest proximity to major port infrastructure and proposed areas of expansion. Future port infrastructure developments would require careful management to ensure minimal impacts on these communities. The fact that seagrass meadows and dugong activity have continued to exist within the port indicates that these important habitats can co-exist with well managed port activities and development. But indicators of water quality within a number of meadows suggest seagrass may already be subject to elevated stress reducing their potential resilience to future anthropogenic impact.

In 2008 and 2009 trial assessments of turbidity, light and temperature provided a glimpse of *in situ* conditions to evaluate changes occurring at the meadow scale. Continued collection of light and temperature information on the seagrass meadows would significantly enhance the effectiveness of the seagrass monitoring program. This would further develop the relationships between meadow dynamics and physical parameters, enabling the separation of natural and anthropogenic drivers of seagrass change.

In general, seagrasses appear to have been resilient to the impacts associated with regular port maintenance dredging during the current monitoring program. However, Fisheries Queensland remain concerned that the loss of some meadows together with potential water quality issues may leave them particularly vulnerable to additional stresses including those associated with dredging. A more complete understanding of the environmental requirements of seagrasses in Port Curtis is required to accurately inform environmental management of future coastal 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 & 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 & 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 & 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 Limited (GPCL) 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, GPCL 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. Seagrass meadows were commonly present in close proximity to existing port facilities and infrastructure. The 2002 baseline survey mapped 13,578 ha of seagrass habitat within Port Curtis and Rodds Bay. Meadows in 2002 mostly appeared to be healthy, however, detailed historical comparisons were not possible as the baseline survey was the first fine scale survey of the region. The 2002 baseline survey recorded the presence of intertidal/shallow subtidal meadows and deepwater meadows within the port limits (Rasheed *et al.* 2003).

An annual seagrass monitoring program was developed in 2004 by GPCL 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.* 2008b, Chartrand *et al.* 2009) and including 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.

Since 2007, the annual port monitoring program has been run as a collaborative program between PCIMP and Fisheries Queensland resulting in an expanded program to include preliminary monitoring of *in situ* light, turbidity and temperature (Chartrand *et al.* 2009). Initial light and temperature data collection was conducted by Central Queensland University (CQU 2004).

In 2009, current and 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 whole of the port limits and adjacent areas. Fisheries Queensland was contracted in 2009 by PCIMP to undertake this repeat of the 2002 baseline survey. This included the annual monitoring program meadows, deepwater meadows, and all additional seagrass meadows within the port limits and adjacent areas (i.e. Rodds Bay).

The objectives of the survey were to:

1. Undertake an updated baseline survey of the intertidal and shallow subtidal seagrass meadows within the whole of Port Curtis and Rodds Bay.
2. Undertake an updated baseline survey of the deepwater seagrass meadows within the whole of Port Curtis and Rodds Bay.
3. Document the spatial extent and biomass of intertidal, shallow subtidal and deepwater seagrass meadows within the whole of Port Curtis and Rodds Bay and compare this distribution relative to the 2002 baseline survey.
4. Conduct annual long term seagrass monitoring within Port Curtis and Rodds Bay based on information collected in the 2002 baseline survey.
5. Provide the distribution, abundance and species composition of seagrass monitoring meadows within Port Curtis and Rodds Bay.
6. Analyse changes in seagrass monitoring meadows measured since the baseline during subsequent annual monitoring surveys.
7. Document temporal physicochemical water quality parameters at selected seagrass meadows within Port Curtis.
8. 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.
9. Place observed changes within a regional and state-wide context.

METHODS

Survey Approach

Seagrass surveys of Port Curtis and Rodds Bay were conducted between the 1st and 15th of November 2009. The survey had three major components:

1. Coastal (intertidal to shallow subtidal) seagrass survey
2. Deepwater (offshore) seagrass survey
3. 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 the previous baseline survey (conducted in 2002) 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. These meadows were representative of the range of seagrass communities identified in the baseline survey 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 modified "visual estimates of biomass" technique described by (Mellors 1991). 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.

In December 2007, PCIMP began collecting light, turbidity and temperature data at seagrass monitoring meadows within Port Curtis (no data collected in Rodds Bay). A complete summary of the methods and data collected is provided in (Wilson 2008). Temperature data was collected at ten meadows (Map 2) whilst light and turbidity data were collected at Pelican Banks (meadow 43), North Fishermans (meadow 8), and Wiggins Island (meadow 4) (see Map 2). This adds to existing sources of daily weather data obtained 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 GPCL/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 2009

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 2009

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 2009

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
300m	Meadow boundary determined from offshore video sites Offshore (deepwater) meadows only Relatively low density of survey sites

Statistical Analysis

To determine inter-annual differences in seagrass biomass of individual meadows, Analysis of Variance (ANOVA) was conducted in Statistix V1. Where data did not conform to the assumptions of ANOVA, data were transformed. Where data continued to differ from the assumptions of ANOVA it was still conducted, but in order to minimise the possibility of recording a type 1 error, an α level of 0.01 was used instead of $\alpha = 0.05$ (Underwood 1997).

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 physical 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 this approach does not provide 'cause and effect', it provides a broad explanation for the potential major environmental drivers in these seagrass communities. With only seven years of seagrass data available, these relationships can only be considered to be 'preliminary' and regression results and conclusions must be considered with caution. Within the Port Curtis monitoring program, the natural variability of six of the largest meadows spread across the harbour was investigated relative to changes in weather.

To investigate which environmental parameters correlated most with annual mean seagrass meadow biomass, a Partial Least Squares Regression (PLS) model was developed in Minitab (version 15). This technique is an extension of multiple regression analysis in which the effects of linear combinations of several predictors on a response variable (or multiple response variables) are analysed. PLS regression is particularly suited to incidences when the matrix of predictors has more variables than observations, and when there is multi co-linearity among variables (Carrascal *et al.* 2009). All annual mean seagrass biomass data for each of the meadows was analysed against mean weather and tidal exposure statistics for the preceding month, three months, six months, nine months, and twelve months. The PLS analysis calculated a predicted residual sum of squares (PRESS) following cross-validation. This allowed for the calculation of a predicted R^2 value in addition to a conventional R^2, hence the determination of the predictive power of the observed relationship. A much lower predicted R^2 value than the conventional R^2 indicates the model is dependent upon only a few observations and will probably not provide a good predictive model. The model then separates the individual predictors and provides regression coefficients (analogous to correlation coefficients).

RESULTS

ENTIRE PORT LIMITS AND RODDS BAY SEAGRASSES

A total of 7150.7 ± 509.4 ha of coastal and 4889.6 ± 2046.7 ha of deepwater (>5m below MSL) seagrass were mapped within the Port Curtis and Rodds Bay survey area in November 2009 (Maps 1 and 2). Six seagrass species (from three families) were identified (Figure 1). Five of these species have previously been identified within the survey area (Rasheed *et al.* 2003). Notably, this survey is the first occasion that *Cymodocea rotundata* has also been identified within the Port Curtis survey area.

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.
Halophila spinulosa (R. Br.) Aschers. in Neumayer

Family ZOSTERACEAE Drummortier:
Zostera capricorni Aschers.

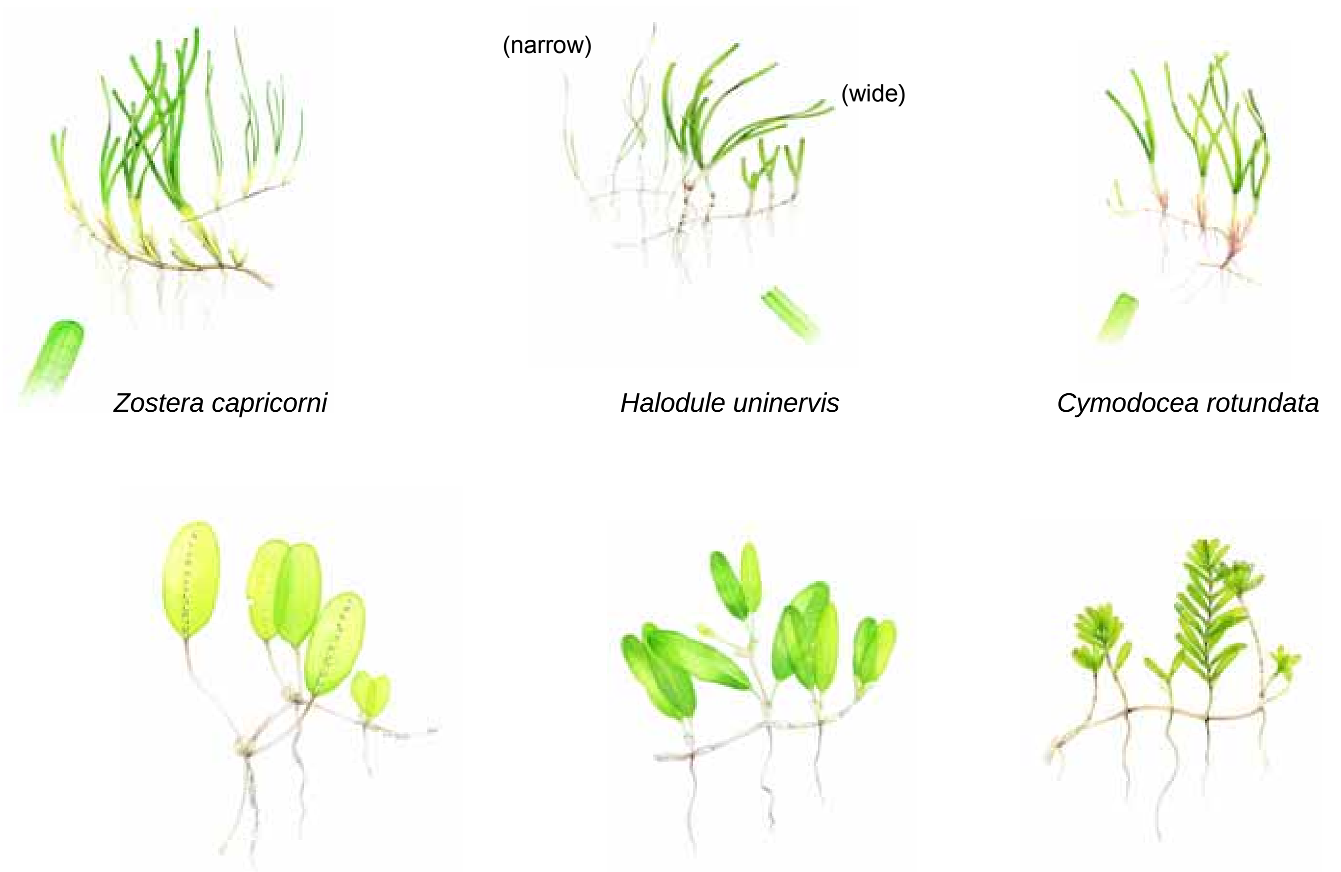


Figure 1 Seagrass species present in Port Curtis and Rodds Bay, November 2009

Coastal Seagrass Species, Distribution and Abundance

A total of 2669 coastal habitat characterisation sites (excluding meadow boundary mapping sites) were surveyed throughout Port Curtis and Rodds Bay Dugong Protection area in November 2009 (Map 1). A total of 7150.7 ± 509.4 ha of coastal seagrass habitat (<5m below MSL) were mapped in 132 separate meadows (Map 2).

Coastal intertidal seagrass meadows dominated the survey area. Individual areas for each of the 132 separate meadows ranged from 0.1 ha for isolated seagrass patches found throughout the survey area up to 736.1 ha for the largest intertidal meadow located at Rodds Bay (Maps 3-9).

The coastal seagrass meadows comprised 16 different community types depending on species presence and dominance (Maps 3-9; Tables 4-10). Communities that were dominated by *Zostera capricorni* were the most common followed by communities dominated by *Halophila decipiens* and *Halophila ovalis*. In the north of the survey area, *Zostera capricorni* and *Halophila ovalis* communities dominated the intertidal sand and mud banks between Mud Island and Fishermans Landing wharves. Further south, *Zostera capricorni* communities occurred from South Trees Inlet to Barney Point and also into Rodds Bay (Maps 3-9; Tables 4-10). An additional species, *Cymodocea rotundata*, was also identified for the first time within the survey area and occurred as isolated patches at three sites along the western shoreline of Facing Island (Maps 6 and 7).

Mean above ground biomass for the intertidal meadows ranged from 0.01 ± 0.01 g DW m^{-2} for several isolated patches of *Zostera capricorni* occurring throughout the survey area to 43.74 ± 4.55 g DW m^{-2} for a relatively small but dense *Zostera capricorni* meadow located adjacent the channel at Pelican Banks (meadow 137; Map 6). Several small meadows that were mapped had no biomass recorded due to all random samples containing zero biomass (e.g. Table 4, Meadow 18). This was due to the patchy and low biomass of these small meadows.

Seagrass cover for intertidal meadows located in The Narrows, Fishermans Landing and Quoin Island regions was relatively patchy with the majority of these meadows consisting of isolated and aggregated patches of seagrass (Maps 3-6; Tables 4-7). Meadows at Wiggins Island were more consistent and were comprised of aggregated patches dominated by *Zostera capricorni* and *Halophila ovalis*. Continuous cover seagrass meadows were observed in the Pelican Banks region and were dominated by *Zostera capricorni*. In other areas including around South Trees Inlet and south to Rodds Bay, seagrass cover was relatively consistent with meadow cover generally comprised of aggregated patches (Maps 7-9; Tables 8-10). The majority of seagrass meadows throughout the survey area were located on sediments dominated by mud but often combined with a smaller component of sand and/or shell. The exceptions were Pelican Banks (meadow 43) and Quoin Island meadows (meadows 48 and 49) which occurred on sediments dominated by sand.

Dugong feeding activity was observed on intertidal seagrass meadows throughout the survey area, from The Narrows region in the north and south into Rodds Bay. The highest density of dugong feeding trails was observed on the light *Zostera capricorni* monitoring meadows at Wiggins Island (meadows 4, 5 and 6; Map 5). A high concentration of dugong feeding trails was also observed at the southern end of the monitoring meadow adjacent South Trees Inlet (meadow 58, Map 7).

Deepwater Seagrass Distribution and Abundance

Large areas of deepwater seagrass (>5m below MSL) were also found within Port Curtis port limits (Map 2). Seagrass occurred at 11% of the 137 offshore survey sites and formed four individual meadows with a total area of 4889.6 ± 2046.7 ha (Map 8; Table 9). Deepwater meadows occurred offshore from Facing Island and around Seal Rocks, West Banks and East Banks (Map 8). No deepwater meadows occurred in the inner port area (inside Facing Island).

Deepwater seagrass meadows were comprised solely of a light cover of *Halophila decipiens* and had very low above ground biomass (maximum 0.09 g DW m^{-2}) (Map 8; Table 9). The maximum depth recorded for offshore seagrass was 18.4m below mean sea level for *Halophila decipiens* in meadow 135 (Map 8).

Comparison Between 2002 and 2009 Baseline Assessments

The seagrass baseline resurvey of 2009 found seagrass to have a broadly similar distribution to those observed in 2002, however an overall loss of ≈1500 ha of seagrass was observed in 2009 relative to 2002 (Maps 10-12). The majority of this loss in area was within the deepwater sections that are outside of the protection of the inner harbour area (e.g. protection by Curtis and Facing Islands) but within Port Curtis port limits (Map 11). Seagrass within these deepwater meadows underwent a net loss of 1442.5 ha from 2002 to 2009.

The coastal shallow intertidal to subtidal meadows were observed to have a net loss of 95 ha. Meadow area changes from 2002 to 2009 can be observed in Figure 2(D).

The northern section of Port Curtis (Map 13) underwent a net loss from 2002 to 2009 of 60 ha of seagrass. This loss was mostly within the Quoin Island monitoring meadow (meadows 48, 49 and 50) and is discussed in greater detail within the annual monitoring section of the present report.

This overall loss also included a net loss of 347 ha in the Rodds Bay region (Map 15). Areas lost in Rodds Bay were mostly within the centre of the bay rather than in the upper channels. A net gain in seagrass area of 312 ha was observed in the southern Port Curtis region (Map 14). This gain was throughout the southern area and included large overall changes in spatial distribution of these mostly subtidal meadows (558 ha loss, and 879 ha area gained).

ANNUAL SEAGRASS MONITORING

In November 2009 a total of 2263 ± 79 ha of seagrass was mapped within the thirteen established Port Curtis and Rodds Bay monitoring meadows. The largest of these meadows was at Pelican Banks (meadow 43) and covered 644 ± 13 ha. The smallest was a 2.6 ha meadow (meadow 94) at Rodds Bay (Table 11).

The thirteen monitoring meadows that were surveyed included six different community types depending on species presence and dominance (Maps 16-19). The majority of these meadows with the exception of Pelican Banks were comprised of aggregated patches. Communities that were dominated by *Zostera capricorni* were the most common followed by communities dominated by *Halophila decipiens* and *Halophila ovalis*. In the north of the survey area, *Zostera capricorni* and *Halophila ovalis* communities dominated the intertidal sand and mud banks between Mud Island and Fishermans Landing wharves with *Halophila decipiens* dominating in subtidal areas. Further south, *Zostera capricorni* communities occurred between South Trees Inlet and Barney Point.

Mean above ground biomass for the monitoring meadows ranged from 0.01 g DW m^{-2} in the once dense *Zostera capricorni* meadow at Rodds Bay to 20.5 g DW m^{-2} in the large Pelican Banks monitoring meadow. The subtidal meadows contained the lowest biomass (apart from meadow 94 in Rodds Bay) (Table 12).

Seagrass cover for intertidal monitoring meadows located on the mainland coast between South Trees and North Fishermans Landing was patchy with the majority of meadows consisting of isolated or aggregated patches of seagrass (Maps 16-19). These meadows were all within a lower range of seagrass biomass (<6 g DW m^{-2}).

The majority of the monitoring meadows were located on sediments dominated by mud often combined with a smaller component of sand and/or shell. The exceptions were Pelican Banks (meadow 43) and Quoin Island meadows (meadow 48 and 49) which occurred on sediments dominated by sand.

Dugong feeding activity was observed on five of the thirteen intertidal seagrass monitoring meadows surveyed. The highest density of dugong feeding trails was observed at the South Trees meadow (meadow 58) where >25% of sites contained dugong feeding trails (Map 7). Dugong feeding trails were also observed at both of the Wiggins Island meadows, the South Fishermans meadow, and the North Fishermans meadow (Map 5)

Inter-annual Variability of Seagrass Monitoring Meadows

Of the thirteen seagrass monitoring meadows, the majority (seven) had declined in mean biomass relative to assessments carried out in November 2008 (Figures 2A – 2C). Only at the Wiggins Island meadow 5, the South Trees meadow 60 and the two meadows in Rodds Bay (meadows 96 and 104) were these declines statistically significant. Only the meadow at North Fishermans (meadow 9) had a significant increase in above ground biomass from 2008 to 2009 (Table 12).

Of cause for concern was the dramatic decline of the meadow at Quoin Island. A scattered, patchy and highly variable distribution in 2008 meant that although significant inter-annual variability was present (since 2002), a 2009 to 2008 biomass comparison was not found to be significant. Despite the lack of significant decline in biomass, the reduction in area for the meadow was well outside the range of expected change, with the meadow fragmenting into three smaller patches of seagrass (Map 6 and 17). This decline was part of a trend since 2006 when the biomass was at its peak for the monitoring program (9.52 g DW m^{-2}) (Table 12).

Species composition of meadows had mostly stayed the same since 2008, except for the Rodds Bay meadow number 94 (Maps 16-19; Figure 2(A-C)).

The dominant species at the Wiggins Island meadows, the South Trees meadow 58 and the South Fishermans meadow has fluctuated during the monitoring program between *Halophila ovalis* and *Zostera capricorni*. In recent years there has been a trend for these meadows to be dominated by *Zostera capricorni* with *Halophila ovalis* forming a smaller component of the biomass (Maps 16-19; Figure 2(A-C)).

Since 2008 the majority of seagrass monitoring meadows have remained approximately the same in area. Only meadow 9 at North Fishermans (that also increased in biomass) and meadow 4 at Wiggins Island have increased in area since 2008. The increase in area at North Fishermans is part of a trend of increasing area since 2005. Meadow 96 at Rodds Bay, meadow 43 at Pelican Banks, meadow 48 at Quoin Island, and meadow 60 at South Trees had all declined in area since 2008 (Table 11).

The decline in area at both Quoin Island and Rodds Bay mirrors their respective declines in biomass. The area of the other monitoring meadows was relatively high when compared with previous monitoring surveys since 2002.

Climate Variability at Gladstone Harbour (2002 to 2009)

Tidal exposure in 2009 (measured as numbers of hours seagrass meadows were subjected to tides <1m during the day) was the lowest recorded since monitoring began in 2002 (197 hrs in the 9 months prior to sampling) (Figure 3).

Annual average wind speed and rainfall were also low in 2009 relative to previous years. The rainfall that had been very high in 2008, more than halved in 2009 to 683mm. Average daily wind speed in 2009 was 17.7 ± 1.1 $km.hr^{-1}$. The highest annual average wind speed was 19.5 $km.hr^{-1}$ recorded in 2005. Levels of solar radiation were above average in 2009 (22.1± 1.1 $MJ.m^{-2}$) and the highest recorded in the program since commencement in 2002 (Figure 3).

In situ temperature data loggers revealed that the average seagrass canopy water temperature in Gladstone harbour was approximately 1 degree higher in 2009 than in 2008 at 23.8 ± 1.0 °C (Figures 4-5). The highest mean daily temperature (24.2 ± 1.1 °C) was at Fishermans Landing on meadow 9, whilst the lowest was at the deeper subtidal South Fishermans meadow 7. *In situ* light data has been collected since 2008 at three locations by Central Queensland University. Due to gaps in the data set it is not clear what differences in light environment exist between locations (Figure 6). The data suggests that Pelican Banks and Wiggins Island (meadow 43 and 4) have a higher light environment than North Fishermans (meadow 8).

Long Term 'Seagrass vs Climate' Correlations of Port Curtis Seagrass Meadows

Monitoring data of *in situ* temperature and light availability in seagrass meadows of Port Curtis and Rodds Bay is currently not sufficiently temporally extensive to be related to long term seagrass biomass dynamics. Seagrass dynamics have therefore only been correlated (using PLS regression) with climate and tidal exposure parameters where a longer data set is available (see Appendix C).

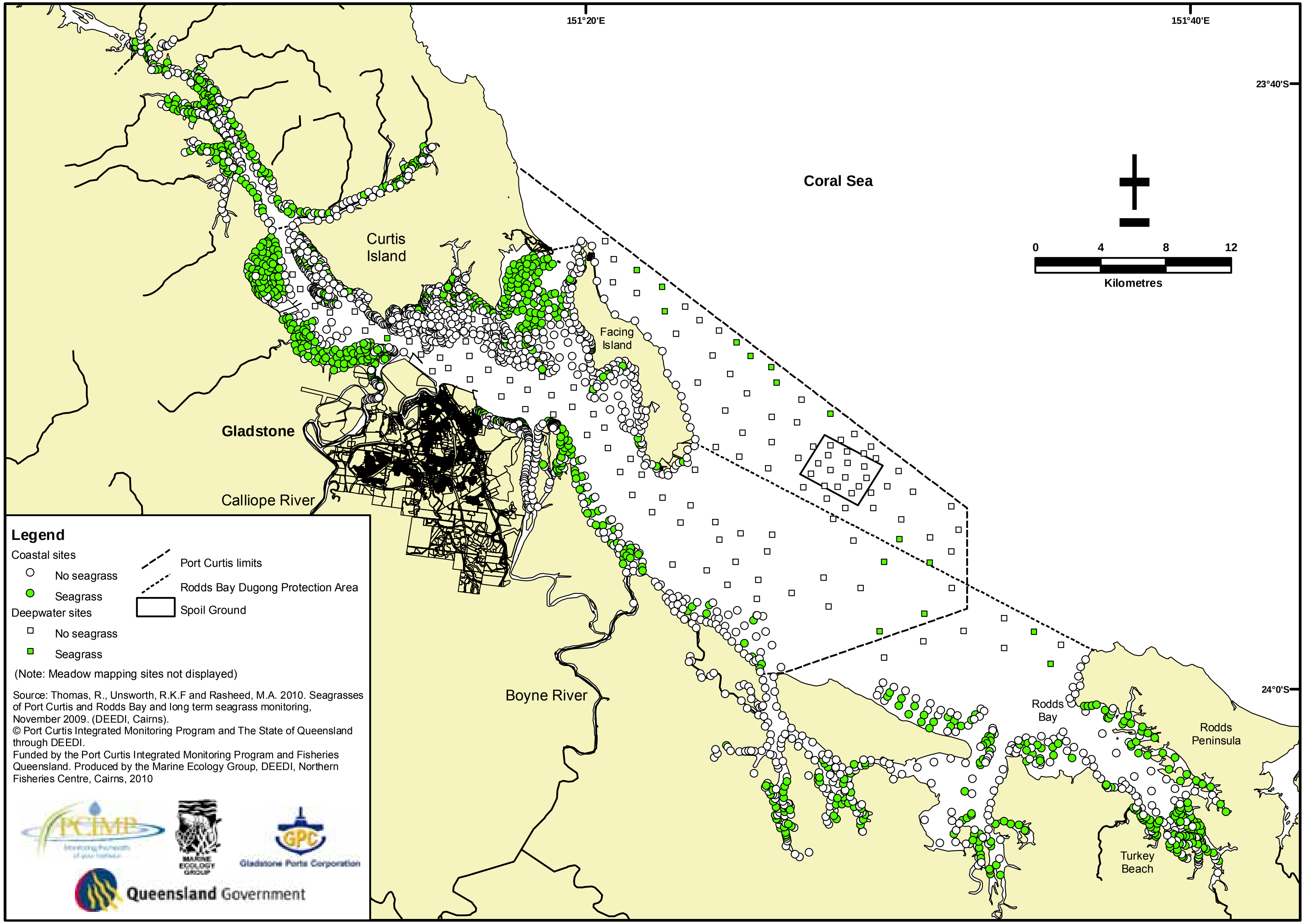
The biomass of the seagrass meadows within the upper reaches of Port Curtis (Fishermans and Wiggins) were found to be negatively correlated with increasing air temperature (see Appendix C). The *Zostera capricorni* meadow at South Fishermans which extends slightly deeper than the other nearby meadows is also negatively correlated with increased river flow (previous twelve months) and benefits from higher solar radiation (previous month). Additionally the biomass of the meadow at Wiggins Island is positively correlated with increased rainfall in the proceeding six months.

The *Halodule uninervis* meadow at Quoin Island, which in 2009 had a dramatic reduction in area, found biomass was positively correlated to river flow (previous two months), increased wind speed (nine months), and increased solar radiation in the preceding three months.

The large intertidal *Zostera capricorni* meadow at Pelican Banks was found to be significantly and negatively correlated with both solar radiation and tidal exposure. The Pelican Banks meadow was also positively correlated with river flow from the previous month.

The *Zostera capricorni* meadows in Rodds Bay and South Trees were found to be positively correlated with increased rainfall and negatively correlated with increased air temperature (Appendix C).

Map 1. Location of coastal and deepwater seagrass habitat characterisation sites in Port Curtis and Rodds Bay, November 2009



Map 2. Distribution of seagrass meadows in Port Curtis and Rodds Bay, November 2009

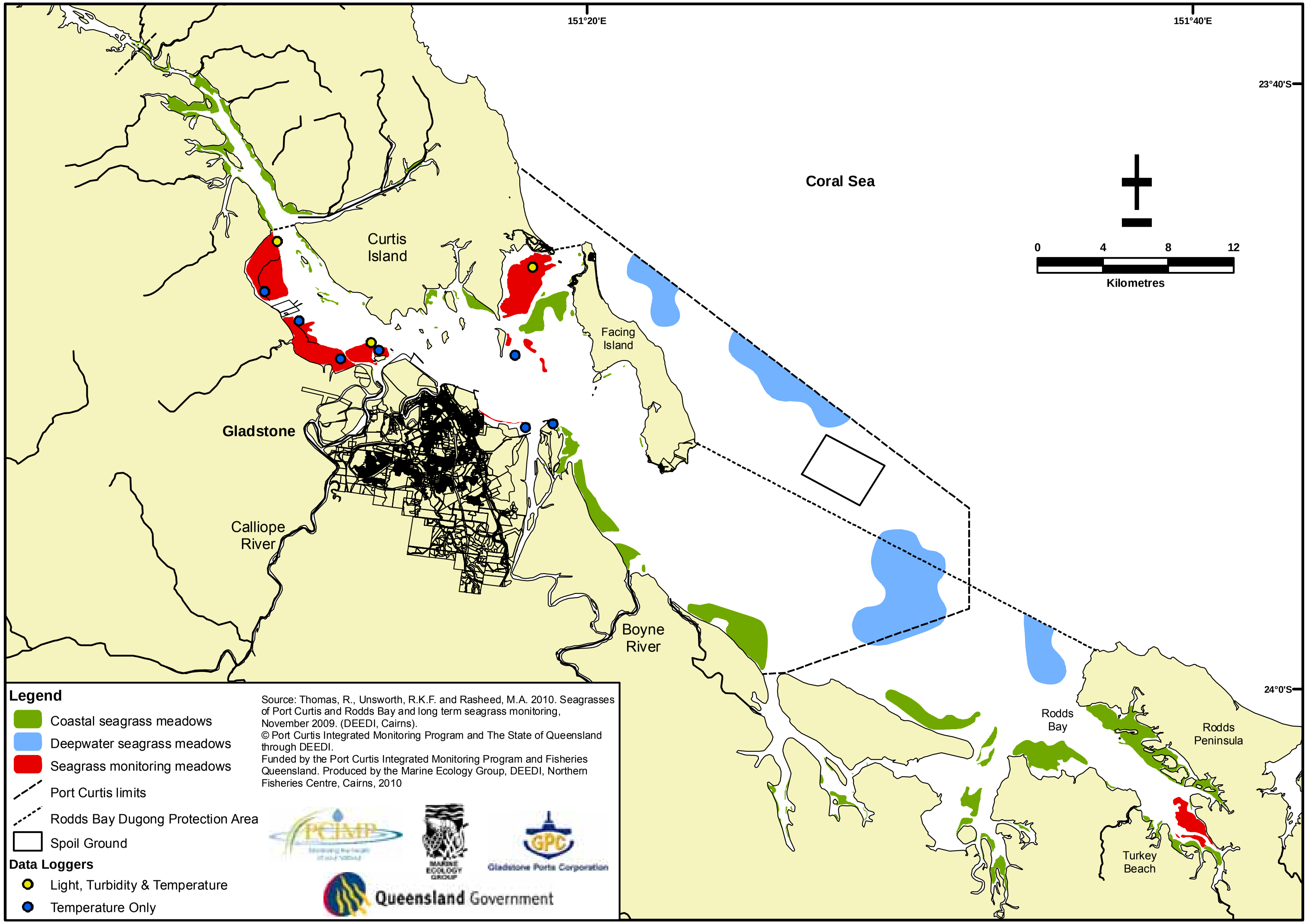


Table 4 Seagrass community type, seagrass cover and species present in The Narrows region, November 2009 (see Map 3) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
1	15.20 ± 8.13	16.9 ± 3.4	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
10	1.80 ± 1.76	17.4 ± 3.5	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
12	1.01 ± 0.84	7.0 ± 3.6	Moderate *Halophila decipiens* with mixed species	Aggregated patches	*Halophila decipiens*
13	1.35 ± 1.19	7.5 ± 4.7	Moderate *Halophila decipiens* with mixed species	Aggregated patches	*Halophila decipiens, Halophila spinulosa*
14	2.66 ± 0.90	21.9 ± 3.2	Moderate *Halophila decipiens* with mixed species	Aggregated patches	*Zostera capricorni, Halophila decipiens*
17	1.14 ± 0.66	8.2 ± 2.3	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
18	nd	0.2 ± 0.2	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
19	7.84 ± 2.24	77 ± 5.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
20	nd	1.4 ± 0.3	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
21	21.18 ± 3.96	194.7 ± 13.1	Moderate *Zostera capricorni* with mixed species	Continuous cover	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
22	0.09 ± 0.06	7.9 ± 1.5	Light *Halophila decipiens* with mixed species	Aggregated patches	*Zostera capricorni, Halophila decipiens*
23	19.33 ± 4.65	111.4 ± 14.4	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens, Halophila spinulosa*
24	0.62 ± 0	2.1 ± 0.6	Light *Halophila decipiens* with mixed species	Isolated patches	*Halophila decipiens*
25	5.09 ± 0	0.6 ± 0.3	Dense *Halophila decipiens* with mixed species	Isolated patches	*Halophila decipiens, Halophila spinulosa*
26	13.43 ± 0	0.5 ± 0.3	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
27	nd	0.6 ± 0.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
28	2.00 ± 0.89	26.5 ± 2.6	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
29	0.16 ± 0.08	55.9 ± 8.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
33	3.13 ± 0.94	106.3 ± 14.6	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
34	0.78 ± 0.36	57 ± 5.4	Light *Halophila decipiens* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*

Map 3. Seagrass distribution and community types in The Narrows region, November 2009

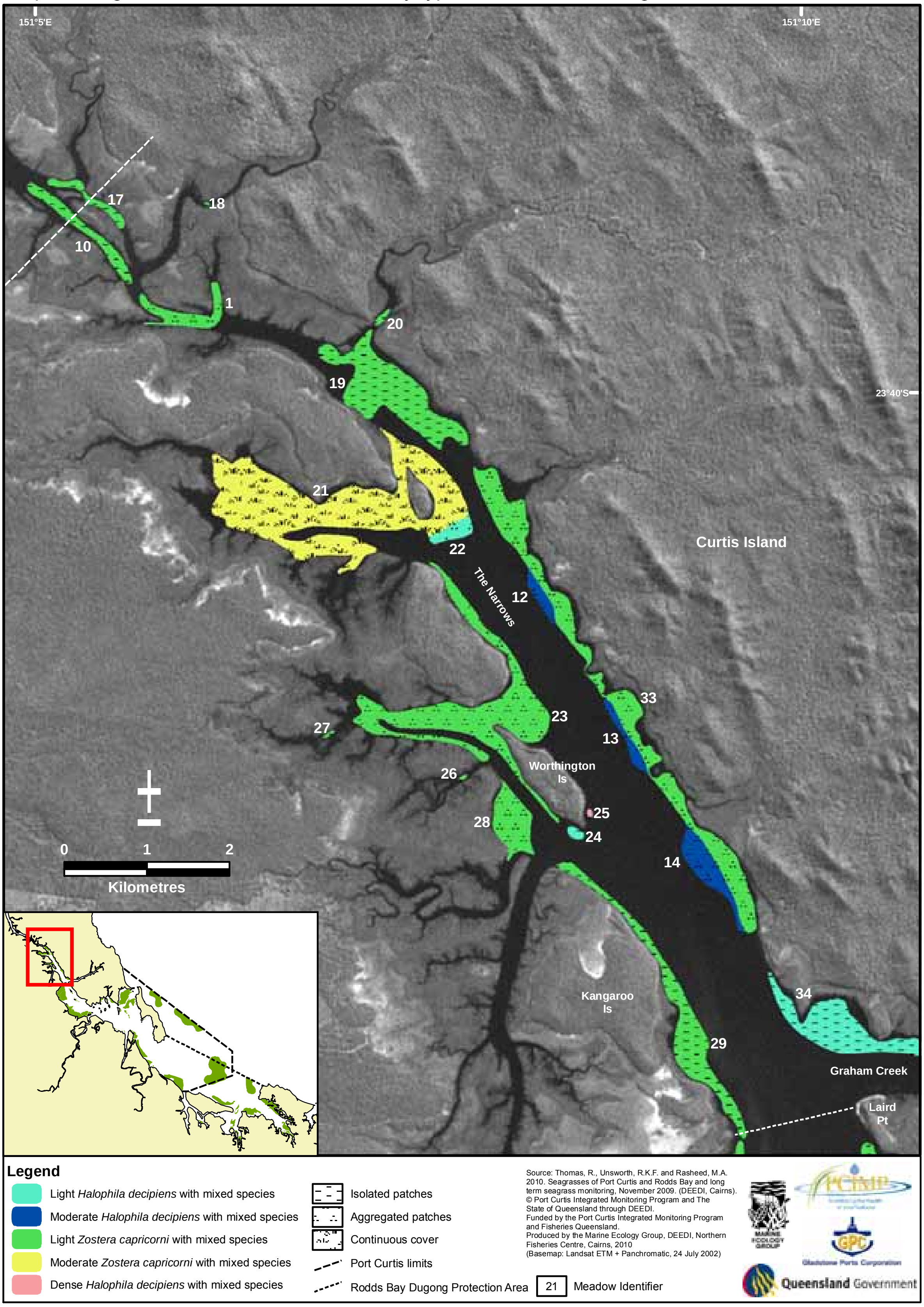
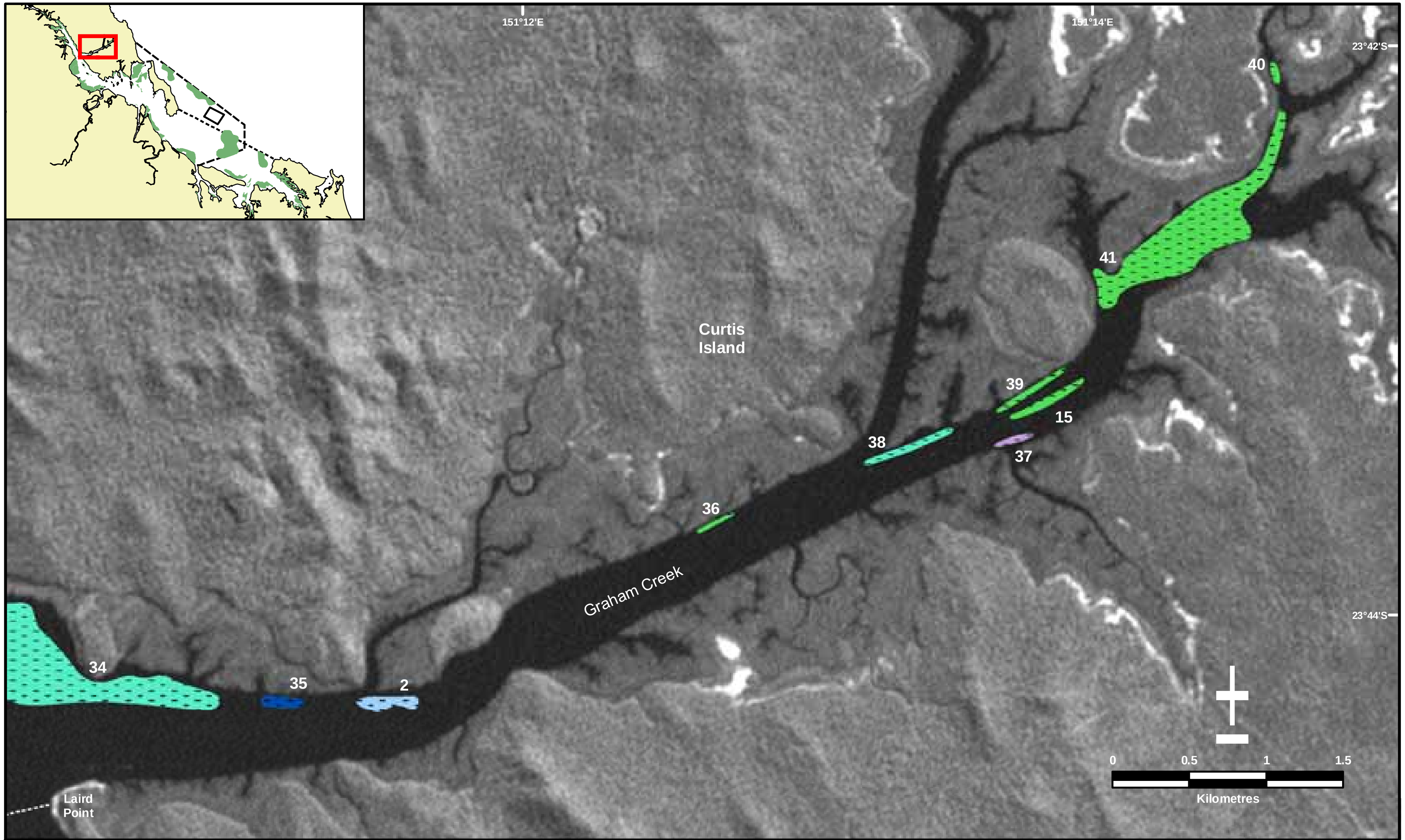


Table 5 Seagrass community type, seagrass cover and species present in the Graham Creek, November 2009 (see Map 4) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
2	0.96 ± 0.87	2.8 ± 0.4	Light *Halophila spinulosa* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis, Halophila spinulosa*
15	0.01 ± 0.01	2.3 ± 0.5	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
34	0.78 ± 0.36	57.0 ± 5.4	Light *Halophila decipiens* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
35	1.22 ± 0	1.8 ± 0.3	Moderate *Halophila decipiens* with mixed species	Isolated patches	*Halophila decipiens*
36	0.01 ± 0	0.7 ± 0.3	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
37	nd	0.9 ± 0.3	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
38	0.40 ± 0.38	2.5 ± 0.6	Light *Halophila decipiens* with mixed species	Isolated patches	*Zostera capricorni, Halophila decipiens*
39	0.01 ± 0.01	1.6 ± 0.5	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
40	0.02 ± 0	0.6 ± 0.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
41	0.57 ± 0.21	32.8 ± 2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*

Map 4. Seagrass distribution and community types in the Graham Creek region, November 2009



Legend

- Light *Halophila decipiens* with mixed species
- Light *Halophila ovalis* with mixed species
- Light *Halophila spinulosa* with mixed species
- Light *Zostera capricorni* with mixed species
- Moderate *Halophila decipiens* with mixed species
- Isolated patches
- Aggregated patches
- Continuous cover
- Rodds Bay Dugong Protection Area
- 36 Meadow Identifier

Source: Thomas, R., Unsworth, R.K.F. and Rasheed, M.A. 2010. Seagrasses of Port Curtis and Rodds Bay and long term seagrass monitoring, November 2009. (DEEDI, Cairns).
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Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland.
Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2010
(Basemap: Landsat ETM + Panchromatic, 24 July 2002)

Table 6 Seagrass community type, seagrass cover and species present in the Fishermans Landing region, November 2009 (see Map 5) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
4	1.47 ± 0.45	41.0 ± 1.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
5	1.38 ± 0.32	154.7 ± 2.9	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
6	3.05 ± 0.97	457.3 ± 6.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens, Halophila spinulosa*
7	0.26 ± 0.12	60.0 ± 10.8	Light *Halophila decipiens* with mixed species	Aggregated patches	*Halophila decipiens*
8	0.74 ± 0.25	311.8 ± 10.4	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
9	2.49 ± 0.44	286.7 ± 14.2	Moderate *Halophila decipiens* with mixed species	Aggregated patches	*Halophila decipiens, Halophila ovalis, Halophila spinulosa*
11	9.52 ± 0	0.3 ± 0.1	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
16	0.004 ± 0	1.9 ± 0.3	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
30	0.01 ± 0	0.5 ± 0.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
31	1.94 ± 1.23	1.9 ± 0.6	Moderate *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
32	1.90 ± 0.81	1.1 ± 0.5	Moderate *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
42	0.73 ± 0.39	25.6 ± 2.3	Light *Zostera capricorni* with mixed species	Isolated patches	*Halodule uninervis* (thin), *Zostera capricorni, Halophila ovalis*
44	nd	2.4 ± 0.3	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
45	nd	1.5 ± 0.3	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
46	0.02 ± 0	1.3 ± 0.2	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
47	0.03 ± 0	2.6 ± 0.3	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (wide)
51	0.02 ± 0	0.7 ± 0.2	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
52	0.03 ± 0.01	5.3 ± 0.6	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
53	0.01 ± 0.01	3.6 ± 0.5	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
54	0.01 ± 0	8.7 ± 0.9	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
55	0.72 ± 0.59	1.1 ± 0.3	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
56	1.10 ± 0.58	5.4 ± 0.8	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
57	0.53 ± 0.52	13.1 ± 1.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
59	18.09 ± 16.47	1.1 ± 0.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*

Map 5. Seagrass distribution and community types in Fishermans Landing region, November 2009

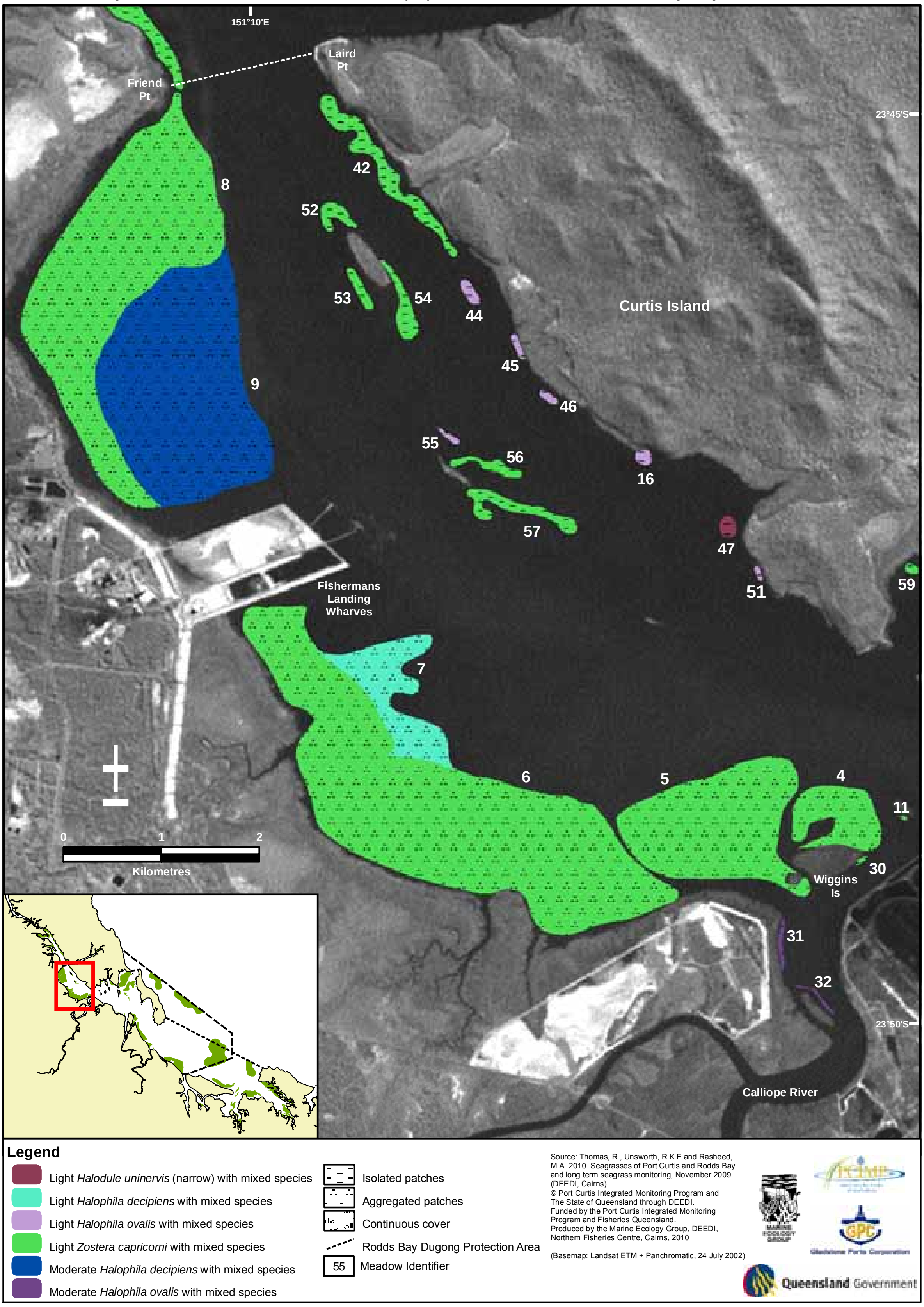


Table 7(A) Seagrass community type, seagrass cover and species present in the Quoin Island region, November 2009 (see Map 6) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
3	11.37 ± 8.98	2.3 ± 0.4	Moderate *Halodule uninervis* (wide) with mixed species	Isolated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin)
4	1.47 ± 0.45	41.0 ± 1.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
5	1.38 ± 0.32	154.7 ± 2.9	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
11	9.52 ± 0	0.3 ± 0.1	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
30	0.01 ± 0	0.5 ± 0.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
32	1.90 ± 0.81	1.1 ± 0.5	Moderate *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
43	20.46 ± 2.02	644.1 ± 13.3	Moderate *Zostera capricorni* with mixed species	Continuous cover	*Zostera capricorni, Halodule uninervis* (wide), *Halophila ovalis*
48	0.0009 ± 0	30.5 ± 2.7	Light *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin), *Halophila decipiens*
49	nd	16.2 ± 2.2	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide)
50	0.27 ± 0.16	16.2 ± 1.9	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide)
59	18.09 ± 16.47	1.1 ± 0.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
61	5.24 ± 3.22	4.1 ± 0.7	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
62	0.03 ± 0	0.7 ± 0.2	Light *Halophila ovalis* with mixed species	Aggregated patches	*Halophila ovalis*
63	1.39 ± 0.15	2.0 ± 0.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
64	nd	3.3 ± 0.3	Light *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (thin)
65	5.63 ± 0.71	3.0 ± 0.4	Dense *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin)
66	9.30 ± 2.13	314.7 ± 52.7	Moderate *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin), *Zostera capricorni, Halophila ovalis*
67	30.43 ± 0	6.6 ± 0.5	Dense *Halodule uninervis* (wide) with mixed species	Isolated patches	*Halodule uninervis* (wide)
68	11.98 ± 0	1.7 ± 0.3	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
69	5.89 ± 1.99	1.4 ± 0.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
70	1.78 ± 0.98	5.2 ± 0.6	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
79	4.57 ± 1.45	36.8 ± 8.7	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
80	3.49 ± 1.70	5.1 ± 0.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*

Table 7(B) Seagrass community type, seagrass cover and species present in the Quoin Island region, November 2009 (see Map 6) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
81	4.32 ± 0.16	0.1 ± 0.1	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
82	0.41 ± 0	0.1 ± 0	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
83	nd	0 ± 0	Light *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
84	38.17 ± 0	0.1 ± 0	Moderate *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
85	6.38 ± 2.23	80.4 ± 57.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
86	18.75 ± 0	0.2 ± 0	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
87	4.80 ± 0	0 ± 0	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
136	6.38 ± 2.29	8.3 ± 4.1	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
137	43.74 ± 4.55	4.3 ± 0.9	Moderate *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*

Map 6. Seagrass distribution and community types in the Quoin Island region, November 2009

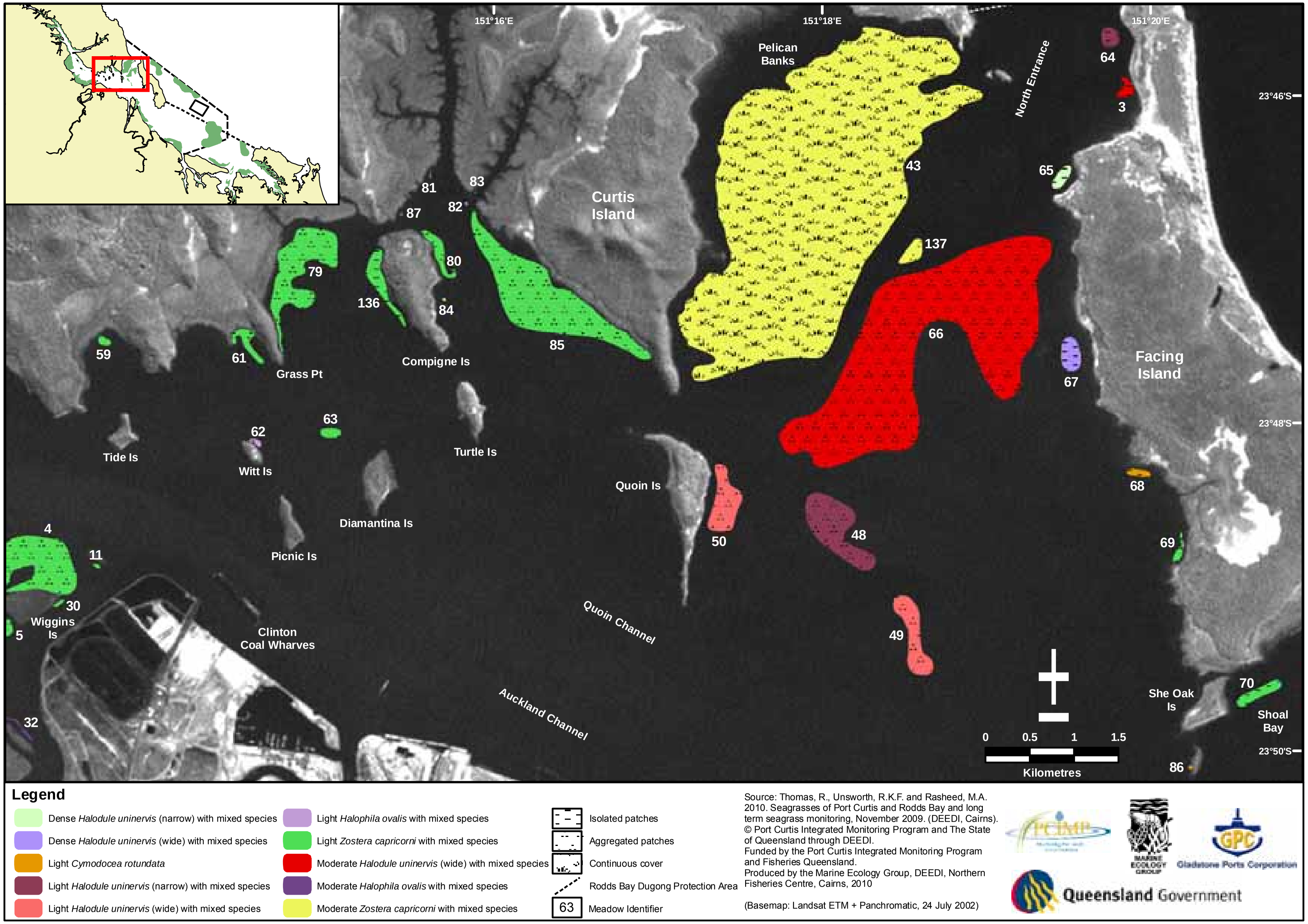


Table 8 Seagrass community type, seagrass cover and species present in the South Trees region, November 2009 (see Map 7) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass (gDWm^{-2})	Area ± R (ha)	Community Type	Cover	Species Present
48*	0.0009 ± 0	30.5 ± 2.7	Light *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin), *Halophila decipiens*
49*	nd	16.2 ± 2.2	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide)
50*	0.27 ± 0.16	16.2 ± 1.9	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide)
58	5.14 ± 1.50	22.2 ± 3.5	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
60	2.16 ± 0.46	6.4 ± 0.7	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
69	5.89 ± 1.99	1.4 ± 0.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
70	1.78 ± 0.98	5.2 ± 0.6	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
71	1.6 ± 0	0.9 ± 0.2	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
72	4.44 ± 2.81	4.9 ± 0.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
73	3.38 ± 0	0.3 ± 0.1	Moderate *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (thin)
74	6.81 ± 0	0.4 ± 0.2	Dense *Halophila ovalis* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
75	1.75 ± 0	1.3 ± 0.3	Moderate *Halophila ovalis* with mixed species	Isolated patches	*Halophila ovalis*
76	16.00 ± 5.54	137.2 ± 5.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
77	26.17 ± 11.79	1.4 ± 0.9	Moderate *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
78	4.39 ± 1.30	317.7 ± 11.2	Dense *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin), *Zostera capricorni, Halophila ovalis*
86	18.75 ± 0	0.2 ± 0	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
88	3.14 ± 1.33	8.1 ± 1.2	Moderate *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin)
89	5.26 ± 1.33	101.6 ± 5.4	Dense *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin)

*meadows 48, 49, and 50 were observed as separate meadows but comprise the broader location of the once continuous long-term monitoring meadow number 48

Map 7. Seagrass distribution and community types in the South Trees region, November 2009

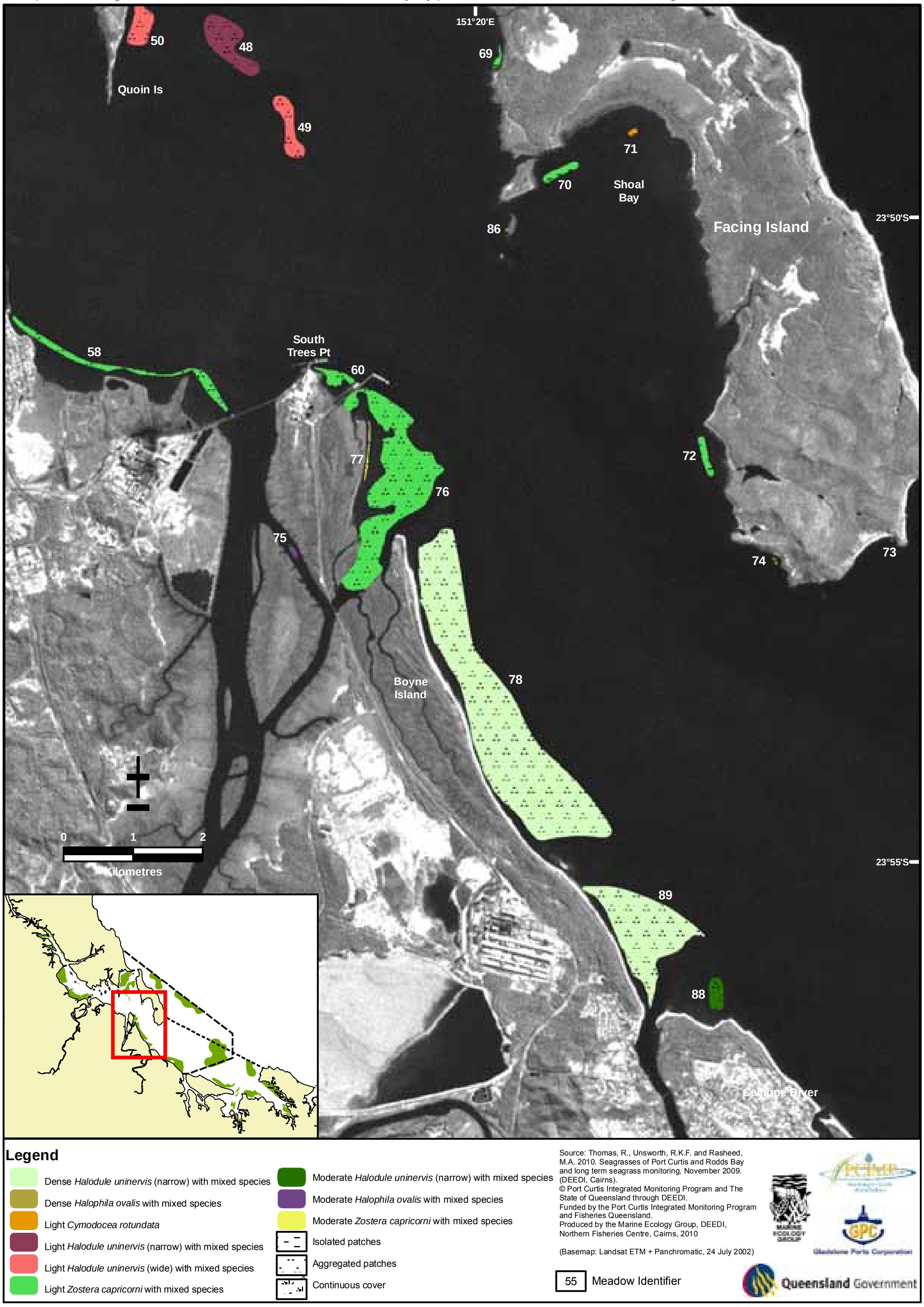


Table 9(A) Seagrass community type, seagrass cover and species present in the Hummock Hill Island region, November 2009 (see Map 8) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
68	11.98 ± 0	1.7 ± 0.3	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
69	5.89 ± 1.99	1.4 ± 0.4	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
70	1.78 ± 0.98	5.2 ± 0.6	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
71	1.60 ± 0	0.9 ± 0.2	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
72	4.44 ± 2.81	4.9 ± 0.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
73	3.38 ± 0	0.3 ± 0.1	Moderate *Halodule uninervis* (narrow) with mixed species	Isolated patches	*Halodule uninervis* (thin)
74	6.81 ± 0	0.4 ± 0.2	Dense *Halophila ovalis* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
78	4.39 ± 1.30	317.7 ± 11.2	Dense *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin), *Zostera capricorni, Halophila ovalis*
86	18.75 ± 0	0.2 ± 0	Light *Cymodocea rotundata*	Isolated patches	*Cymodocea rotundata*
88	3.14 ± 1.33	8.1 ± 1.2	Moderate *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin)
89	5.26 ± 1.33	101.6 ± 5.4	Dense *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (thin)
90	0.41 ± 0	0.2 ± 0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
91	1.57 ± 0.61	31.6 ± 3.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
92	0.72 ± 0.29	4.6 ± 1.4	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
93	0.05 ± 0.03	3.4 ± 0.5	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
95	0.01 ± 0	6.5 ± 1.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
97	nd	7.1 ± 1.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
98	0.07 ± 0.07	3.7 ± 0.4	Light *Halophila ovalis* with mixed species	Aggregated patches	*Halophila ovalis*
99	nd	48.3 ± 4.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
100	0.01 ± 0	1.7 ± 0.6	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
101	nd	4.2 ± 1.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
102	nd	3.8 ± 0.6	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
105	nd	0.5 ± 0.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*

Table 9(B) Seagrass community type, seagrass cover and species present in the Hummock Hill Island region, November 2009 (see Map 8) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
106	nd	1.0 ± 0.2	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
107	nd	0.5 ± 0.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni*
108	0.37 ± 0.15	423.9 ± 26.5	Light *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin), *Halophila ovalis*
109	0.40 ± 0.18	703.7 ± 28.9	Light *Halodule uninervis* (narrow) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin), *Halophila ovalis*
110	0.34 ± 0.22	48.9 ± 5.3	Light *Halodule uninervis* (wide) with mixed species	Aggregated patches	*Halodule uninervis* (wide), *Halodule uninervis* (thin)
111	0.43 ± 0.25	30.4 ± 3.5	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halodule uninervis* (thin)
112	1.78 ± 1.02	118.6 ± 3.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
113	0.36 ± 0.35	30.3 ± 1.6	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
114	nd	3.4 ± 0.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni*
115	0.03 ± 0.02	34.7 ± 6.0	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
116	0.01 ± 0.01	84.5 ± 7.2	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
117	0.01 ± 0	0.7 ± 0.2	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
118	0.67 ± 0.40	12.4 ± 1.7	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
119	1.74 ± 0.62	439.9 ± 12.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halodule uninervis* (wide), *Halophila ovalis, Halophila decipiens*
121	11.49 ± 5.11	736.1 ± 45.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
122	0.01 ± 0	10.6 ± 0.7	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
126	nd	0.5 ± 0.1	Light *Halophila ovalis* with mixed species	Aggregated patches	*Halophila ovalis*
127	1.32 ± 1.32	1.9 ± 0.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
132	0.09 ± 0.09	2503.5 ± 682.0	Light *Halophila decipiens*	Aggregated patches	*Halophila decipiens*
133	nd	669.4 ± 367.0	Light *Halophila decipiens*	Aggregated patches	*Halophila decipiens*
134	nd	623.6 ± 395.3	Light *Halophila decipiens*	Aggregated patches	*Halophila decipiens*
135	nd	1093.1± 602.4	Light *Halophila decipiens*	Aggregated patches	*Halophila decipiens*

Map 8. Seagrass distribution and community types in the Hummock Hill Island region, November 2009

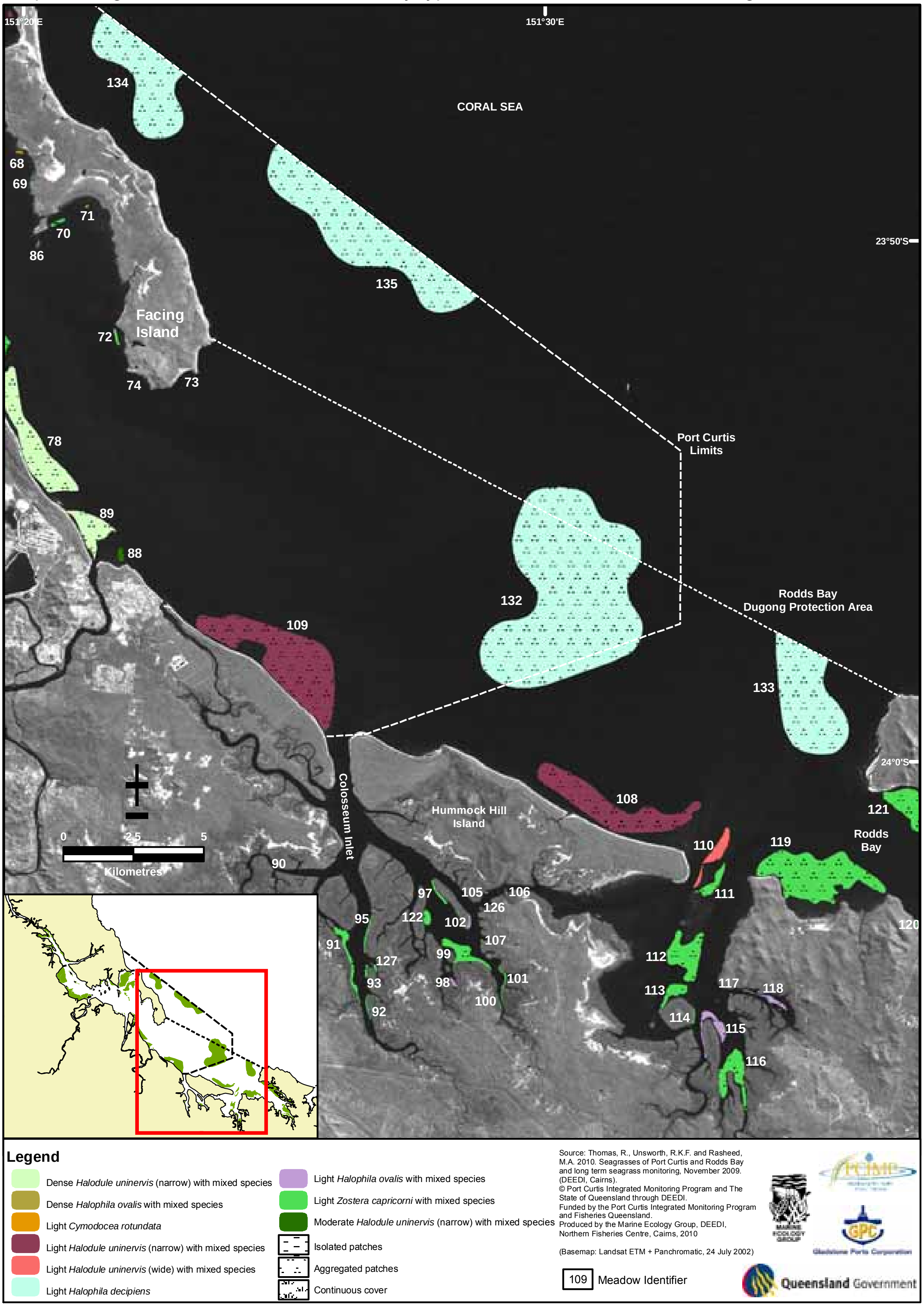
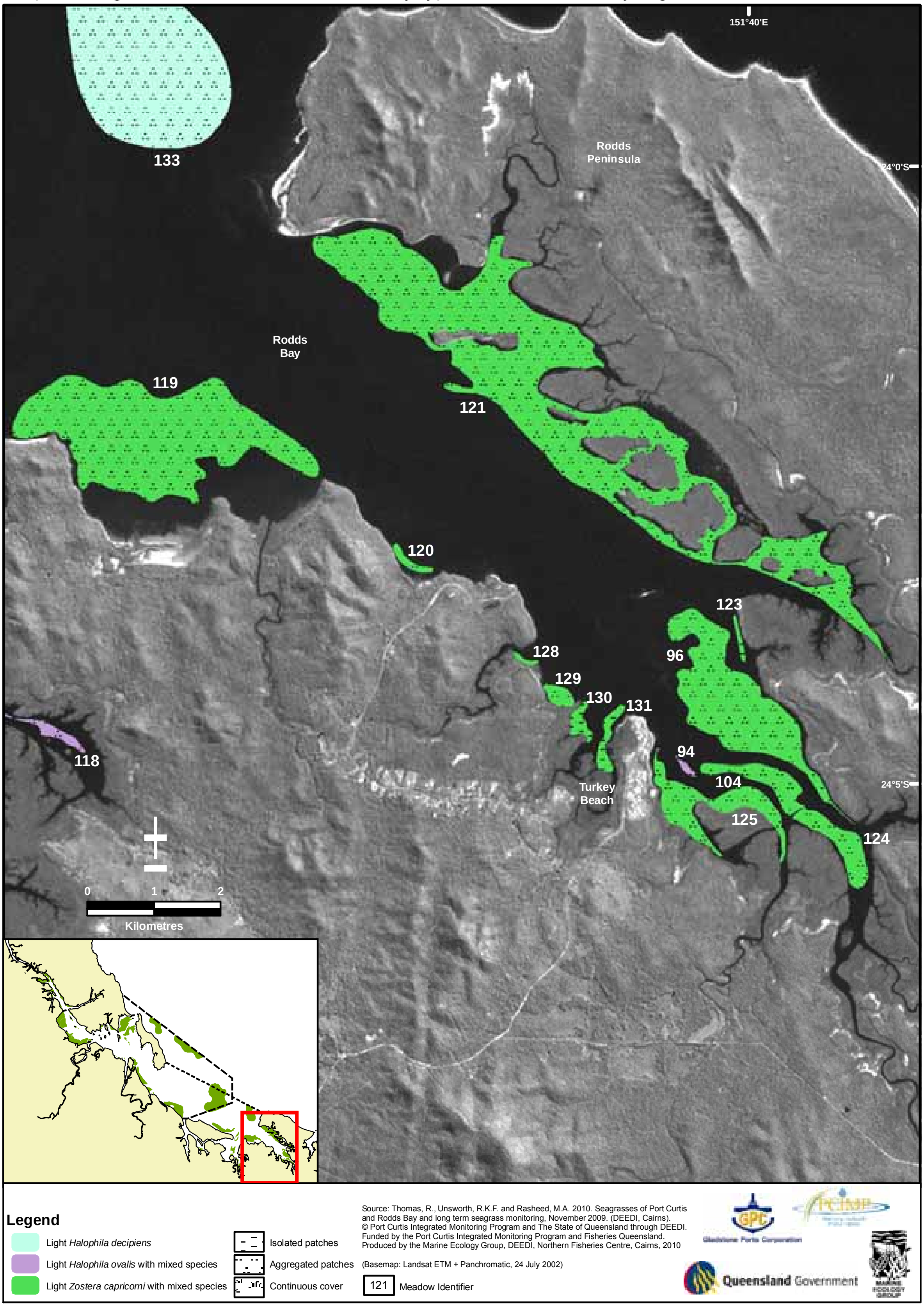


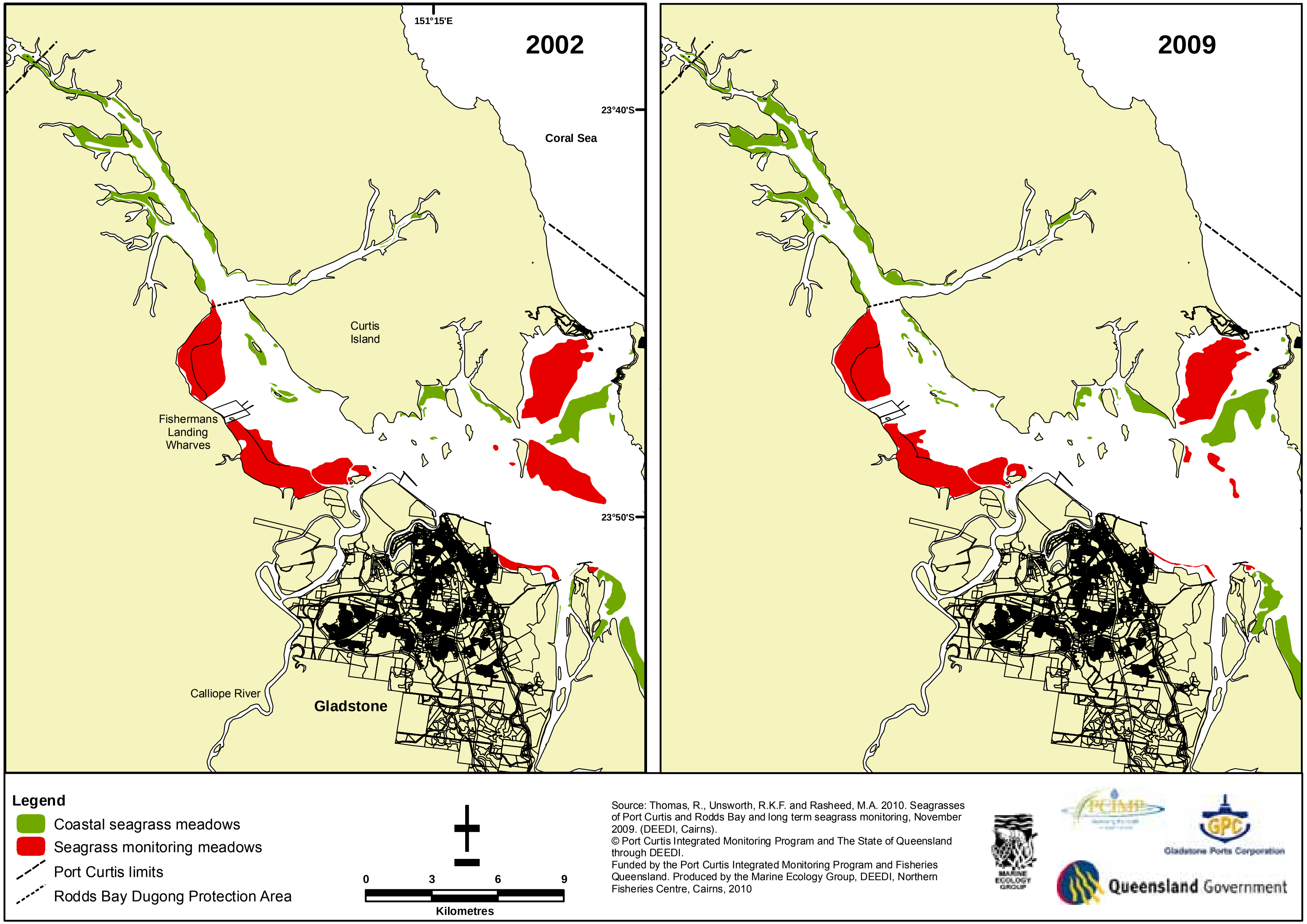
Table 10 Seagrass community type, seagrass cover and species present in the Rodds Bay region, November 2009 (see Map 9) (nd = seagrass observed at site but biomass not detected in random samples)

ID	Biomass ($gDWm^{-2}$)	Area ± R (ha)	Community Type	Cover	Species Present
94	0.01 ± 0.01	2.6 ± 0.5	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
96	8.96 ± 1.38	209.1 ± 10.0	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
104	2.56 ± 0.89	36.4 ± 1.9	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
118	0.67 ± 0.40	12.4 ± 1.7	Light *Halophila ovalis* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
119	1.74 ± 0.62	439.9 ± 12.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halodule uninervis* (wide), *Halophila ovalis, Halophila decipiens*
120	0.71 ± 0.68	6.7 ± 0.8	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
121	11.49 ± 5.11	736.1 ± 45.3	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
123	nd	3.9 ± 0.7	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
124	3.83 ± 3.82	39.1 ± 1.7	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
125	0.72 ± 0.33	73.7 ± 4.1	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis, Halophila decipiens*
128	6.65 ± 3.79	2.5 ± 0.5	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
129	10.37 ± 3.55	9.7 ± 0.6	Light *Zostera capricorni* with mixed species	Aggregated patches	*Zostera capricorni, Halophila ovalis*
130	4.23 ± 1.63	9.7 ± 0.8	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*
131	1.85 ± 1.07	13.3 ± 1.2	Light *Zostera capricorni* with mixed species	Isolated patches	*Zostera capricorni, Halophila ovalis*

Map 9. Seagrass distribution and community types in the Rodds Bay region, November 2009



Map 10. Comparison of seagrass meadow distribution in the northern Port Curtis region from November 2002 to November 2009



Source: Thomas, R., Unsworth, R.K.F. and Rasheed, M.A. 2010. Seagrasses of Port Curtis and Rodds Bay and long term seagrass monitoring, November 2009. (DEEDI, Cairns).
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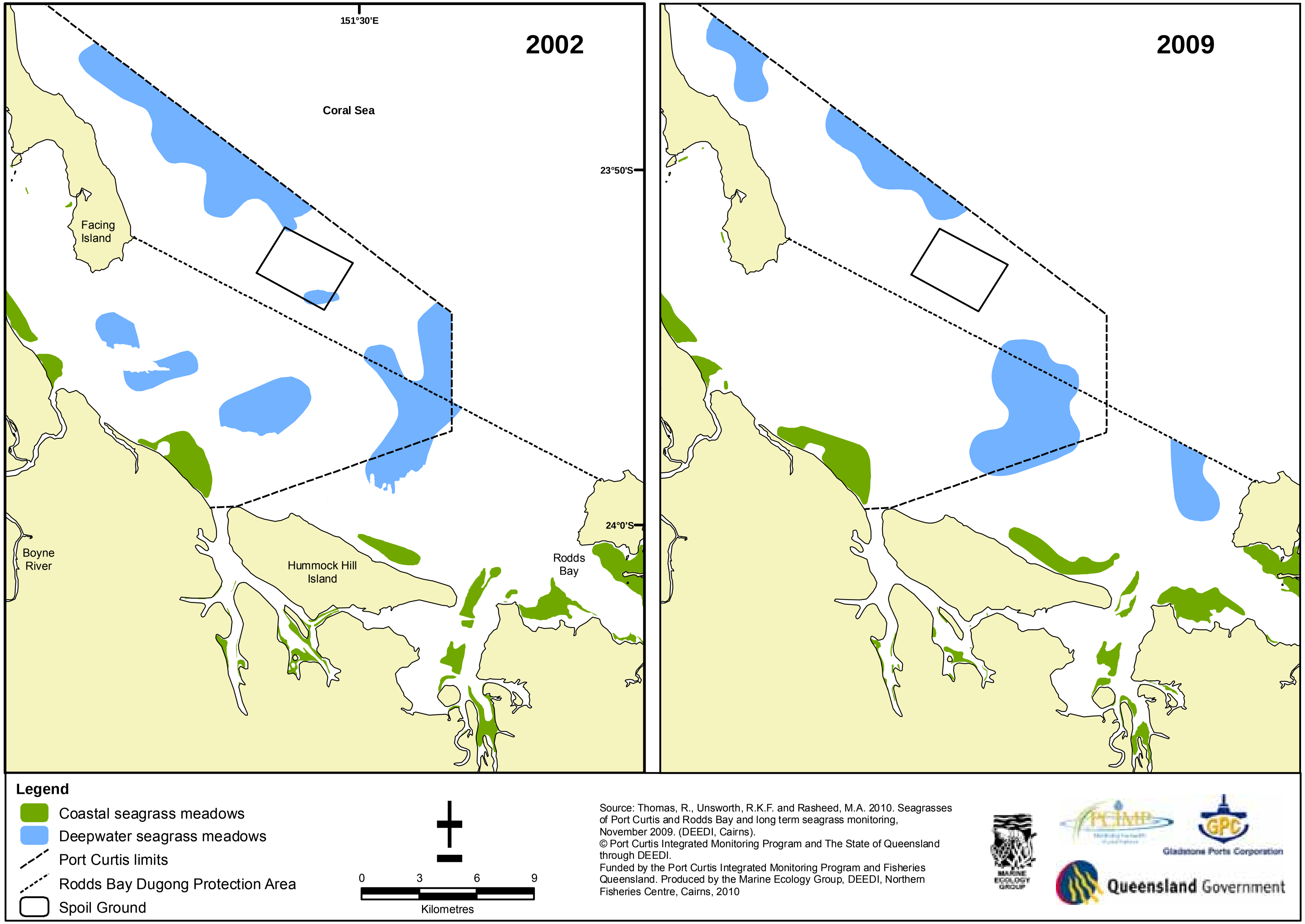
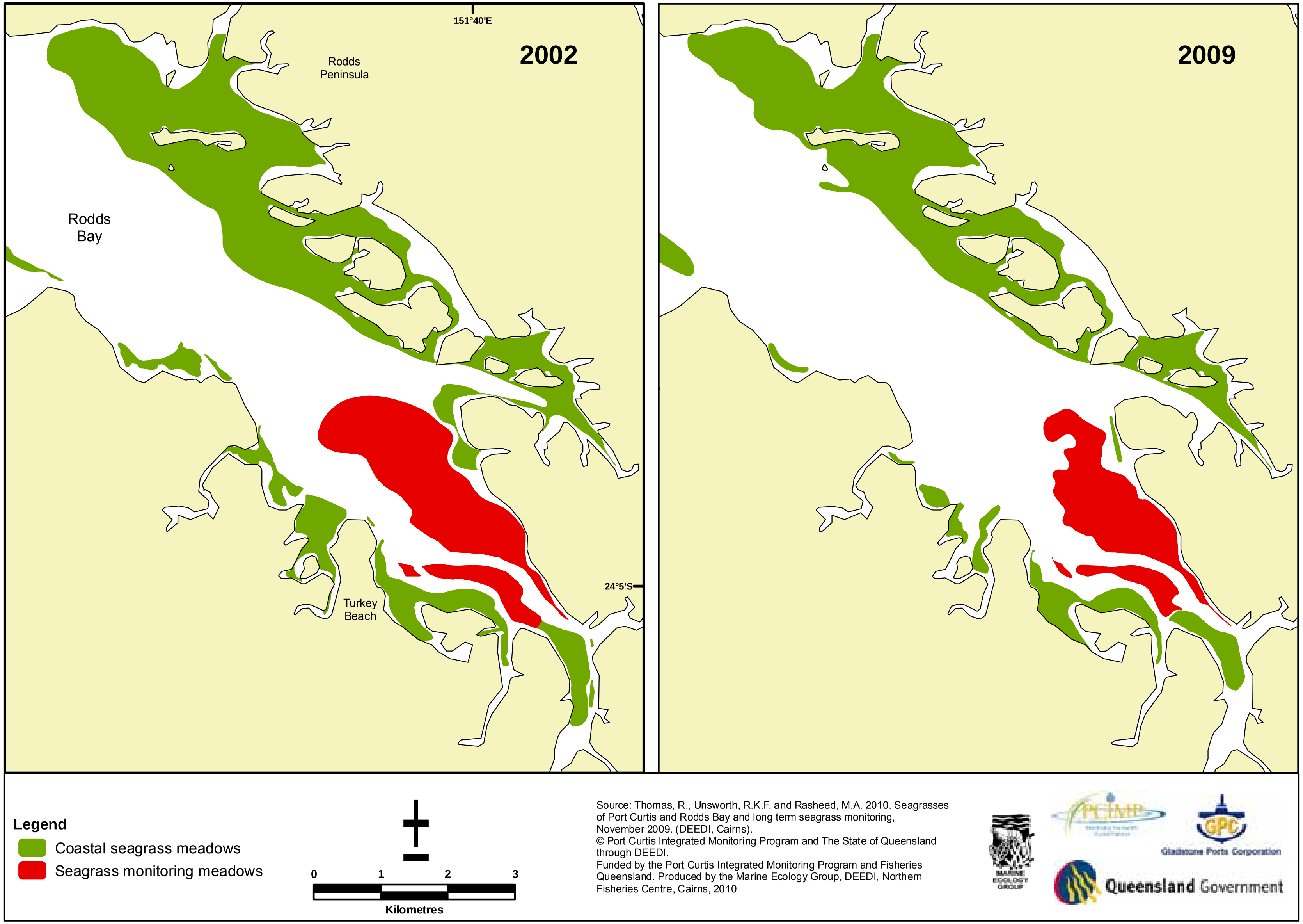
Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2010

Map 11. Comparison of seagrass meadow distribution in the southern Port Curtis region from November 2002 to November 2009



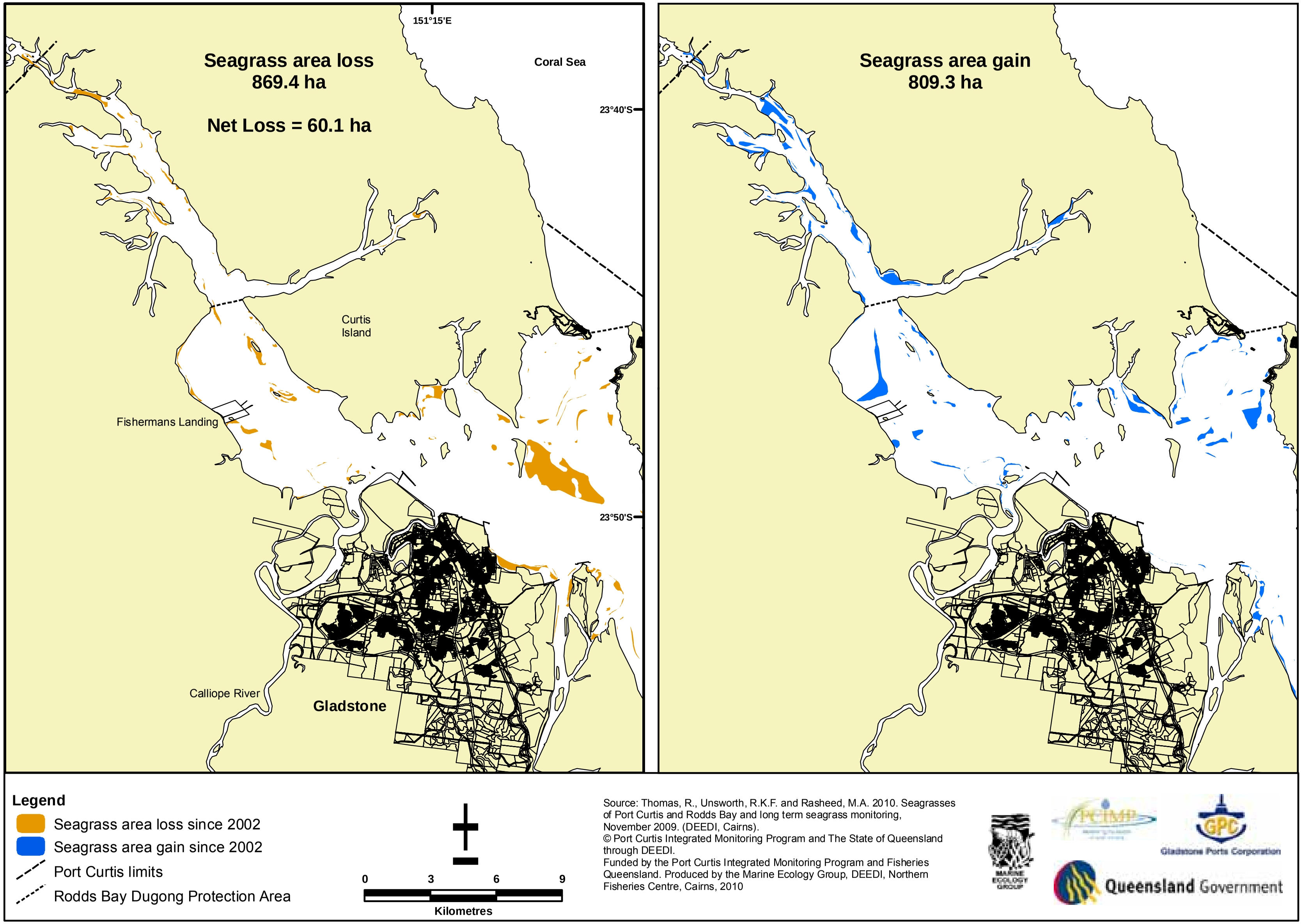
Map 12. Comparison of seagrass meadow distribution in the Rodds Bay region from November 2002 to November 2009



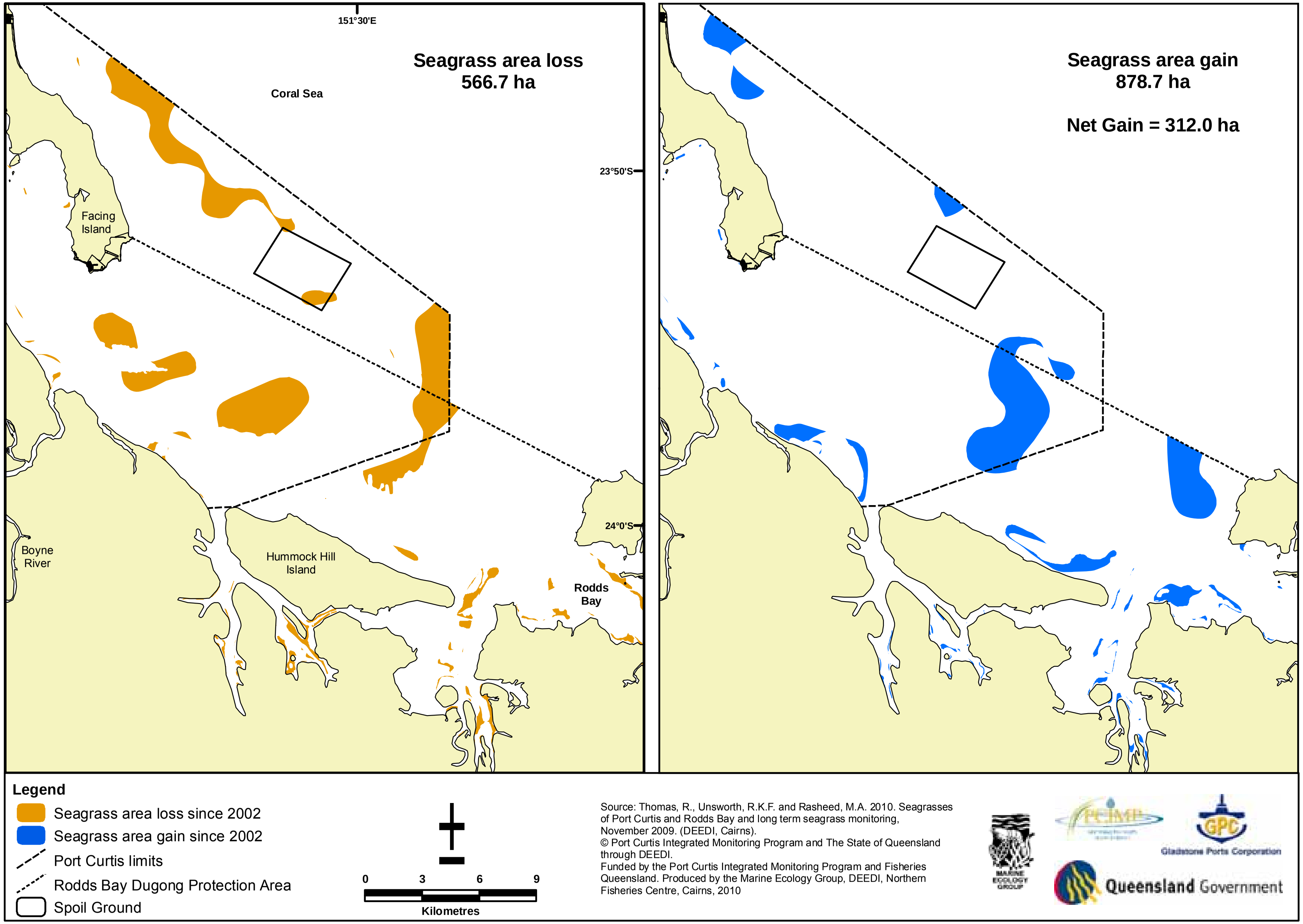
Source: Thomas, R., Unsworth, R.K.F. and Rasheed, M.A. 2010. Seagrasses of Port Curtis and Rodds Bay and long term seagrass monitoring, November 2009. (DEEDI, Cairns).

Funded by the Port Curtis Integrated Monitoring Program and Fisheries Queensland. Produced by the Marine Ecology Group, DEEDI, Northern Fisheries Centre, Cairns, 2010

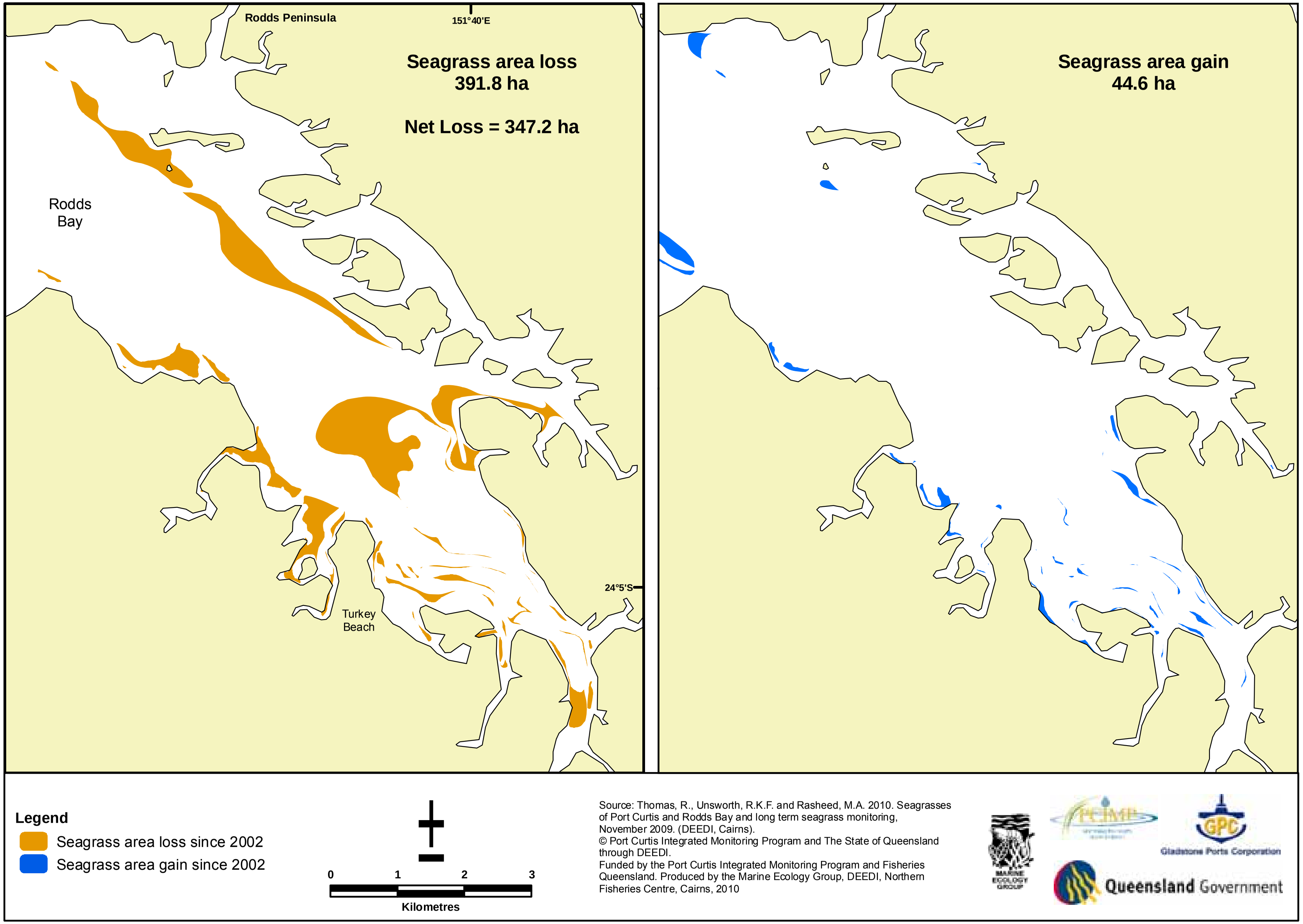
Map 13. Seagrass area loss and gain in the northern Port Curtis region from November 2002 to November 2009



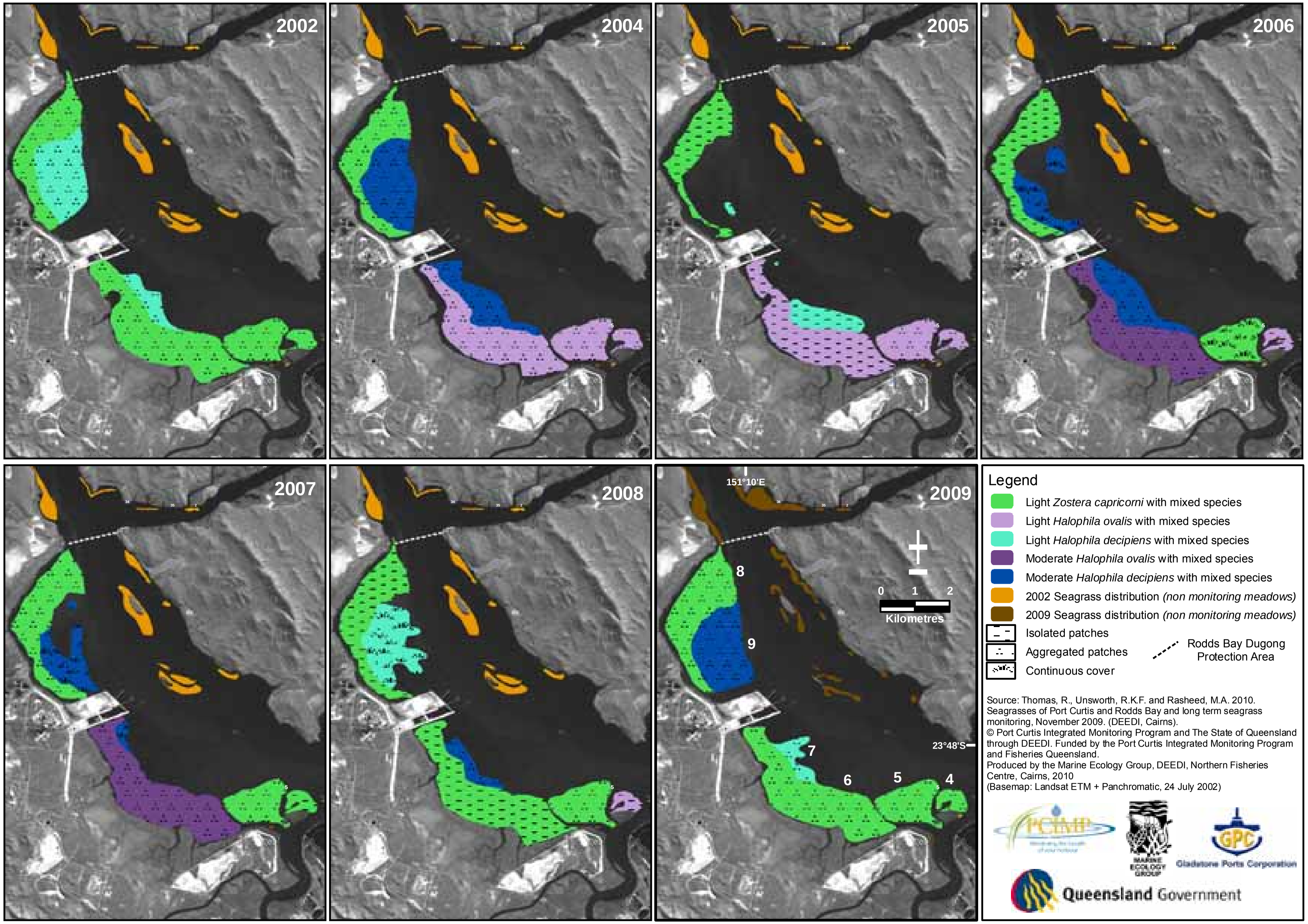
Map 14. Seagrass area loss and gain in the southern Port Curtis region from November 2002 to November 2009



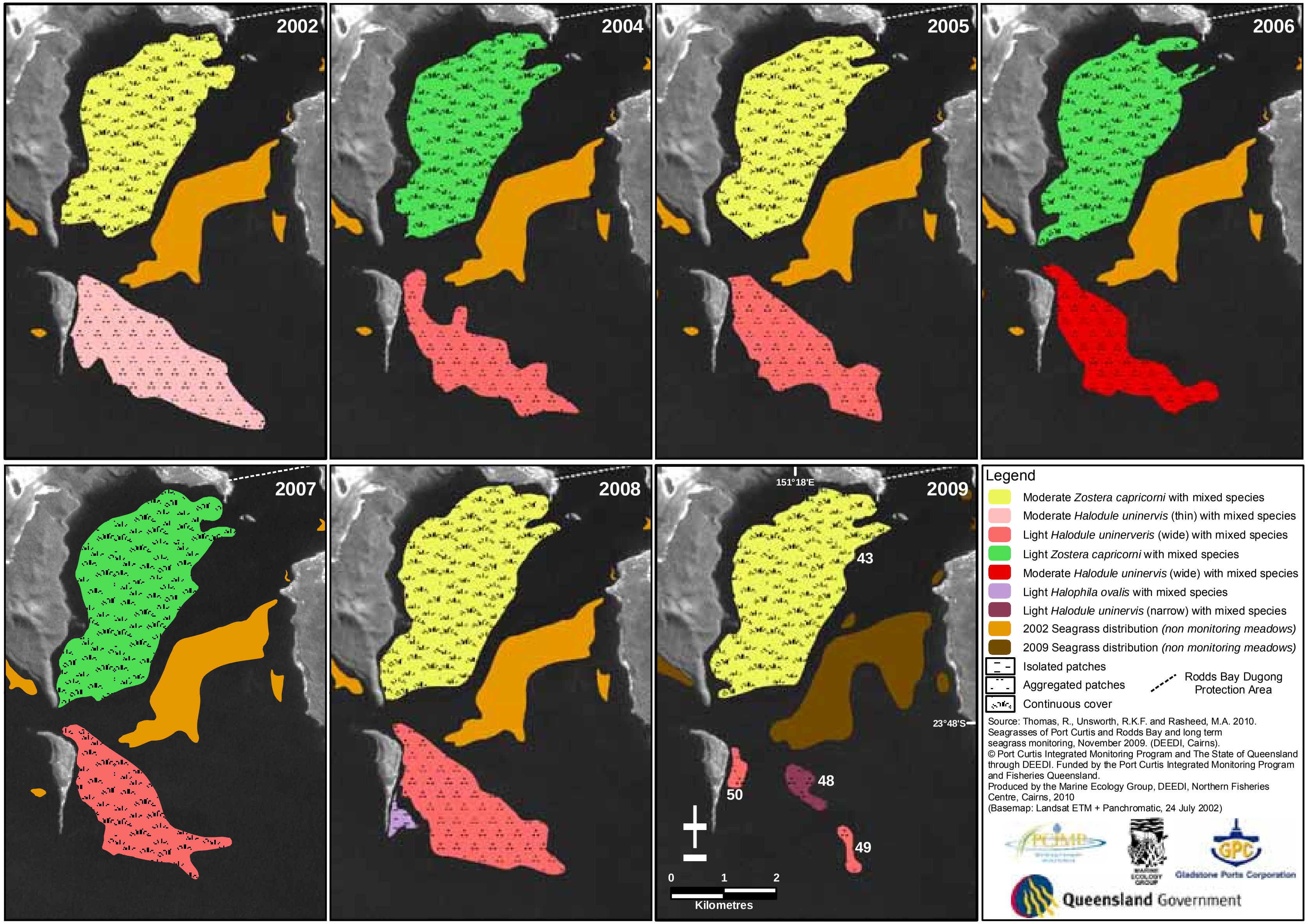
Map 15. Seagrass area loss and gain in the Rodds Bay region from November 2002 to November 2009



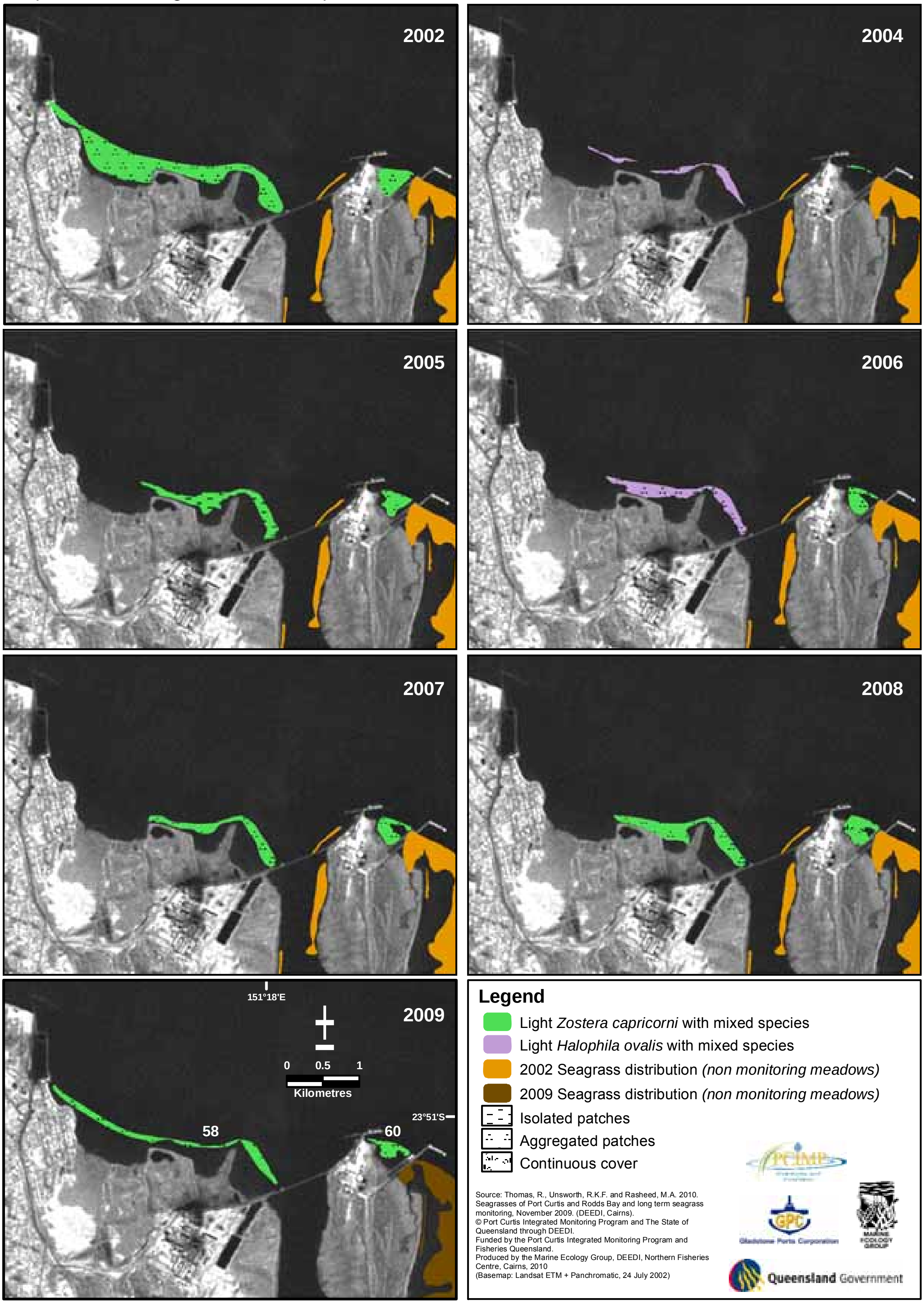
Map 16. Monitoring meadows comparison, Fishermans Landing region, 2002, 2004, 2005, 2006, 2007, 2008 & 2009



Map 17. Monitoring meadows comparison, Quoin Island region, 2002, 2004, 2005, 2006, 2007, 2008 & 2009



Map 18. Monitoring meadows comparison, South Trees, 2002, 2004, 2005, 2006, 2007, 2008 & 2009



Map 19. Monitoring meadows comparison, Rodds Bay, 2002, 2004, 2005, 2006, 2007, 2008 & 2009

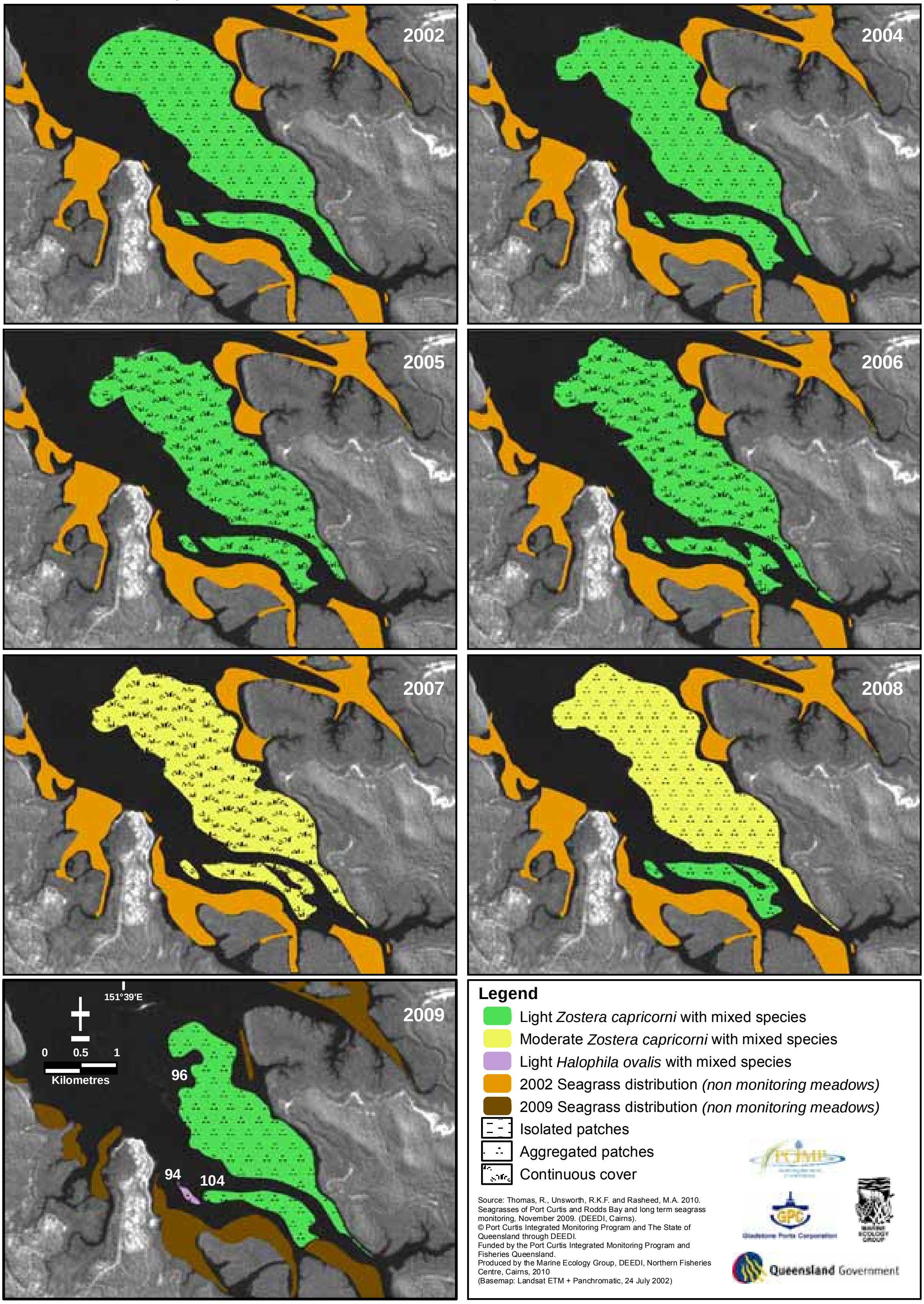


Table 11 Area (ha) for monitoring meadows in Port Curtis and Rodds Bay, November 2002, November 2004, October 2005, November 2006, October 2007, November 2008 and November 2009

Meadow ID	See map	Location	Meadow Depth	Meadow Area (ha)						
				2002	2004	2005	2006	2007	2008	2009
4	16	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
5	16	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
6	16	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
7	16	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
8	16	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
9	16	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
43	17	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
48*	17	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
58	18	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
60	18	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
94	19	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
96	19	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
104	19	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

* In 2009 this is an aggregation of meadows 48, 49 and 50 (see baseline Table 8)

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 and November 2009

Meadow ID	See map	Location	Meadow Depth	Mean biomass (g DW m^{-2})						
				2002	2004	2005	2006	2007	2008	2009
4	16	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
5	16	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
6	16	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
7	16	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
8	16	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
9	16	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
43	17	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
48*	17	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
58	18	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
60	18	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
94	19	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
96	19	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
104	19	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

* In 2009 this is an aggregation of meadows 48, 49 and 50 (see baseline Table 8)

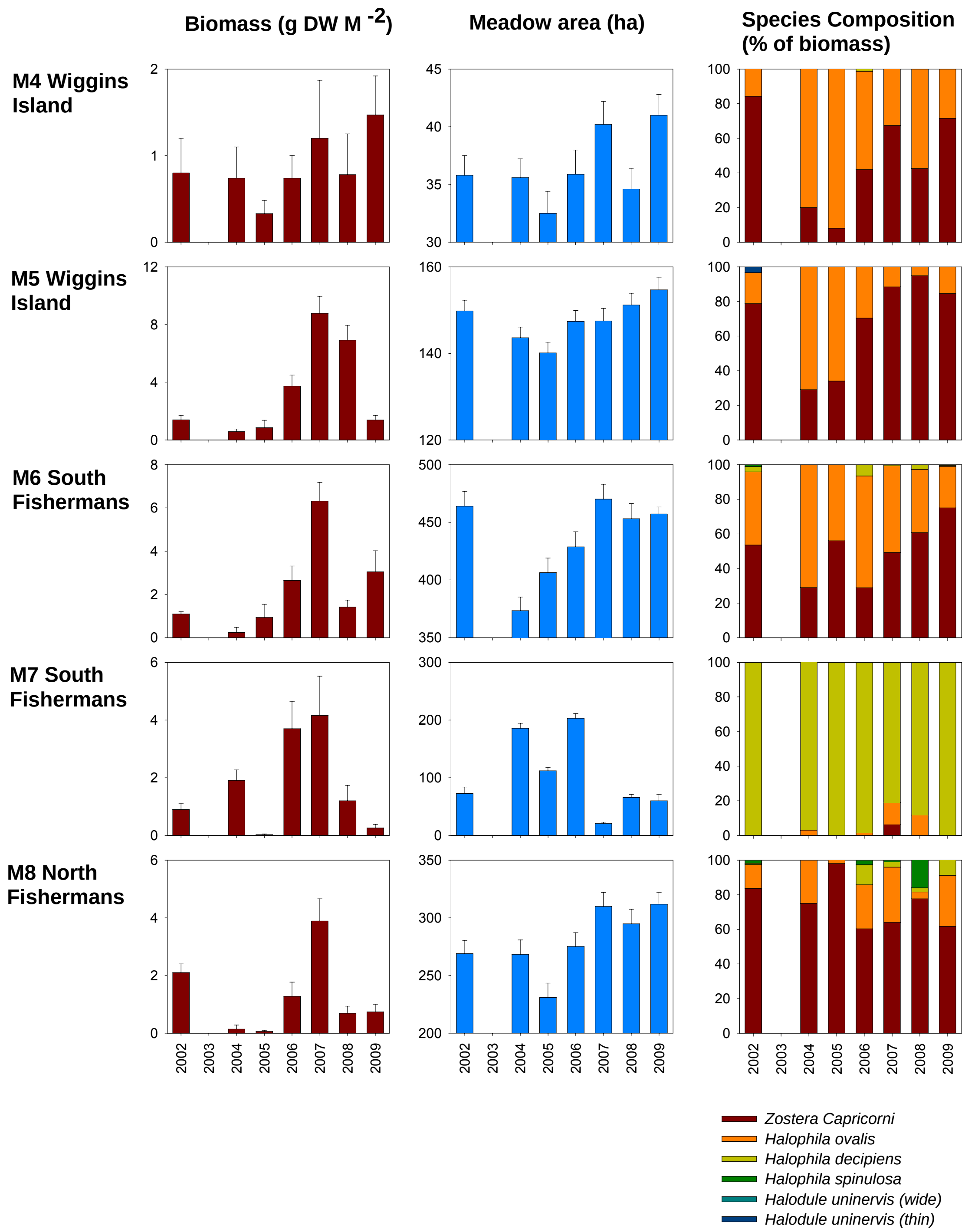


Figure 2(A) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2009 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

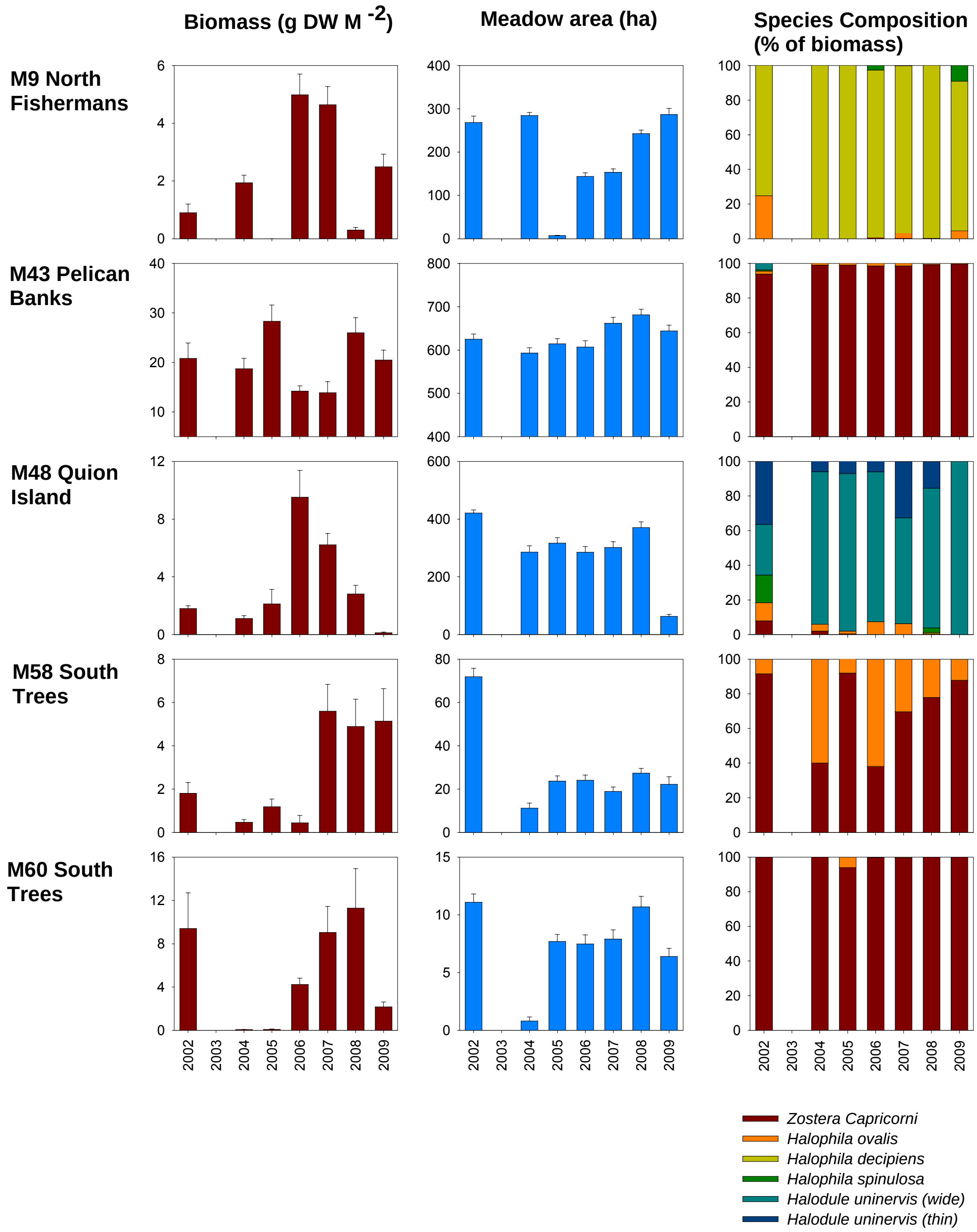


Figure 2(B) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2009 (Biomass error bars = SE; Area error bars = “R” reliability estimate)

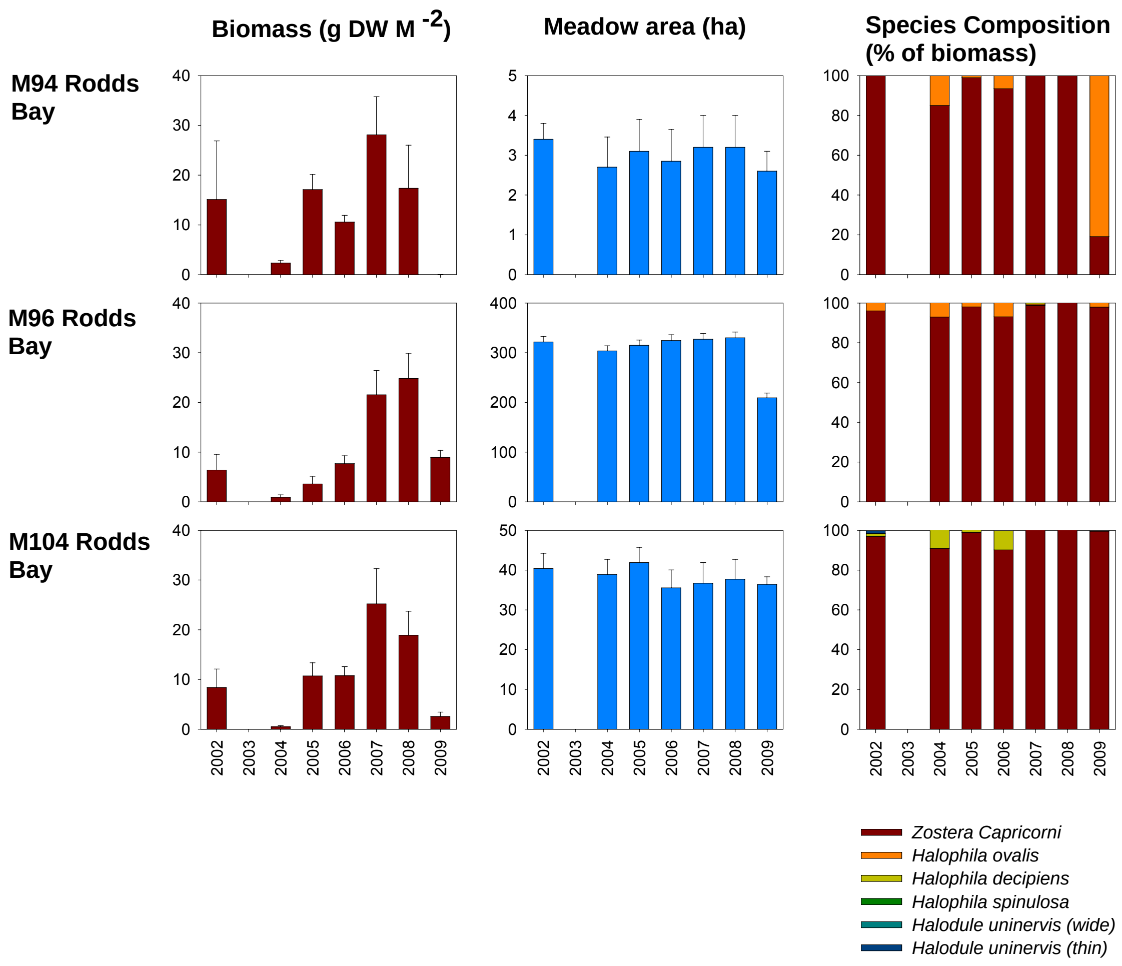


Figure 2(C) Changes in biomass, area and species composition for monitoring meadows in 2002 and 2004 - 2009 (Biomass error bars = SE; Area error bars = "R" reliability estimate)

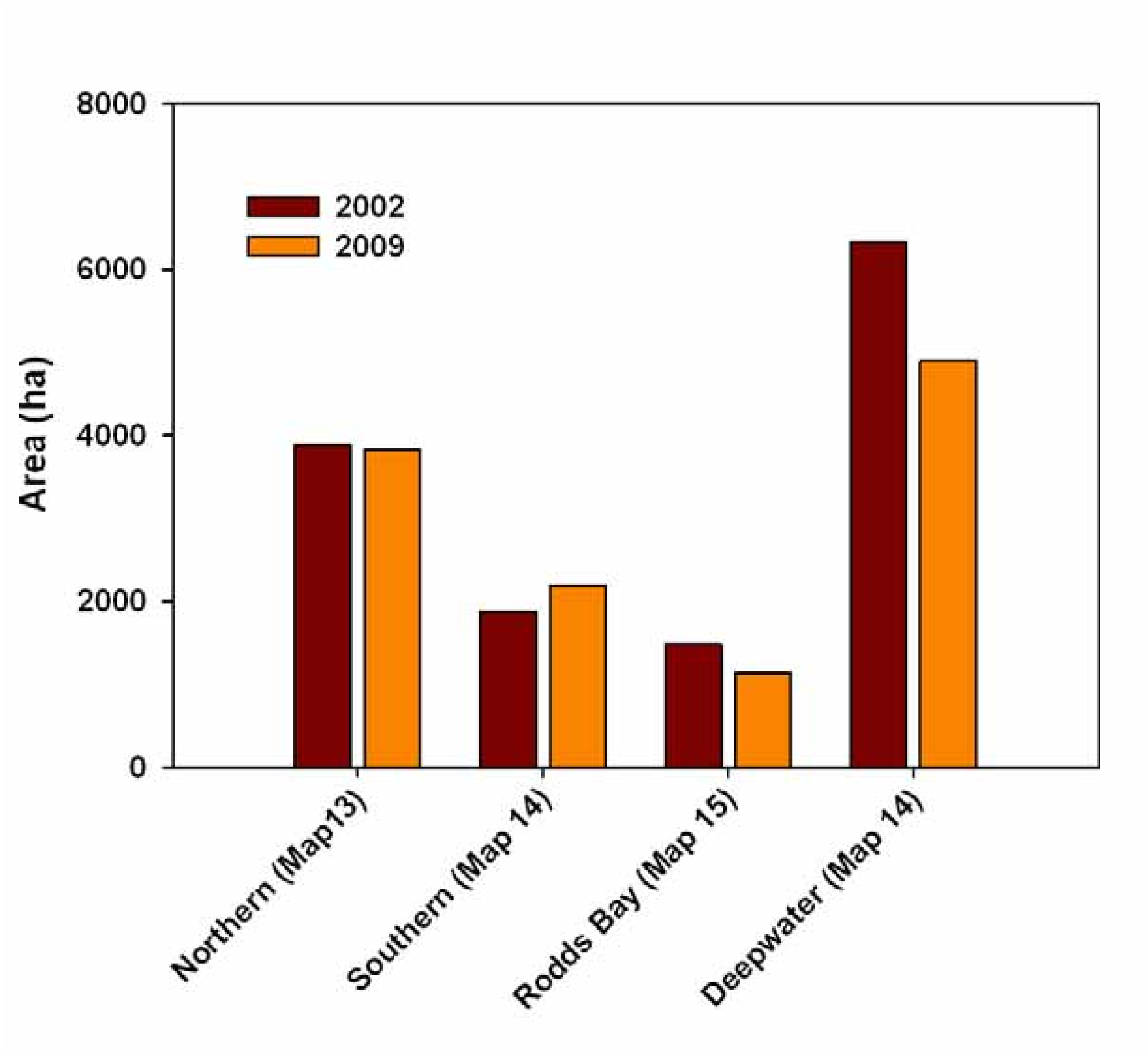


Figure 2(D) Changes in meadow area (ha) between the two baseline surveys (2002 and 2009) for four broad regions of Port Curtis and Rodds Bay (labels provide reference to Maps 13-15)

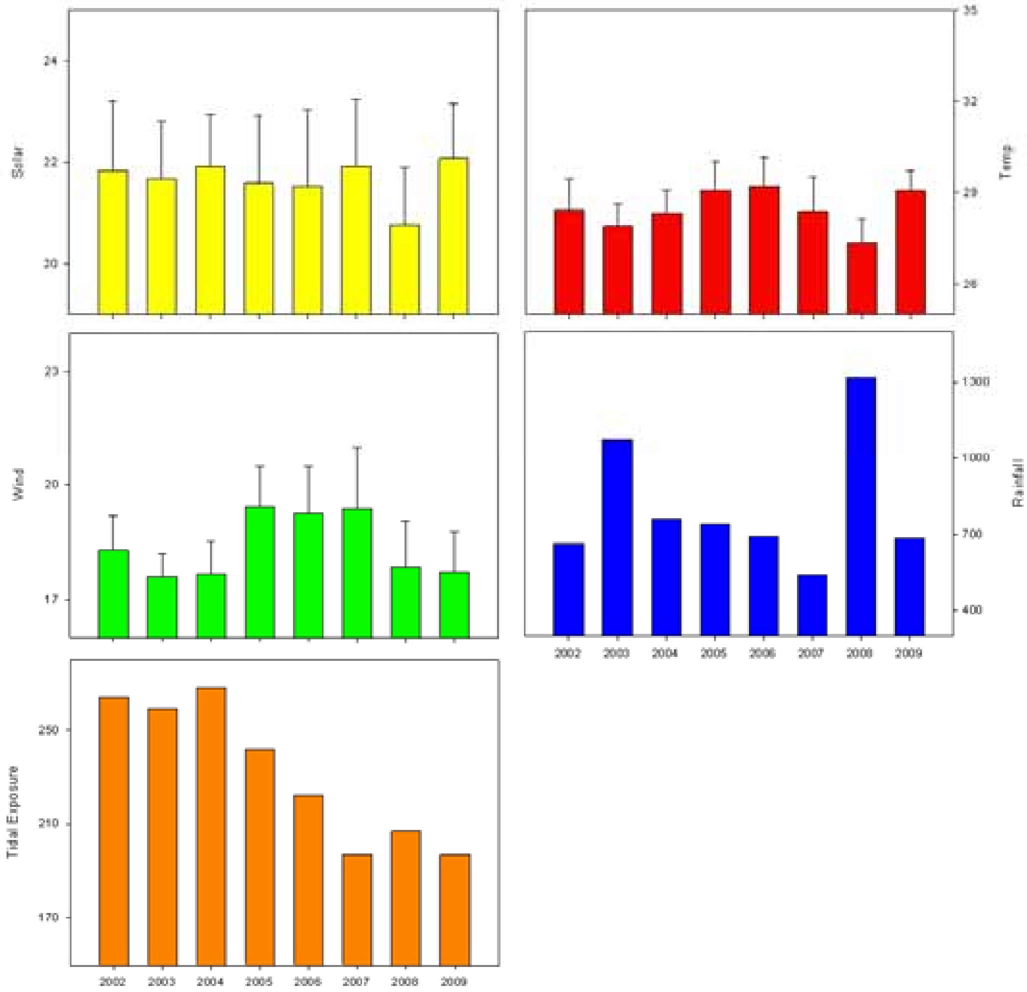


Figure 3(A-E) Mean (±SE) annual (Nov to Oct) climate and environmental parameters for Gladstone from 2002 to 2009. A) mean annual total daily solar radiation B) mean annually daily maximum air temperature C) mean annual daily wind speed D) total annual rainfall E) total annual day light tidal exposure at <1.0m. 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)

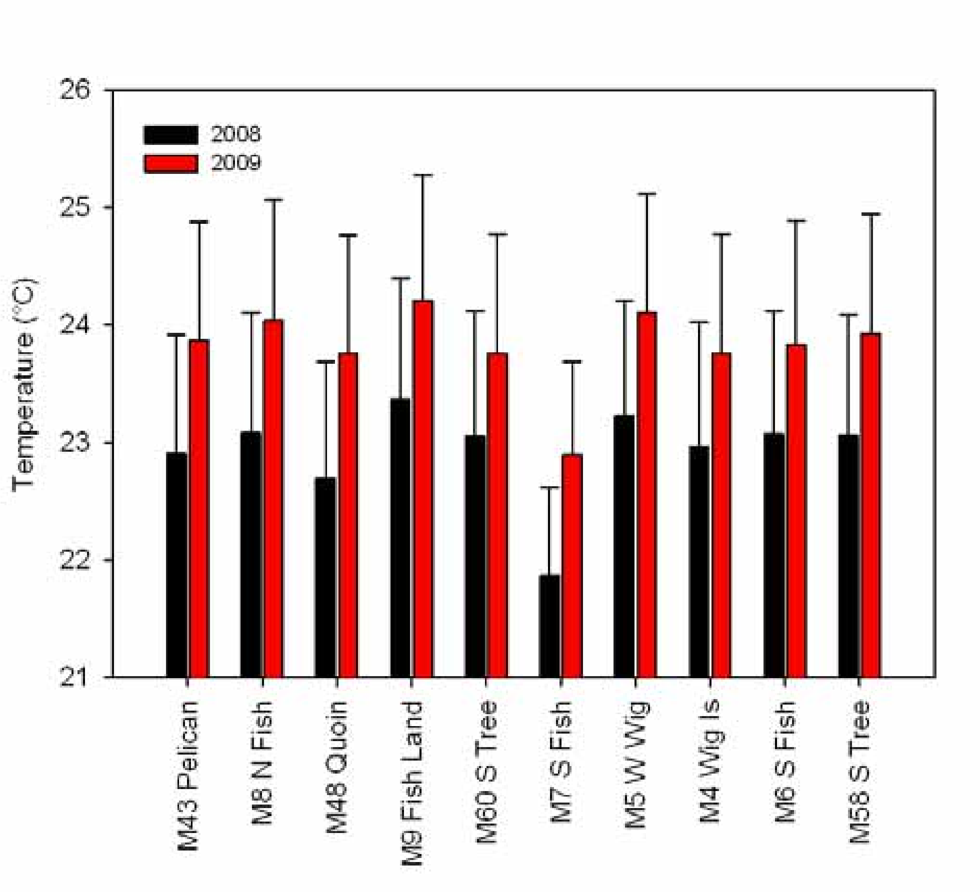


Figure 4 Mean annual daily maximum temperature of the seagrass canopy (previous nine months – Feb to Oct) at ten sites within Gladstone Harbour in 2008 and 2009

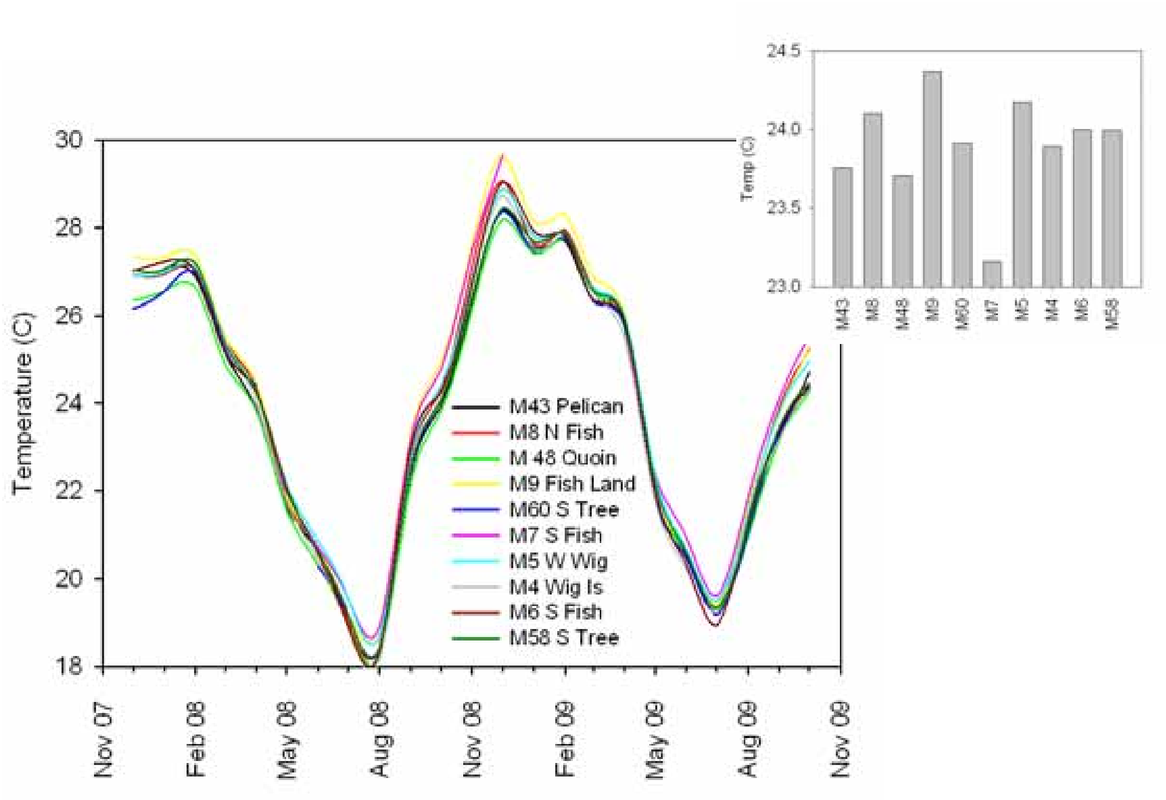


Figure 5 Mean monthly seagrass canopy temperatures at ten sites within Gladstone Harbour from Nov 2007 to Nov 2009. Inset graph shows the average temperatures for each site throughout the whole period

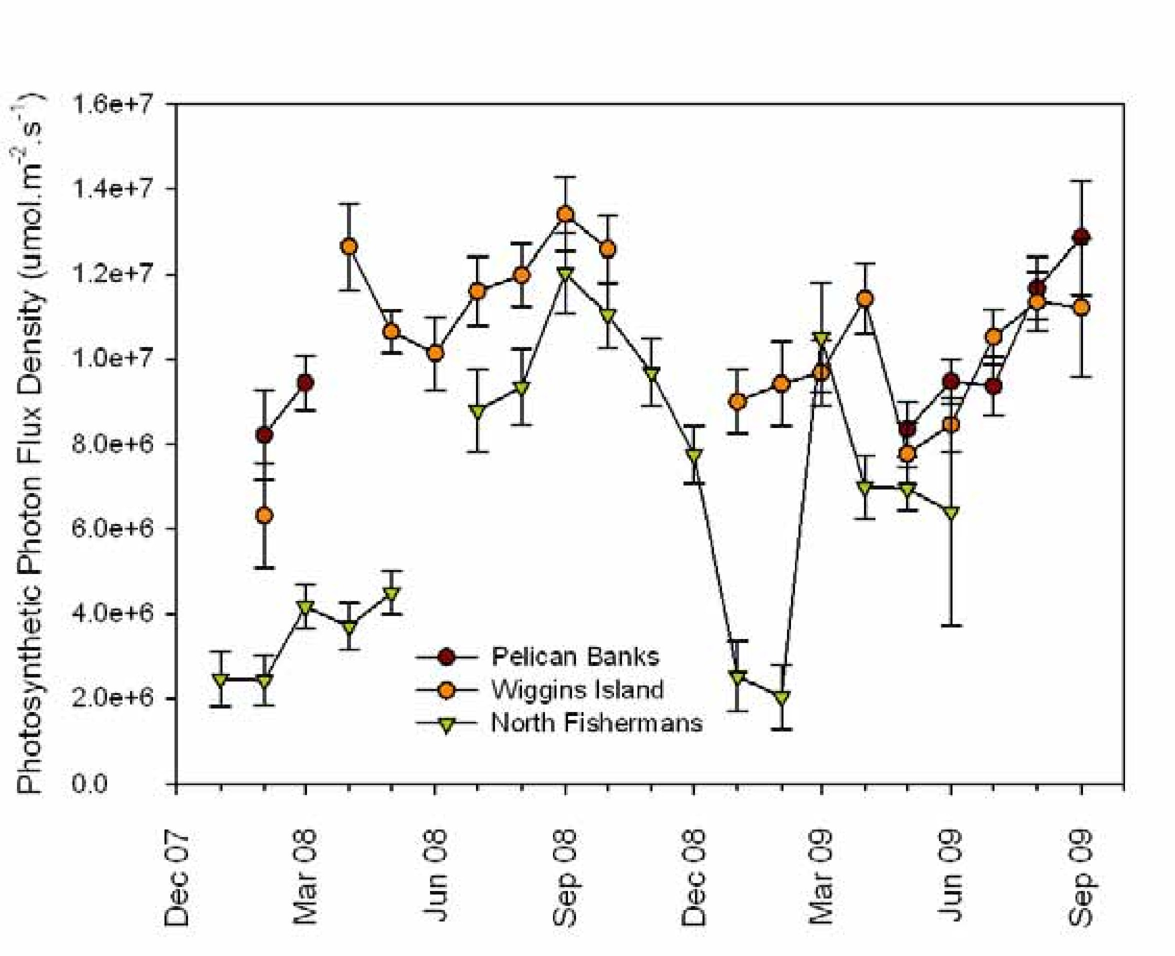


Figure 6 Mean (±SE) monthly total daily light availability at three seagrass meadows in Gladstone Harbour (Pelican Banks is meadow 43, Wiggins Island is meadow 5, and North Fishermans is meadow 9)

DISCUSSION

Seagrass meadows in Port Curtis and Rodds Bay covered a total of 12040.3 ± 2556.1 ha in 2009. These extensive seagrass meadows are likely to be of regional significance as they are the only known major area of seagrass between Hervey Bay (170 km south) and Shoalwater Bay (170 km north) (Lee Long *et al.* 1992).

These seagrass meadows are of high ecological and economic value. This is due to their role in 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 & Cullen 2010), and playing an important role in nutrient and carbon cycling within the coastal environment (Costanza *et al.* 1997, Hemminga & 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). Dugong and turtle (and their feeding trails) have been commonly observed throughout Port Curtis and Rodds Bay by the Marine Ecology Group (DEEDI) during seagrass surveys over the last two decades (1988 to 2010). This value is recognised by the Dugong Protection Area (DPA: Zone B) declared for the majority of the surveyed area (www.gbrmpa.gov.au) (Figure 7).

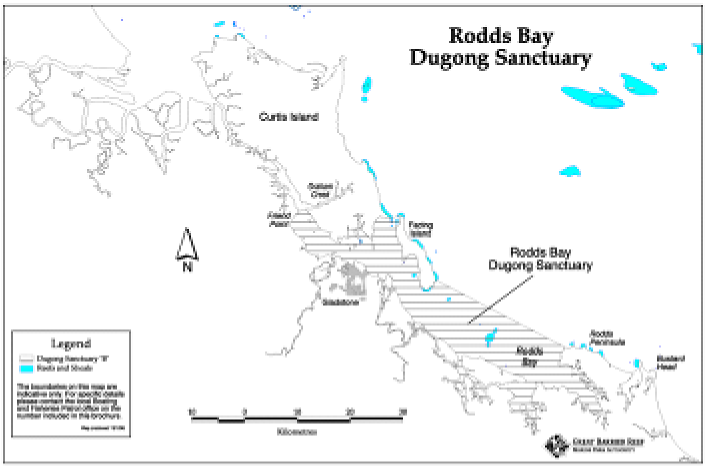


Figure 7 Spatial extent of the Dugong Protected Area in Port Curtis and Rodds Bay (Source – www.gbrmpa.gov.au)

Port Curtis and Rodds Bay have a high diversity of seagrass species, containing 38% of the known species occurring in the Great Barrier Reef World Heritage Area (GBRWHA) (Coles *et al.* 2007). These species and communities are typical of the Indo-West Pacific region (Short *et al.* 2001). 136 meadows were mapped in Port Curtis and Rodds Bay in November 2009, the majority of these meadows were intertidal to shallow subtidal and contained or were dominated by *Zostera capricorni*. In the fully subtidal and deeper waters, meadows were dominated by a mix of *Halophila* species. These species shifts with depth and substrate type are typical for meadows in tropical Queensland (Coles *et al.* 2007). Meadows tended to be denser and more structurally complex in the intertidal to shallow subtidal sections of the survey areas than they were in the subtidal and deeper waters.

The broad distribution of the meadows observed in 2009 is similar to those observed in 2002 (Rasheed *et al.* 2003), but there was an overall reduction in area of ≈1500 ha. The majority of this loss was within the deepwater meadows, but there was also some additional shallow coastal seagrass loss observed around Quoin Island and in Rodds Bay. It is difficult to ascertain the specific reasons for this decline in deepwater seagrass relative to 2002, but it is likely that climate variability and the passing of Cyclone Hamish in early 2009 along the Capricorn coast may have had some level of detrimental effect on the deeper water seagrasses outside of the protected inner harbour area. Given the continued presence of seagrass in the majority of the industrial and urban areas of Port Curtis, where anthropogenic stress is probably at its local maximum, it is unlikely that deepwater seagrass loss is the result of port related disturbance.

Changes in the availability of light with increasing depth, together with the effects of exposure and climate related stress at the intertidal margin, are major factors shaping the observed distribution of seagrasses (Erftemeijer & Herman 1994, Short *et al.* 2001, Carruthers *et al.* 2002, Rasheed *et al.* 2008a) (Figure 8). The pattern of species and biomass changes observed in Port Curtis and Rodds Bay results from the differing responses of seagrass species to these and other factors controlling seagrass growth. *Halophila* species for example, are well adapted to lower light conditions and typically dominate deepwater and highly turbid areas (Kenworthy *et al.* 1989, Durako *et al.* 2003). At the other extreme, seagrasses growing in areas exposed at low tide are dominated by species that can cope well with exposure related stress such as *Zostera capricorni* and *Halodule uninervis* (narrow leaf form) (McKenzie 1994, Björk *et al.* 1999, Rasheed *et al.* 2008a).

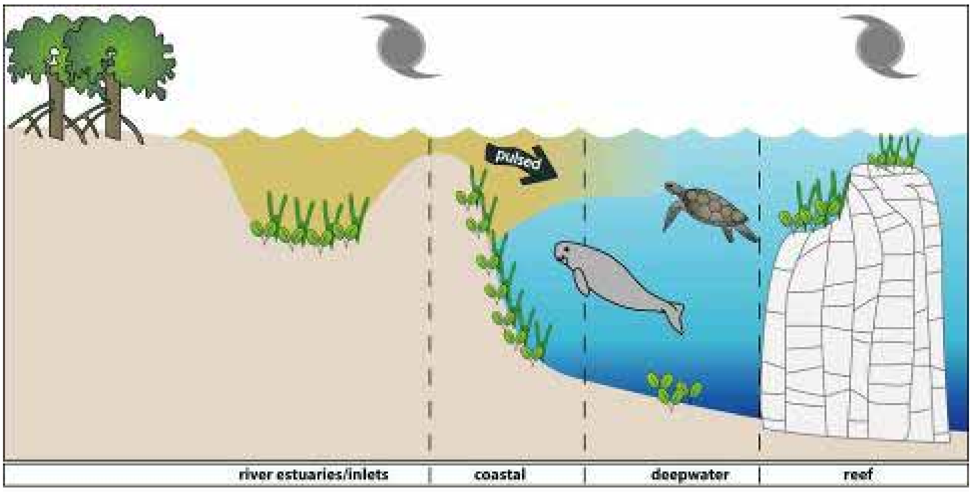


Figure 8 General conceptual model of seagrass habitats occurring within Port Curtis and Rodds Bay (from Carruthers *et al.* 2002)

Seagrass Distribution and Abundance: Long term Monitoring

In 2009, long term seagrass monitoring meadows in Port Curtis and Rodds Bay were mostly in reasonable condition relative to previous years of monitoring data; however specific meadows and locations were of concern. Total aerial coverage of the thirteen monitoring meadows was approximately 10% below the average (since 2002) in 2009. This decline relates to the reduction in area of specific meadows rather than declines throughout all meadows. Meadow biomass was mostly consistent relative to previous year's data, but some meadows showed some similar location specific declines. Analysis of available environmental data indicates declines are most probably linked to inter-annual climate variability.

Notable long term change in the species composition has occurred at both of the Wiggins island meadows, the South Trees meadow (meadow 58) and at South Fishermans. This is a change from *Halophila ovalis* dominated meadows to *Zostera capricorni* dominated meadows and is a shift from a pioneer dominated flora to a climax flora indicating potential reducing levels of disturbance and/or reduced environmental change.

A major loss of seagrass has occurred at Quoin Island, which has been part of a pattern of decline for this meadow since 2006. The monitoring meadow at Quoin, that had once covered 421 ha (in 2002) and at its maximum in 2006 had a biomass of 9.6 g DW m^{-2}, had significantly reduced to three meadow patches of low biomass *Halodule uninervis* in 2009. Average daily wind speed, monthly river flow (October and September), and solar radiation (August, September and October) were significantly and positively correlated to biomass at Quoin Island, suggesting climatic variability may be a significant driver of change. Understanding the mechanisms of these drivers is speculative but probably relates to nutrient and light limitation (Udy *et al.* 1999, Ralph *et al.* 2007). Although such correlations don't provide cause and effect evidence of change, they do indicate that climate variability is a major potential influence on the decline of this meadow.

Potential drivers of seagrass biomass change at other annual monitoring meadows in Port Curtis and Rodds Bay were principally related to rainfall, solar radiation, and elevated temperature. In intertidal seagrass meadows pooling water can become super-heated at low tide resulting in temperatures in excess of 40°C. Such temperatures have been found to have a lethal effect on seagrass tissue (Campbell *et al.* 2006) and both the present program and the reef rescue marine monitoring program have recorded temperatures in the intertidal seagrass meadows to exceed 40°C for short periods (McKenzie & Unsworth 2009).

Several correlations of increased monitoring meadow biomass with increased river flow or rainfall were recorded. This was specifically the case at Rodds Bay where major seagrass loss had also been observed. Increased rainfall may benefit seagrass by providing an increased abundance of nutrients. As monitoring is conducted at the end of the dry season, seagrass meadows at such a time may be nutrient limited due to low rainfall and river flow. An alternative (and/or possibly cumulative) explanation could be related to the positive impact of freshwater in reducing epiphytic cover on seagrass leaves (Gillanders & Kingsford 2002), enhancing seagrass light availability.

Increased daytime tidal exposure and levels of solar radiation were also found to be negatively correlated with seagrass biomass (at Pelican Banks). This supports observations on a number of occasions of seagrass being 'burnt', indicating temperature, desiccation and UV light stress (Stapel 1997, Campbell *et al.* 2006).

The relationships observed between seagrass biomass and climate variability are indicative only, and the monitoring program would be enhanced in the long term by dedicated light and temperature monitoring conducted at the individual seagrass meadow level. This will allow for the more complete separation of natural and anthropogenic influences upon seagrass meadows in Port Curtis and Rodds Bay.

Seagrass Meadow Resilience

The changes in seagrass cover and area observed in Port Curtis and Rodds Bay are typical of tropical and sub-tropical meadows (Mellors *et al.* 1993, McKenzie 1994), with climate variability commonly observed to be an important driving force of such changes (Agawin *et al.* 2001). Such natural changes in assemblage biomass and plant growth can commonly vary by up to a factor of four (Brouns 1985, Erftemeijer & Herman 1994, Lanyon & Marsh 1995) similar to those observed in Port Curtis and Rodds Bay.

Our initial analysis (see methods) of long term patterns of seagrass variability suggests that localised losses of seagrass in Port Curtis and Rodds Bay are probably the result of climate variability rather than anthropogenic disturbance. Temperature and rainfall/river flow appear to be strongly correlated to changes in seagrass biomass.

It is likely that a full recovery of seagrasses will occur if not further impacted by any additional stressors (natural or anthropogenic), allowing the seagrass to utilise any natural reproductive resilience (e.g. presence of a seed bank). 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 mostly in a reasonably healthy state. Their continued persistence in a highly industrialised port indicates that they do have some level of resilience to human activities, including current levels of dredging and other port and urban activities. Such activities during 2009 were unlikely to have had a significant impact on seagrasses in the area, however, water quality from localised periods of elevated nutrients (CQU 2004, McKenzie & Unsworth 2009) and climate variability, were environmental stressors potentially impacting on seagrass health. Water quality has been monitored extensively in Port Curtis under PCIMP since 2005 (Storey *et al.* 2007, Vision Environment QLD 2009, 2010) and has been determined to be of relatively good quality. The majority of measured parameters including physicochemistry, metals and nutrients have been recorded as generally meeting available guidelines. However, with increasing industrialisation and associated urbanisation, water quality in Port Curtis may become a more important and influential environmental stressor.

The marine environment of Port Curtis and Rodds Bay, although possibly resilient to current (2009) levels of port related anthropogenic stress, continues to be at risk from the shipping activities at the port and other future development projects. Dredging and shipping activities have commonly been observed in many locations to damage seagrass (Erftemeijer & 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.

Although a causative link between seagrass loss and reduced light availability is well established (Erftemeijer & 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 required for 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 have the capacity to reduce the resilience of seagrasses in the region to current human activities.

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APPENDIX

Appendix A Results of one-way ANOVA for mean above ground biomass versus year for the thirteen seagrass monitoring meadows in Port Curtis and Rodds Bay (2002, 2004, 2005, 2006, 2007 & 2008) (*significant difference in biomass between years)

Meadow 4	DF	SS	MS	F	P
Between years	6	17.542	2.924	0.793	0.577
Within years	131	483.184	3.688		
Total	137	500.727			
Meadow 5					
Between years	6	2009.524	334.921	25.052	<0.001*
Within years	219	2927.782	13.369		
Total	225	4937.306			
Meadow 6					
Between years	6	1051.476	175.246	13.452	<0.001*
Within years	282	3673.754	13.027		
Total	288	4725.231			
Meadow 7					
Between years	6	286.055	47.676	6.257	<0.001*
Within years	105	800.096	7.62		
Total	111	1086.151			
Meadow 8					
Between years	6	400.956	66.826	13.672	<0.001*
Within years	253	1236.601	4.888		
Total	259	1637.557			
Meadow 9					
Between years	6	629.694	104.949	15.817	<0.001*
Within years	166	1101.415	6.635		
Total	172	1731.109			
Meadow 43					
Between years	6	10125.75	1687.625	4.648	<0.001*
Within years	414	150308.2	363.063		
Total	420	160433.9			
Meadow 48					
Between years	6	1744.002	290.667	24.772	<0.001*
Within years	235	2757.413	11.734		
Total	241	4501.415			
Meadow 58					
Between years	6	969.905	161.651	5.099	<0.001*
Within years	200	6340.422	31.702		
Total	206	7310.327			
Meadow 60					
Between years	6	1460.418	243.403	7.521	<0.001*
Within years	85	2750.833	32.363		
Total	91	4211.251			
Meadow 94					
Between years	6	7313.228	1218.871	4.852	<0.001*
Within years	72	18085.44	251.187		
Total	78	25398.67			
Meadow 96					
Between years	6	15676.13	2612.689	9.036	<0.001*
Within years	211	61011.52	289.154		
Total	217	76687.65			
Meadow 104					
Between years	6	8426.783	1404.464	6.524	<0.001*
Within years	129	27772.37	215.29		
Total	135	36199.15			

Appendix B Pair-wise comparisons following one-way ANOVA (Holm-Sidak method) between mean yearly meadow biomass from 2008 to 2009

Meadow	Difference
Meadow 4	NSD
Meadow 5	P<0.01
Meadow 6	NSD
Meadow 7	NSD
Meadow 8	NSD
Meadow 9	P<0.01
Meadow 43	NSD
Meadow 48	NSD
Meadow 58	NSD
Meadow 60	P<0.01
Meadow 94	NSD
Meadow 96	P<0.01
Meadow 104	P<0.01

Appendix C Partial least squares (PLS) regression analysis of annual mean November seagrass biomass relative to available climate and environmental data at six seagrass meadows spread throughout Port Curtis and Rodds Bay. Table shows the overall 'global' ANOVA statistics for each of the regression models, the individual principal components and their cumulative R^2 values. Individual regression coefficients of the specific biomass predictors (environmental variables) are also shown.

		PLS ANOVA			**Model Selection and validation**				**Biomass Predictors**										
Site		**P**	**F**	**DoF**	**Component**	**X Variance**	**R-Sq**	**R-Sq (pred)**	**Wind 9**	**River flow 2**	**Solar 3**	**River flow 1**	**Tidal Exposure**	**Rainfall 9**	**Temp 9**	**Rainfall 6**	**Temp 6**	**River flow 12**	**Solar 1**
M6	ANOVA	<0.01	14.0	1,6															
South	PLS Model				1	0.36	0.74												
Fishermans					2		0.74												
ZC					3		0.74												
	Coefficients																-0.50	-0.47	0.47
M5	ANOVA	<0.05	7.9	1,6															
Wiggins	PLS Model				1	0.74	0.61	0.40											
Island					2		0.61	0.29											
ZC	Coefficients														-0.45	0.46			
M43	ANOVA	<0.01	24.0	1,6															
Pelican	PLS Model				1	0.64	0.82	0.59											
Banks					2		0.87	0.40											
ZC					3		0.87	0.57											
	Coefficients										-0.41	0.43	-0.29						
M48	ANOVA	<0.01	25.6	2,6															
Quoin	PLS Model				1	0.36	0.91	0.10											
Island					2	0.67	0.93	0.70											
HU					3		0.93	0.45											
	Coefficients								0.73	0.48	0.37								
M60	ANOVA	<0.05	8.8	1,6															
South Trees	PLS Model				1	0.93	0.64	0.26											
ZC					2		0.73	0.00											
	Coefficients															0.36	-0.46		
M 96	ANOVA	<0.05	13.0	1.6															
Rodds	PLS Model				1	0.86	0.72												
Bay					2		0.73												
ZC	Coefficients													0.48	-0.44				